MANIPULATING PIG PRODUCTION IV

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Editor: E.S. Batterham

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CONTRIBUTORS

B. Adler	Department of Microbiology, Monash University, Clayton, Vic. 3168.
S.E. Aplin	Department of Biochemistry, University of Adelaide, Adelaide, SA 5000.
D.H. Baker	Department of Animal Sciences and Division of Nutritional Sciences, University of Illinois, Urbana IL 61801, USA.
C.I. Ball	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
R.O. Ball	University of Guelph, Guelph, Ontario N1G 2W1, Canada.
F.J. Ballard	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
B.J. Barnett	Department of Animal Science, University of New England, Armidale, NSW 2351.
J.L. Barnett	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
T.N. Barry	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
E.S. Batterham	NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.
R. Bawden	Faculty of Agriculture and Rural Development, University of Western Sydney, Hawkesbury, Richmond, NSW 2753.
J.C. Beattie	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
R.S. Biden	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
P. Bikker	Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands.
M.L. Billinghurst	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
P.H. Bird	CSIRO Division of Wildlife and Ecology, PO Box 84, Lyneham, ACT 2602.
J.L. Black	CSIRO Division of Animal Production, Prospect, PO Box 239, Blacktown, NSW 2148.
P.J. Blackall	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
A.W. Blackshaw	Department of Physiology and Pharmacology, University of Queensland, St Lucia, Qld. 4072.
J.K. Blackshaw	Department of Farm Animal Medicine and Production, University of Queensland, St Lucia, Qld. 4072.
H.J. Bray	Department of Animal Science, University of Sydney, Camden, NSW 2570.
S.C. Brown	Department of Animal Science, University of Sydney, Sydney, NSW 2006.
J.L. Burgoyne	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
D.J. Cadogan	Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

R.D.A. Cameron	Department of Farm Animal Medicine and Production, University of Queensland, St Lucia, Qld. 4072.
R.G. Campbell	Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.
C. Cargill	South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.
J.R. Carr	J.R. Carr and Associates, PO Box 1655, Toowoomba, Qld. 4350.
K. Casey	Queensland Department of Primary Industries, Agricultural Engineering Section, Toowoomba, Qld. 4350.
G. Cassar	Department of Animal and Poultry Science, Univeristy of Guelph, Guelph, Ontario N1G 2W1, Canada.
R.J. Chappel	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
R.P. Chapple	Purina Mills Inc., St Louis, MO 63144, USA.
M. Charles	Berrybank Farm, Vallarat, Vic. 3352.
W.A. Clarke	NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.
K.J. Coates	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
M.F. Comber	Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.
M.A. Conlon	Department of Biochemistry, University of Adelaide, Adelaide, SA 5000.
P.W. Cook	Queensland Department of Primary Industries, PO Box 597, Dalby, Qld. 4405.
M.R. Cowan	Department of Primary Industry and Fisheries, PO Box 46, Kings Meadows, Tas. 7249.
P.D. Cranwell	School of Agriculture, La Trobe University, Bundoora, Vic. 3080.
G.M. Cronin	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
F. Crosling	NSW Agriculture, PO Box 547, Tamworth, NSW 2340.
R.S. Cutler	Pig Research and Development Corporation, Barton, ACT 2604.
A.J. Darragh	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
G.T. Davies	DSL Systems Centre, CSIRO Division of Animal Production, Prospect, PO Box 239, Blacktown, NSW 2148.
H. Derix	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
L.G. Dickenson	School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.
J.P. Drinan	University of Newcastle, Callaghan, NSW 2308.
G.McL. Dryden	Department of Animal Production, University of Queensland, Gatton, Qld. 4343.
F.R. Dunshea	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
B.G. Easton	Department of Animal Health, University of Sydney, Camden, NSW 2570.

A.C. Edwards	Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.
G.A. Eldridge	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
W.A. Ellis	Department of Agriculture, Veterinary Sciences Division, Stormont, Belfast BT4 3SD, Northern Ireland.
G. Evans	Department of Animal Science, University of Sydney, Sydney, NSW 2006.
D.J. Farrell	Department of Biochemistry, Microbiology and Nutrition, University of New England, Armidale, NSW 2350.
P.H. Fearon	Department of Primary Industries, Toowoomba, Qld. 4350.
Feng Yu	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
D.M. Ferguson	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
J.K. Findlay	Prince Henry's Institute of Medical Research, PO Box 152, Clayton, Vic. 3168.
G.L. Francis	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
J.B. Gaughan	Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.
L.R. Giles	Department of Animal Science, University of Sydney, Camden, NSW 2570.
N.W. Godfrey	Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.
J.M. Gooden	Department of Animal Science, University of Sydney, Camden, NSW 2570.
K.M. Griggs	Cefn Stud, Pilton Rd, Clifton, Qld. 4361.
D.J. Hampson	School of Veterinary Studies, Murdoch University, Murdoch, WA 6150.
D. Harrison	Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.
P.E. Hartmann	Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.
M.J. Haskell	The Scottish Agricultural College, West Mains Road, Edinburgh EH9 3JZ, UK.
M. Hathaway	Department of Animal Science, University of Minnesota, St Paul, MN 55108, USA.
T. Henderson	Department of Animal Science, University of Minnesota, St Paul, MN 55108, USA.
K.A.K. Hendry	Hannah Research Institute, Ayr, Scotland KA6 5HL, UK.
D.P. Hennessy	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
G.M. Higgs	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
N.W. Hodgens	Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.
C.I. Houseman	Pig Research and Development Corporation, Barton, ACT 2604.

P.E. Hughes	School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.
G.D. Hutson	School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.
I.R. Jones	Cefn Stud, Pilton Rd, Clifton, Qld. 4361.
L. Kamperman	Department of Agricultural Science, University of Tasmania, Hobart, Tas. 7001.
V. Karabinas	Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands.
D.J. Kennaway	Department of Obstetrics and Gynaecology, Medical School, University of Adelaide, Adelaide, SA 5000.
G.J. King	Department of Animal and Poultry Science, Univeristy of Guelph, Guelph, Ontario N1G 2W1, Canada.
R.H. King	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
W.A. King	Biomedical Sciences, Univeristy of Guelph, Guelph, Ontario N1G 2W1, Canada.
C. Klupiec	Department of Animal Science, University of Sydney, Sydney, NSW 2006.
H.M. Knowles	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
J.S. Kopinski	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
I. Kruger	NSW Agriculture, PO Box 547, Tamworth, NSW 2340.
A.B. Lawrence	SAC Edinburgh, Genetics and Behavioural Sciences Department, Bush Estate, Penicuik, Midlothian BH26 0QE, Scotland, UK.
P.R. Le Tissier	Department of Animal Science, University of Sydney, Sydney, NSW 2006.
M.L. Lorschy	Department of Animal Science, University of Sydney, Camden, NSW 2570.
R.J. Love	Department of Animal Health, University of Sydney, Camden, NSW 2570.
L. Ma	School of Agriculture, La Trobe University, Bundoora, Vic. 3080.
N.K. Masterman	South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.
K. McGuigan	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
J.P. McNamara	Department of Animal Science, Washington State University, Pullman, WA 99164-6320, USA.
C.P. McPhee	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
G.P. Moberg	Department of Animal Science, University of California, Davis, Davis, CA 95616, USA.
G.A. Moore	Department of Civil and Environmental Engineering, University of Melbourne, Parkville, Vic. 3052.
M. Moore	South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.
C. Moran	Department of Animal Science, University of Sydney, Sydney, NSW 2006.

I.R. Morgan	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
B.A. Moss	Peptide Technology Limited, Dee Why, NSW 2099.
P.J. Moughan	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
P.C.H. Morel	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
K.J. Moyse	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
Muladno	Department of Animal Science, University of Sydney, NSW 2006.
B.P. Mullan	Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.
S.V. Myler	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
K.A. Nairn	Milne Feeds, Welshpool, WA 6106.
F.W. Newman	Department of Farm Animal Medicine and Production, University of Queensland, St Lucia, Qld. 4072.
F.W. Nicholas	Department of Animal Science, University of Sydney, Sydney, NSW 2006.
K.R. Nicholas	CSIRO Division of Wildlife and Ecology, PO Box 84, Lyneham, ACT 2602.
B.L. Nielsen	SAC Edinburgh, Genetics and Behavioural Sciences Department, Bush Estate, Penicuik, Midlothian BH26 0QE, Scotland, UK.
D.I. Officer	NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.
P.C. Owens	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
J.L. Pahoff	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
A.M. Paterson	Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.
H.G. Payne	Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.
R.W. Payne	Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.
G. Pearson	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
D.W. Pethick	School of Veterinary Studies, Murdoch University, Murdoch, WA 6150.
J.E. Pettigrew	Department of Animal Science, University of Minnesota, St Paul, MN 55108, USA.
A.M. Pointon	South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.
D.B. Preston	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
I.K. Priebe	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.

P.D. Reiser	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
D.K. Revell	Animal Science Group, School of Agriculture, University of Western Australia, Nedlands, WA 6009.
J.E. Riley	JCR Associates International, "Warreners", Mail Service 150, Pittsworth, Qld. 4356.
S.M. Rutherfurd	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
R.J.F. Sasse	Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands.
B. Schutte	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
F.D. Shaw	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
B.J. Shay	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
P.M. Siba	School of Veterinary Studies, Murdoch University, Murdoch, WA 6150.
G.J. Simpson	Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.
D.N. Singh	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
S.Z. Skirrow	Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.
D.E. Slinger	School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.
C.R. Smith	Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.
R.A. Spencer	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
I.B. Stephens	Department of Primary Industries and Energy, Bureau of Resource Sciences, PO Box 778, Brisbane, Qld. 4001.
B.J. Stevenson	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
G.J. Storie	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
I. Tarvid	School of Agriculture, La Trobe University, Bundoora, Vic. 3080.
D.G. Taylor	Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.
G. Taylor	NSW Agriculture, PO Box 547, Tamworth, NSW 2340.
G.J. Terry	"Juniper Lea", Deloraine, Tas. 7304.
F.J. Thomas	Department of Farm Animal Medicine and Production, University of Queensland, St Lucia, Qld. 4072.
M.J. Thompson	Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.
E.J. Thornton	Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

F.M. Tomas	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
T.E. Trigg	Peptide Technology Limited, Dee Why, NSW 2099.
S.M. Tritton	Rhône-Poulenc Animal Nutrition, 19-23 Paramount Rd., West Footscray, Vic. 3012.
G.R. Trout	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.
R.J. van Barneveld	South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.
R. Vavala	School of Agriculture, La Trobe University, Bundoora, Vic. 3080.
M.W.A. Verstegen	Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands.
C.M. Wakeford	Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.
B. Walker	NSW Agriculture, PO BOX 546, Gunnedah, NSW 2380.
K.H. Walker	NSW Agriculture, Elizabeth Macarthur Agricultural Institute, PMB 8, Camden, NSW 2570.
J.C. Wallace	Department of Biochemistry, University of Adelaide, Adelaide, SA 5000.
P.E. Walton	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
S.S. Wan	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
P.R. Widders	Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.
G.C. Wigan	NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.
C.J. Wilde	Hannah Research Institute, Ayr, Scotland KA6 5HL, UK.
I.H. Williams	Animal Science Group, School of Agriculture, University of Western Australia, Nedlands, WA 6009.
K.C. Williams	Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.
S.R.O. Williams	Department of Civil and Environmental Engineering, University of Melbourne, Parkville, Vic. 3052.
G.F. Wilson	Monogastric Research Centre, Massey University, Palmerston North, New Zealand.
J.D. Wood	Division of Food Animal Science, School of Veterinary Science, University of Bristol, Langford, Bristol BS18 7DY, UK.
K. Wright	CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000.
A. Yang	CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.

ACKNOWLEDGEMENTS

It is with pleasure that the Australasian Pig Science Association acknowledges the efforts of all those who presented papers and participated in the discussions of this Conference and thus ensured its success. We are indebted to those who acted as Chairpersons or Symposia Leaders: Messrs P.D. Cranwell, M.R. Cowan and Drs E.S. Batterham, R.S. Cutler, R.J. Love, J.L. Barnett, F.R. Dunshea, R.G. Campbell, G. Evans, B.P. Mullan, S. Hawkins, J.L. Black and G.R. Trout. The Committee would also like to thank all those who acted as referees, often at short notice, of the Abstracts, Reviews and Symposia.

The Proceedings was prepared at the Wollongbar Agricultural Institute, Wollongbar, NSW, and we are grateful to the Institute for it's support, and in particular to Miss Julie Leeson, who prepared the manuscript and Mrs Marilyn Copeland for assistance with the processing of Abstracts. We are also appreciative of the administrative support given to the Organising Committee by the Department of Agriculture, Victorian Institute of Animal Science.

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PREFACE

These are the Proceedings of the Fourth Biennial Conference of the Australasian Pig Science Association (APSA). The Association was formed in 1987 with the objectives of encouraging and promoting scientific discussion and collaboration amongst scientists interested in pig research and pig production. A strength of APSA is its support from scientists across a broad range of disciplines and in all areas relevant to the pig industry. For a pig industry of relatively small international significance, APSA boasts a membership approaching 150 includng established scientists of international standing, emerging young scientists and students and industry specialists.

For the fourth time, an APSA group of more than 200 local and international scientists meets to interact both scientifically and socially. These are the Proceedings of that meeting held in Canberra in late 1993. This year's Conference will provide new information, interpretation and discussion on topics related to the major scientific disciplines including nutrition, growth, reproduction, genetics, health and animal behaviour and welfare. However, the meeting will address an even broader range of subjects as it will include a major symposium on pig meat quality, outdoor pig housing and shorter papers associated with environmental and effluent treatment. Furthermore, the meeting will also address the issues of transfer of technical and research information. In an adventurous departure from the scientific disciplines, the program includes a Symposium on technology transfer and a Review from a leading producer on the impact of science on the industry.

The major Reviews and Symposia are presented by internationally renowned scientists. These papers are supported by 67 Abstracts presented by scientists of the Society and other local and international participants. These Proceedings will be extremely valuable to people interested in pig research and pig production.

The Executive of APSA is confident that the scientific and social program organized for the Fourth Biennial APSA Conference, as with previous APSA Conferences, will result in improvements in the understanding of pig research and pig production. Furthermore, it is anticipated that the Conference will stimulate and encourage high standard research in the critical areas of pig production. Improvements in these aspects will undoubtably result in gains in pig productivity and improvements in animal welfare.

The Editor of the Proceedings was Dr E.S. Batterham who, with his capable staff, requires special mention for an outstanding effort.

I would like to thank the Organising Committee for their excellent contributions to this Conference. The Committee consisted of Drs D.P. Hennessy (Secretary), G.M. Cronin (Treasurer), P.H. Hemsworth, R.J. Love, B.P. Mullan, R.S. Cutler, E.S. Batterham and Mr P.D. Cranwell. Dr A.J. Peacock also provided valuable assistance to the Committee and ACTS Pty Ltd proved excellent conference organisers.

M.R. TAVERNER
President
APSA

A REVIEW - HOW DOES SCIENCE CONTRIBUTE TO THE PIG INDUSTRY - A PRODUCERS PERSPECTIVE

I.R. Jones and K.M. Griggs

Cefn Stud, Pilton Rd, Clifton, Qld. 4361.

Scientists and pig producers need to work closely together to gain the maximum advantages for the Australian pig industry. To maintain this relationship, producers and researchers need to understand the issues important to each other and develop communication channels for the benefit of both groups.

For a relationship to be successful, producers must believe that science is worthwhile and has a major contribution to the Australian pig industry and simultaneously, researchers must appreciate the needs of the pig industry.

Modern Australian pig farming

Profits in pig production in Australia are steadily declining. The major constraints on production are the rising costs and the decreasing returns on product sold. Australian pig production can only remain profitable by becoming more efficient - producing the same or more product for reduced costs.

The document "25 Years at Huntly" (Cleary, 1991) depicts this trend on one of the largest piggeries in Australia. Figure 1 shows that the nominal cost of producing pigs has risen from approximately 40c/kg live weight (LW) in 1969 to 150c/kg LW in 1990. The largest influence on this rise in costs has been the increase in feed costs.

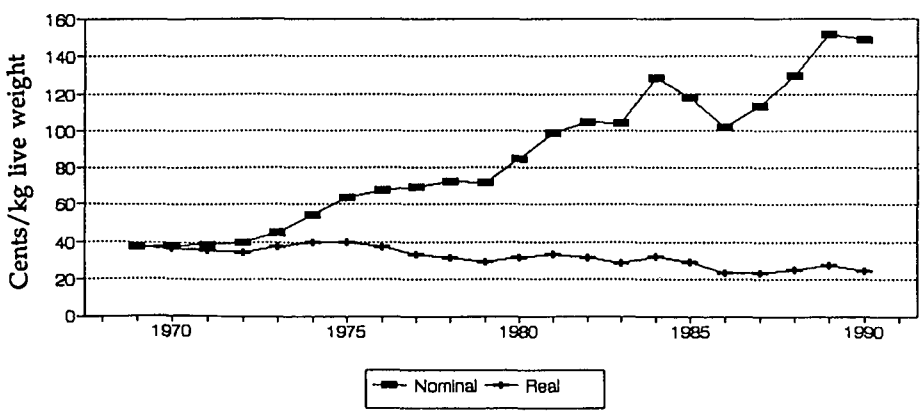

Figure 1. *Production cost per kg live weight (Cleary, 1991).*

However, while the nominal production costs have increased, real production costs have decreased as pig producers become more and more efficient in the production of their pigs.

Figure 2 shows that the nominal bacon price has increased over this time, however, the real value for this meat has decreased.

Australian pork is used almost exclusively for domestic consumption. Domestic consumption has increased slowly but constantly over the last decade, with the average Australian eating 19 kg of pig meat in 1992.

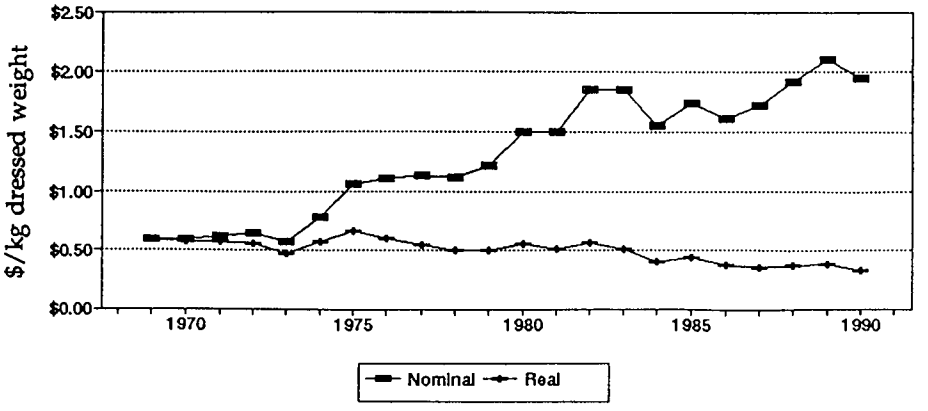

Figure 2. *Bacon price per kg dressed weight (Cleary, 1991).*

Currently, only 2% of Australian pig meat is being exported. Those companies exporting pig meat report substantial losses due to a number of factors including strict government regulations, large government charges, the fluctuation in the Australian dollar and Australia's inability to meet the technologies of some companies overseas.

The lack of a significant export market has meant that the Australian pig industry is of little importance to the Government. This has had a large influence on the industry, both in the issue over Canadian pork importation, but also with the decreasing emphasis on research and extension in pig science by the State Governments.

The number of producers in pig production is steadily declining, with 1000 pig producers leaving pig production in 1992, according to the APC/PRDC producer database. However, over this same period the number of sows did not decline - the average herd size in April 1993 was 63.29 sows/producer, compared to 55.58 sows/producer in December 1992.

Even in the current financial situation, producers need to become increasingly more efficient, lowering their cost of production to the bare minimum. Current data show an industry cost of production of $1.41/kg LW (PigStats92, 1993). For long term viability and profitability, producers will need to decrease this cost by at least $0.30 over the next 5 years. The advantages of efficiency are with the large producers, due to the obvious economies of size in both buying and selling power, but also due to the expertise often employed by these organisations.

Australian pig research

Australia is fortunate in having an extremely strong research field in pig science. Australia supports some of the world leaders in research in areas of nutrition, behaviour, genetics and reproduction. This is a proud boast by a country producing relatively small amounts of pig meat, 0.4% of the total world's production (R. Ransley, personal communication).

State Departments have been traditionally supportive of pig research, but have cut down their research facilities in all areas and have often put emphasis on the export- orientated industries.

Researchers are having to become more competitive for funds. Industry support for research is now essential for researchers to maintain their position and to gain

promotion. Research institutions are requesting more and more funds to support their projects. A typical application now includes requests for salaries, operating, travel and capital items. Table 1 shows the increasing costs of pig research projects in Australia.

Table 1. The increasing costs of R&D - the average size and cost of the research programs of the PRC and PRDC since 1985/86[1]

	N° of projects	Total expenditure ($m)	Average expenditure ($'000/project)
1985/86	53	1.01	19.4
1986/87	60	1.22	20.3
1987/88	74	1.64	22.1
1988/89	76	1.84	24.2
1989/90	87	2.82	32.5
1990/91	79	2.94	37.2
1991/92	72	3.31	46.0

[1]Taverner (1991).

Since 1987, despite levy increases from 30 cents to 55 cents (to June 1992) per slaughtered pig, only approximately the same number of projects have been supported. Over the same period the average cost of each research project has increased by 108%.

The average cost of research projects is expected to continue to increase. To support these costs, the research levy from producers is continuing to rise. In the Pig Research and Development Corporation Five Year Plan (1990), a rising levy of 15c every second year has been recommended until an upper ceiling of $1.00 per pig is reached. This proposal has been accepted by both the Australian Pork Producers Federation and the Pork Council of Australia, the bodies representing the pig producer.

The pig producer currently pay a levy of 70 cents for every pig slaughtered to support pig research, an estimated $3,934,000 every year from the pig farmers. Currently, this is being matched dollar for dollar on expenditure by the Federal Government. This arrangement has already come under threat once and future government policies may threaten this arrangement once again.

With such a large investment in research, it is logical and essential that producers have a major say in the direction of pig research.

What issues for research are relevant to Australian pig farming in the 90's - Survey results

A small survey was conducted at two pig industry days to support some of the comments made in this paper. In all, 50 pig farmers were questioned. Farmers were asked a series of questions about pig research and problems in the industry.

Table 2. Distribution of surveyed pig farmers on a State basis

State	NSW	Vic.	SA	Qld.
Number	28	14	3	5

This survey is only small and fairly biased towards medium-sized producers. However, we believe that the key points highlighted from this survey indicate the majority of producers opinions well.

What are the main problems faced by pig farmers?

Pig producers were firstly asked what main problems they had over the last 10 years.

Answers from this question showed that producers are primarily concerned about their profit margins. A number of areas were raised by farmers concerning the volume of output and the cost of production with volume of output being the 'top of the mind' issue for most pig farmers.

Other problems listed by farmers as their main problem over the last 10 years are shown in Table 3.

Table 3. Factors in pig production identified by producers as problems over the last 10 years

Issue	N° mentioned (%)
Profitability	35
Breeding stock supply	12
Pigs per sow per year	9
Respiratory disease	7
Production planning	6
Building design	6
Information	6
Staffing	6
Baby pig scours	6
Summer infertility	3
Monopolisation of meat market	2
PSE	2

Only 24% of producers believed that pig research had helped solve these problems. In some cases, producers had a problem which had been significantly reduced by pig research (for example baby pig scours), but were unaware of research's contribution.

What profile do Australian researchers have?

Recent estimates suggest that there are approximately 30 State Government research staff servicing the pig industry. Universities, particularly when considering postgraduate students, would support an even greater number of pig research staff. If we assume an equal number of researchers, plus another 10 employed by private firms, we have an approximate number of 70 pig researchers in Australia.

Unfortunately, many of these researchers are not associated with advisory officers and both their projects and themselves maintain a very low profile.

We asked each surveyed producer, if they could name one Australian researcher working with pigs. If they could name one, did they know who they worked for.

Table 4. Pig producers' knowledge of Australian researchers

Knew an Australian pig researcher + who they worked for (%)	Knew an Australian pig researcher but did not know who they worked for (%)	Did not know of an Australian pig researcher (%)
37	26	37

Many (37%) producers could not name a single researcher. Producers generally have a poor knowledge of who is doing their research and this has implications for

research adoption.

Of those researchers that were named by producers, the most commonly mentioned are listed in Table 5.

Table 5. The best known researchers in Australia

Researcher	Known (%)
Ross Cutler (Health)	25
Ted Batterham (Nutrition)	16
Paul Hemsworth (Behaviour)	6
Roger Campbell (Nutrition)	4
Graham Trout (Meat quality)	3
Ray King (Nutrition)	3
Paul Hughes (Reproduction)	3
Judith Blackshaw (Behaviour)	3

From this small survey, Ross Cutler was the best known researcher. However, 83% of people who mentioned Ross Cutler still believed that he worked for the Victorian Department of Agriculture.

Also of interest, all researchers mentioned, except for Judith Blackshaw and Graham Trout, worked for a Department of Agriculture, the traditional advisory arm of research. Both Judith Blackshaw and Graham Trout have unusually high levels of contact with pig producers for University/CSIRO bodies, probably explaining their mention.

When we consider that the main ways research is passed back to the industry is through articles, seminars and workshops, the above lack of knowledge of Australian researchers is particularly poor.

This survey was exclusively conducted at two Pig Industry Days - one in NSW and one in Victoria. At both these events researchers were present and seminars were being held. Despite this, we still found 37% of producers attending these days not being able to name a researcher.

This lack of knowledge could be argued as irrelevant if producers are aware of the research projects that are being conducted on their behalf.

Are pig producers aware of what research has or is occurring?

Producers were asked if they were aware of any research that has occurred over the last 10 years and that is occurring now. Respondents who could mention some research were then asked if they knew who conducted the research and where it was conducted.

Table 6. Producers awareness of past and current research

Aware of research in the last 10 years (%)	Aware of research with some details (researcher, institution) (%)	Aware of current research (%)	Aware of current research with some details (%)
70	54	38	30

The large majority of producers were aware of some research that had occurred over the last 10 years. In many of these cases the degree of knowledge was quite high. However, knowledge of current research was much less.

Producers were primarily aware of research that had assisted them on their farm or that they had co-operated in - for example, Paul Hemsworth's work with the Detection Mating Area and mating work was mentioned.

However, despite the fact that the surveyed producers had enough interest to visit field days, they had not retained a large proportion of information from published material or seminars some had visited only hours before. The PRDC is circulating regular newsletters informing producers about current research but either this information is not being absorbed or is not seen as relevant to the farmer.

Knowledge of PRDC

Producers were asked if they knew what PRDC stood for. Forty four percent of producers knew that PRDC stood for Pig Research and Development Corporation, 30% had no idea what PRDC stood for and 26% of producers thought they knew but got it wrong. Further, producers were asked if they could name anybody on the PRDC Board. Seventy one percent of producers surveyed could not name a single member on the PRDC Board. Of those mentioned, Trevor Hope (Chairman) and Mike Taverner (Executive Director) rated with the highest scores of 8% of respondents each.

The PRDC Board is nominated by representatives from the industry. However, the majority of industry could not name a single member on the Board. Indeed, over one third of producers had never heard of the PRDC.

Pig producers also seem to be confused about how research is funded. All producers were aware that they were paying a levy but were uncertain how this was used. There was a lot of confusion over whether the levy was being paid to the Pig Research and Development Corporation (PRDC), the Australian Pork Corporation (APC) or the Pork Council of Australia (PCA). Pig producers ignorance regarding their levy is largely because all levy's are compulsory and considered out of their control. Generally, producers have read some articles criticising industry bodies use of funds and often consider all industry bodies together. In general, surveyed producers commented about the large levy that they were paying.

How do farmers want to learn about research?

Farmers were asked how much information they required about research and what the best way for this information to be passed onto the producer.

The majority of producers (48%) said that they wanted to be informed of research only when it could be used on their farm, 28% said that they wanted to be informed when the research had some chance of success and 24% said that they wanted to be informed of research in the early stages.

When this information is considered along with the previous questions, it suggests that the majority of farmers want to know about what has happened that will improve their profit now. A smaller proportion of farmers want to know various ranges of details, just as some stock holders want to know the innermost secrets of their invested company.

This survey suggests that scientists and the PRDC need to plan for a mechanism to distribute information that can be used by farmers as soon as it becomes available. Any delay in this transfer of information will mean that the information may be superseded or research will not gain the credit for whatever possible improvement is gained.

Most farmers suggested newsletters or magazines as the best way to learn about research projects, but are keen to attend seminars or workshops, if they will learn something new that can help them on their farm. However, the earlier results suggest that the current newsletters, magazines, seminars and workshops are not succeeding in catching the attention of the average producer.

To end the questionnaire, pig producers were asked a series of yes or no questions, represented in Table 7.

Research and Australian pig production?

The results of the above survey are of course somewhat biased. There is a section of pig producers, either the larger farmers or those involved in industry

politics, that are very well informed about pig research and are always interested to learn more. However, these farmers, although generally representing larger amounts of pigs, are still in the minority. Other (often smaller) pig producers are mainly interested in technologies that can be easily applied to their farm for an increased return. These farmers are less informed and their best source of information is often from their neighbours.

Table 7. Producers responses to the survey summary

	Yes	No
	(%)	
Should pig producers have access to full research project information including methods and full statistical results?	83	17
Should pig producers be told how much money is spent on each research project?	96	4
Should pig producers money be used to put completed research into a form that farmers can use?	96	4
Is the PCA an adequate way for PRDC to report to the pig farmer?	54	46
Do you believe that research money in pig production is well spent?	62	38

Despite the results in some aspects of this survey, the majority of producers believe that research money in pig production is well spent.

As pig farmers have become more efficient, Australian pig science has become more sophisticated.

A review of current research projects supported by the PRDC include terms such as 'long R3 insulin-like growth factor 1', 'enzyme immunoassay for porcine y-interferon', 'role of fibroblast growth factor in pig placental development and embryogenesis' etc. The majority of pig farmers have little hope of understanding the topic of this project or the implications of this research for their production efficiency. Perhaps, with the sophistication of basic research, research should be promoted through its specific objectives to improve pig production rather than the mechanism of this approach.

Progress in research over the last two decades has meant that the modern pig farmer must be an expert in a number of disciplines - an engineer, a veterinarian, a welfare specialist, a nutritionist, a trainer of staff and an administrator. Even when a farmer can employ some expertise to assist in his operation he still must be sufficiently skilled in the above operations to undertake maintenance, vaccinate/inject a pig, monitor individual animals for their welfare, understand feeding habits of different ages of pigs, look after the day to day requirements of their staff and keep the business profitable.

When we consider the current research projects being funded, the pig farmer of the future will have to maintain all his current expertise, but may also have to become an expert in some new fields such as manipulating growth hormones, running four computer programs simultaneously, selecting pigs for meat colour as well as the current measurements, having a working understanding of pig genes, and injecting multiple vaccines into any one pig.

In reality, the sophistication of research is developing a situation where the advantages of much of the research can only be used by knowledgable producers, with a medium to large extent of in-house or private expertise.

As already mentioned, the small to medium farmers in Australia are decreasing at a rapid rate. Large farmers, on the other hand, are getting larger. Traditionally,

smaller farmers have sourced their advice either free or cheaply from the State Department of Agricultures. However, as these resources are declining, this source is less available to the individual producer. There is also some argument that no generalist adviser can become an expert in the diverse fields required for pig farming. Many pig farmers cannot afford private advisory counsel and particularly not from multiple sources. However, without maintaining step with the directions of research and the improvements of the larger companies, these farms cannot remain viable.

Pig scientists and pig producers

Where industry funds are being used, scientists must have a commitment to both the long term future of the Australian pig industry and also to the individual levy payers.

Scientists should be complemented in their interest in the long term future of the industry. Basic and applied research is concentrating on improving the profitability of the industry and in some cases Australian scientists are leading the world in this work. However, communication of research to the individual levy payer has not been as good.

For producers to gain the full benefit from pig science they must have rapid access to the newest technology available, understand the basic thrust of the research findings and know how to apply this technology.

Owners of the research developed using pig producers funds have a responsibility to communicate, promote and assist adoption of research findings to the pig industry at large. Current communication channels are resulting in communication to a 'favoured few', while the rest of the industry only has access to this information some period after it is applicable.

Scientists must remain in some contact with the commercial pig industry. This contact is not only important, so that producers stay informed of future advancements, but also so that the scientists perspective of the industry and its problems are continually honed and their research projects retain relevance.

The PRDC should be applauded for its recent efforts to encourage more applied research projects with commercial producers. This collaboration greatly assists in the producer, scientist communication process. However, this process has not gone far enough. Industry-based research projects should not be funded unless there is built-in co-operation with a commercialiser of the research. This co-operator must have a financial commitment to the project at the beginning of development.

Collaboration of this extent would ensure that a much higher proportion of projects have industry relevance and that the expertise is available for the results of this research to be transferred to the farmer. Commercial partners need to contribute some research funds. This does not necessarily need to be at the beginning of the work but must be written in from the start. The commercial partner would then have full ownership of the technology or information and could sell this at a market price to the producer.

Conclusions

Australian pig production is undergoing a number of changes and to remain viable in the long term, pig farmers must become more and more efficient.

Australia is fortunate in its high standard of research personnel. However, in a survey of producers, these researchers, their research projects and details of the funding body were not at all well known.

Pig science is becoming increasingly sophisticated and is encouraging the existing trend where only the larger or more expert farmers can afford to stay in the pig industry long term.

Communication channels between pig scientists and pig producers are generally poor. The existing research-extension models have little future in the emerging

industry. To ensure 'worthwhile research' in the future, the industry bodies should encourage collaboration between commercial partners and researchers.

A fable for today (de Mello, 1989)

A flea decided to move with his family into the ear of an elephant. So he shouted, "Mr Elephant, sir, my family and I plan to move into your ear. I think it only fair to give you a week to think the matter over and let me know if you have any objection."

The elephant, who was not even aware of the existence of the flea went his placid way so, after conscientiously waiting for a week, the flea assumed the elephant's consent and moved in.

A month later Mrs Flea decided the elephant's ear was not a healthy place to live in and urged her husband to leave. The flea wanted to wait another month at least so as not to hurt the elephant's feelings.

Finally, he put it as tactfully as he could: "Mr Elephant, sir, we plan to move to other quarters. This has nothing at all to do with you, of course, because your ear is spacious and warm. It is just that my wife would rather live next door to her friends at the buffalo's foot. If you have any objection to our moving, do let me know in the course of the next week."

The elephant said nothing, so the flea changed residence with a clear conscience.

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A SYMPOSIUM - INTEGRATING TECHNOLOGY, KNOWLEDGE AND FARMING

R.S. Cutler

Pig Research and Development Corporation, Barton, ACT 2604.

Introduction

Technology transfer implies a flow of technical knowledge from one point to another. It's an appropriate term for research groups seeking a simple model for the distribution of their findings. For the end user, it's simplicity denies the complex processes involved, and the skills and attitudes of both the end user and the effective extensionist.

People acquire information in many different ways. They acquire it from experience, from actively seeking it, from being alert to new opportunities and from being driven by sheer necessity to survive in a tough economic environment. They read, they use radio and television, they talk to one another and they follow formal educational methods to gather knowledge.

In the pig industry it is clear that some people are able to gather and apply information better than others. Rather than size, educational background or hard work, it is attitude that determines whether farmers apply the information that enables them to efficiently manage their farms. Efficiency determines whether they will stay in the pig industry or be driven from it by cost pressures.

Precise technical information is available for just about every facet of pig production. Intensification has isolated the industry from the climatic factors that determine the fate of the broad acre industries. Despite this, producers continue to leave the pig industry at an alarming rate. In 1977 there were 22,000 producers in the pig industry. By 1981, the number had fallen to 17,000, by 1984; 8,000, by 1992; 5,800 and by 1993; 4,800.

Efficient production in international terms is possible. Practically the information about how to farm pigs is being taken up and integrated into farm practices, but only by a relatively small group, if the trend in farm numbers is any guide.

The information is not being delivered quickly enough to, or received by, many producers perhaps because it is not being delivered in an appropriate form or just doesn't meet the needs of the individual.

Clearly existing extension models are failing to keep many pig farmers profitable. The spread in profitability is demonstrated in cost of production figures for a sample of Australian farms, (PigStats92, 1993). The three most efficient producers were still making about $21 per pig when the worst six were making at best about $1.40 to a loss of $11.20 per pig.

An environment must be developed where opportunities are created for pig producers to sample information from a range of sources. Many of these opportunities will be offered by the private sector, by veterinarians in practice, private farm consultants and managers of significant farming groups in addition to the public sector. This trend is evident internationally but in Australia there are relatively few people who can contribute significantly to the development of farm businesses.

In this Symposium four themes are presented. Ian Houseman describes the European climate and how Britain's extension service has responded to market driven forces. He describes how information technology approaches are being used as an important component of fee-based service delivery.

Peter Cook focuses on 'Pig Pulse', a Queensland Department of Primary Industries initiative and a component of a wider quality assurance program. 'Pig Pulse' is a powerful farm analysis and information retrieval tool which will have enormous implications for pig farm managers.

John Drinan predicts the changes in attitude and approach necessary to effect

changes in service delivery and describes the skilled communicators of the future who will guide farm development.

Richard Bawden adds to Drinan's theme with a personal odyssey. He suggests that there are different 'ways' of knowing, different approaches to development, which are used concurrently as the industry progresses towards more sustainable systems. He explores the concept that an extensionist is one who engages in a series of conversations which have persuasion at their heart; of conversations which are appropriate to the producers view.

The papers presented in this Symposium deal with what is already being applied, the technology of the future, and the communication skills and philosophies necessary to sustain our small industry in the face of intense inter-farm competition at a national and international level.

GETTING VALUE FOR MONEY FROM EXTENSION

C.I. Houseman

ADAS Oxford, Marston Road, Oxford OX3 OTR, UK.

Abstract

This paper reviews the various extension systems in Europe and describes in detail the position of ADAS in the UK. Changes in Government policy which brought about a move to a fee-paid extension service are described as well as some of the processes which ADAS went through to make itself a market responsive organization. In particular, the issues of product and service development, pricing and promotion, training and organizational restructuring are covered in detail.

Many extension organizations have well developed information technology (IT) systems and this paper also reviews the role of IT in supporting a modern market-led extension organization. ADAS developed an IT strategy over a 4-year period through a series of studies. The implementation of this strategy is described and the establishment of a new IT Unit in ADAS was seen as an important pre-requisite in order to bring about the required benefits from a substantial level of investment.

ADAS operates in a competitive market place and has to ensure that the requirements of existing and potential clients are properly assessed, and that services and products are developed in a way that meets these requirements to the satisfaction of the client. The use of market research to accomplish these tasks and some of the main findings of various studies are described.

Finally, the role of ADAS as an agent for implementing Government policy is reviewed. This has required some important structural changes and has, at the same time, required ADAS to invest in a completely new range of management information systems (finance, work recording, job costing etc.) in order to demonstrate cost effectiveness and value for money. The requirement to develop output measures for policy related work is also investigated.

Introduction

He who pays the piper, calls the tune - Scottish proverb.

A recent survey of Agricultural Advisory Services (AAS) in 16 countries (OECD, 1989) stressed the efforts being made to improve the efficiency and quality of services being provided to farmers. It noted that farmers were conscious of the fact that either directly, or indirectly, they financed the services and were therefore becoming increasingly demanding. In addition, funding problems due to budget restrictions were leading to radical changes to reform organizations, their orientation and structure.

The agricultural industry which is still the main client for extension

organizations is also changing. The number of farms is diminishing and the trends to increased size and greater specialization continue. Farmers' business and technical problems are becoming ever more complex and yet the importance of agriculture in the national economy, as measured by contribution to gross domestic product, is reducing. The general public increasingly impacts on agriculture through heightening concerns about conservation and the environment, food safety and animal welfare. Extension must take account of these concerns in its work.

Agriculture in the UK economy

The agricultural industry in the UK has a gross domestic product of about £6.8b, which represents 1.3% of the national GDP. In terms of land use, agriculture occupies about 75% of the UK land area, with around 18.5 million ha devoted to agricultural production. There are about 240,000 agricultural holdings in the UK, of which about 105,000 are part-time. Around 570,000 people are engaged in agriculture and this represents 2.1% of the total work force (MAFF, 1993). In contrast the food industry, including meals out and alcoholic drinks, is worth more than £90b, with imports of food and feed running at more than 40% of total consumption.

In some areas such as Wales, agriculture is much more a feature of the rural economy and consequently occupies a much higher proportion of the work force. In these remoter rural areas, agriculture and the associated support industries often account for 20% of the working population. Nonetheless, in many of these areas there has been a substantial depopulation, leading to the closure of local village schools and the withdrawal of other services, such as health and library facilities.

Government policy

The Government in the UK has supported agriculture in a wide variety of different ways for many years. That support in real terms has been diminishing over the last 15 years. A constant feature of Government support since 1946 has been a state-funded Advisory Service (Read, 1985). In addition, the Government has protected good quality agricultural land and controlled animal and pest diseases, as well as funding substantial areas of research and development work. These additional functions were embodied into a new organization, the Agricultural Development and Advisory Service (ADAS) in 1971.

Recent land use changes have seen the introduction of 'Set-Aside' and the Farm Woodland Scheme, to try and take some land out of agricultural production. Inevitably, this is the poorer quality land (set-aside) and the most inaccessible land (farm woodlands). As McInerney (1987) points out, this is a substantial change of agricultural policy from previous policies of simply continuing to support the prices and production of agricultural products. These policies are no longer sustainable in Britain and agriculture today is condemned for doing what was, a few years ago, applauded and commended. This turn-around of views has caused a sudden and deep transformation in public attitudes towards agriculture.

Since 1979, the Government has progressively reduced the amount of public funding available for research and development and advisory work. In R & D in particular, the cuts have been quite substantial and have led to major reorganisations in the Agriculture and Food Research Council (AFRC). As far as research work in ADAS has been concerned, the Government has reduced its funding of 'near to market' work and has invited the agriculture industry to fund this directly. ADAS has had some success in encouraging farmers to support work which is of direct relevance to them through for example, crop centres. The Government has just announced the formation of a new body for research to be known as the Biotechnology and Biological Sciences Research Council which will encompass all the work of the AFRC.

The introduction of fee paid advisory work

In 1984, a new Director General for ADAS was appointed and in his report he recommended that ADAS should introduce fee paid advisory work (MAFF, 1984). Commercial advisory work was introduced in England and Wales by ADAS and in Scotland by the Council of Scottish Agricultural Colleges in March 1987. The original target was for the recovery of 20% of the cost of the advisory work. In contrast, it was anticipated that the commercially funded research work should recover all of its cost from the outset. Some areas of advisory work, however, remain free and these are concerned with the environment and conservation, rural diversification and animal welfare. As far as the environment is concerned, the Ministry of Agriculture, Fisheries and Food has introduced a series of Environmentally Sensitive Areas within which MAFF reaches an agreement with land-owners and farmers about the agricultural practices to be employed, and the occupier of the land is paid a subsidy for farming at a less intense level.

More recently, there has been the introduction of a number of Nitrogen Sensitive Areas, where it is intended that the amount of nitrogen applied to the land will be reduced by altering cultural practices and again this is subsidized. In addition, ADAS is committed to provide an intensive program of free advice, with specific aims of reducing the overall amount of nitrogen applied in these areas, to ensure that as little nitrogen as possible is leached out of the soil.

Following Professor Bell's report, the necessary primary legislation to allow the introduction of charging passed through Parliament in 1986, in time for ADAS to start its commercial activities in March 1987. This meant that there was a period of some 1.5 years which allowed ADAS to plan and implement a whole series of changes. In order to assess the potential market demand for advisory services, ADAS undertook a major market research exercise in 1986 which tested a number of charging strategies (Bawcutt, 1989). The potential methods of charging were:

1. Subscription schemes where a fixed amount is paid per annum for telephone or visit contact.

2. A fee paid per hour.

3. A range of fixed priced products, eg; laboratory services.

4. A contract negotiated with the individual.

5. Other services such as conferences, publications and other information.

ADAS market research

In preparation for the introduction of charges for advice a substantial independent research exercise was carried out to establish:

1. Information about how ADAS was viewed and used when operating as a free service.

2. Potential customer's attitudes towards the type of services required and the need to pay.

3. How much users would be likely to pay and in what quantities would services be required.

The research findings revealed very low levels of criticism about ADAS, with high levels of usage, particularly amongst the larger farm business. ADAS was

regarded as a very important source of information on new techniques, products and enterprises. It also rated very highly in the way it attended to immediate problems on the farm and in its provision of farm business management advice. Generally speaking, the larger and more specialized the farm, the greater the requirement for specialist extension support. This was particularly noticeable in the pigs and poultry sector, where around 90% of farmers specified a requirement for specialist advice, compared with only 10% for generalist advice. The findings of this market research exercise showed that ADAS could be reasonably confident about reaching its first year financial targets. In 1990, it was estimated that the total market for advice was around £50 m and that ADAS had a market share of around 20%. It was also clear from the research that the perceived benefit of taking advice related to increased profit margins, cost savings, increased yields and output and, improved financial control.

Training

In order to equip its advisers for these changes a substantial training program was undertaken. This covered such areas as marketing, selling, sales management, contract negotiation, presentation skills and communication. These training courses involved some 2,000 personnel and the emphasis was mainly on selling skills and embraced the 'ACE' factor to successful selling: Attitude, Commitment and Enthusiasm.

Throughout the training program a number of fundamental points, which had become clear from the market research, were communicated to staff. These were as follows:

1. ADAS had a high level of spontaneous awareness.

2. Trust and confidence in the adviser are vital.

3. Increasing technical complexity is the main reason for seeking advice.

4. Independent impartial advice based on unbiased research is a key feature of the ADAS offer.

5. There was potential for high levels of repeat business.

6. ADAS was most commonly used for arable advice, livestock health and nutrition, and farm management.

7. ADAS needed to develop greater commercial and business awareness.

8. ADAS needed to develop a more personal service with a stronger adviser/farmer relationship.

9. Different services needed to be developed to meet the needs of different target groups.

The training courses also provided a useful means of ventilating peoples' concerns and fears about moving from a free to a fee-charged service. To assist in carrying out the training program the services of external consultants from the commercial sector, who had experience in privatising public sector bodies, was sought. A lot of the concerns were dealt with during the courses but many others were left to be picked up as more information was revealed about how ADAS would operate in the new environment. As time went on and as their experience of the new situation developed, advisers become more confident in their abilities to sell services and to raise revenue. Inevitably some advisers performed better than others and additional

help and training was provided where necessary.

Organizational structure

It became clear during the move to a more commercial service that the existing structure of ADAS was not the most appropriate for an organization which purported to be market-led. In the lead up to ADAS being turned into an independent executive agency, a whole series of change programs was put in place and one of these dealt with the shape of the organization. This report (ADAS, 1991) said that the eventual shape of the ADAS agency should be determined by the profitable services it supplies, which in turn will be the function of its ability to meet the demands of the market. The previous structure had several layers of management and a large number (over 35) of internal disciplines. This structure was therefore very much inward looking and not adapted to meeting the demands of the market place. As in the classical extension model, front line advisers were supported by a range of science and subject matter specialists, each represented and managed at HQ level. There was a strong notion that, for example, only a soil scientist could manage soil scientists, whereas, at the sharp end what was required and made to work in spite of the organization, was a multi-disciplinary team approach. It was felt that in order to satisfy customer's needs in the future, ADAS would have to deliver:

1. Skills with breadth and depth relevant to the profitability of the client's business.

2. Value for money through demonstrable benefits.

3. Impartiality.

4. Customer care features such as ready contact and accessibility, knowledge of the client's business, trust, quality service, after sales contact and an avenue for complaint and remedial action.

5. An R & D base to consultancy work.

6. Facilities and capabilities for long and short term R & D.

7. A track record of dealing with similar business needs.

8. An organisation with good geographical spread and contact with land-based industries, both locally and nationally.

9. Back-up laboratory facilities offering a timely service.

10. Knowledge in the wider context covering marketing and processing products, statutory requirements and implications of Government policy.

In the event, a number of principles were devised, which guided the choice of structure. The first principle was that the structure needed to become much flatter and allow local managers both the responsibility and authority to manage their part of the ADAS business. Secondly, that the subject matter specialists and science specialists should be much closer to the front line, in terms of servicing clients. Thirdly, that it should not be necessary to have to move staff in order to reward them financially or status wise. Fourthly, that all staff working in the consultancy teams would be involved in selling and delivering services and that organisational boundaries would not be solid. In other words, to allow the client an element of choice across the boundary working would be encouraged.

Special consideration was given to the management of knowledge within ADAS

so as to ensure that front line staff were kept as up to date as possible. In the event, six development centres were established to provide technical information and training, a lead in product development, liaison with R & D, as well as being a focus for policy advice to MAFF.

The current structure therefore has 15 Consultancy Centres providing the bulk of the consultancy advice to farmers and other land using industries, and 11 Research Centres, mainly carrying out work for MAFF, but with about 15% of their income coming from commercially-funded research. In addition, three so called Statutory Centres were included in the organization to provide MAFF with policy implementation services, which were regarded as too sensitive for the commercial arm of ADAS to deliver. Finally, there is a Laboratory Centre providing a wide range of analytical and diagnostic services, either free-standing, or as part of consultancy contracts.

Development of products and services

From the outset, it was clear that ADAS would need to develop a range of products and services, which would be offered to the market place in a way which advisers would find easy to sell and the clients would find easy to identify benefits. Initially, 10 product service sectors were established covering the whole range of services which ADAS could offer (Bawcutt cited by Houseman, 1990a).

The 10 product sectors are:

1. Livestock
2. Cropping
3. Horticulture
4 Business management
5. Land management
6. Product marketing
7. Design
8. Research and development
9. Laboratory
10. Special projects.

These product sectors provided a broad framework for classifying the services available from ADAS, but were still a reflection of the internal organizational structure. They did not accurately reflect the different categories of clients with which ADAS now works. For each of these main areas of business activity, ADAS had a product service manager, who was responsible for the development of new consultancy products (Bunney and Bawcutt, 1991).

Currently ADAS is working hard to redefine its main product offerings and to identify which markets they should be offered to. This market/product matrix will be used to analyse, monitor and develop the ADAS business. It is already possible to see where our main areas of revenue earning are and where there may be new possibilities for the future. It is also intended to use this approach to identify the staff resource requirements needed to service particular markets and at the same time to redeploy any surplus resource through re-training. The flexible structure that has now been created should be capable of adapting to the changes in the ADAS business as markets grow or diminish.

Promotional activity

Although the market research had shown that there was a very high level of spontaneous awareness of ADAS, later research showed that farmers and other clients really had very little knowledge of what the service had to offer. A big part of the promotional activity was to educate the market place about the sorts of products,

services and skills which ADAS could bring to bear. A starting point was to try and ensure that ADAS personnel themselves were well informed about all the Service's capabilities. The concept of cross referrals and cross selling rely very heavily on all consultants being well acquainted with what others in ADAS can do for clients.

In promoting the services of ADAS of course it is vital that we have good knowledge of the market place. This is relatively straightforward in the main market in which we have operated for many years, that of the traditional farmer and grower sector. In other areas, such as the food industry, local authorities, land restoration, transport, leisure and sport, there is a requirement to make a positive effort to gather information about the market as a whole and individual clients within that market place.

Whilst ADAS does spend substantial sums of money in providing its clients with a quality technical magazine ('Farm Strategy') and has a presence at all the major national and regional agricultural shows, by far its most effective form of promotion is through the personal recommendation of satisfied clients. A considerable amount of effort also goes into keeping farm magazines and newspapers supplied with a steady stream of technical information and comment, as well as supporting them at other promotional events and demonstrations. ADAS continues to organize conferences and demonstrations, some of which are charged for and are specifically set up for particular clients. Local radio and occasionally television are also media which provide useful opportunities to keep the ADAS name in front of our main markets. As the ADAS business moves into new areas of activity, it has been supported by promotional programs designed to fit those markets. Very little straight-forward advertising is done through any of the media, apart from some occasional low-level advertising in specialised magazines. Nonetheless, the ADAS promotional effort is considerable and includes the retention of the services of a public relations company.

ADAS information technology strategy

In his report, the Director General of ADAS also made a commitment to the wide-spread introduction of the use of IT into the work of ADAS (MAFF). It was noted that ADAS, like most extension organizations, was essentially an information trading organization. It generated, collected, digested and passed on huge volumes of information in many different ways and in a wide range of formats.

ADAS had been planning its IT strategy and carrying out various studies even before charging was introduced. These covered a detailed analysis of the technical data flows in ADAS (MAFF, 1985), an investigation into the IT requirement and finally, a strategy study (MAFF, 1989) leading to implementation. A strategic business decision was taken early in this process to concentrate on the provision of programs for advisers for use in their day to day consultancy work with clients. Some of the systems would be run as central bureau services and some would be provided on personal computers for use on the farm. The rationale for this was based on a simple business model, which viewed providing information and giving advice as a value added process. It was decided that ADAS would not compete directly with the agriculture software houses, but would use its unique position to bring its wide range of skills and expertise together to develop systems which would be powerful aids to advisers in their consultancy work with clients. The provision of laptop PCs (Houseman, 1992) to advisers has been a big step forward in this process. All the systems which have been developed provide a tangible outcome to the consultancy process in the form of reports, rations, financial results etc. In addition, the use of IT gave ADAS a modern dynamic image which was important from a marketing standpoint. The bureau services cover dairying, sheep, pigs, poultry, irrigation and arable crops. Around 3,500 clients have their data processed on a weekly or monthly basis, with the emphasis on fast turn around and high quality laser printing. The advisers use these services as a basis for consultancy contracts with clients. Currently, these bureau services support over £3m worth of consultancy work.

Systems business classification

It has been important from a strategy management viewpoint to classify the systems in their contribution to the overall business aims of ADAS. The classification is as follows:

1. Support systems which are valuable but not critical to current success. The major benefit is economy.

2. Operational systems on which ADAS currently depends and for which the main benefit is efficiency.

3. Business impact systems which are critical to support the present and future success of the business. The major benefit here is effectiveness.

4. Opportunity systems which may be important in the future. Allowance is made for innovation and technology in a forward looking manner.

Each requires a different style of management. For example, support systems require low risk solutions with proven technologies, with justification based solely on tangible return on investment, with optimal use of resources. Operational systems are automating the primary business activities and the systems should deliver solutions with a good fit to the essential business requirements. Integrity and cost effectiveness are the key components. Business impact systems require users to play a central role and the emphasis should be on problem solving using new technologies, where appropriate, and accepting an element of risk. Opportunity systems, however, are often user initiated and contain high levels of risk. Again, they are driven from a problem-solving viewpoint and represent essential investment in exploring forward. There needs to be an encouragement of innovation and risk taking but control by stringent reviews (Houseman, 1991).

The ADAS Information Technology Centre

This was established in 1988 and has current staffing of around 60 full-time staff, at all levels. The importance of establishing a centrally managed and funded IT Centre cannot be over-estimated. The main areas of work cover software development, user support and training, operations and data management and there is a separate biometrics unit. The staff of the IT Centre were drawn from the user population and also from the world of IT. This synergistic measure provided the necessary impetus to bring about change and to implement the ADAS IT strategy. As well as providing support for technical systems for use in consultancy work, this IT Centre also is responsible for operating the main management information systems which ADAS uses to control its resources.

Extension as an agent of government policy

Although ADAS is now an independent executive agency, it is still jointly owned by the Ministry of Agriculture, Fisheries and Food and the Welsh Office and as such is seen as a major instrument for the implementation of Government policy. The commercial objectives of ADAS need to be seen in the light of its requirement to provide services on behalf of its parent departments. As Harter (1992) notes, the survival of ADAS will not depend solely on its ability to generate more income from client fees; it still has an important responsibility to support the overall mission of MAFF and the Welsh Office. As mentioned earlier, a substantial amount of ADAS R & D effort is in support of Government policy work. In addition to this, a further 500 staff years are delivered to over 40 policy programs, covering areas such as conservation, farm woodlands, marketing, meat hygiene, pollution and statistics. All the ADAS input to these programs is the subject of internal contracts with the policy

divisions concerned. ADAS is paid on the basis of the agreed amount of time delivered into these contracts. Clearly, a certain amount of flexibility is required so that resources under-used in one area could, if needed, be transferred to other more demanding areas. All the programs have detailed objectives built into them and control and quality criteria are applied to the ADAS delivery. Others are dependent on demand arising from within the farming industry and often it is difficult to estimate the level of resource to be taken up. ADAS operates a work recording system, which collects time booked to the various programs, and the ADAS contract manager agrees to the time input with the sponsoring policy division, and payment is made on a monthly basis.

Clearly, these programs are monitored and controlled on the basis of resource inputs, but increasingly the Government and the public at large are developing interest in the results of these policy programs. In other words, there is now a keener interest in the development of output measures, so that it is possible to examine more rigorously value for money. In a time of stretched Government resources, Ministers and their policy advisers are trying to establish means to demonstrate the value of their various programs. This is an area where ADAS can be of great help because often ADAS has the knowledge and information to assist with the development of worthwhile output measures.

In the current situation, the Government has stated its intention to market test many of the programs which it funds and ADAS will have to compete with commercial and other organizations for this work, as the market tests come forward.

At the moment ADAS is not allowed to make a profit on its work for MAFF but on the other hand, neither does it make a loss! In other words, the work is all fully funded, covering direct and overhead costs at an agreed rate per staff year. Increasing pressure on Government budgets does mean though that ADAS has to manage its costs most carefully and to this end has established a comprehensive suite of management information systems. These cover finance (accounts receivable, accounts payable, general ledger), personnel, work recording, job costing and a client database.

Subsidised extension work

At the moment the Government subsidizes extension work to all sectors of agriculture, at around 50% of the cost of providing the service. This subsidy will diminish over time and may completely disappear in due course. However, the Government has the option of deciding to subsidize various disadvantaged sectors of the agricultural industry. In order to do this, ADAS must be able to show where it is providing a fully cost recovered service and where it has provided a subsidized service. A comprehensive suite of management information systems will be vital in showing the Government that its subsidy is going to the right sectors of the agricultural community. However, the vexed question of deciding who is eligible for subsidy and to what extent the service should be subsidized, has yet to be resolved.

Discussion

According to Siardos (1990), the ancient Greek Triptolemus is regarded as the first agricultural adviser who travelled all the known world, and supplied farmers with inputs they needed, and trained them to make efficient use of their resources. Triptolemus was initiated in the secrets of agriculture by Demeter, the Goddess of Agriculture, who trained her priests on agricultural matters. It is perhaps this desire to preach rather than discuss or as Bunney and Bawcutt (1991) describe it, as a desire to tell rather than listen, which has been the downfall of so many extension services. It is also the tendency to avoid giving positive advice and a lack of understanding of the farmer's circumstances, which in the past, has weakened the delivery of what undoubtedly have been very technologically well-developed services. It is this ability to communicate with clients in the working environment of a partnership which has characterised the development of commercial services in ADAS. A recent small scale

informal survey of ADAS clients who had expressed dissatisfaction with the quality of service provided by ADAS revealed a number of interesting factors. The main reason for dissatisfaction was the lack of any perceived positive impact on the client's business. In other words, the extension service, through the individual consultant, had failed either to make an impact on the client's business or, and this was admitted by clients in some cases, to have made explicit, precisely what the business benefits of using the extension service were. In general, most clients were happy with the performance of the individual consultant and it was particularly noticeable in a few instances that the personality, enthusiasm and drive of the individual consultant more than made up for perceived deficiencies in the delivery of a dairy costing service. The reasons for using ADAS were basically in two broad areas. The first, as previously described, was to achieve some long-term business benefit largely centred around the need to improve business performance. The other requirement mentioned by clients was the need to have an independent view of the course the business was taking and the assurance that no opportunities were being missed. This could be largely viewed as a security/insurance investment on behalf of the client.

In ADAS, all the front line extension staff are educated to at least Bachelor of Science first degree level and increasingly, a proportion have post-graduate qualifications of one form or another. However, the characteristics of the agricultural industry and the people in it, mean that the best approach is one of a business partnership with the client. In their book on the training and visit (T & V) system, Benor and Harrison (1977) note that any restructuring of an extension service should allow for flexibility, but at the same time have a unified command structure. They also point out that the fundamental requirements are firm decisions to set priorities and concentrate efforts to ensure success right from the start. Whilst the T & V system would be inappropriate for many developed agricultures, the need to identify very clearly the objectives of the organization and the individuals within it is an area which has been addressed with some vigour in ADAS. Extension workers are regarded as agents of change and yet they operate in an environment which is constantly changing. To operate effectively in this environment, the individual extension worker needs to have the necessary authority to make decisions about the service provided to clients. In many extension organizations the bureaucratic structure divorces responsibility and authority, with the result that the ability of individuals to take decisions and act is often impeded. In the ADAS framework document (ADAS, 1992), which is the enabling charter for the operation of ADAS as an independent executive agency, a number of key strategic performance indicators are identified. They are as follows:

1. Cost recovery, after taking account of all funding including Departmental contributions to certain charged advisory services.

2. Average total cost per direct hour charged for contracts.

3. Surveys of customer satisfaction.

4. Percentage of R & D project milestones completed on time.

5. Due debt in relation to sales.

These key indicators are translated down through the organization in the form of financial and operational objectives for each consultancy centre and the teams and individuals within it. Each team has a business plan and each individual has a work plan setting out his objectives in terms of revenue and the delivery of other services. However, the way in which these targets are achieved is left to the individuals that comprise the organization through discussions with their managers.

When extension is offered as a free service, the major requirement is to ensure

efficient information transfer, so that the results of research are translated rapidly into practice (Cunningham, 1983). Yet R & D work is of little avail unless it can be translated into benefit for the farmer (Fleming and Robertson, 1990). Whilst there have been a large number of studies into information systems and the delivery of information (Blackie and Dent, 1979; Craig, 1979; Buntrock, 1980; CEC, 1980; Nielsen, 1982; Shimoda, 1992) and in the communication of information (Carter, 1978; Hoey, 1980, 1985; Fearne and Ritson, 1989; Houseman, 1990b), much of this work has its roots in the classic work on adoption and diffusion (Rogers, 1962; Rogers and Shoemaker, 1971; Rogers, 1983). There are now, however, some interesting discussions related to the understanding and development of agricultural knowledge and information systems (Barrett and Jones, 1989; Kuiper and Roling, 1991) which suggest that our understanding of the research-extension-practice continuum really needs to take a more fundamental systems-oriented look at how new knowledge is adopted by the agricultural industry. The ADAS mission statement clearly identifies the issue of benefit. The mission of ADAS is 'to be the leading consultancy to land-based industries in the UK, working with our customers through the provision of quality services *'for the benefit of their businesses'!* It is this issue of benefit which is the most difficult for extension services to quantify and yet clearly is the yardstick by which clients using extension services will assess their value. In order to help farmers to understand the benefits or cost consequences of taking some advice or consultancy from an extension service, means of making these more visible and explicit is required. In the pig industry, for example, the main areas that farmers could make an impact on their business are as follows:

1. Genetic
2. Nutritional
3. Breeding, disease control and other husbandry
4. Engineering, environment and waste management
5. Labour and business management.

It is suggested that a value/cost matrix is established for these main areas of activity and that baseline costs (from previous accounts) could be established for these major areas. For example the purchase of replacement gilts, the cost of bought-in feed etc. could all be established for a pig breeding and/or fattening business. It should then also be possible to quantify the value/cost of various performance improvements and, just as importantly, potential performance losses due to for example, disease factors. The next step is for the extension worker and the farmer to set objectives for various performance improvements in each of these main areas and for the extension worker in particular to identify how these improvements may be brought about. Most modern farm businesses operate a variety of management practices and financial controls (Gasson, 1989) and any extension worker worth his salt should be providing a substantial management input in the form of financial analysis, budgeting etc. and so some key areas for examination, improvement and monitoring could be identified. In this way, it should be possible to provide a framework to identify the benefits of using an extension worker or consultant as a professional business adviser. The main strength which extension possesses is the ability to look at both the financial and technical performance of a business and analyse the reasons for good or bad performance. The difficult part is to establish a cause/effect relationship between the provision of the consultancy and advice and the improvement in performance. However, in the pig industry it is possible to isolate other factors, such as price improvements and costs reductions etc. and remove them from the matrix. Market research for ADAS has indicated that there is a large pool of farmers and growers who have yet to be convinced of the benefits of purchased consultancy (Bunney and Bawcutt, 1991) and that many still see consultancy as a cost rather than an investment in their business. Using a matrix such as the one described should enable the adviser and client clearly to understand the benefits which have been brought to the business

by the purchase of advisory consultancy.

Conclusions

It is clear that the funding of extension services the world over is under threat, due to reduced budgets and financial pressures in many economies, of both developed and developing countries. In this environment, Governments, tax payers and even the extension organizations themselves are posing questions about the value for money which such services offer. Increasing public interest in the environment, conservation, food safety and animal welfare mean that the activities of extension services are also under the gaze of the man in the street. Societies are expecting their food to be produced in a safe, humane and sustainable manner, at reduced cost. Support for agriculture through various price adjustment mechanisms and subsidy funding is also an increasing burden on the tax payer and there is great momentum to reduce the overall level of subsidy to world agriculture, vis the current GATT round.

In the past, the provision of a free extension service has proved to be a dilemma for both the provider and the recipient. It is extremely difficult to value the provision of free advice. In a charging situation, both the provider and receiver can rationalise their transaction by negotiating a price which satisfies both their needs. An added advantage for the extension service and the client is that the action of paying almost completely ensures that the advice will be put into practice. In the previous free situation, farmers would often poll many sources of information and advice and at the end of the day would perhaps still do nothing. An experienced consultant always works extremely hard to establish what the client's objectives are when considering buying consultancy and advice. This act focuses the delivery of service to the client in a way which did not happen when the extension service perceived a religious-style mission to deliver information to the widest possible audience.

Of course, there are dangers in that it can be argued strongly that, only those who are able to pay, can benefit from the advice and yet almost all extension services freely acknowledge that those people who could benefit most from their help, even when free, are the ones who are the most difficult to reach. This has long been a problem for all extension services and a number of approaches to try and overcome the problem have been proposed (Dexter, 1986).

Any modern extension service must be able to justify its existence, either by raising a proportion or all of its income direct from its clients, or by establishing its value through the provision of 'public good' programs, which meet the objectives of agricultural policy makers (NAO, 1991). In order to secure their future therefore, extension services need to demonstrate that they can provide a value for money service to their clients, be they farmers, Governments or the general public.

PIGPULSE: A CONCEPTUAL DEVELOPMENT IN PIG INFORMATION TECHNOLOGY

P.W. Cook, D.B. Preston* and R.A. Spencer*

Queensland Department of Primary Industries, PO Box 597, Dalby, Qld. 4405. *Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.

Summary

The pig industry is rich with data. The potential to generate and capture knowledge revolves around turning data into useful information. The processing and manufacturing industries (eg; Western Electric, Bell Telephone Laboratories) have developed these technologies (Garvin, 1988) into a managerial discipline referred to as

Total Quality Management (TQM). This discipline is directly applicable to intensive agricultural production.

TQM is founded upon applying statistics to production data to clearly signal real changes from within confounding variation. This provides the basis for intervention to alter the process. The object is to continually improve the process to improve customer satisfaction.

The PIGPULSE computer program turns pig data into usable information. The PIGPULSE 'system' activates people to generate knowledge to influence production. It incorporates producers, consultants, agribusiness representatives, researchers, extension officers and educational institutions into an information network.

Introduction

Intensive pig production has similarities to other industries with assembly lines. Some of the technologies developed for these industries are appropriate for pig production. Most pertinent of these is Total Quality Management, (TQM), which offers the pig industry a way to accelerate the adoption of research findings. There are many aspects of TQM (eg; Total Quality Control - TQC) suitable for direct application to pig production.

"TQC is the application of statistical principles and techniques in all stages of design, production, service, marketing and administration to achieve disruption-free, error-free activities that produce defect-free products and services at a quality and cost suited to the market, and with dependable delivery. In TQC terms, statistics is the science of converting data into information". Most people recognize that variation exists but do not know what to do about it (McConnell, 1988).

Grant and Leavenworth (1988) proposed that a stable pattern of variation exists in any production process and provides the basis to discover special causes of excessive variation.

The managerial concepts and production monitoring systems embraced by TQM are potentially valuable to the pig industry. TQM enjoys broad-based support in secondary and tertiary industries. The exposure of primary industries to TQM principles has, however, been rare. Sard (1979) working with cattle feedlots provides a notable exception.

Cook (1991) investigated the application of quality control techniques to monitor slaughter data. In a project called GROGRADE, more than 35,000 pigs were processed from the piggeries of 20 co-operating producers. Mean growth rate improvements of 48 g/day, as well as fat reductions of 0.8 mm, were demonstrated as a result of changes implemented in nutrition, housing and genetics. Performance responses of this order have the potential to inject about $60 million additional annual profit into the Australian pig industry. The GROGRADE work established the value of distinguishing real production changes from confounding normal variation. Change signals clearly demonstrated responses to managerial intervention or identified issues worthy of further investigation.

Unlike GROGRADE, which processed data from the end of the production process, PIGPULSE seeks to analyse data generated during the production process.

Currently under development, PIGPULSE will be a management information system centred upon a computer program that monitors pig production to detect changes in performance. Historical farm data and research findings will be applied to explain performance changes. Alarms will be prioritized according to their financial effects and an expert system will provide information to help producers control production. This framework will also provide the basis to organise, deliver and evaluate future research and extension services to industry.

Industry situation

The Australian pig industry will continue the current trend to contract into fewer

but larger specialist units in the next decade. Cresap (1990) predicts "By 2000 we would expect specialist dedicated producers to control approximately 90% of the herd ... Their relative growth will be driven by access to **good management information,** and premium markets". Information demands will change accordingly to address technical production issues.

Data collection is well supported in the Australian pig industry for the purposes of carcass payment and monitoring enterprise performance, be it physical or financial. On-farm computer recording packages represent a rapidly emerging industry data source. A survey of 113 Queensland producers indicated that 35% of respondents used a computer in their enterprise (Preston, 1990).

The commercialisation of electronic identification transponders (Street, 1979) will further accelerate the demand for on-farm data processing facilities. Currently, the data captured at slaughter comprises the major component of the data pool. Producers get feedback about each pig carcass in terms of its weight, fatness and sex, but are not equipped to use the data to advantage. The problem areas are:

1. The sheer volume of data accumulated each week
2. The mathematical skills required to use the data
3. The confounding variation in results often defies interpretation (see Figure 1)
4. Once the pigs have been slaughtered it is too late to do anything.

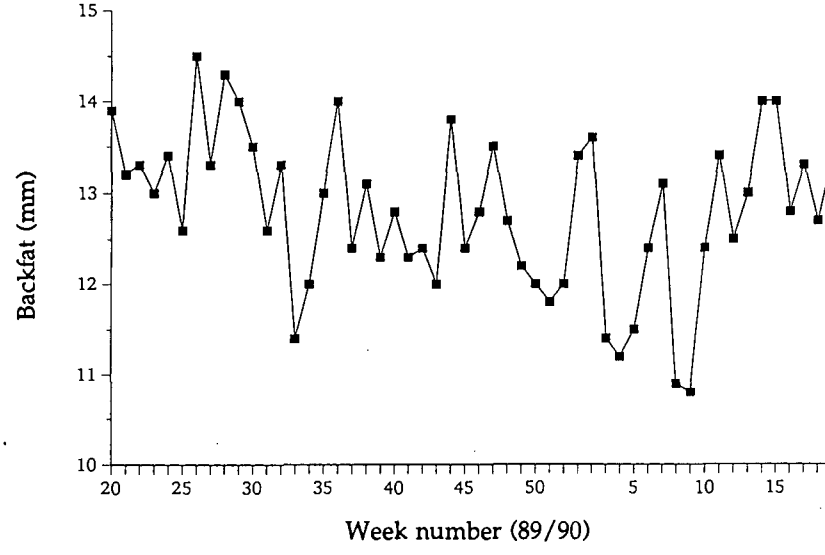

Figure 1. *The variability of weekly mean slaughter P_2 fat depth from a 300 sow piggery.*

A primary difficulty faced by producers in improving production efficiency is to marry causes or problems to their effects on production. The manager's objective is to manipulate the on-farm causes to produce the desired effect at slaughter. For example, an effect could be the increase in carcass fatness and a possible cause could be over-feeding. The difficulty is that for every effect there are independent or interrelated causes. Fatness may be due to disease, genotype, temperature or nutrition. The complexity of cause and effect relationships poses a barrier to informed on-farm decision making. The confusion also impedes educational processes.

"If the pig industry is to refine its future management skills it will need to sharpen its analytical tools as a precursor. The production sector is fertile ground for a TQM approach during the production process. In particular the intelligent use of Time Series Analysis to scrutinise changes and trends in performance traits will be an essential adjunct to current herd recording activity" (Cleary, 1992).

The 1980's also ushered in a sharp rise in the intensity of production recording both on and off-farm. The computer era in agriculture is accelerating this trend to the point where the pig industry faces 'data-overload'. However, while the industry recognises the potential value of production data by collecting vast quantities, the data are severely under-utilized. Data recorded originally for production organisation or financial purposes can also be used to monitor and control production processes.

The 1980's also saw many technological breakthroughs in the pig industry. The absence of research findings is no longer the limiting factor. The 1990's offer the potential to utilize farm data to learn how to apply existing technologies within the production sector. This can be achieved by using farm data to:

1. Quantify and demonstrate the variability of performance traits to unit managers.

2. Transform variable physical performance into financial effects so as to provide incentives to understand the factors involved.

3. Provide relevant supportive information.

4. Motivate people to control production variability by way of managerial intervention.

Integrated computer systems are currently being developed to provide and automate these functions. Advanced computer information systems that have been developed include: CHESS (Huirne *et al.*, 1992), GTEP (Pomar *et al.*, 1992), BIPS (Petersen and Rosendaal, 1992) and the BIG-system (Backus *et al.*, 1992). These systems are now actively employed to support European pig production and service a significant portion of the industry's information needs there. A French system (Dagorn, 1992) services 5000 herds comprising 30% of the national herd. A Danish system (Herlov and Vedel, 1992) services 55% of piglet production units and 35% of slaughter production units. A Spanish system (Noguera *et al.*, 1992) services 1050 herds of which 52.5% are integrated companies.

What is PIGPULSE?

A management information system is defined by Davis and Olsen (1985) as an integrated, user-machine system for providing information to support operations, management, and decision-making functions in an organisation. A decision support system allows the user to retrieve data and to generate and test alternative solutions during the process of problem solving (Huirne *et al.*, 1992).

The PIGPULSE computer program is founded on the principles of Statistical Process Control (SPC) and incorporates a management information system. The inputs into PIGPULSE are computer-generated industry data sets. The output is useful managerial information. The program is in an early developmental stage and the database, graphing and alarm modules are functional. The financial, analysis and expert modules are to be developed. The components of the program are illustrated in Figure 2.

The alarm module uses statistical process control techniques (Oakland, 1986) to monitor the production process. Cumulative Sum (CS) analysis is the predominant method used to signal shifts in the process mean and/or variance. The level of significance applied in this analysis is infinitely variable. The lower the confidence interval the higher the incidence of false alarms. A CS analysis is performed by testing data accumulated in real time against an established target value. The analysis decides if the data is varying about the target as it normally should, or whether it is beginning to stray from the target.

FARM DATA:	Data is generated from independent computer sources.
↓	
DATABASE:	Stores, collates and processes data from many farms.
↓	
GRAPHS:	A graphical presentation of production traits for each
↓	farm.
ALARM MODULE:	Looks at individual traits to automatically detect
↓	production changes.
FINANCIAL MODULE:	Prioritizes alarms by transforming the physical
↓	performance changes detected into financial effects.
ANALYSIS MODULE:	Looks at other farm data and research findings to
↓	technically explain alarms.
EXPERT MODULE:	Presents useful production information to enable producers to respond to alarms.

Figure 2. *Components of the PIGPULSE computer program.*

When a cumulative sum analysis is conducted (see Figure 3), the program begins at the first datum and scans through the data accumulating information. It keeps accumulating information from each datum point in sequence until it has enough evidence to prove that a change has occurred (point of detection). It then backtracks through the data to find the point where the change first began (point of change). The current average is calculated from the data contained between the point of change and the point of detection. The initial target is rejected and replaced by the current average and the process is reset to begin again. Thus the 'new target' is founded from the evidence that rejected the initial target.

The process of rejecting and replacing targets continues until the end of the data sequence is reached. The resultant output is a graph consisting of a series of steps (up and down). The height of each step represents the current or local average. The length of the step indicates the duration of the local average. The output of the alarm module will be predominantly graphical with detected process deviations returned to the financial module for transformation.

A simple profit model will be developed by quantifying a profit equation for pig production. Partial derivatives of this function will quantify profit responses to single trait performance changes. Where a single trait change may also influence secondary traits, a more complex modelling technique may be required. The output of the profit model will enable the prioritization of production changes detected. These signals will be passed through an analysis module to activate an expert system that interactively presents relevant information. In conjunction with the expert module, the analysis module will apply standard statistical techniques to seek explanations of process deviations.

An expert system (ES) can be defined as a computer program using expert knowledge to obtain high levels of performance in a narrow problem area. It thus can be considered as a modelling of the human reasoning process, making the same decisions as its human counterpart (Turban, 1990). Boehlje and Eidman (1984) described decision-making in five steps:

1. Define the problem or opportunity
2. Identify alternative courses of action
3. Gather information and analyse each of the alternative actions

4. Make the decision and take the action
5. Evaluate the outcome.

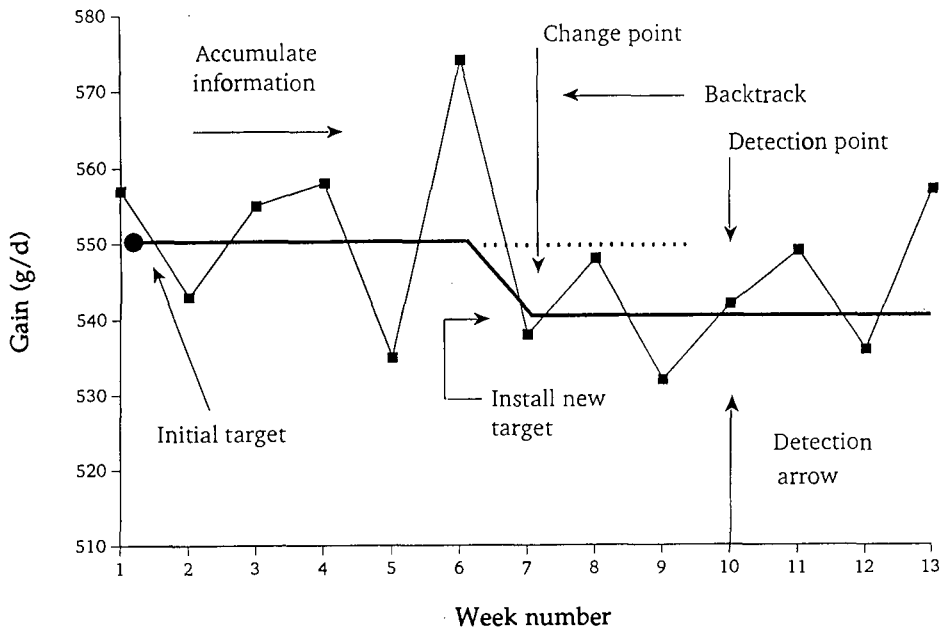

Figure 3. *The cumulative sum analysis technique.*

CONSULTANT-C is an expert system shell currently being developed by the Queensland Department of Primary Industries and the Queensland University of Technology. CONSULTANT-C provides the expert system shell for 'intelligent' diagnosis or interpretation of process deviations in a multi-variate environment. Known relationships and interactions will be coded in the expert system and further developed as the output of the alarm and analysis modules are evaluated. The presentation format will not be restricted to a simple text-based system, but will incorporate multi-media concepts. In particular, CD-ROM technology will be used to include context sensitive imagery in the output. A multi-media presentation format enables text, pictures, video and speech to convey this information to the end user. The expert system's information base will be constructed from existing industry sources and new information captured through research and extension activities. The potential sources of information for the expert system are:

1. Relevant literature
2. Industry training programs
3. Educational institutions
4. Industry information packages
5. Producers' practical experiences
6. Field investigations
7. Internationally developed expert systems.

What PIGPULSE does

PIGPULSE is initially being developed to support SOWTEL data but a range of

other computer data sources will also be incorporated into the system. SOWTEL is the Queensland DPI's piggery management monitoring scheme. A representative sample of historical piggery data is required to develop and test various statistical techniques. SOWTEL data spans 10 years across 100 production units representing 20% of Queensland's pig production and is readily accessible. There are six producer discussion groups associated with SOWTEL that will accelerate the evolution of PIGPULSE by:

1. Giving a practical and informed user's perspective
2. Validating results
3. Developing presentation formats
4. Providing a balancing link between information agents, industry and software developers.

Farm data are processed in 'batches' in chronological order. Mean performance measures for different production traits (see Figure 4) are entered on a periodic basis (as received weekly/monthly). Farm data are processed to produce a periodic list of the traits that were detected to have changed between two designated points in time (see example in Table 1).

Table 1. An example change list generated from SOWTEL data

Month	Trait	Was	Is now	Change	Profit[1]
Oct 92	Farrowing (%)	58.0	86.0	28.0	$$
Oct 92	Av. born dead/litter	1.49	0.79	(0.7)	$$
Oct 92	Preweaning mortality (%)	11.4	16.7	(5.3)	$$
Nov 92	Av. born alive/litter	9.39	11.7	2.3	$$

[1]Not yet developed.

The objective of the list is to focus attention on the important issues promptly. This re-directs managerial effort from identifying a change to actually dealing with the issue. Investigations can commence before the evidence disappears or human memories fail. Negative production changes signal opportunities to isolate causative effects and develop preventative strategies. Positive production changes signal opportunities to isolate beneficial aspects for incorporation into routine management practices.

	Throughput traits		Efficiency traits
Sows	• on hand • number mated • number farrowed • lactation length	Sows	• farrowing percentage • average lactation length
Piglets (total)	• born alive • born dead • mummified • birthweight • number weaned • weaner weight	Piglets (average per litter)	• born alive • born dead • mummified • total births • birthweight • number weaned • weaning weight
			Pre-weaning mortality percent

Figure 4. *Traits to be monitored by PIGPULSE.*

Cook (1991) demonstrated a practical example of positive and negative changes affecting male pig growth rate (Figure 5).

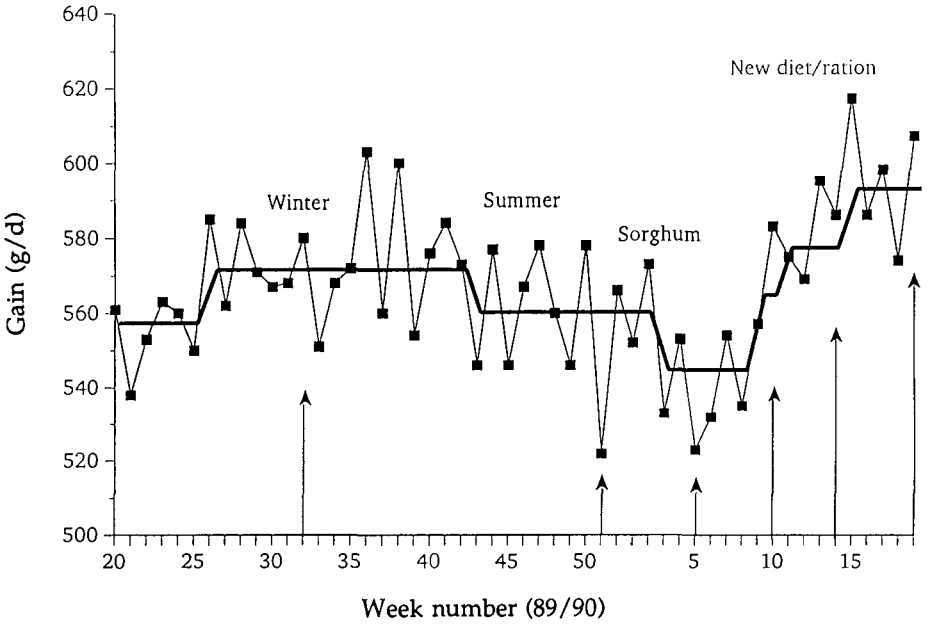

Figure 5. *Male pig live-weight gain - birth to slaughter.*

Relevant observations are:

1. ADG fell by 15 g/day in week 43 (1989). Depressed finisher feed intake due to high ambient temperatures was thought to be responsible. Feed wastage was apparent.

2. In week 45 (1989) the finisher diet was reformulated exchanging red sorghum for wheat. This diet was formulated to the same nutrient specifications with the same protein meals. The finisher diet was fed from 14 weeks of age to slaughter (approximately 24 weeks ± 1 week). In week 3 (1990), growth fell by a further 20 g/day. This depression was thought to be due to 14 week-old pigs changing to an unpalatable red sorghum diet in the heat of summer (lag effect).

3. Red sorghum was removed from the finisher diet in week 1 (1990). Wheat-based diets were reformulated, to raised nutrient specifications, in accordance with new research findings (Wang and Fuller, 1990). As positive growth responses eventuated, feed intakes were incremented from 32 to 37 MJ/day. Backfat's for the corresponding period, weeks 9 to 19 (1989), remained unchanged.

A cross-sectional analysis of 56 SOWTEL farms, averaging 125 sows, demonstrated immense production variability between farms and across time within farms. A representative farm example is given in Figure 6 showing mating throughput to vary from 53 to 89 matings per month. Variability of this order can influence production efficiency in the farrowing shed. Investigation of these relationships will serve to quantify problem factors and initiate the design and implementation of preventative actions.

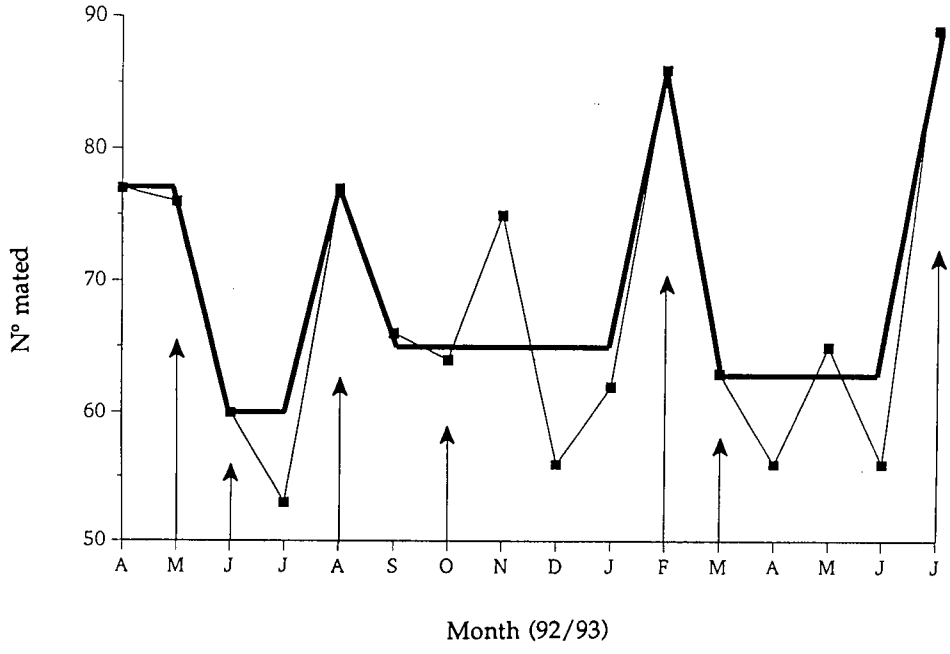

Figure 6. *The number of sows mated per month (SOWTEL).*

A preliminary investigation of larger farms (300 to 3,000 sows) sourcing PigCHAMP data indicates a similar situation (Figure 7). The periodicity of sample data influences the practical value of production changes signalled. Monthly data (Figure 6) are largely historical compared to the real time value of weekly data (Figure 7).

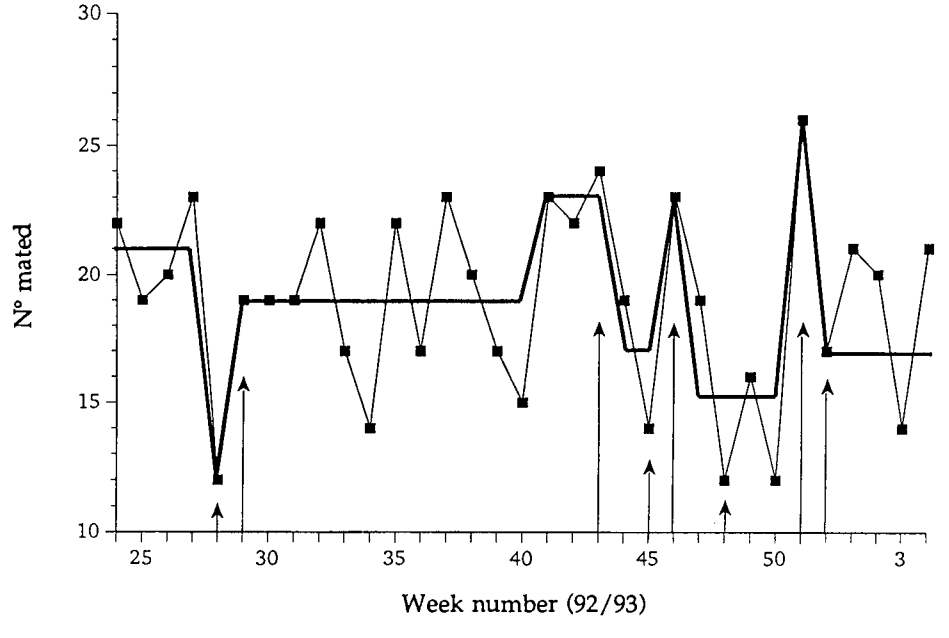

Figure 7. *The number of sows mated per week (PigCHAMP).*

Figure 8 demonstrates a positive response in weaning performance achieved by managerial interventions, such as using spray cooling in the mating shed during summer and paying greater attention to mating management. These actions improved farrowing rate and the number of piglets born alive, resulting in greater weaner throughput.

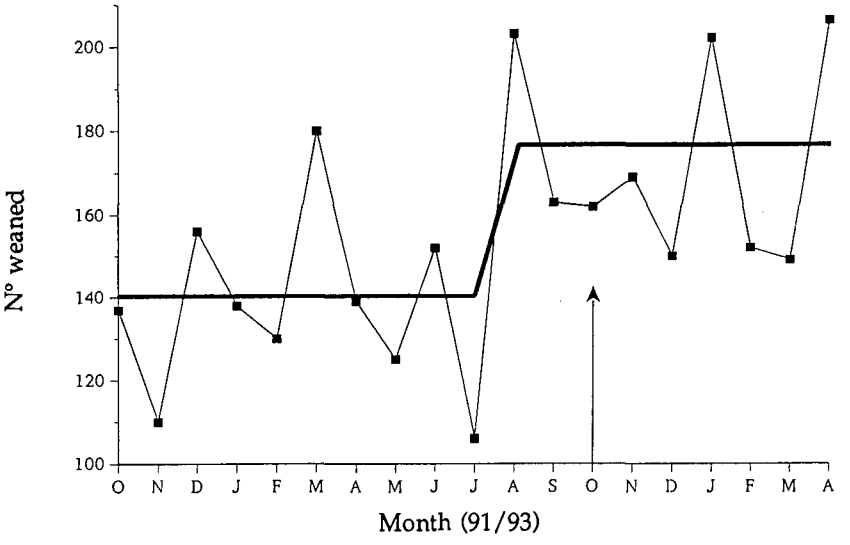

Figure 8. *Weaning performance response to managerial intervention.*

Using PIGPULSE in practice

PIGPULSE will trial the development of an educational package utilizing current computing technologies. In the longer term, the product has the potential to independently provide information services on site at farm level. During the developmental period end users can be serviced via information agencies, eg; producer groups, agribusiness, public or private or institutional sources.

The provision of farm data precedes servicing. The automation of alarms, analysis, explanation, and information provision spares repetitive effort. Collectively, across a group of collaborating information agents, efforts can be concentrated into breaking new ground as opposed to re-working old dirt. A team approach presides over the independent free agents of traditional extension.

The new work to be done is determined by the financial priority of collective industry intelligence. Industry issues predominate over independent producer demands to focus planned extension activity. A sample analysis of 56 producers indicates that the number of sows mated per month is the key determinant of the number of pigs weaned per month. Figure 9 prioritizes the key factors influencing the number of pigs weaned per month. The variation observed in monthly matings explains 50% of the variation observed in monthly weanings. This identifies breeder production planning as the major issue influencing production throughput in Queensland surpassing fertility, litter size, stillbirths and piglet mortality. Once an issue is identified, field investigations are conducted and documented as case studies using three standard TQC tools; flow-charting production processes, cause and effect diagrams and Pareto charts (McConnell, 1986). These tools standardise the problem-solving process. Farm visits thus have a legitimate mandate and a defined purpose with measurable outcomes and impact.

Pooling of case studies provides the basis for the convergence of collaborators' knowledge. Where technical agreement exists, unification commences through

information exchange. Areas of controversy identify needs, being either research or technical training.

The completed new work is added into the system and the sequence is repeated. With each sequential evolution more time is spared from repetitive servicing, and more deficiencies are revealed in our research directions and educational methodologies.

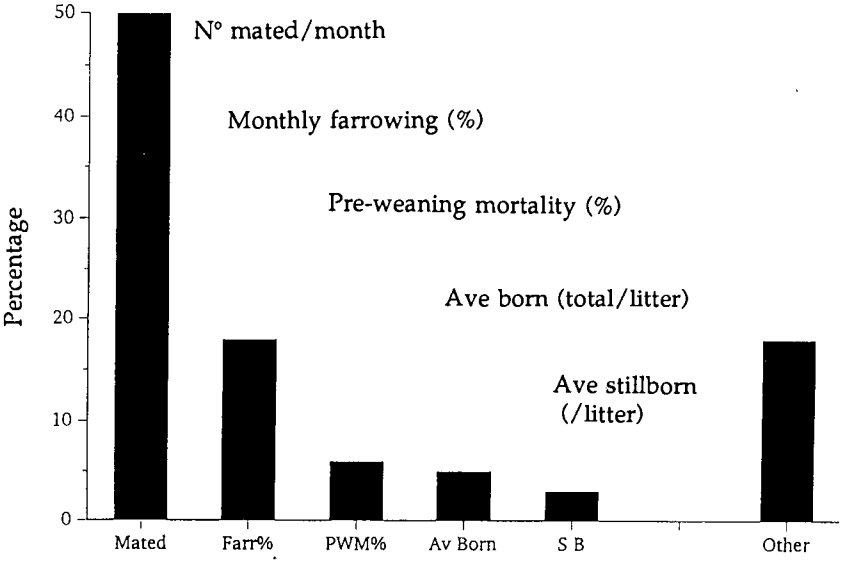

Figure 9. *Pareto chart of the factors affecting the number of pigs weaned per month.*

The PIGPULSE strategy

There are two high priority market segments: commercial software users and holders of pig meat processors' slaughter data. These sectors are fundamentally different and share market priority for totally different reasons. The significance of slaughter data is that all pig farmers receive it and that it can be directly linked to financial effects. Its real value lies in demonstrating variable market performance in financial terms across a wide industry base. A short sharp campaign to collect, collate and analyse a large cross-section of slaughter data will identify industry problems and the potential financial benefits of controlling production.

The weakness of slaughter data is that it merely quantifies the problem and provides only limited scope to address production issues. This is because the data are collected at the end point of the production process and are confounded by 'over-life' effects. In contrast, users of commercial software (eg; PigCHAMP, PIGMANIA) collect data throughout the production process and can selectively pinpoint problem areas to a discrete production phase.

The PIGPULSE development strategy is to focus on three major data sources:

1. SOWTEL data:

   i) Develop a simple but effective system using the limited data (20 traits) available from SOWTEL.

   ii) Utilize SOWTEL producer discussion group meetings to help develop a prototype of PIGPULSE.

2. Commercial data:

    i) Many producers use commercial herd recording packages that are much more comprehensive than SOWTEL.

3. Abattoir data:

    i) All pig producers receive slaughter data after their pigs are killed.

    ii) These data directly link carcass characteristics to carcass price.

The rationale behind this strategy is to use SOWTEL as a training ground to pilot the functional development of PIGPULSE. The system will then be expanded to support commercial data reserves. This growing market sector offers the greatest scope to influence industry performance. Abattoir data will be used to demonstrate the problems and values of managerial control in pig production.

PIGPULSE can be delivered to industry via a centralized bureau service, and/or local information centres, and/or sale of the software. The PIGPULSE project has no distinct end point and will gradually transform from a series of logical tasks, into a mode of routine extension practice.

Conclusion

PIGPULSE monitors and evaluates farm data. It is also capable of pinpointing strengths and weaknesses in the extension/advisory/consultative services delivered to industry. It provides, in a sense, an acid test of the current effectiveness of technology transfer within the industry. The PIGPULSE project can potentially deliver benefits derived through direct or indirect success in identifying and prompting attention to problem areas.

The TQM concepts embodied in PIGPULSE have generic application to other intensive agricultural industries such as: dairy, poultry, aquaculture, feedlots and horticulture. The concept is characterized by:

1. Recognizing that production performance varies continuously
2. Measuring variation is a precursor to its control
3. Identifying the bad effects and preventing them
4. Identifying the good effects and indoctrinating them
5. Systematically identifying and removing sources of product variation to achieve product uniformity.

Kilpatrick and Walker (1990) observed that the development of this type of system is an ongoing process and that new procedures have to be added regularly in response to user demand. In PIGPULSE, the continual cycle of improvement and evaluation guarantees results. It is the term within which the results arise which is the unknown quantity. This is solely dependent upon the current state of effectiveness within industry advisory/extension services and the level of resources applied to them.

EXTENSION FOR THE FOURTH PHASE OF AGRICULTURE

J.P. Drinan

University of Newcastle, Callaghan, NSW 2308.

Not a good word, 'extension'! It belongs to another era, doesn't it? You know,

an era in which a caste called scientists pursued their understandings of what had to be found out, to generate types of knowledge called science and technology. This knowledge was recorded in scriptures known as 'reputable scientific journals'. These were pondered upon by another caste called extension officers whose role was to **receive** the message and **transfer** what was now accorded the status of dogma to a third caste called farmers. The farmers demonstrated their gratitude for the new wisdom by immediately applying it in their farming practice. Failure to do so could, if repeated, lead to excommunication from the ranks of the true believers, ie; the progressives.

Of course, we don't do things that way any more, do we? Well?

This folly presents a challenge. What values and understandings influence our practice of extension? What do we expect it to achieve? For whom? What type of extension do we need now for the future? In addressing these questions, this paper will explore a personal construction of the history of Australian agriculture, the values it exposes, and what those values have done to shape the practice of extension. It will argue that our present model of extension remains largely based on past values and requirements, and that it is, therefore, lacking. The paper concludes by offering a view of the future of agriculture and argues that it can only be reached if it is supported by a new model of extension.

A history of Australian agriculture

My construction of the history of Australian agriculture proposes three phases. The first phase begins when someone put the livestock ashore on 26 January 1788, and ends sometime during World War 2. The second phase runs into the Seventies. We have been in the third phase ever since and may be presiding over its demise if we do not rise to the challenge of creating a fourth phase.

Phase 1

The Europeans who arrived in Port Jackson that day in 1788 could not have had a more inauspicious start. They were composed of the outcasts and soldiers of a caste-ridden society, both of them brutalised by the scant regard for lower forms of human life which allowed the rich and powerful to remain so. They could not expect, nor did they receive, much in the way of support as they tried to survive and establish a colony in the new land.

The new land, too, was one of climatic extremes, populated by people, plants and animals totally different from their homeland. Their lack of understanding of the land, the neglect of their superiors, and droughts, fires and floods, often brought them close to ruin. Given these desperate straits, it is revealing to think about how little they learned from the people they displaced, who had survived in the land for a long period of time. They saw wisdom only in those above them, and worth only in the things of their homeland.

In short time, others who were neither soldier nor prisoner came to the colony. They were skilled in the ways of farming their 'green and pleasant' homeland, and proceeded to simply beat the new land into conformity with it. They put the axe to the trees, brought sheep and cattle to graze on the grassland, and sowed the crops of home. All they brought flourished, and the new land became renowned for the quality of its wool. They moved over the mountains, slopes, plains and deserts, replacing the native animals with their imports, and spreading all kinds of plants from other lands to replace the ones that were there. Some found soils of great richness which grew excellent wheat, so they cleared the trees and scrub to grow more and more. In no time at all, the whole land had felt the touch of the colonisers and was changed beyond redemption.

Many years passed during which the people farmed in the ways of their forebears, sending the products of their labours back to the land they still called home. They looked to the homeland for approval, wisdom, expertise, fashion, structures and

practice. They steadfastly disdained the wisdom and cultures of those they had displaced and those with whom they shared a neighbourhood. They lived comfortable in their belief in the superiority of their origins, the seemingly limitless wealth they were able to take from the earth and their freedom to dispose of things they found troublesome anywhere in the 'wide, brown land'.

The culture of Phase 1 of Australian agriculture might, then, be distinguished as being essentially derivative, exploitative and eliminative. It was marked by exploitation of the resources of the land using mainly British techniques and approaches, with little consideration of the detrimental effects of these practices. Its production and productivity would not have increased further without the sort of changes wrought by World War 2.

Phase 2

In 1945, a new world began to rise out of the ashes of World War 2. The war had unleashed untold suffering and destruction throughout Europe and Asia, aided by and engendering a technological revolution. By War's end, this revolution had brought about amazing efficiencies in killing power, advances in land, sea and air transport, exploitation of the power of the atom and the opening of the gateway to space. Millions of displaced people were seeking new lives and homes in other lands. Colonialism was on its knees and a host of new and independent nations were about to be confirmed. Pessimism caused by realisation of the depths of barbarity of which we are capable, was tempered by optimism stemming from nobility of purpose and action and, significantly, belief that the new and burgeoning technology offered a far better world for all.

During the next fifteen or so years, Australia's London-oriented torpor was shaken. The experience of the war had demonstrated that salvation was not going to come from Britain and we firmly embraced the new saviour, the United States of America. Australia opened its doors to displaced people from all over Europe, an event which would also bring about enormous change in the way Australians think and behave. We began to recognise that Asia would be a major trader in the new world order, and formal trading links were established with a demolished Japan. Australians began to see themselves differently and capitalise on other opportunities using the new technology, but we still looked to others for wisdom.

Agriculture could not remain immune from this high tide of change. Surplus war machinery and equipment enabled the large-scale substitution of labour and the development of more capital intensive agriculture. Events such as the embargo placed on the importation of ruminants meant that new reliance had to be placed on local material and expertise. The alliance with the USA opened our thinking to the developments made in that powerhouse of technology. There was a new awareness of the accelerating growth of the human population and a sometimes idealistic, sometimes commercial concern to provide enough food for it. Given the grinding stimuli of the cost-price squeeze and dynamic markets, these developments led to increased adoption by many farmers and a rise in the importance and application of agricultural science. Governments began to increase their investment in agricultural education, research and extension.

Extension officers entered the field in the Fifties, a decade in which all things seemed possible. What drove this move? I suggest that it was recognition of the power of technology to bring about massive increases in production, and belief that such increases would, in turn, engender improvements in the incomes of farmers and the nation by feeding the hungry world. Agricultural research was churning out more and more technologies which had to be adopted quickly if they were to be of benefit. Extension would assist in meeting these goals by promoting the adoption of new technology. The key beliefs underpinning this might be seen as:

Technology was good and unlimited in its potential for creating good and solving problems.

- Increasing production would benefit farmers and, thereby, the nation, so recouping the costs of the service.

- Support for farmers was electorally popular.

- Farmers would be thirsty for the new knowledge and would be eager and able to use it if given to them.

- Information simply had to be passed down the line from scientists to extension to farmers for adoption to occur.

The spirit hope of the Fifties continued on into the Sixties. A rapidly increasing standard of living, the authority of Menzies, and the 'warm and fuzzies' stimulated by the Royals contributed to a national sense of well-being. Electoral support for farmers was demonstrated in dams and other subsidies. Great advances were made in pasture and crop technologies, animal nutrition, reproduction and genetics, and tractors grew bigger than Fergies. Huge increases in productivity were achieved, seen in increased yields per acre or per animal and, most tellingly, per farmer. Unemployment was low and we all gaped in awe at Sputnik and the apparent invincibility of technoscience. It was a wonderful, exciting, supremely confident period!

Then things began to get complicated. The euphoria of optimism and success probably reached its zenith in Kennedy's Camelot, the Beatles and Stones, the sexual revolution, Vatican 2, jumbo jets and our arrival on the moon. But sometime during the Sixties, erosion of authority triggered an avalanche of questioning and rebellion, most vigorously demonstrated in the Vietnam demonstrations, 'flower power', and Germaine Greer's feminism. More ominously for agriculture, Rachel Carson's 'Silent Spring' sowed the seeds of disquiet about the triumph of technoscience in industry. In a different sphere, the European Economic Commission was born, with enormous implications for the future of Australia's agricultural markets. Perhaps this was the decade of complication!

However, for the most part, Phase 2 was marked by an unquestioning belief in the potential of technology. Agriculture was nothing more than the application of technoscience, a belief which informed and marked the scientists, extension officers and educators and which, I believe, remains widespread today.

Phase 3

The late Sixties saw the first big wool crash which brought the greatest of Australia's rural industries to its knees. The problems of many wool-growers were exacerbated by trading near-worthless sheep for expensive beef cattle, then enjoying a boom. In the early Seventies, those wool-growers and the beef producers crashed again as the first Great Oil Shock trimmed two-thirds off the value of Australian beef cattle. These adverse economic conditions were shared by other agricultural industries, making the Seventies a period many would like to forget. Interestingly, the adverse markets were no respecters of those who were faithful adopters of new technology - sometimes they were worse off because their fixation on technoscience kept their gaze from straying on to market projections and social and economic trends, or it led them into dangerous levels of debt. Unfortunately, the turbulence of that decade was a harbinger of more misfortune: grains collapsed in the mid-Eighties and again at the beginning of the Nineties, and the wool boom of the Eighties was followed by the ignominy of the early Nineties. All of this was preceded by buying sprees which left thousands of farmers in impossible debt and the reputations of lending institutions in tatters. Hanrahan has been pretty accurate about the last couple of decades, except that it has been market collapses rather than droughts and floods that have created the greatest calamities.

Phase 3 has clearly been, to date, a period of heightened economic uncertainty for agriculture. But that is not all. During this period, Rachel Carson's first grim

warnings about the dangers of chemicals became inescapable, and the magnitude of soil erosion hit home. Vast areas of irrigation land and cleared dryland were recognised as devastated by salinity, groundwater reserves were declining and river waters were becoming unusable. People began to look at our treatment of animals in a new light and see them as feeling beings which could be treated more sympathetically. Consumers began to worry about what they were eating: did it have too much cholesterol, were there any chemical residues?

As a consequence of all this, rural communities are declining in numbers and services. Rural infrastructure is being abandoned or simply not maintained by governments. With some notable exceptions, there is a general malaise in the bush where people see their living standards steadily falling, and wonder whether there is a future for agriculture.

During this phase, too, the effectiveness of the existing model of extension began to be questioned.

The past reflected in the present

What traces of Phase 1 attitudes may be found among agriculturalists today? Are we still derivative, for instance? We do depend substantially on home-grown research, but much of it is inspired or illuminated by the research published by an essentially English-speaking world. There is very little effort to be eclectic about the non-Anglophone R & D that is carried out, for instance, in Asia and the Hispanic world, while R & D based on indigenous species and soils can only be described as meagre. R & D efforts to attempt innovative approaches to the problems thrown up during Phase 3 are distinguished by their isolation. On the other hand, a growing number of farmers are attempting to break out of the straitjacket and are teaching the professionals.

Our forebears were also derivative in the sense that they sought wisdom from higher levels. However, it seems that those higher levels were occupied by established, successful farmers rather than information professionals, and that scepticism about us remains widespread to this present day. The contrast of models is striking: mono-disciplinary scientists relying on the scientific method for wisdom, while inter-disciplinary farmers, in the main, rely on intuition and field experience. The difficulty of communicating from such divergent reference points undoubtedly deters adoption of scientists' findings.

Do we remain exploitative? I suspect this has moderated somewhat since the landclearing binges of the Sixties, but surges in profitability in particular industries still stimulate expansion of farming area, intensification of land use, and/or acquisition of a larger share of finite resources such as water, with little thought for their implications beyond those demanded by statute. I suspect that agricultural professionals are less implicated here than are farmers, but some professionals steeped in technoscience remain unconvinced about Ecologically Sustainable Development.

Our eliminative characteristics are probably moderating more rapidly than our exploitative ones. Widespread concern about chemicals has elicited increasing care and control of the disposal of chemicals. Growing understanding of the effects of agricultural wastes on, for instance, the ecology of streams is challenging us to think about these as resources rather than wastes, and develop systems appropriately. Agricultural professionals seem much in sympathy with these moves.

Turning to Phase 2, while there are obvious pockets of contradiction, extension generally remains rooted in the values of that phase. Extension is still seen as something whereby farmers are encouraged to take up new technologies. In grasping for alternative terms for extension, we commonly speak of technology transfer. It is as if the farmers' experiences of Phase 3 have not touched many of the agencies and extension groups. They, in fact, defend their stance by arguing that adoption of new technology is the only way of staying competitive and viable. They simply accept as harsh reality that enhancement of production in static markets can only mean that

more farmers must leave the land. Who are they working for? The State, the industry or the farmer? Whose well-being are they supposed to be looking after?

Extension for the future

Extension has to be grounded in the real needs of its clients who may be farmer, industry or government. A major step toward improvement of extension services will occur when we differentiate among them and their purposes, and become very clear about the latter. Those purposes which are recognised as contributing primarily to the well-being of a farmer should be treated as a private service to be purchased by the farmer according to need. If the purposes are those of an industry or one of its commercial agencies eg; a processor, the service should be provided and paid by the industry or agency. If the purposes are those of government, government should provide and pay for the service. In this way, we will gain the extension services that will anticipate and respond appropriately, because clients will not pay for services they do not need. Such services will certainly not be based only on a narrow, technoscience vision, nor will they employ the traditional understanding of the extension process.

We have laboured through Phase 3 of agriculture with an extension service largely based on the values of earlier phases. We can only speculate about how much healthier agriculture might be today had extension services based on the above been available. For instance, had banks provided services to safeguard their investments, the high level of chronic debt might not have occurred. Had farmers access to more whole farm management extension services, they might have been better prepared for the problems that occurred. However, we should not fall into the trap now of redesigning extension to fit Phase 3 - it is too late for that! We have to design for Phase 4, a phase which will only come into being if we create it. If we do not, there seems little doubt that Australian agriculture will continue to wither through the combined effects of destruction of its natural resource base, erosion of infrastructure, the depredations of protectionism, debt and limited vision.

If we are to design a new agriculture, we have to consider the certainties and probabilities which will influence it for better or worse, but which cannot be avoided. There are a surprising number of certainties, the first of which is uncertainty. We do not know when there will be other Chernobyls, collapses of empires, fights over pesticide residues, poor decision-making, adverse trade decisions, droughts, pest invasions, fashions and other forms of natural and human capriciousness, but we know they will happen. They can, of course, be two-edged swords.

We also know that individual, group and national self-interest will always take precedence in the affairs of the world. This principle is fundamental in international trade, and is crucial to Australian agriculture, whose strength depends on export. It can be detrimental as in the present trade war between the USA and the EC, but it can also be turned to advantage in trade-offs. The point is that we can expect no-one except ourselves to look after us in world trade. The international trading environment will remain difficult, and success will depend on a complex of inter-governmental negotiation, clever, strategic marketing, and strict attention to guarantee of continuous supply of clearly specified, safe product.

We can also be certain that government interest in agriculture relative to other sectors will, not unreasonably, depend on its perceived ability to contribute in financial and electoral terms. This has huge implications.

Moving away from certainties, the high order probabilities are several. Community concern about the environment, food safety and animal welfare will, almost certainly, increase, with consequent regulation. Inputs of inorganic pesticides, herbicides and fertilisers will be required to be exactly matched against requirements, and replaced by 'natural' alternatives where possible. We should not assume certain application of the products of molecular biology. It is likely that monocultures will have to yield to polycultures, and that increasing advantage will be taken of the

synergies and recycling opportunities offered thereby.

There is also a high degree of probability that emancipation of women and the growing level of education in the community will continue to markedly change perspectives and behaviours, not only in the general community but in the rural one as well. The effect of this can only be guessed at, but it is likely to be far-reaching.

Faced with such a challenging, even dangerous, environment, farmers might reasonably become purely reactionary and do little more than sit on their hands, conserving their resources against the evil day. Such an approach would mean under-investment and continuing decline. A more sensible and worthy approach will be to create a new agriculture, which takes account of the opportunities arising from this environment, and which takes precautions against adversity through intelligent risk management. This phase of agriculture will be marked by reliance on the growing intellectual resources of all its people, our deepening understanding of the uniqueness of this land, stewardship of our remarkable variety of natural resources, increasing diversity and integration of enterprises, a high degree of awareness of opportunities and ability to create more, intelligent aggressiveness in the export market and a high degree of organization, production technology and quality control to ensure continuance and development of those markets. This phase will be marked by a genuine partnership of equality among scientists, economists, sociologists, extension personnel and farmers. On this, healthy rural communities and a healthy rural environment depend.

The growing complexity of agriculture is such that professional assistance will be steadily more crucial to achieving success. The extension professionals who work alongside the farmers of the future will have rejected the notion of extension as a one-way, linear process of transferring technoscience from scientist sources through themselves as conduits to farmer recipients. They will understand it as a collaborative process of enquiry and learning, involving their client(s), themselves, scientists and other professionals, and the farmers, by which rural situations of mutual interest or concern will be improved. Skilled in situation-improvement methodologies, the extension professional will see the client's concerns as the starting point and will use appropriate techniques drawn from a battery of communication skills to ensure a high degree of success in meeting those needs. They will understand the multi-disciplinary complexity of agriculture and will have rejected the notion that it is simply a manifestation of technoscience. Accepting the reality of not knowing everything, they will have highly developed networks of professional sources on which to draw. Whether generalist or specialist, they will be alert to the social, economic, political and technological developments which might affect agriculture or which might be used to advantage.

Not a good word, extension! Information brokerage, perhaps?

OF PIGS, PARADIGMS AND PROGRESS

R.J. Bawden

Faculty of Agriculture and Rural Development, University of Western Sydney, Hawkesbury, Richmond, NSW 2753.

Of Pigs and I

From my inglorious past, I have memories of three close associations with pigs. There were firstly, the mandatory three or four Wessex Saddleback sows running around the farmyard with piglets at foot, on the mixed farm in Cornwall where I grew up. Then, for a couple of years during the mid sixties, I managed a piggery of some 40 or 50 sows, on a commercial research station in the Midlands in England, whilst concurrently researching into relationships between nutrition and baconer production. And finally, for a number of years, before we closed the facility down, I was, as Head

of the School of Agriculture, ultimately responsible for the commercial viability of the piggery here at Hawkesbury.

I cannot claim to have gained any profound insights into the science of pigs from any of these personal experiences; nor for the record, did I find much about their behaviour that was particularly endearing. Maybe that's why my interests as an agricultural scientist, have shifted over the years, to focus on the ways by which people learn to improve their agricultural practices through science, rather than on the science of agriculture *per se*. My presence at this Conference therefore, has much less to do with **knowledge** of animal science, than with the art and science of **ways of knowing** in the quest for improvements in the industry.

Please note that I talk of **ways of knowing**, rather than **way**: my basic submission is, that the assumption that conventional science provides the **only** 'real way of knowing the truth' and that conventional extension provides the **only** 'real way of disseminating that truth', is misguided and indeed, unprofessional.

I want to present the view that, just as there are different perceptions of what actually constitutes **progress** in any industry including yours, so too are there different **paradigms** (ways of knowing and doing) for pursuing it. Each might be said to represent a different **approach to development**.

In this paper I want to explore the submission that it is useful to appreciate **four** fundamentally different development approaches within the pig industry. Whilst the four approaches (each with its own **concept of progress** and each with its own **pervasive paradigm**) are not mutually exclusive of each other, and all four continue to co-exist today, they can also be construed as four **stages** in a **sequence of paradigms towards sustainable systems.**

So, whilst I am in the business of **paradigms for progress**, rather than the business of **pigs**, I do believe that I have something to say which is of particular relevance to discussions about 'extension and technology-transfer' in this industry in its current quest for more **sustainable systems**.

Of paradigms and progress

Pioneering through trial and error

Back on the farm of my youth, we regarded our Saddlebacks as much 'a waste-disposal system' as we did 'an occasional meal-producing system'; or even more infrequently, as 'a revenue-producing system'.

Skim milk and kitchen slops were as important in their diet, as were the crop residues and organic matter that they foraged in the fields and woods of their free range.

There was a somewhat delicate balance to be achieved here: a 'homeostatic system' which we had to pioneer through a cognitive process of **trial and error**. Too many slops for the number of pigs, and we had a waste disposal problem. Too many pigs for the amount of slops, and we had a combination of greatly increased (and environmentally damaging) foraging, and/or thin pigs!

Let me suggest that this type of **progress through pioneering** with its **trial and error paradigm**, represents the first of four different (and quite legitimate) approaches to the business of pig keeping! Whilst my specific example clearly has significant limitations in terms of its commercial application, just as it does in a number of other ways including environmental degradation, as an **approach** to pig husbandry, it is still quite prevalent today throughout Australia.

I clearly don't just mean free-range pig management here: I am really referring to the notion of **progress** as an interpretation of the purpose of a particular system by the manager of that system, and achieved through the idiosyncratic knowledge of that individual manager as gained through his or her own personal experiences in that particular system.

Production growth through reductionist science

Our research goal at that station in England in the mid-sixties, was to improve the amount of **production** of Landrace x Large White pigs from that particular enterprise. We chose a number of different parameters as measures for our progress, and we pursued the improvements in these through the application of a particular way of inquiry which I will call here, **reductionist science**.

Applying principles of genetics, physiology, nutrition, veterinary science, ethology and even psychology, essentially in isolation from each other, we would bring scientific knowledge to bear to inform our practices.

We would set meaningful hypotheses, and design rigorous controlled experiments to test them. We would gather empirical data, and interpret these in the context of the propositions of others working in the same scientific field. Specifically our aim was to design a 'better' pig and to produce as many of these as possible from the resources we had available to us.

The 'quality standards' we set for ourselves reflected the sort of parameters which the 'industry' of the day considered both desirable and feasible - an industry which at that time comprised about six million head nationally.

Specifically, our aim was to produce 100 kg baconers at 27 weeks. They would gain, we hoped, an average of 600 g per day, and with a feed conversion ratio of around 3.5:1, would consume around 280 kg of feed from weaning to slaughter. They would be 800 mm long, have a loin backfat measure of 25 mm, and a shoulder backfat value of 40 mm. We would aim for our sows to produce 1.80 litters per year, and wean 10 piglets per litter.

As all of these parameters were directly measurable, we would be able to keep a running eye on progress. My own two major areas of research were on 'growth promotants' and artificial insemination.

My involvement with this **progress through production growth** (as applied to both the sow and her individual progeny) through the experimental methods of **reductionist science** - the application of principles drawn from a variety of separate scientific disciplines which I had studied at University in the intervening years - represented a big shift from the trial and error methods of my earlier days down on the home farm. This change in my practices reflected shifts both in my sense of purpose of the whole enterprise, and the ways of inquiry upon which my practices for progress were now based!

My new emphasis on **production growth** and my use now of a **scientific experimental paradigm**, were entirely appropriate under the new circumstances. **It is important to emphasise, however, that they did not invalidate either the nature, or the circumstances of my earlier experiences.** It was a matter of horses for courses: or pigs for gigs...or something!

Obviously I am able to confidently state that in addition to the paradigm of **pioneering for balance through trial and error** this new paradigm of **production growth through the application of reductionist science** is also widely pervasive across the whole Australian pig industry today.

Productivity growth through (hard) systemics

The limitations of my experimental approach in pursuing progress through **growth in production** became particularly poignant many years later, when I assumed responsibility for the total allocation of resources across the School of Agriculture at the then Hawkesbury Agricultural College.

Faced with the need to curtail the escalating costs of the enterprises on campus, I asked each of the managers in turn, to examine ways by which they could improve the **productivity** of their units - in other words to inquire into changes which might be made to improve the **efficiency by which the inputs into the production systems were transformed into the outputs from them.**

This third approach in my experiences of pig management, saw both **trial and error** and **scientific empiricism** as inadequate to the task of addressing the new notion

of **progress** as **growth in productivity.** Unlike the previous development approach, with its emphasis on directly measurable parameters of inputs and outputs, I now had the more difficult task of dealing both with the relationship between inputs and outputs, and how this relationship itself changed with time.

Dealing with **growth of productivity** meant dealing with abstractions and relationships associated with the optimisation of the performance of 'whole systems', as distinct from dealing with the direct measurements of individual aspects or components of such systems.

As we were now dealing with relationships, **progress** could be brought about in a number of different ways:

- Level of output rises faster than rises in the level of inputs.
- Level of output continues to increase, albeit more slowly, in spite of reduced level of inputs.
- Level of output increases only slowly whilst level of inputs shows no increase at all.
- Level of output remains static whilst level of inputs is reduced.
- Level of output falls, but at a slower rate than the fall in inputs.

These methods of improving productivity are further complicated: 1) by reference to **rates** of increase in productivity gains, in addition to levels of gain, 2) by using a number of different **efficiency measures** (financial, energy, partial factor, total factor, etc.), and 3) by using different **indexing procedures** based on different assumptions about **weightings** or **statistics.**

The calculations which were necessary in order to inquire into **changes in the level and rate of gain of productivity** in our pig enterprise at Hawkesbury, were indeed complex. Not only did they reveal that productivity gains were insufficient to offset the declining terms of trade, but also that changes in the operational efficiencies that were achieved over time in the pig enterprise were generally lower than those which were able to be achieved in other production units on campus.

All parameters involved in the quest for **gains in productivity** are calculations rather than measurements; and calculations, moreover, that invariably involve assumptions about relativities which must be made explicit if sense is to be truly made of the data. The fundamental assumption in this regard, is that gains in productivity can best be appreciated in terms of the performance of **whole systems.** And this in turn, assumes that such whole systems can be described, observed, measured, and manipulated. It is in this sense of enterprises as **tangible wholes** that they can be referred to as **hard systems.**

Hard systems analysis is a complex matter involving knowledge about subtle relationships between components within such systems, between the system as a whole and its environments, as well a between its inputs and its outputs. Little wonder that rare indeed is the production system in Australian agriculture, that focuses its notion of progress in productivity on anything more complicated than **feed conversion efficiencies** or **carcass dressing percentages** or **comparative gross margin analyses.** Little wonder too that models which attempt to simulate the workings of whole systems of pig production are so difficult to accurately construct.

Yet given the oft quoted connections between declining terms of trade and productivity gains, this matter of the nature of (hard) systems of production is a vitally important issue within the pig industry; as it is also elsewhere. At the level of the industry as a whole of course, gains in productivity are being achieved through continuing changes in the macro-structure of the industry. In essence, the number of producers continues to decline whilst the size of individuals herds continues to

increase.

I read somewhere recently that the old familiar 80:20 principle, applies in your industry as it does so often elsewhere: 80% of the production of pig meat now comes from 20% of the producers. And that ratio, it is predicted, will move inexorably towards 85:15, and beyond.

Or will it?

Persistence through (soft) systemics

In the quest for gains in productivity, or for increased levels of production, little has traditionally been thought of any negative impacts that such quests might have on the environments in which pig production systems operate - whether bio-physical or socio-cultural. Back at my research station in the midlands of England for instance, I was hardly concerned at all with the possibility that the materials I was using to promote the growth of the pigs in my experiments, might pose a potential health hazard to either the pigs themselves, or to those humans who handled the feed; or indeed to those who would eventually consume the meat of their carcasses.

I was equally dismissive of the concerns of those neighbours who made gentle complaints about the smells, the squeals, and the flies which drifted from our enterprises to invade their privacies. If I did anything at all about tail chewing, it was far more because of its detrimental effects on growth rates, than for any real concern for the welfare of the animals. And if each pig seemed content with only a couple of square metres or so of space, then who was I to reduce the density of their housing, with my production targets including 'dress weight of pig meat per square metre of floorspace'?

Well, the agenda has now changed quite dramatically; and quite rightly too. We must now concern ourselves as much with the issues of ethics and the integrity of the environments in which we operate our systems, as with the nature, dynamics and performance of the systems themselves.

This is the essence of this fourth **approach to development** - persistence through (soft) systemics. Where **progress** is assessed in terms of the **sustainability of the system**, and where the **paradigm** of inquiry of that assessment, addresses ethical, moral and aesthetic dimensions of interrelationships between that system and its environment, as well as the physical and financial ones associated with its production and productivity. Our concerns must embrace the health and safety of all those who work within our systems, or who live in the vicinity of them, or who consume their outputs. And where we must also appreciate the welfare of the animals within our production systems, as much as we must be concerned with the impacts of those systems on the integrity of the environments with which they are associated; even in apparently indirect and remote ways. Pig producers must appreciate, for instance, the significance of their demands for grain as feed, on environmental impacts like the rate of soil degradation, which is associated with the cultivation of land by the graingrower.

These are complex and highly interrelated - or systemic - issues which are 'soft', only in the sense that they are extremely difficult to quantify and thus to respond to. Yet they are as important in determining the strategic future of the industry as any other factors are.

The macro-structural march of progress towards fewer, larger, more intensive production systems, could falter yet in the face of these complex, systemic issues. The major difficulty here is that few people have yet explored how to think (and act) in these terms. The idea of **hard systems analysis** was difficult enough, with its demands on the identification of often subtle interrelationships within tangible systems. The **soft systems paradigm** is more difficult again; it demands imagination, empathy, appreciation of vastly different beliefs and values, and of unseen complexity which is usually beyond the concerns of all but the most philosophical of us.

Herein lies the challenge for **extension** - it needs to meet a host of different needs for knowledge, ranging from technical answers to technical problems, through

to the facilitation of philosophical debates about the 'good' and the 'just'.

Of perspectives and extension

By now I hope that I have put forward a convincing case for the general proposition there are multiple perspectives within the pig industry; just as there are within any complex system of human activities. **Progress** is NOT simply a matter of growing more pigs with less fat that eat less to gain more. Nor is it simply a matter of individual producers continuing with their quest for ever-improved rates of productivity gain.

Just as there is a confusion about the question of what actually constitutes progress within a given piggery, or for that matter across the entire industry, so too is there a complexity about different paradigms for different purposes.

Clearly what represents vital information and knowledge for one of our four different approaches to development, can be totally irrelevant at another. Where the 'transfer of technology' seems perfectly appropriate to one deeply engaged in seeking to increase production, it might be singularly inappropriate for addressing the moral issues of the 'health and safety' of the consumer of pig products, or the 'rights and welfare' of the pigs themselves.

And the vast majority of producers are fully aware of this.

I want to suggest that the concern to 'improve' the transfer of technology to 'laggard producers', could well be the wrong focus for discussions about improvements in the pig industry. Indeed I want to propose that we would be much better off if we focussed instead, on a comprehensive review of the way we tend to think about the process of extension, taking our new multiple perspective argument into account.

My own starting point for such a review, is the introduction of the notion of **extension as conversation.** And let me emphasise that, for the purposes of this discussion, I include under the heading of **extension**, all forms of **conversations which have persuasion at their heart!** In this manner, the technical adviser, the consultant, the adult educator, the TAFE teacher, the broadcaster, the advertiser, even the salesperson and marketeer, play essentially the same role as the formal government extension agent.

I submit that the **extensionist** is essentially someone who can engage producers in the type of conversation which is appropriate to their view of development, in such a way that actions which constitute improvements within that particular approach, are firstly informed through the conversation, and then actually taken! These are **conversations within prevailing paradigms.**

It is also possible of course, that such conversations can trigger changes in particular views of development; and this is equivalent to **paradigm shifts.**

The **competent extensionist** knows which to do when!

Practicalities

Having established the case for the multi-perspective (poly-paradigmatic!!) extensionist, I should close with some brief remarks about how that might be achieved in practice. And to do so, I will continue with my own personal odyssey!

Upon reflection, the close encounters with pigs which I have had, as described above, could be interpreted as a sort of slow **maturation of mind.** Over the years, I have had occasion to think about 'pig enterprises' from different perspectives as I have found myself in different situational associations with them. I can now suggest that each of the four approaches to development which I have outlined as separate **paradigms of progress,** could also be presented as four steps in a **developmental sequence** towards **sustainable development.** Pioneering leads to production leads to productivity leads to persistence; each new step complementing the ones that came before it, rather than replacing them.

As I have personally travelled this developmental path, I have been prompted to explore **new ways of thinking** about the **next order of challenges**, even as I was dealing with the present lot! The motivation to do so has come from a combination of: 1) a sense of inadequacy with the way I was dealing with the present set of issues, and 2) a fascination with 'day-dreaming' about what tomorrow could bring.

From a concern with pigs as farmyard scavengers and waste disposal systems, I had to learn how to reappraise them as improvable units of production: and from trial-and-error interventions, I had to learn how to apply scientific principles in practice. And then the next shift, from gains in production, to gains in the efficiency of production; from rates of growth of each animal, to rates of growth in the efficiency index of the whole system. From measurement and scientific logic applied to the individual 'components of the system', I had to learn to shift to calculation, approximation, and hunch-laden judgements about how to improve the performance of whole 'hard' systems. From the **assurance of the quality** of the **outputs of the system**, to a pervading concern for the **quality of the total management of the system.**

Each of these shifts in what I might call my **frame of mind**, has come in response to **critical conversations** I have had with other managers, with extensionists, with academic peers, with the authors of books and articles, and most commonly with my own conscience.

And this now brings me to my most recent excursions, into a **softly systemic world**; the world of interconnected ethical, moral, and aesthetic concerns, where I must focus as much on **systems of beliefs, values, and visions of betterment**, as on the 'facts of the matter', and the theories which support them. The immediate challenge is for me to establish my own views on 'rights' and 'wrongs': and on 'fairness' and 'unfairness' - to workers, consumers, neighbours, indeed society at large. These concerns take me beyond TQM into **critical quality**. I can no longer accept that the consumer is always 'right', nor that anything is permissible in the way I treat my animals in my quest for productivity gains. I must now accept that notions of **quality** can be very individual; and what I believe is a perfectly acceptable environmental state, say in terms of the smell of my enterprise, is quite unacceptable to others. And so on.

From TQM of my system I must turn my attention to that which constitutes improvements in the **overall quality of rural life**.

Each step along the developmental pathway that I have described, therefore has its own **domain of conversations**. At Stage One, talk is of **effectiveness**; progress is assessed by virtue of how effective any change is at improving the way the manager/worker does things in the piggery. At the second stage, the conversation extends to talk of **explanations**. The 'adoption' of new production technologies relies heavily on an understanding of the scientific logic behind it. Thirdly, the conversation must include discussions on **efficiencies**; and how any new technology or procedure can improve the performance of the transformation of the systems inputs into its outputs. And finally, the conversation must embrace the **ethics** of the whole industry as well as of the individual production, marketing, transporting, processing and other key systems within it.

Extension from this perspective is therefore the **facilitation of critical conversations** across the whole network of people involved in the industry. Sometimes these conversations will involve just a few producers, at other times, like on this particular occasion, the conversation will address major issues of concern to a broad spectrum of professionals who are in the **knowledge business** end of the industry.

Institutions like mine are recognising that the most important role they can fulfil in these complex and turbulent times, is to help professionals and practitioners to **facilitate conversations** across all of the domains necessary for the responsible development of **sustainable systems.** And in this context, conversations are designed to lead to **new ways of learning.**

Progress in the **pig** industry will depend increasingly on mastery of multiple **paradigms** by all involved in that industry ..... and this is where I came in!

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THE NATIONAL PIG INDUSTRY TRAINING PROGRAM - THE GATTON EXPERIENCE

N.W. Hodgens

Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.

The National Pig Industry Training Program (NPITP) was established to help overcome the acute shortage of skilled piggery attendants, supervisors and managers in Australia.

Three levels of training are proposed:

Level 1 - **Piggery Attendants Certificate** - one year training on-the job and at Technical and Further Education (TAFE) Colleges;
Level 2 - **Certificate in Piggery Supervision** - one year of external studies with pre or co-requisite competencies in pig husbandry skills; and
Level 3 - **Pig Management** - four years external studies at Associate Diploma level.

Each level of training will meet the required National Competency Standards described by the National Training Board (Anonymous, 1992). The course content is to be adaptable for all states and regions and the qualifications are to be portable nationally.

Roberts (1991) has described how the NPITP should operate and was instrumental in developing study material for levels 1 and 2. Negotiations are in progress for The University of Queensland Gatton College (UQG) to develop administrative and study materials for the Piggery Management Course for possible commencement in the 1994 academic year. It is proposed to adopt university nomenclature for subjects offered in this course to enable successful students to claim credit for award courses where appropriate. Some subjects may articulate with related degree programs.

The Gatton Experience - The Department of Animal Production UQG supported the NPITP by offering two courses in 1993. A 'train-the-trainer' three day course was held in February for producers who prefer to train their own attendants (level 1), on-the-job without TAFE input. Thirteen pork producers from Queensland and New South Wales received Certificates of Competency as trainers of piggery attendants together with ready-to-use training material - a distinctive feature of the course. A level 2 course in piggery supervision commenced in March with 12 enrolments. Participants include leading hands, supervisors, managers and owners of piggeries of from 100 to 5,000 sow capacity. The courses will be reviewed when each intake completes its studies.

Experience to date has indicated that graduates from UQG award courses with major studies in pig production, meat science and nutrition are sought for positions as technicians, supervisors and managers in the pig industry. The Department of Animal Production is confident that graduates from the NPITP courses offered by the College will be equally successful.

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NATIONAL TECHNOLOGY TRANSFER PROGRAM ON PIG HOUSING AND ENVIRONMENT

I. Kruger, G. Taylor and F. Crosling

NSW Agriculture, PO Box 547, Tamworth, NSW 2340.

The Problem? Sub-optimal housing and environments affect 80% of Australian pig production. This costs the industry about $70 million or 10% of total production each year. Major upgrading of old facilities, expected over the next five years, is estimated at $250 million. This program aims to compile the latest and best information available and to extend it quickly to producers.

Who? The program is a joint venture between NSW Agriculture and the Pig R and D Corporation assisted by Australian scientists and agribusiness. The three-year program concludes in June 1994.

How? Market research in the form of focus groups and a national survey was used to define the current state of housing technology in the industry, producers needs for housing and environment information, the type and style of information required, and the presentation, packaging and marketing of the information.

The Result? The technology transfer medium is the Australian Pig Housing Handbook Series comprising three titles "Summer Cooling", "Plan-it Build-it" and "Effluent at Work". The unique style, based on the results of the market research, has been readily endorsed by producers. The style elements are: plain english but not condescending; technical correctness without scientific jargon; hard facts simplified to clear, bare essentials; stand alone magazine style articles which, combined, form a complete overview of the subject/s; enjoyable reading; visually attractive layout with plenty of photos, drawings, graphics, cartoons, colour and highlighted factboxes to illustrate main points and break up text; inclusion of known Australian agribusiness and service suppliers to the pig industry and advertorial material to illustrate points or provide immediate solutions to producers; the inclusion of advertising which producers deem to be one of the most effective forms of information transfer.

This technology transfer program operates through a multidisciplinary, multi-talented team comprising an Agricultural Engineer (Extension), Pig Scientist (Extension) and an Editorial/Publications Officer who, together, perform all functions in-house, using desktop publishing, up to the point of final commercial printing. Information is co-ordinated, written, edited, illustrated and typeset using international literature sources, personal contact and contributions from many Australian and research, extension and agribusiness personnel and producers. This method of operation has fast tracked the information development and transfer process compared with traditional approaches.

TECHNOLOGY TRANSFER USING A MARKETING PLANNING MODEL

B.J. Stevenson

Monogastric Research Centre, Massey University, Palmerston North, New Zealand.

Recent economic performance and Government initiatives in New Zealand have had led to massive change. The change has affected the provision of research and technology transfer within the primary industries. The withdrawal of government support and competitive pressure on margins has restructured and reduced subsidised services. Structural change in New Zealand has rendered many organisations obsolete. The thinking that produced the culture, plans, and either products or services is also obsolete. There is a risk that this fact may not always be recognised and accepted. Failure to accept the need to change means that both organizations and people will continue with the beliefs and behaviours of the past reinforced by the old paradigms. Accepting responsibility for failure and need for personal transformation is often not recognised.

The new Monogastric Research Unit Extension Service at Massey University delivers technical transfer services in this commercial environment. The service was set up by the Pork Industry Board to provide an integrated research, extension and training centre. The extension service operates recognising that:

1) All funding and decisions will be made by commercial clients.
2) The concerns and priorities of these clients may not be those of the research community.
3) There is an opportunity to lead and influence the direction of the industry and individual clients by assisting industry planning and decision making processes.

The use of a marketing planning system to identify industry needs through analysis of client feedback is therefore a critical extension tool. The marketing planning system consists of a process that starts by using marketing tools such as focus groups, client interviews, or surveys to collect data. The key component of the process is the development of an industry-led plan, designed to meet the needs identified by the industry clients.

The *marketing planning* process consists of:

Situation analysis
S.W.O.T analysis
Setting objectives
Formulation of the marketing Strategy
Plans
Controls
Action.

Marketing planning is a process that *forces organisational change* by providing very clear signals about requirements and performance. The signals are collected from the market as it is, not as it was, or as it would be preferred. The actions and goals are those that the clients want, not those preferred by researchers and extension workers.

EVALUATING PIG PRODUCERS' WORKSHOPS

R.A. Spencer

Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.

There is a need for extension workers to gauge the effectiveness of their extension efforts. This paper reports on an evaluation carried out on the effectiveness of technology transfer through extension workshops.

One-day workshops involving the Queensland Department of Primary Industries (DPI) pig extension team, pig producers and industry personnel on the subject of 'Strategies for Summer Problems' were held in three locations (Toowoomba, Wondai and Biloela) in October 1991. The aim was for workshop participants to develop strategies to counter the effects of summer on both breeder and grower pigs. An overview of the effects of summer on pig production and economics, as influenced by the shed environment, nutrition and reproduction, was delivered by guest speakers in general sessions. Participants worked on strategies in small groups and reported back in plenary sessions. After the workshops, the results from the three venues were pooled, printed in a booklet and sent to participants.

A survey was taken at the end of the workshop to obtain immediate feedback on the effectiveness of the workshop process and content (93 responded from 102 surveyed). In addition, a postal survey was carried out at the end of summer (April, 1992) to see if the workshop contributed to adoption of strategies to address summer problems (52 responses from 96 producers surveyed). The survey results are summarised in Table 1.

Table 1. Summary of responses to surveys

Question	Number responded	Positive response (%)
New information learned?	93	63
Plan to introduce changes?	91	68
Implemented changes?[1]	52	63
Source of information for changes?		
Workshop	33	40
Producers	33	17
Discussed strategies with others later?	51	69
With producers	51	47
With DPI extension officer	51	29

[1]Eighty six percent of strategies implemented were considered successful.

The workshops were considered an effective extension method because a majority of respondents learned new information and subsequently adopted new practices. This could be due to the involvement of producers in pre-workshop planning and the interaction of participants (leading to increased understanding of the problem and the strategies developed). Changes in production levels due to adopted practices were not specifically determined in this evaluation. This will be more easily done by statistical processes as part of the PIGPULSE computer program.

Evaluation was useful in gauging the effectiveness of the extension effort. It also identified information sources available in different localities, highlighted the importance of producer discussion networks and yielded suggestions for improving future workshops for successful technology transfer.

NETWORKING IN EXTENSION

P.H. Fearon

Department of Primary Industries, Toowoomba, Qld. 4350.

Introduction

The changing role of government agricultural extension officers, from reactive to proactive extension methods, is resulting in less one to one advice to farmers. In the pig industry this is being increasingly undertaken by private consultants. However, extension officers still have a role in transferring technology, providing information and helping to develop producers' personal and business management skills.

Pork producers are now receiving advice, assistance and information from many sources: government extension officers, industry consultants, veterinary consultants, field officers and sales representatives.

Information and advice flowing to producers from so many directions is sometimes conflicting, generating confusion, not up-to-date on new developments and often conveying preconceived ideas, which are not based on technical data.

To address this problem a discussion group of pig industry consultants and government pig extension officers was formed. The aim was to establish closer liaison and promote the transfer of new technology and developments, which could then be extended to a greater number of pork producers. Others, from outside the group, were invited to attend when the discussion topic could be enhanced by their presence. Specialists were also invited to present topics in their area of speciality.

Evaluation

A postal survey of the eight consultants and six extension officers was conducted to find out: 1) if the groups objectives had been met, 2) whether the group process was the best method, 3) the participants priorities, their constraints and use of resources, and 4) whether the group should continue and, if so, what changes were needed. Thirteen of the 14 participants responded to the survey.

Results and Discussion

The evaluation of the group showed that most of the participants found it useful and wished it to continue with no change to the discussion group process. The discussion group format was considered by 10 of the respondents as the best way of achieving the objectives. Three of the six government workers thought the objectives could be achieved in other ways. Two of whom suggested meeting periodically as a group. It was evident that the majority of the groups objectives had not been met and needed to be redefined. Additions to the group of other key industry personalities was also evident.

The importance of and commitment to the concept of enhancing knowledge, professional development and the better use of resources, by networking through such a group, was not realized by some of the participants. The usefulness of the group, using a scale of 1 (not useful) to 5 (extremely useful), showed that the private sector participants found it slightly more useful (average 3) than the public sector participants (average 2.5). The priority rating, for the group, using a scale of 1 (very low) to 5 (very high) showed the private sectors responses ranged from 2 to 4 (average 2.9) and the public sectors from 1 to 4 (average 2.5).

The group was probably prematurely formed in that the need for such a group was not seen as useful, and still is not, by some professionals advising and consulting pork producers. However, the group served a useful purpose to some of the participants and has layed the foundation and future directions for a new more committed group of influential people working within the Queensland pig industry.

Consultants, educationalists and government extension workers alike need to determine if this method of networking is effective in the light of diminishing resources.

ACTION LEARNING IN PIG INDUSTRY TRAINING - A 'LIVING TEXTBOOK' APPROACH

N.W. Hodgens

Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.

Action learning in pig industry training is accomplished when the learner is provided with an opportunity to question and reflect, as an individual or member of a group, on various practical and technical exercises. Traditionally, training exercises include reading print material, viewing visual (video and slide transparency) media and practising techniques (skills) designed to apply technical detail in husbandry and/or management programs.

Pig industry personnel who enrol in training programs, use these exercises to understand the technology available for improved production and profit. Some succeed in their endeavours and are able to complete the transfer of technology from published material to the animal by way of improved husbandry and/or management. Others find the training difficult, even frustrating and terminate their studies, while still others complete the program to lower than expected standards.

Pigs don't read books. Successful technology transfer to the animal must incorporate training of the people who operate at the human/animal interface. Extension methodology does not necessarily ensure that the knowledge gained from research and technical publications is able to materialise in improved production. Pork producers are not necessarily good communicators of technology to the employee, who is ultimately responsible for implementing the husbandry program. According to Revans (1991), learning is a function of programmed knowledge and questioning insight (L=P+Q). This recognises the need for people to be motivated into questioning why things are done, reflecting on their application and evaluating workable options in science and technology. *This is action learning!*

'The **living textbook**' is the animal; it should be used in training exercises wherever possible to provide a practical base for learning techniques and for continual evaluation of the training program. Pig husbandry training programs carried out in a class room environment invariably lack a sense of application. The domestic lounge room study technique is comfortable but suffers from the 'valium effect'; little knowledge is absorbed, less is understood and applied, and the technology is often not implemented at pig level.

The 'living textbook' approach to action learning is in use at the Department of Animal Production at Gatton and will be incorporated, wherever possible, in training programs for the pig industry. Students are continually exposed to problems where there is no immediate solution. They do not just learn the solution; they learn to analyse the problem, consider the technology available, arrive at possible options, test their application by computer simulation or by animal performance and arrive at a cost- effective solution. In this way action learning is in progress and technology is being transferred to the animal. This approach is most effective in on-the-job training and should appeal to the industry and to the educational and training establishments with access to the necessary resources.

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A REVIEW - PHYSIOLOGICAL CONTROL AND MANIPULATION OF VOLUNTARY FOOD INTAKE

D.K. Revell and I.H. Williams

Animal Science Group, School of Agriculture, University of Western Australia, Nedlands, WA 6009.

Introduction

Voluntary food intake (VFI) is regulated at two levels. The first is short-term regulation, which involves the factors regulating meal eating behaviour, ie; meal size, meal length and the interval between meals. The second is long-term regulation, which determines the average daily intake over a period of some days. Daily feed intake is obviously the sum of the meals consumed during each day and it may appear, therefore, that distinguishing between short- and long-term regulation of VFI is unnecessary. However, the mechanisms that regulate VFI in the short-term may be overridden by other factors that operate in the longer-term.

If we intend to manipulate an animal production system to optimise VFI, we need to understand the mechanisms that control VFI. Collier (1985) described the paradox that has puzzled thinkers since the time of Plato, namely that the rates of digestion and absorption are slow relative to the rate of ingestion, yet a meal terminates before the products of absorption can be quantitatively interpreted by the animal. Therefore, the factors that terminate a meal must be acting as 'surrogates' to the factors which limit intake in the long-term.

Short-term control of VFI

Signals generated from the mouth and stomach

If satiety signals are generated shortly after a meal has begun, and hence are responsible for the cessation of a meal, they may originate from the mouth or gastrointestinal tract. The role of the mouth and the anterior end of the gastrointestinal tract, has been investigated by sham feeding animals, that have been fitted with oesophaeal and/or gastric fistulae (see review by Houpt, 1982). From these studies, it appears that the ingestion of food is, in general, a rewarding experience (assuming no adverse sensory factors such as taste are generated) because feeding continues in sham-fed animals despite no postingestional signals. The oral cavity may be important in the maintenance of hunger, but contact of food with the anterior end of the gastrointestinal tract alone is not sufficient to induce satiety.

The stomach is involved, in part, in providing the sensations of hunger and satiety. However, the persistence of the hunger sensation following vagotomy and following gastrectomy in humans indicates that the stomach is not essential for hunger (see Houpt, 1982). It is also not essential by itself for satiety. Work with dogs that were sham-fed, or where food was placed directly in the stomach (Janowitz and Grossman, 1949), suggests that both oral and gastric stimuli must be present to produce satiety.

Although it has become clear that the presence of food in, or the passage of food through, the stomach is involved in inducing satiety (see le Magnen, 1983), it is also evident that other factors are equally or more important. As Forbes (1986) pointed out, if the distension of some part of the digestive tract was the main controlling factor, then dilution of food with inert material would reduce VFI. This does not occur unless the food is diluted by more than 30% with an inert material.

Signals generated from the intestines

It has been proposed that the intestines, rather than the stomach, are involved in satiety (see Forbes, 1986; Houpt, 1982; le Magnen, 1983). The mechanisms that have

been considered most frequently are mediated via glucoreceptors, osmoreceptors or cholecystokinin (CCK). There is now considerable evidence that osmoreceptors and glucoreceptors are involved in the process of satiety (see review by Houpt, 1982). For example Houpt *et al.* (1979) has measured a reduction in short-term (10 minutes) VFI in pigs between 5 and 80 kg live weight that were infused with either glucose or NaCl into their duodenum (at 5 ml infusate/kg live weight). The magnitude of the depression in VFI was dose-dependent on the concentration of the solution that was infused (0-40% for glucose and 0.9 - 6.5% for NaCl).

Cholecystokinin

The role of CCK in satiety has received detailed attention recently but its role is still unclear. CCK is released from the small intestine in response to the presence of food, in particular partially hydrolysed fat. CCK causes contraction of the gall bladder and expulsion of bile into the intestine and stimulates the production and secretion of digestive enzymes by the pancreas. Doses of CCK (between 5 and 40 IDU/kg live weight) into the jugular vein, portal vein, duodenum or peritoneal cavity have reduced short-term VFI in pigs (Anika *et al.*, 1981), but it has been argued that the responses to CCK have been detected with pharmacological doses and may be due to a reduction in all motivated behaviours resembling that seen during normal satiety (Baldwin *et al.*, 1982, 1983). This does not exclude the possibility that CCK may be involved in satiety, at physiological doses. Koopmans (1981) has argued against the role of CCK in satiety based on work with rats that had a 30 cm segment of their upper intestines sewn into the small intestines of a partner rat. One of these rats was fed, but the signals arising from the upper intestine arose in its partner because of the crossed intestines. The second rat was fed 30 to 60 minutes after the first rat was fed. The data showed that CCK released from the upper intestines in the second rat, in response to its partner consuming food, did not produce satiety. Moreover, the lack of CCK in the rat that was fed (because the CCK was released into its partner) did not prevent satiety in the fed rat. Two points can be made from these results. The first is that CCK cannot be the only factor in satiety because rats without any release of CCK still become satiated. The second is that the lack of satiety in the second rat that was fed 30 to 60 minutes after its partner may be due to the released CCK being rapidly removed. The effects of a single infusion of CCK are short-lived; normal eating resumes after only 5 minutes following a single dose (Baldwin *et al.*, 1983; Houpt, 1985). Therefore, the possibility remains that CCK may be involved in satiety but only as one of a number of signals that arise in the gastrointestinal tract. Houpt (1982), in her review, also pointed out the need for multiple, or at least more than one stimulus to be present before satiety is produced.

Despite these arguments against CCK as a normal satiety agent, Morley (1990) has reviewed this topic recently and found mounting evidence that CCK is involved as a satiety agent. He concluded that CCK decrease VFI without producing aversion and that doses of CCK that reduce VFI are within the range expected for a paracrine effect. He also noted, as further evidence that CCK acts as a satiety agent, that trypsin inhibitors and D-phenylalanine cause both a decrease in VFI and a release of CCK, and that CCK antagonists increase VFI.

If CCK is involved in satiety, then there are at least three mechanisms that may mediate the response in feeding. The first is via vagal afferents (nervous connections from the gastrointestinal tract to the brain) since vagotomy reduces CCK's satiety effect (eg; see Scharrer, 1991). This, in turn, may be because the vagus transmits CCK-induced signals directly to the brain, or because inputs from the vagus may increase brain sensitivity to CCK (Hoebel, 1985) or stimulate release of CCK within the brain itself (Baile and Della-Ferra, 1984). The second possible mechanism may be via a small but significant rise in the concentration of insulin in plasma that occurs following 'presumably physiological' infusions of CCK (Frame *et al.*, 1975). Small doses (between 0.03 and 0.25 IU/kg body weight) of insulin are known to reduce short-term (10 - 20 minutes) VFI in pigs although the precise mechanism is not known;

it may be due to low levels of insulin facilitating the entry of glucose into the neuronal elements of the hypothalamus. Larger doses of insulin (> 0.25 IU/kg body weight) did not reduce meal size but this may be due to other effects that insulin may have at higher concentrations (Frame *et al.*, 1975), such as a reduced blood glucose concentration or reduced utilisation of glucose in certain brain cells (Sticker and McCann, 1985). The third possible mechanism by which CCK reduces feeding may be by release into the ventricular system and transported to sites of action in the brain (Baile and Della-Ferra, 1984). Injections of CCK into the cerebral ventricles of sheep (Della-Fera and Baile, 1979) has reduced VFI, while injections of a CCK-antibody into the cerebral ventricles of sheep has stimulated VFI (Della-Ferra and Baile, 1981). It appears that in the pig, however, the role of CCK as a satiety agent is mediated principally by peripheral mechanisms (Pekas and Trout, 1990), such as signals generated at the gut by the vagus nerves.

Immunisation against CCK or the use of antagonists to CCK may offer ways to manipulate VFI of pigs. These aspects will be discussed in more detail later in our review.

Other peptides

CCK is one of many peptides that influence feeding behaviour. Some peptides stimulate VFI while others inhibit VFI. Only two families of peptides have been demonstrated to increase VFI consistently, the opioid and pancreatic polypeptide families. The opioid family consists of encephalins, endorphins and dynorphins (Levine *et al.*, 1985) while the pancreatic polypetides include neuropeptide Y, peptide YY and pancreatic polypeptide (Morley *et al.*, 1985). We will discuss the possible involvement of neuropeptide Y and peptide YY in regulating carbohydrate intake later. The list of peptides that inhibit VFI when administered into the brain is long and in addition to CCK includes insulin, calcitonin, bombesin, neurotensin, thyrotropin releasing hormone, somatostatin, glucagon and corticotropin releasing factor (for a recent review of these peptides see Morley *et al.* (1985) and for a review of the gut endocrine system see Uvnas-Moberg (1992)). Besides insulin, we will not discuss these peptides further, but it is important to recognise that the physiological control of VFI by CCK descibed above is unlikely to be exclusive to that peptide. Hence, manipulation of the mechanism by which CCK affects feeding in an effort to increase VFI may be applicable to other peptides, although less attention has been focused on them compared to CCK.

The relevance of short-term control of VFI to long-term control

The large, and rapidly increasing, amount of literature on the regulation of VFI can generally be divided into two categories; the short-term regulation and the long-term regulation. It is difficult to determine the relevance of short-term controls when we examine food intake responses over a period of some weeks. We are aware of only very few experiments that have continued a treatment that has usually been used in the short-term for an extended period to determine if the effects on VFI persist. Two such experiments were by Owen and Ridgman (1967, 1968) who fed pigs between 29 and 118 kg live weight diets that were diluted with varying amounts of sawdust. The animals were able to increase their VFI as the proportion of sawdust in the diet increased but this compensation was not immediate (ie; > one week). The increase in VFI was not, however, sufficient to maintain energy intake. Similar results have been found with sheep in which polypropylene fibres were inserted into the rumen (Welch, 1967). During the first two weeks after the inert fibres were introduced, VFI had dropped to 33% of control values, but progressively increased to reach 75% of control values over the next two-three weeks. These data would suggest that VFI may be limited in the short-term due to factors that may include gastrointestinal signals, but in the longer term, these are overidden to some extent by other factors that control VFI. Perhaps it is important that compensation in the

long-term is not complete, hence factors that are normally considered as short-term regulators, may have effects in the long-term but at a diminished level.

There is evidence that animals are able to adjust their meal-eating behaviour so that their total daily intake remains the same. For example, altering the meal frequency of lactating sows (NCR-89, 1990; Figure 1) or sheep (R. H. Weston, personal communication) does not alter daily intake. With the sheep data, a few days were required before the animals had fully adjusted their meal size. This is consistent with the results from Collier (1985) with cats trained to press a bar to obtain access for food. If the number of presses on the bar that was required to gain access was increased, the cats adapted over the next few days by reducing the number of meals per day but increasing the size of each meal so that their daily intake remained the same.

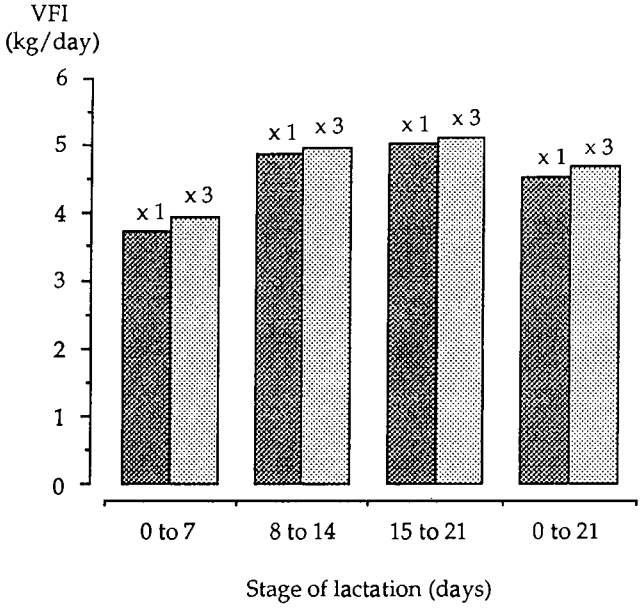

Figure 1. *VFI of lactating sows fed either once (x 1) or three times (x 3) per day (adapted from NCR-89, 1990).*

Understanding short-term regulation of VFI may be important in devising ways to manipulate VFI in the long-term. It is important, therefore, that we begin to tackle the problem of relating short-term mechanisms to long-term regulation.

Long-term control of VFI

Energy balance

Long-term VFI can be considered as part of the homeostatic system that controls energy balance. The homeostatic control involves both signals from the central nervous system (efferent signals) that regulate VFI and the mobilisation of body tissue and signals sent back to the central nervous system (afferent signals) from body tissues (Figure 2). The demand for energy is dependent on many factors, including genotype, gender, age, stage of maturity and physiological state but, given any particular set of conditions, the animal will endeavour to eat sufficient food to satisfy its energy requirements to maintain itself and to deposit energy for growth or for later use (reserves). An ultimate limitation to VFI exists because of the limited amount of energy that an animal can use. Under certain circumstances, VFI may be insufficient to satisfy the requirements and, from an animal production point of view, these situations need to be identified and manipulated to improve VFI. This latter point will

be discussed later in our review where we will attempt to evaluate the importance of VFI in modern pig production, focus on situations where VFI limits productivity, provide possible explanations for the low VFI and suggests possible ways to manipulate VFI under these conditions.

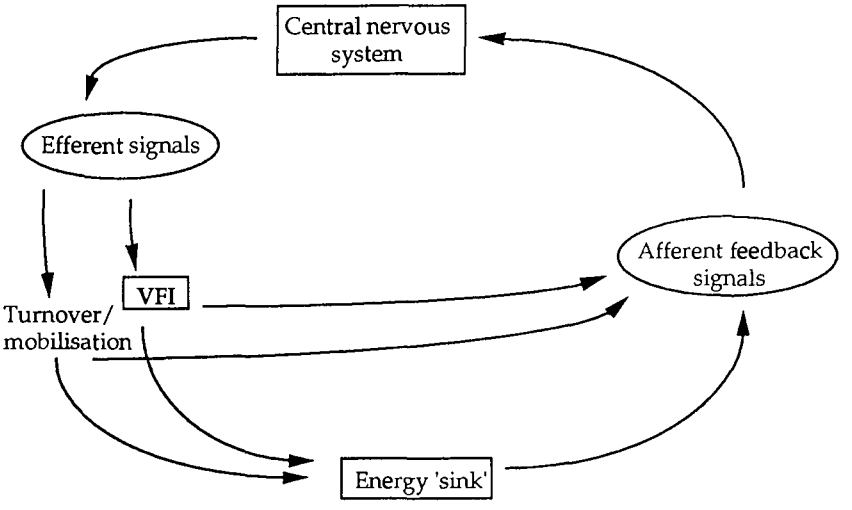

Figure 2. *The schematic representation of the homeostatic control of energy balance.*

Energy density of the diet

Animals that have access to a nutritionally-adequate diet and that are kept in their zone of thermal comfort (see later), adjust their VFI to met their energy demands. The concentration of energy in the diet has a major effect on both voluntary food intake and energy intake. At high concentrations of digestible energy (DE) in the food VFI of dry matter (DM) is at its lowest but the total intake of DE is at its maximum. As the concentration of DE in the diet is reduced the pig attempts to maintain its energy intake by increasing its intake of dry matter. A point is reached, however, where the increase in VFI is not sufficient to compensate for the decrease in concentration of DE in the diet and energy intake suffers. This is well illustrated in the data of Campbell *et al.* (1975) for young pigs between 5 and 20 kg live weight (Figure 3) where a dietary concentration of DE of 15 MJ/kg promotes maximum energy intake. At lower concentrations VFI increases but energy intake decreases, while at higher concentrations, VFI decreases but energy intake remains the same. Similar principles apply to older animals, for example, O'Grady and Lynch (1978) increased the energy density of the diet from 12.5 to 13.8 MJ DE and found a small stimulation in VFI (4.92 to 5.08 kg/d) but a larger stimulation (61.2 to 70.3 MJ/d) of DE intake in lactating sows.

Ambient temperature and VFI

Before discussing how nutrient balance regulates energy balance an understanding is necessary of how the physical environment influences energy balance. The energy an animal absorbs from the food it eats is either stored in body tissues or dissipated as heat, which in turn is regulated by environmental temperature. Environmental temperature therefore affects the animal's energy balance and ultimately its food intake. When ambient temperature falls below the zone of thermal comfort (that is, below the lower critical temperature) the animal has to increase its heat production to maintain body temperature and, as it does so, its food intake increases, but not sufficiently to balance the extra heat loss, so production is decreased. When air temperature rises above the lower critical temperature the animal maintains

its body temperature and increases its heat loss by simple mechanisms (stops huddling, changes in posture to allow more contact with cooler surfaces, dilating peripheral blood vessels) which require little effort. With further increases in air temperature (above the evaporative critical temperature) the pig can only control its body temperature by increasing its heat loss through evaporation (mainly the lungs) or by reducing its heat production by eating less (Figure 4). Reductions in VFI in response to heat stress can be very large; for example, Giles and Black (1991) reduced VFI from 2.8 down to 0.9 kg/day when they increased ambient temperature from 22.7 to 31.4°C in pigs of 90 kg live weight. For the most efficient production (that is maximum productive energy) the pig must be kept within its zone of thermal comfort somewhere between the lower and evaporative critical temperatures. The lower critical temperature and zone of thermal confort is not constant but varies with a host of other factors including skin wetness, air movement, relative humidity and the amount and composition of the diet, all of which interact with ambient temperature to determine the extent of heat loss.

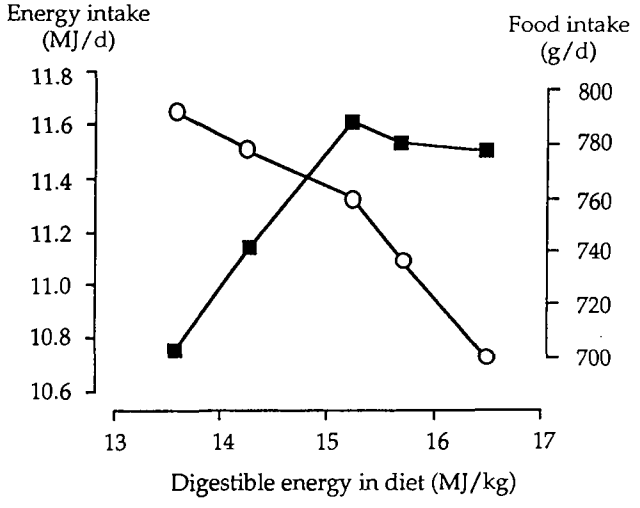

Figure 3. *Relationship between the digestible energy concentration in the diet and voluntary intake of energy (■) and food (○) for pigs from 5 to 20 kg live weight (from Campbell et al., 1975).*

Nutrient balance

The regulation of energy balance is likely to be achieved by regulating the balance of nutrients. Animals do not possess receptors to measure energy *per se* (Jequier, 1992), but controls for the balance of protein, carbohydrate and fat are known to exist (Flatt, 1988; Friedman *et al.*, 1986). Bray (1991) raised the following concepts in relation to a regulatory system for nutrient balance; 1) each major nutrient may be regulated separately, 2) net oxidation of each nutrient is in proportion to the amount of each nutrient in the diet, and 3) the regulation of nutrient stores is subject to positive and negative feedback signals that operate through the central nervous system.

Carbohydrate balance

The mechanisms of nutrient balance appear to differ in the extent of control that can be achieved. The regulation of carbohydrate balance is under strict control (Jequier, 1992) while the mechanism for fat balance does not appear to be so finely controlled (Flatt, 1987; Jequier, 1992). If carbohydrate intake exceeds requirements, regulation of balance is attained, principally, by oxidation of the excess. In humans,

Acheson *et al.* (1988) showed that even under massive carbohydrate loads of over 1 kg, balance is maintained by an increase in carbohydrate oxidation and, when glycogen stores are eventually saturated, by an increase in conversion of carbohydrate to lipid. It was noted that the stores of carbohydrate were not saturated under normal physiological conditions, so the *de novo* lipogenesis from carbohydrate is not a common mechanism for handling excess carbohydrate in humans. What is not clear is the extent of carbohydrate conversion to fat in pigs, but with diets that are frequently high in carbohydrate (eg; diets based on cereal grain), lipogenesis from carbohydrate substrates may be more important in the pig than in the human.

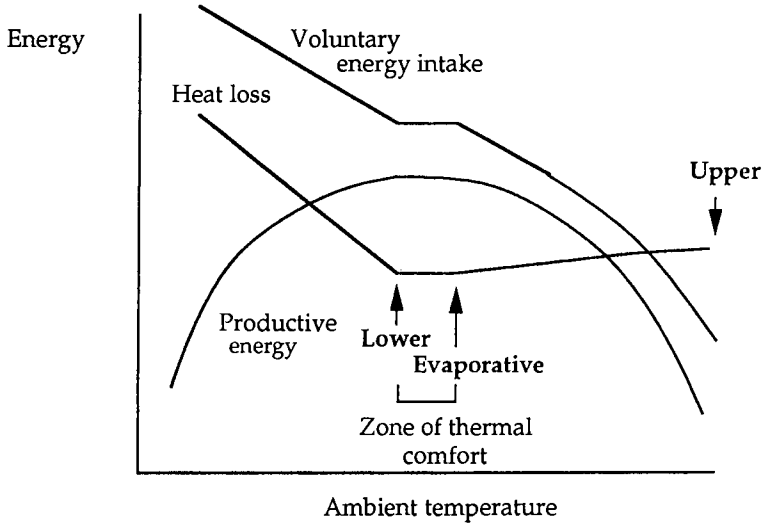

Figure 4. *How ambient temperature influences heat loss, voluntary energy intake, and productive energy (critical temperatures are shown in bold). See text for details.*

Carbohydrate intake, when animals are given an appropriate choice of rations, may be under the control of peptide hormones. The hormones that have been investigated the most are the pancreatic polypeptides, peptide YY and neuropeptide Y (Stanley *et al.*, 1985) and norepinephrine (Leibowitz *et al.*, 1985). It has been proposed that these peptides act as neurotransmitters in the noradrenergic innervation of the paraventricular nucleus in the brain. Their involvement in the control of VFI has arisen from experiments in which previously satiated animals, usually rats, received an injection into the paraventricular nucleus of the peptides and subsequently began to consume food. If a choice of the three macronutrients was available, the animals selected almost exclusively for carbohydrate. The importance of these peptides in long-term regulation is yet to be determined conclusively, but Leibowitz *et al.* (1985) infused norepinephrine into the paraventricular nucleus of rats for 14 days and measured an 8 - 10% increase in total VFI throughout this period. The daily intake of carbohydrate increased by nearly 80%, while the daily intake of protein decreased by about 25% and fat intake remained unchanged, although variable. Given the similarity in the proposed modes of action of neuropeptide Y, peptide YY and norepinephrine (Stanley *et al.*, 1985), it would appear that all of these peptides may be involved in long-term control of VFI. Presumably their concentrations or activities respond to the energy status of the animal (eg; food deprivation stimulates hypothalamic production of neuropeptide Y and during refeeding neuropeptide Y levels become normalised (see Schwartz *et al.*, 1992) and they stimulate the intake of carbohydrate specifically if a choice of the macronutrients is available, because carbohydrate is the most readily

available source of energy (Stanley *et al.*, 1985).

Fat balance

The mechanism that regulates fat balance is likely to involve, in part at least, signals sent to the central nervous system from hepatic vagal nerves (Booth, 1990) in response to the oxidation of fatty acids and glycerol (Wirtshafter and Davis, 1977; Vandermeerschen-Doize and Paquay, 1984; Langhans *et al.*, 1985; Scharrer and Langhans, 1986). Inhibition of fatty acid oxidation by pharmacological manipulation (Friedman *et al.*, 1986) can increase VFI.

An alternative mechanism may be related to the concentration of insulin in circulation (Tybirk, 1989) since this increases as body weight increases (Woods and Porte, 1976). The central nervous system may respond to the concentration of insulin in cerebral spinal fluid, rather than to its concentration in plasma, because the concentration of insulin in cerebral spinal fluid responds more slowly than any increase in plasma insulin and does not respond to transient fluctuations in plasma insulin (Woods and Porte, 1976). However, whether insulin mediates a response in the central nervous system via cerebral spinal fluid or by directly reaching the brain from capillaries to the neuropil (ie; crossing the bood-brain barrier) is a topic of current debate (Bartness, 1990; Woods *et al.*, 1990).

Under situations when the mass of adipose tissue increases (eg; in obese animals or humans) due to the imperfect regulatory system, the concentration of insulin in plasma rises presumably because insulin insensitivity develops (McCann *et al.*, 1986; McNeill *et al.*, 1991). Insulin usually operates by regulating both plasma glucose levels and fat mobilisation, with the result that plasma free fatty acids are depressed more powerfully than plasma glucose (Kronfeld, 1971). Insulin insensitivity tends to reduce the rate of glucose oxidation, relative to that of fat, which provides a mechanism that promotes the oxidation of fat relative to that of glucose, and would appear to be involved in preventing adipose tissue increasing beyond certain levels (Flatt, 1988). However, opposing these responses is a reduced thermic effect of food with insulin resistance, and the decrease in energy expenditure that this entails may be a factor promoting further fat accumulation (see review by Flatt, 1988).

Insulin insensitivity may be involved in the reduced VFI observed in fat animals. Insulin resistance in adipose tissue will lead to an increase in blood glucose that, in turn, will lead to an increase in plasma insulin. Although this increase in insulin may be a mechanism to counter the reduced sensitivity, it also may lead to a reduction in VFI as described above (Woods and Porte, 1976; Tybirk, 1989).

An hypothesis has been proposed by Schwartz *et al.* (1992) that states that insulin may be involved in feeding behaviour by affecting the production and release of neuropeptide Y. Insulin may inhibit the gene encoding neuropeptide Y (ie; neuropeptide Y mRNA) in the hypothalamic arcuate nucleus, or affect the stability of neuropeptide Y mRNA, or have some affect, other than direct genome action, on the release of neuropeptide Y. The increased production of neuropeptide Y in a specific population of the arcuate neurons that occurs during feed deprivation (see Schwartz *et al.*, 1992) appears to be dependent on low ambient insulin levels. The corollary of this is that, if insulin levels are high, then neuropeptide Y-induced feeding may not occur, or at least be suppressed. This mechanism may be involved in the reduced VFI found in fat animals that have high levels of insulin in the circulation and in cerebral spinal fluid (Woods and Porte, 1976).

The extent to which fatty acid oxidation increases in response to an increase in fat intake or fat mobilisation does not appear to be finely controlled; Jequier (1992) has stated that, in humans, a metabolic response serving to increase fat oxidation in response to an increase in fat intake is lacking. Faust (1981) has found that for a given diet and quantity consumed, the mass of adipose tissue and even the size of adipose cells is regulated, but if food intake is altered then corresponding changes in the amount of adipose tissue occur. One possibility that has not been addressed is that fat balance may be achieved by an interaction between the signals generated by oxidation

of substrates and by the concentration of insulin in plasma or cerebral spinal fluid. If this were so, then altering the intake of fat in the short-term (hours to days), as in the study by Jequier (1992), may lead to an imbalance between fat intake and oxidation, because insufficient time was allowed for possible changes in insulin to reach the central nervous system. That is, fat balance may ultimately be achieved but it could take days (or weeks). Such an hypothesis is compatible with the statements by Faust (1981) and Mrosokvy (1981) that body fat is regulated, but the levels of adipose tissue which are regulated can change. We will argue later in this review that a slow regulatory mechanism may account for a depression of VFI in sows during the first week or two of lactation.

Protein balance

The controls of fat and carbohydrate balance have received detailed attention because these two macronutrients are the predominant energy substrates for an animal. Protein balance has received less attention despite clear evidence that the protein content and amino acid balance affects VFI (Anderson, 1979). Recent evidence that the pig is able to monitor its protein 'status' can be found in the experiments by Kyriazakis and colleagues (Kyriazakis and Emmans, 1990, 1992; Kyriazakis *et al.*, 1990, 1993a, 1993b). When pigs, between 12 and 103 kg live weight were offered two rations that differed in protein content, but were energetically adequate, they selected a diet that decreased in protein content as they grew. This has been interpreted as the pig eating to meet its protein requirements, which are known to decrease as it grows.

The mechanisms by which an animal is able to determine its protein requirement and subsequently eat in an attempt to meet this requirement is likely to involve the central nervous system (Anderson, 1979) but the signals which the hypothalamus reads are not clear. Various suggestions have been put forward including:

1. Serotonin or catecholamine concentration in the brain.

2. Tryptophan concentration in plasma or in the brain (tryptophan is a precursor to serotonin).

3. The ratio of tryptophan: neutral amino acids (the large neutral amino acids valine, isoleucine, leucine and phenylalanine, compete with tryptophan, which is also a large neutral amino acid, for uptake into the brain).

4. The ratio of tryptophan: phenylalanine (see review by Anderson, 1979).

5. The concentration of branched-chain amino acids in plasma (Harper and Peters, 1981).

Ashley *et al.* (1979) decreased the concentration of serotonin in the brain by treating rats with agents that either inhibited the synthesis of serotonin or acted as a neurotoxin of serotonin. The rats reduced their protein intake but maintained their energy intake for the study period of two weeks. This indicates a positive relationship between brain serotonin and protein intake, and is in contrast to the negative relationship measured by Wurtman and Wurtman (1977), who used fenfluramine or fluoxetine to deplete brain serotonin. In the latter work, the relationship between brain serotonin and protein intake was established over a short time-period (4 hours), whereas in the work of Ashley *et al.* (1979), measurments were made over a much longer period of time (1 to 14 days). This highlights the importance of establishing the relevance of short-term responses to long-term effects. Although Fuller *et al.* (1978) found that fenfluramine caused an immediate (within 30 minutes) decrease in the concentration of brain serotonin, Trulson and Jacobs (1976) measured an initial increase in the concentration of serotonin in the neural synpase following fenfluramine injection, that occurred, presumably, by either an increase in flenfluramine release

and/or a reduction in its reuptake. Therefore, short-term increases (0 - 4 hours) in protein intake following fenfluramine infusion may be partly due to a transient increase in brain serotonin.

Henry *et al.* (1992) have recently provided evidence with pigs that VFI is influenced by the ratio of tryptophan: large neutral amino acids and this presumably is via an effect on brain serotonin. They found that adding protein to a basal diet low in tryptophan (0.09% of diet) reduced VFI from 2.4 to 1.6 kg in pigs of 30 kg live weight. Adding non-essential amino acids had no effect on VFI. When the concentration of tryptophan was high (0.13% of diet) and considered adequate, there was no effect on VFI by adding protein or non-essential amino acids to the diet. They suggested that when the ratio of tryptophan: large neutral amino acids was low, the brain was prevented from taking up tryptophan (because of competition from the large neutral amino acids) and, consequently, brain serotonin was low, which caused a reduction in VFI.

Changes in brain serotonin have also been linked to changes in the selection of carbohydrate when rats have been presented with a choice of rations differing in protein and/or carbohydrate contents (Wurtman and Wurtman, 1979). These authors suggested that serotonin may be specifically involved in regulating the consumption of those nutrients which affect its own synthesis and release. That is, following a protein-rich meal, the concentration of plasma tryptophan increases less than the concentration other neutral amino acids that compete for uptake into the brain, and the reduced level of tryptophan in the brain leads to a diminished level of serotonin in the brain. This, in turn, would lead to a reduction in the intake of protein in animals provided with an appropriate choice of rations (Ashley *et al.*, 1979). Following a carbohydrate-rich diet (ie; low or free of protein), the carbohydrate-induced secretion of insulin alters the plasma amino acid pattern, which increases the uptake of trytophan into the brain and subsequently increases the concentration of serotonin in the brain. This, in turn, may lead to a reduction in the intake of carbohydrate (Wurtman and Wurtman, 1979).

Protein intake, similar to carbohydrate intake, is believed to be under control at the central nervous system. For example, drugs such as chlorpromazine that block dopaminergic receptors stimulate feeding, with a clear preference for protein, and little selection of carbohydrate, being evident (Leibowitz *et al.*, 1978; cited by Leibowitz *et al.*, 1985).

Although the interactions between the various mechanisms are unclear, there is now strong evidence that a pig, when given the opportunity, can and does vary its protein intake to match its protein requirement. We believe that this is particularly relevant to the modern-genotype pigs that have been selected for rapid lean growth rates and, consequently, have a high protein requirement. Providing two diets, differing in protein content to growing pigs, as developed by Kyriazakis and colleagues, may be a practical method of optimising growth rate and minimising feed costs. This point will be developed later.

Characteristics of the modern-genotype pig and consequences on VFI during growth

Genetic selection of pigs over the past 25 years has increasingly been towards rapid-growing, lean pigs. A great deal of success has been achieved; for example, in a Norwegian central boar testing station between 1959 and 1984, daily gain increased by 11.8 g/day per year and average backfat decreased 0.73 mm per year (Vangen and Kolstad, 1986). Doornenbal (1971, 1972) compared data for fat and lean growth rates of Lacombe pigs in his experiment with the growth rates for Danish Landrace pigs from the 1950's (Clausen, 1953) and bacon pigs from the 1930's (Hammond, 1933). In the 1930's, maximum lean gain was 190 g/day, while in the 1950's and 1970's, maximum lean growth had increased to over 300 g/day. Another important difference between the growth patterns was the live weight at which maximum rates of lean growth were attained. Through the decades, this weight has increased from 60

kg in the 1930's to about 110 kg in the 1970's. Whittemore *et al.* (1988) predicted the daily rate of protein retention from an equation based on growth rate, empty-body weight and mature-body weight, and found maximum protein retention to be between 100 and 120 g/day, which is equivalent to over 400 g lean tissue/day. This maximum rate of accretion was attained at about 70 kg live weight. Even these figures from Whittemore *et al.* (1988) do not represent the capacity of some of the modern genotypes to deposit lean tissue. For example, Campbell and Taverner (1988) have measured rates of lean tissue deposition up to 190 g/day in one commercial strain of fast-growing pigs.

Genetic selection has increased both the rate of lean growth during the growth phase, and the total lean mass of a mature pig. These changes are likely to have 1) reduced the voluntary food intake of pigs (at any given weight), and 2) increased the mature body size of pigs. This latter point implies that at any given weight, a modern pig is at a lower degree of mature body weight (Taylor, 1982) than a pig 20 years ago. The implications of both points will now be discussed.

The emphasis in selection criteria for increased leanness (reduced backfat) has reduced the appetite of pigs (Smith and Fowler, 1978; Ellis *et al.*, 1979, 1983; Smith *et al.*, 1991). The reduction in VFI in response to a selection index for growth performance and backfat thickness under *ad libitum* feeding, has been most clearly demonstrated by Smith *et al.* (1991). Over an 11-year period of selection, they have shown a reduced VFI for both boars and gilts over the live-weight range of 30 to 90 kg. For 'selected' boars, VFI remained about 8 - 11% below control boars throughout the live-weight range while for 'selected' gilts, VFI was similar to control boars at 30 kg live weight but began to diverge, such that by 90 kg live weight, gilts consumed 13% less than control boars (Figure 5). An earlier study by Ellis *et al.* (1983) found that VFI of 'selected' boars was about 10% lower than control boars at 60 kg, but this difference was not present as the pigs approached 90 kg. The apparent contradiction between the results of Ellis *et al.* (1983) and Smith *et al.* (1991) may be a reflection of differences in the rates of lean tissue growth or in the selection methods. In the earlier study (Ellis *et al.*, 1983), differences in lean growth rates between the 'selected' and control boars may have been minimal by 90 kg live weight, whereas in the latter sudy (Smith *et al.*, 1991), the rates of lean tissue growth may still have been different at 90 kg live weight.

In the long term, selection against VFI may limit the animal's ability to express its genetic potential for growth (Ellis *et al.*, 1983). It is important, therefore, to find the optimum balance between selection for carcass quality, growth rate and food intake (Kanis and de Vries, 1992). If selection is mainly for maximum rates of protein deposition, it is likely that the optimum feeding strategy will be *ad libitum* or almost *ad libitum* feeding (Kanis and de Vries, 1992). It is important to note that although *ad libitum* intake is required to maximise lean tissue growth, financial returns may be limited by extra feed costs associated with *ad libitum* feeding. If we continue to improve our understanding of the regulation of VFI, we may be able to manipulate the feeding system so that the quantity consumed by a pig fed *ad libitum*, and the composition of the diet, is optimal for financial returns.

With the selection for increased growth rate, pigs are now heavier at any particular age. As a consequence, there will have been a steady increase in the mature body weight of pigs (Aherne *et al.*, 1991). This increase in body size is a common phenomenon of selection programs for mice, rats, dogs, sheep, cattle and pigs that have included selection criteria, such as weight at a given age, or growth rate over a specific time period (see Taylor and Murray, 1987). A point of practical importance in the pig industry today is that, since gilts tend to be mated at a given weight or age, sows begin their reproductive life at a lower proportion of mature body size and hence are physiologically younger than gilts 20 years ago at their first mating. The influence of age and body weight on the onset of puberty in gilts and subsequent productivity has been reviewed recently by Paterson (1989). In animals that are still growing during pregnancy, there may be a diversion of nutrients away from the

developing foetus towards maternal tissue. As a consequence, birth weights may be reduced. The extent of the problem in the modern gilt is uncertain.

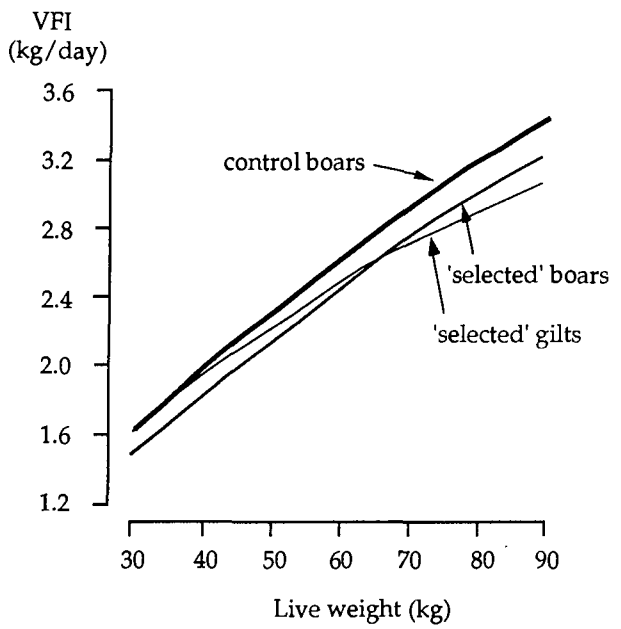

Figure 5. *VFI of gilts and boars selected for increased growth rate and reduced backfat and VFI of control boars (redrawn from Smith et al., 1991).*

A further consequence of leaner, heavier pigs is an increase in the energy requirement for maintenance (Campbell and Taverner, 1988; McCracken, 1993). The energy needed for maintenance is proportional to protein turnover which, in turn, is proportional to the weight of protein in the mature body and the weight of protein at any given body weight (Emmans and Kyriazakis, 1989). Black *et al.* (1986), in a simulation of energy utilisation of the pig, calculated the maintenance requirement based on protein mass and growth rate. The value from this prediction agreed closely with the calculation from Rao and McCracken (1991) based on a linear regression approach.

VFI and limitations to productivity during lactation

Changes in the management of lactating sows

The current production system differs from that in practice during the 1970's in many ways, and VFI during lactation is more important now than it was previously. To demonstrate this point, we have calculated the energy balance of sows during lactation and compared the current situation with that of the 1970's (Figure 6). Milk yield and composition from sows 20 years ago were assumed to be as described by Elsley (1971). During the 1970's, the energy content of the diet and the amount fed to lactating sows was assumed to 14.5 MJ DE/kg and 4.1 kg/sow/day, while the length of lactation was taken to be 8 weeks. These figures were obtained by an examination of the literature from the late 1960's and early 1970's (Elsley *et al.*, 1966, 1969, 1971; Lodge *et al.*, 1966a, 1966b; Lodge, 1969; MacPherson *et al.*, 1969; O'Grady *et al.*, 1973, 1975). In general, daily intakes during the course of lactation were not presented in these papers, but only the average consumption of food during lactation. However, in

a number of studies it was noted that there were some feed refusals during the first week or two of lactation. Since these refusals were not quantified, we have assumed that during the first week of lactation, VFI was only 3.0 kg/sow/day, during the second week it had increased to 4.0 kg/sow/day and subsequently food intake equalled the amount offered (4.1 kg/sow/day). These chosen levels are arbitrary, although are approximately the same as has been measured during the first two weeks of lactation in recent studies at the University of Western Australia (Williams and Head, unpublished).

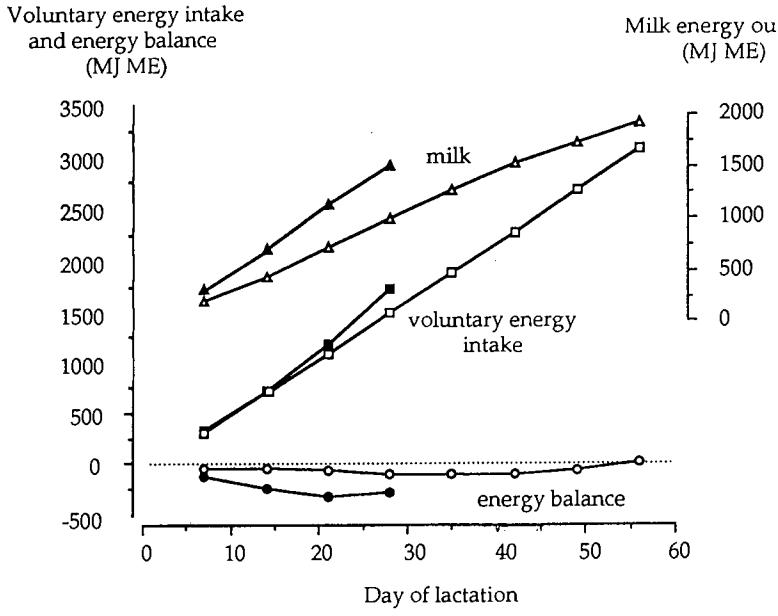

Figure 6. *Cummulative measurements of voluntary energy intake (■,□), milk energy output (▲,△) and net energy balance (●,○) for gilts in the 1970's (open symbols) and 1990's (closed symbols). See text for details.*

The chosen levels for milk production in the 1990's were taken from King *et al.* (1989) and King *et al.* (1993). We have assumed that food is offered *ad libitum* during lactation, that the energy content of the diet is 14.5 MJ DE/kg, that VFI is at the level measured by Williams and Head (unpublished data) and that the length of lactation is four weeks. Heat production during lactation, both in the 1970s and the present day, was assumed to be 0.439 MJ ME/kg 0.75/day (Close and Cole, 1986).

The most important points from this comparison (Figure 6) are:

1. Maximum milk yield has increased by 35% and the maximum energy content of sows' milk has increased by 14%.

2. VFI during the first two weeks of lactation is often low in modern gilts and the extent of any depression in VFI during the 1970's is difficult to gauge from the literature. Despite gilts being offered feed *ad libitum* during lactation in the modern commercial piggery, these sows appear to be eating no more during the first 2 weeks of lactation than their counterparts did in the 1970s.

3. The length of lactation has halved over the past 20 years. This means that, in the 1970s, gilts had about 3 weeks at the end of their lactation in which they were in positive energy balance, such that net cummualtive balance over their entire lactation was about zero. The modern gilt, in comparison, has a net loss of energy over her lactational period of nearly 300 MJ ME.

4. If all of the energy lost from sows during the first 4 weeks of lactation was as fat, modern sows would be losing 7.4 kg of body fat compared to only 2.5 kg from sows in the 1970s. This estimated loss of body tissue in the modern sow, from our simulation presented here, is identical to the amount of fat mobilised by gilts in the work of Williams and Smits (1991), although these latter authors also measured a 1.4 kg loss of body protein.

An apparent paradox exists when comparing the modern sow with her counterparts from 20 years ago. Despite a similar food intake during the first two weeks of lactation and a greater negative energy balance during the first 4 weeks of lactation, in the present production system compared to the past, modern sows still produce more milk and return to oestrus following weaning more quickly than did the sows in the 1970s. Why then, do we need to be concerned with VFI? A number of studies, as summarised by Aherne and Williams (Aherne *et al.*, 1991) have demonstrated that sows, especially primiparous sows that lose excessive amounts of body tissue (Aherne and Kirkwood, 1985; Baidoo, 1989; Cole, 1989, 1990; Hughes and Pearce, 1989) have extended remating intervals, a lower percentage of sows in oestrus within 10 days of weaning, reduced pregnancy rate and reduced embryo survival.

Mechanisms affecting VFI during lactation

It is now well established that the more a sow eats in pregnancy, the less she will eat in lactation (Figure 7). The mechanism(s) by which this response occurs may be linked to body reserves of fat and protein. The fatter a sow is at farrowing, the less she will eat during lactation (Figure 8), particularly during the first week (see Figure 10 later).

As well as the mass of fat in the body affecting VFI in lactation, the size of body reserves of protein also appear to be involved (Mahan and Mangan, 1975; Figure 9). If a diet containing less than 13% crude protein is fed during pregnancy, and hence protein reserves in the body are low at farrowing, VFI during lactation depends on the protein content of the diet that is fed in lactation; higher protein diets stimulate VFI. However, if a high-protein diet (17%) is fed during pregnancy, then food intake during lactation is less affected by the protein content of the lactation diet.

Previously in this review, we discussed two possible mechanisms by which fat metabolism may affect VFI. First was the inhibitory effects of hepatic oxidation of fatty acids and glycerol and second was the inhibitory effects of high levels of insulin. During early lactation, animals are in a catabolic state, but it is difficult to determine if VFI is reduced as a consequence of this catabolic state, or if a reduced VFI leads to the catabolism of body tissue. Catabolism, and hence weight loss during lactation, may be a programmed event rather than a result of extra energy expenditure in peripheral tissues (Mrosovsky, 1981). The evidence for this hypothesis is that weight loss in lactating women is of a similar magnitude to mothers bottle-feeding their infants (see Mrosovsky, 1981). It is possible that endocrine signals associated with lactation, or associated with the completion of pregnancy, stimulate tissue catabolism. The loss of weight in lactating pigs is predominantly fat provided high-protein diets are fed in lactation (Aherne *et al.*, 1991; Williams and Smits, 1991) and, consequently, there will be an increase in the circulating concentration of free fatty acids and glycerol.

If this leads to an increase in hepatic oxidation of these substrates, VFI may be inhibited. Early in lactation, before body fat levels decrease significantly, the level of insulin in plasma and in cerebral spinal fluid will be high and this may generate signals to the central nervous system that inhibit VFI. As we mentioned earlier, fat balance does not appear to be regulated rapidly. It is possible that the delay in the decrease in insulin, especially in cerebral spinal fluid, may delay any positive effects on VFI that may arise from a decrease in insulin. This could explain the low VFI seen in sows during the first week of lactation (Figure 10). The general response of an increase in VFI in later lactation (ie; after three weeks) may be partly the result of a reduced energy requirement as milk yield begins to decrease and partly because of a

decrease in insulin. Hence fat balance, albeit at a set-point lower than in pregnancy (Mrosovsky, 1981), may be obtained in late pregnancy when an 'equilibrium' is established between the two proposed mechanisms, namely hepatic oxidation and insulin concentration (Figure 11).

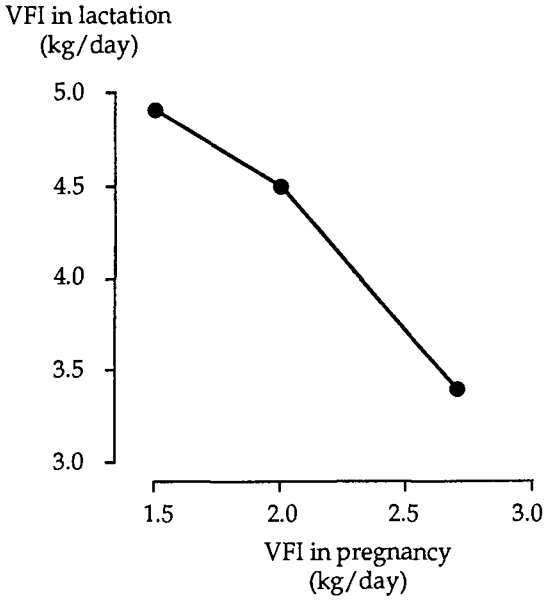

Figure 7. *VFI in pregnancy and lactation for first-litter sows (from Mullan and Williams, 1989).*

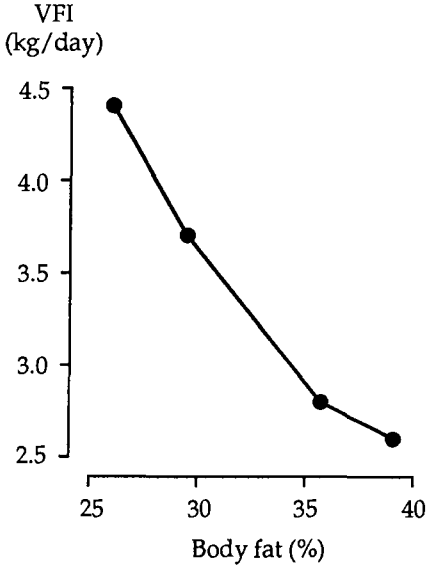

Figure 8. *Relationship between body fat at parturition and VFI during lactation for first-litter sows weighing 150 to 160 kg after farrowing (from Williams and Smits, 1991). Body composition was manipulated during pregnancy by controlling both the intake of protein and energy from mating onwards.*

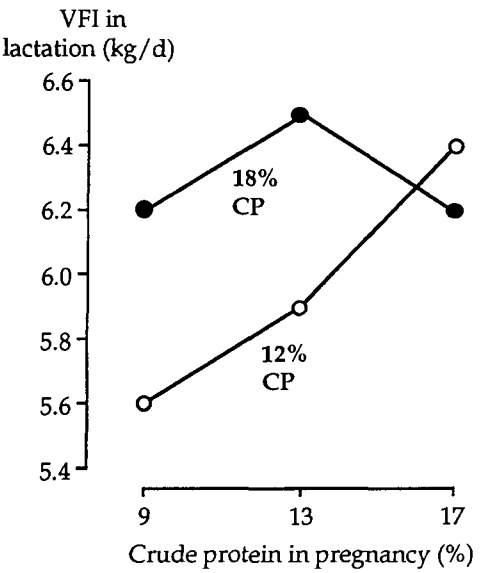

Figure 9. *VFI of lactating sows fed either 12 or 18% crude protein after receiving either 9, 13 or 17% crude protein during pregnancy (from Mahan and Mangan, 1975).*

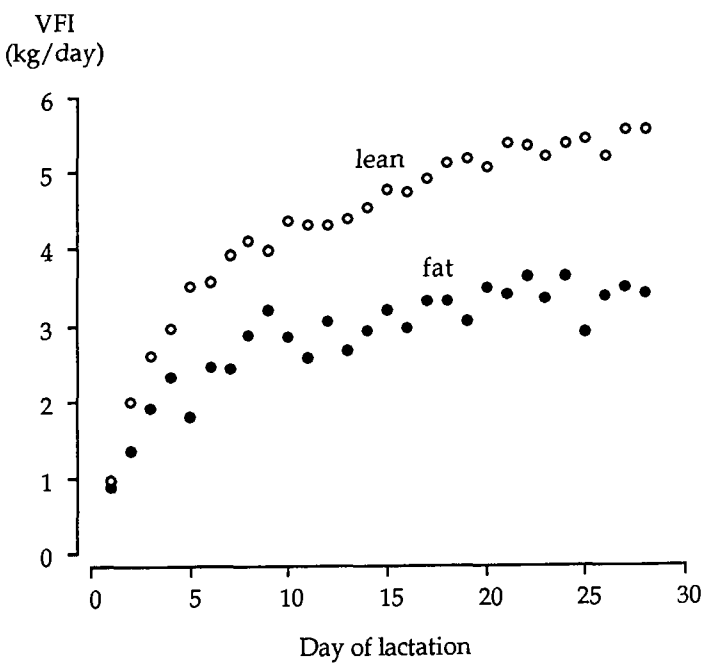

Figure 10. *VFI during lactation of lean and fat first-litter sows (Williams and Head, unpublished data).*

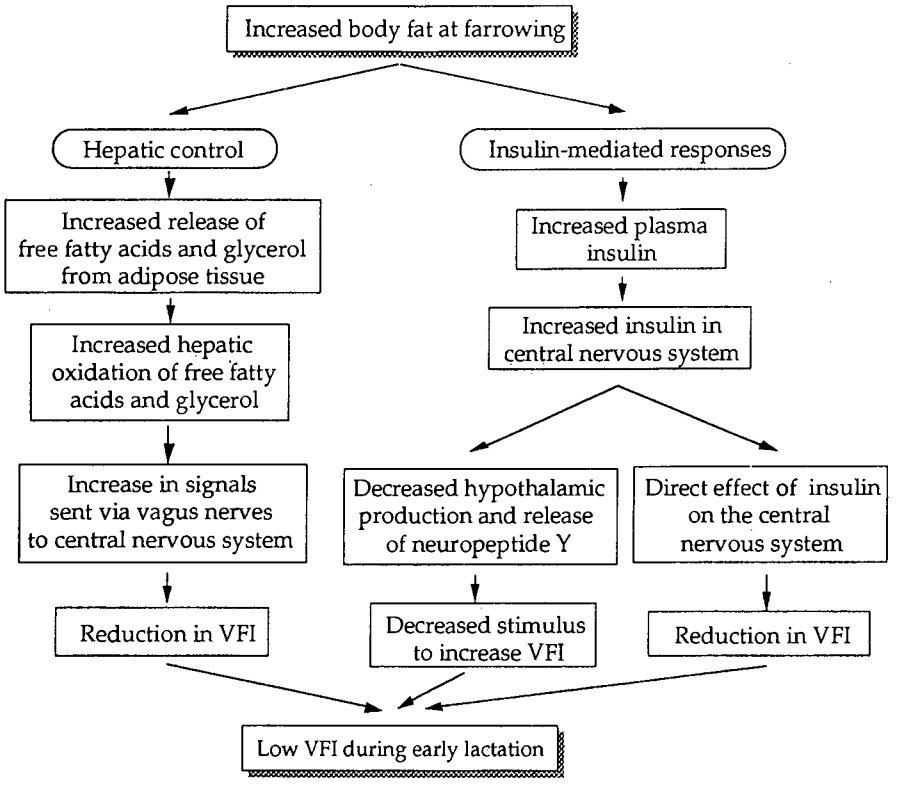

Figure 11. *Model for the role of body fat in influencing VFI during early lactation.*

Options for manipulating VFI

Factors that effect appetite and options for manipulating VFI in lactation

Many factors influence VFI during lactation. They can be grouped for convenience under three main headings, although some of them interact with each other because they regulate food intake through the same mechanism.

1. Animal factors:
   - genetics
   - gender
   - parity, littersize, length and stage of lactation
   - body weight and body composition.

2. Environmental factors:
   - thermal (temperature, windspeed, humidity, insulation, radiation, evaporative cooling)
   - air quality (ammonia concentration)
   - stock density
   - photoperiod
   - disease.

3. Dietary factors:
   - digestibility and energy density
   - protein and amino acid balance

- physical characteristics (particle size, mash, pellets)
- availability of water
- feeder design and feeding frequency.

Several of these factors can be controlled and used by producers to increase VFI at crucial stages of production, particularly the pig at weaning and the young lactating sow. For example, it is well established that VFI during lactation will be reduced if feed intake and live-weight gains during pregnancy are high, or if the protein content of the diets offered during either pregnancy or lactation is low (see earlier). Increasing the energy content of diets, by adding fat, is well known as a means of increasing energy intake and has particular application for young pigs (see earlier; Campbell *et al.*, 1975), lactating gilts or sows (Lynch, 1989), or it might be useful under conditions of heat stress (Close, 1989).

Close (1989) has quantified the response in VFI and energy intake to many environmental factors. For example, he calculates that metabolisable energy intake falls by 0.65 MJ/day as air temperature rises by 1°C above the zone of thermal comfort, by 0.52 MJ/day as wind speed increases by 10 cm/sec, by 0.36 MJ/day as ammonia concentration increases by 10 ppm, and by 0.65 MJ/day as stock density increases or area per pig is decreased by 0.1 m^2. Taken by themselves, these may seem relatively small depressions in energy intake; a reduction of 0.6 MJ/day only represents a decrease of 2% in VFI to growing pigs consuming 30 MJ/day. However, many of these factors often change together causing large reductions in VFI, for example, if windspeed increases, air temperature often goes down.

Not only do environmental factors depress VFI, but they can also change the efficiency of energy utilisation. For example, in recent work on space requirements for finisher pigs (54 to 113 kg live weight), the NCR-89 (1993) concluded that the decline in growth rate, as they increased stock density, was due to a decline in both energy intake (0.68 MJ of ME/day for a decrease of 0.1 m^2) and a decrease in food conversion ratio. Similarly, when VFI is depressed by high temperature, the reduced amount of food eaten is often used with a lower efficiency. For example, temperatures above the critical temperature not only reduce VFI, but also reduce milk output, and this reduction in milk output is more than would be expected from an equivalent decline in VFI for sows kept within the zone of thermal comfort (Black *et al.*, 1993).

In the following sections, we will concentrate on areas that are not covered elsewhere in this Conference (eg; see section on stocking density) and areas that have received little attention as possible means to increase VFI.

Inhibition of the hepatic oxidation of fatty acids or glycerol

We have argued earlier, that the low VFI observed in lactating gilts and sows during the first week or so of their lactation may be due, initially, to hepatic oxidation of free fatty acids, resulting in negative feedback signals being sent to the central nervous system via the vagus nerve. Therefore, inhibition of free fatty acid oxidation by the liver may reduce the inhibitory affects on VFI.

Two pharmacological agents have been used to manipulate the oxidation of free fatty acids; first, 2-mercaptoacetate, which inhibits the oxidation pathway of fatty acids by inhibiting the activity of the enzyme acyl-CoA dehydrogenase (Bauche *et al.*, 1981) and second, pent-4-enoic acid, which inhibits oxidation of long-chain fatty acids and ketone bodies (Corredor *et al.*, 1967). Scharrer and Langhans (1986) have found an increase in VFI of rats injected intraperitoneally with Na-2-mercaptopacetate but only if the rats were fed a high-fat diet. Booth and Campbell (1975) found no effect of pent-4-enoic acid injection on VFI of rats, but they used a diet that was low in fat. It appears that inhibition of free fatty acid oxidation, under normal circumstances, will only be effective in increasing VFI if the diet has a high fat content (Forbes, 1988). This, presumably, is because with diets low in fat, the level of free fatty acid oxidation by the liver will be low also, and is unlikley to be a major factor that limits VFI. Hence, inhibition of this small amount of free fatty acid oxidation will not lead to any

change in VFI.

In the lactating gilt or sow, large amounts of fat are mobilised from adipose tissue to meet the demands of milk production. In this situation, hepatic oxidation of free fatty acids will be high. We suggest that inhibition of this oxidation may have potential in reducing the depression of VFI in lactating sows. If free fatty acids are not oxidised by the liver, they may either be converted to ketone bodies or diverted to the mammary gland (Kronfeld, 1971). With both of these outcomes, there is likely to be a reduction in the negative signals sent to the central nervous system via vagal afferents with the possible consequence of increased VFI. This, in turn, may lead to an improved milk production. If, however, the free fatty acids that would normally be oxidised are not converted to ketone bodies, but re-directed to the mammary gland for milk synthesis, there may be a direct improvement in milk production, that is greater than the response we may expect from an increase only in VFI.

Immunisation against cholecystokinin

As we discussed earlier, CCK is known to be involved in satiety. A corollary is that a reduction in the levels of CCK may enhance VFI. Pekas and Trout (1990) vaccinated growing pigs (26 kg live weight) with CCK-8 (an octapeptide of CCK) conjugated to human serum globulin. A primary injection was given on day 1 of the experiment and three booster injections were given on days 29, 43 and 64. Once the binding between CCK-8 and its antibody had reached its maximum, at day 43, the VFI of the immunised group of pigs began to increase above the control group; by day 78, VFI was about 10% higher in the immunised group (ca. 2.9 compared with 2.6 kg/head/day) (Figure 12). This difference in VFI was reflected in body weight with the immunised group being 7% heavier than the control group (94.7 compared with 88.5 kg live weight).

If an improvement in VFI of growing pigs is necessary to continue the improvements in the rate of lean tissue growth (Kanis and de Vries, 1992), active immunisation against satiety agents may be useful and appropriate techniques.

An alternative to immunisation against CCK is the use of antagonists to CCK. Two antagonists that have been used in studies of VFI are L-364, 718 which has been described as a highly selective and potent antagonist of peripheral CCK receptors (Chang and Lotti, 1986), and proglumide which has been described as a competitve antagonist of the action of CCK on pancreatic secretion, gallbladder and intestinal motility (Davison and Najafi-Farashah, 1982). These antagonists have increased the meal size of satiated rats (Shillabeer and Davison, 1984; using proglumide) and mice (Silver *et al.*, 1989, using L-364, 718). Although these reports add to the evidence that CCK is involved in 'normal' satiety, it is not clear how effective they may be in the long-term control of feeding. However, since immunisation against CCK has led to long-term increases in VFI (Pekas and Trout, 1990), there is the potential that pharmacological manipulation with CCK antagonists also may increase long-term VFI.

Administration of somatotropin

In the above discussion, we have described possible ways in which it might be possible to increase VFI, particularly that of protein, and thus improve production. The two types of animal we have focussed on are the growing pig, and the lactating gilt and sow. Increased production does not necessarily depend on an increase in VFI and can result from a more efficient partitioning of nutrients at the metabolic level. There has been a large amount of work around the world on repartitioning agents (for example, see MacRae and Lobley (1991), but we will briefly describe the effects of just one, somatotropin, on VFI and production of growing pigs.

Somatotropin (or growth hormone) affects nutrient partitioning by increasing the rates of lean tissue accretion and decreasing fat deposition (eg; Campbell *et al.*, 1988). The effect of somatotropin on VFI has been clearly demonstrated by Dunshea *et al.* (1992a), who gave daily intramuscular injections of porcine somatotropin to 71 kg barrows. They found that within one day of treatment, there were increases in the

plasma concentration of somatotropin, insulin, nonesterified fatty acids and glycerol, an increase in blood glucose concentration and a decrease in plasma urea concentration. VFI, in contrast, was unchanged for the first three days of treatment before beginning to decrease and, by five days after the start of treatment, it had dropped by 30% below the control pigs (Figure 13). It has been suggested that somatotropin may reduce the insulin sensitivity of adipose tissue and possibly also hepatic tissue. This would reduce the rate of lipogenesis in adipose tissue, and decrease the inhibitory effects of insulin on hepatic gluconeogenesis, and the resulting increase in blood glucose levels would stimulate insulin secretion. The hyperglycemia and hyperinsulemia are likely to explain the decrease in VFI that is observed after three days of somatotropin administration (Dunshea *et al.*, 1992a, 1992b).

Treatment with somatotropin increases productivity by two ways; first by increasing the rate of lean tissue accretion while decreasing adipose tissue accretion and, second, by reducing VFI at the same time. Hence, lean tissue accretion per unit of feed intake is increased markedly.

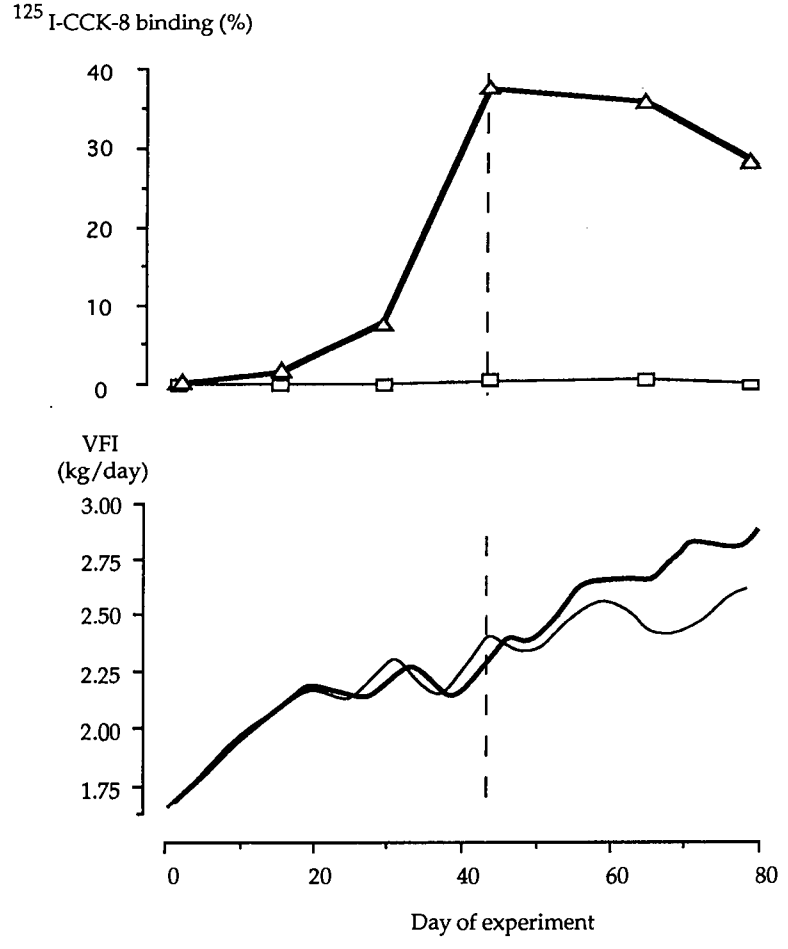

Figure 12. *CCK binding to its antibody and VFI in response to CCK immunisation for the control group (——) and the immunised group (——) (from Pekas and Trout, 1990). The upper panel, showing CCK binding, represents the degree to which CCK was bound to its antibody and shows that by 43 days the immune response reached its maximum. The lower panel indicates that once the immune response reached its maximum, VFI began to increase above the control group of pigs.*

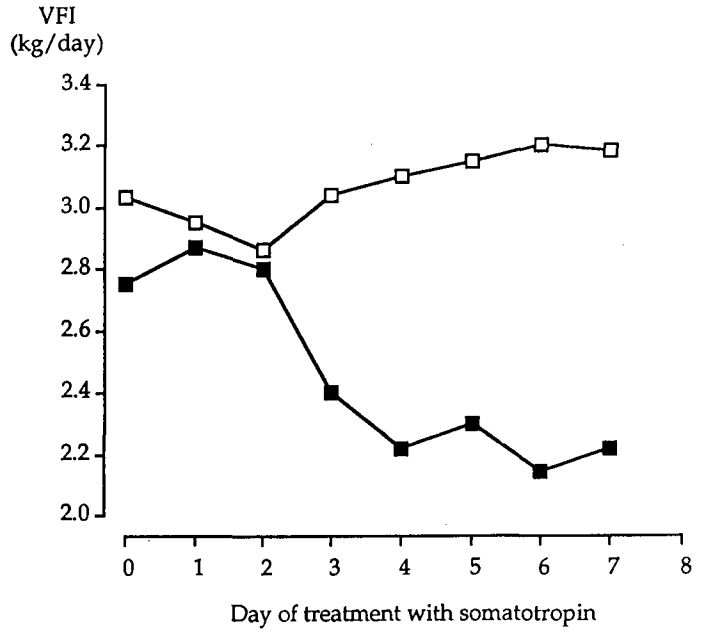

Figure 13. *The decrease in VFI observed in pigs receiving somatotropin (■) compared with control (□) pigs (from Dunshea et al., 1992a).*

Summary

The control of VFI is complex and involves factors operating in the short-term (minutes to hours) and long-term (days). Although it is often difficult to evaluate the importance of short-term regulators of VFI to long-term control, it is generally accepted that the long-term regulation of VFI is part of the homeostatic system that controls energy balance. Animals appear to regulate their energy balance by regulating the balance of the macronutrients, carbohydrate, fat and protein.

VFI in commercial piggeries is often limited by stocking density, disease, energy density of the diet and environmental factors such as ambient temperature, humidity and ammonia concentration. In most cases, these can be minimised if the problem is detected.

There are a number of crucial stages of production where VFI may limit production. These are at weaning, during the grower-phase and during lactation in young sows. The problem of reduced VFI at weaning is an area that requires additional research because, despite many attempts to improve weaning conditions, such as the provision of creep feed before weaning, alternative feeder designs in weaner pens and familiarising non-littermate piglets during suckling prior to mixing, VFI still declines and hence growth is penalised.

Genetic selection for fast-growing, lean pigs has led to impressive gains in the rate of lean tissue accretion (up to 190 g protein/day). Little attention has been given to VFI, with the consequence that modern genotypes have a lower VFI than their counterparts in the past. It is possible that continued improvement in the growth rate of lean tissue may require an increase in VFI. Perhaps it is time that we turn some attention towards selecting animals that eat more.

Food intake of sows in lactation is important because it controls the amount of milk produced and hence the growth rate of piglets, and it influences the subsequent reproductive activity of the sows. Food intake is more important now than it was in the past because management strategies have changed. Traditional strategies were aimed at using the animal's own body reserves built up outside lactation (bacon

weight to first pregnancy, during pregnancy, from weaning to re-mating) to buffer the high energy demands of milk output. Modern strategies use a different genotype of animal and do not encourage sows to accumulate large amounts of reserves. Rather, they involve strategic feeding of the sow to meet specific requirements. Optimising the nutrient specification of diets offered to lactating gilts and sows is one avenue that may be used to increase performance, and future research is needed to define this optimum for the modern-genotype animal.

Interactions between different factors that affect VFI are important in the lactating sow. For example, exposing sows to high temperatures will reduce VFI and, because the sow's cooling mechanisms are turned on (eg; blood flow diverted away from mammary tissue to the skin), there is a larger than expected decline in milk output.

We need to understand the mechanisms that control VFI if we are to use novel methods to manipulate VFI. For example, if we immunise animals against CCK we can improve growth rate but, because CCK is important in stimulating the secretion of enzymes from the pancreas and bile discharge from the gall-bladder, is the increased growth rate achieved at the expense of digestive efficiency? The physiological consequences of such novel interventions need to be understood fully to ensure improved productivity.

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FOOD INTAKE, HEAT PRODUCTION AND MILK YIELD OF LACTATING SOWS EXPOSED TO HIGH TEMPERATURE

M.L. Lorschy, L.R. Giles, C.R. Smith*, J.M. Gooden and J.L. Black**

Department of Animal Science, University of Sydney, Camden, NSW 2570. *Department of Biochemistry, University of Western Australia, Nedlands, WA 6009. **CSIRO Division of Animal Production, Prospect, PO Box 239, Blacktown, NSW 2148.

Although several studies have demonstrated the depression in voluntary food intake (VFI) and milk yield (MY) of lactating sows following exposure to high ambient temperatures, the effects on physiological responses and heat production are unclear. Previous studies with finisher pigs (Giles and Black, 1991) indicated that VFI declined above the evaporative critical temperature (ECT), a temperature at which evaporative heat loss begins to rise in association with a rise in respiration rate (RR), an increase in body temperature (BT) above 39.5°C, and a decline in heat production. This study investigated the association between VFI, RR, BT, MY and oxygen consumption (VO_2) of lactating sows exposed to ambient temperatures above thermal comfort.

Three commercial hybrid gilts (mean ± SEM; live weight, 165 ± 1.1 kg; P_2 backfat thickness, 19 ± 2.0 mm) were surgically prepared for the continuous measurement of VO_2 and housed at 20°C in commercial farrowing crates which prevented wetting of the skin surface. Each sow was fed *ad libitum* a pelleted diet containing 13.0 MJ DE/kg and 0.8% total lysine. The experiment commenced at 12 ± 1.5 days post-partum (P/P). All sows were exposed progressively to ambient temperatures of 30, 24 and 27°C for 3 days, with 4 days at 20°C prior to each raised temperature treatment. RR, BT and VFI were measured at intervals of 1 h and VO_2 was measured continuously at 1 min intervals. All measurements were recorded at 20°C for 48 h prior to each temperature treatment as a thermal-comfort control. Milk intake of piglets was calculated by isotope dilution using deuterium oxide. Litters were standardised to 8 piglets. Live weight and P_2 backfat (mean ± SEM) declined by 20 ± 2.8 kg and 2.7 ± 0.88 mm respectively, during the experiment.

Table 1. Ambient temperature (Temp) and lactating sow performance (mean ± SEM)

Temp (°C)	Days P/P	RR/min	BT (°C)	VFI (g/d)	MY (g/piglet/d)	VO_2 (ml/min)
20	12-15	22 ± 0.7	39.5 ± 0.05	5502 ± 344.3	1217 ± 90.6	615 ± 2.5
30	16-18	93 ± 2.6	40.4 ± 0.04	3143 ± 475.3	1038 ± 113.9	479 ± 2.2
20	19-22	23 ± 0.9	39.8 ± 0.04	4250 ± 557.2	717 ± 93.1	560 ± 2.2
24	23-25	34 ± 1.3	39.7 ± 0.03	4948 ± 327.2	953 ± 166.9	553 ± 2.5
20	26-29	24 ± 1.0	39.8 ± 0.04	4032 ± 546.7	1097 ± 234.3	629 ± 2.3
27	30-32	39 ± 1.7	40.2 ± 0.03	2538 ± 246.3	503 ± 41.8	436 ± 4.1

The increase in RR at 24°C indicated that ECT in lactating sows, prevented from wetting their skin surface, is close to 24°C. VFI declined after 24°C in association with a rise in RR above 34 respirations/min, an increase in BT above 39.7°C and a decline in VO_2. An increase in temperature from 20 to 30°C at 16 to 18 days P/P caused VFI and MY to decline by 43% and 15% respectively. MY however, declined by 54% when temperature increased from 20 to 27°C at 30 to 32 days P/P. This suggests that the stage of lactation affects the response of VFI and MY to high temperature.

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DEVELOPMENT OF TECHNOLOGY FOR THE MEASUREMENT OF FEED WASTAGE FROM SINGLE SPACE FEEDERS BY PIGS

S.R.O. Williams and G.A. Moore

Department of Civil and Environmental Engineering, University of Melbourne, Parkville, Vic. 3052.

Estimates of feed wastage in the pig industry range from 4% to 30% (Payne, 1991). The purpose of this work was to develop a reliable methodology for measuring the amount of feed wastage from feeders by a group of pigs.

Possible mass transfers that may occur while a pig feeds at a wet and dry single space feeder are: transfer of feed from the hopper to the trough, addition of water to the trough, removal of feed or water or both from the feeder by the pig, spillage of feed or water or both to the floor. Also possible are transfers from the pigs mouth to the floor and vice versa. In an attempt to measure these transfers a single space feeder was instrumented. The trough was removed from the feeder and positioned on a load cell, and the hopper was suspended by a load cell directly above the trough. This enabled each to be weighed separately without changing the appearance of the feeder significantly. In front of the feeder a weigh platform was located, also on load cells, to allow weighing of half pigs in a manner similar to that used by Turner *et al.* (1985). Underneath the weigh platform was a spill tray on a load cell to measure the wastage. In addition, a positive displacement flow meter was used to record the amount of water used in the feeder. An electronic identification system was installed in the feeder to facilitate identification of the pigs as they fed. The data were collected with an IBM compatible computer, using software written expressly for that purpose.

With a concrete weigh platform in place approximately 74% of the wastage was caught in the spill tray, the remainder falling into auxiliary trays that were used to determine the amount of spillage not being recorded and where it was falling. Using a mesh platform, approximately 82% of the wastage was caught when the feeder was used dry. Water overflowing the trough prevented accurate measurement when the feeder was used wet. At present a hose attached to the trough directs this overflow into a bucket, the contents being recorded manually. A selection of the accuracies of the system for a trial using a single pig are given in Table 1.

Table 1. Accuracy of system when used with a single pig (all measurements in grams force)

	Pig weight	Hopper weight	Trough weight	Spill weight
Measured (for dynamic loading)	1,800	22	23	4
Theoretical (for static loading)	24	56	12	2

Successful operation of the test rig has been verified, however, planned improvements include a larger spill tray to catch all the wastage, a stiffer, free standing, feeder support frame, and new data collection software to give real time results. These improvements will be incorporated into a second prototype which will be useful in determining spillage, pig weights and the temporal response of the feeding pig.

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LOCATING SOME QUANTITATIVE GENES IN THE PIG

C.P. McPhee

Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.

Most economically important traits in pigs are under the control of quantitative genes. Locating these on the pig genome will facilitate genetic improvement in pig productivity. Substituting portions of the chromosome (haplotypes) with standard haplotypes containing marker genes and observing changes in a quantitative trait can help to locate genes affecting that trait, as was demonstrated in *Drosophila* by McPhee (1971). This study uses the same principle to locate haplotypes of the pig which appear to contain genes for appetite and growth rate. The effect on these traits of substituting haplotypes containing the halothane gene *n* was examined in a genetic line which had been selected for rapid lean growth then relaxed for 4 generations, and in an unselected line of the same origin. The *n* haplotype was segregating in both lines and its substitution effect was measured from *(nn - NN)/sd* where *nn* and *NN* are the means of the halothane and normal homozygotes and *sd* is the line standard deviation of each trait. The least square mean growth rates, appetites and backfats of *NN* genotypes ($N = 50$) and substitution effects of the *n* haplotype are given in Table 1 for pigs from both lines grown to 90 kg on *ad libitum* feeding.

Table 1. Line means of *NN* genotypes and *n* gene substitution effects

Trait	Line means (*NN*)			Substitution effects		
	Selected	Unselected	Sign.[1]	Selected	Unselected	Sign.[1]
Growth rate (kg/d)	0.63±.01	0.55±.01	**	-2.2	-0.4	**
Feed intake (kg/d)	2.55±.05	2.37±.01	**	-2.0	-0.6	**
Backfat (mm)	14.0±.6	19.4±.5	**	-0.6	-0.4	NS

[1]NS, non significant, P>0.05; ** P>0.01.

Compared with the unselected line, the selected line grew faster and had a higher appetite and less fat. Substitution of *n* for normal *N* gene containing haplotypes reduced all traits in both lines, the effect being much greater in the selected than in the unselected line for growth rate and appetite, but about the same for fat.

These observations are consistent with a model in which the halothane locus is the site of a series of normal haplotypes affecting growth rate and appetite (say N_1, N_2, N_3, N_4) in the unselected population. During selection, those with a neutral or negative effect on these traits (say N_3, N_4) are removed leaving N_1, N_2 in the selected line. The replacement of some of these *N* containing haplotypes with *n* haplotypes would be expected to have a much greater depressing effect on growth rate and appetite in the selected than in the unselected line, as was observed. In contrast, low fatness genes accumulated in the selected line seem to have been at loci away from the halothane locus since the substitution effect of the *n* haplotype on fat did not differ significantly between the lines. It is intended to explore other statistical techniques (eg; DFREML) to check for bias in estimating haplotype effects.

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A SYMPOSIUM - STOCKING DENSITY AND PIG PERFORMANCE

J.L. Black and J.R. Carr*

CSIRO Division of Animal Production, Prospect, PO Box 239, Blacktown, NSW 2148. *J.R. Carr and Associates, PO Box 1655, Toowoomba, Qld. 4350.

Symposium introduction

The rate of animal growth and the efficiency of feed use both have a substantial influence on the profitability of a pig production enterprise. Yet, these performance characteristics of pigs raised commercially are well below the animal's potential and the levels achieved under experimental conditions. For example, Campbell and Taverner (1985) measured a growth rate of over 1100 g/day for entire male pigs growing from 45 to 90 kg live weight during experiments, whereas the identical strain and sex of animals grow at less than 800 g/day over the same period in commercial piggeries. Similarly, the rate of growth of pigs raised in boar test buildings on commercial piggeries are 20 to 30% greater than for similar animals reared in the commercial production units.

J.R. Carr and B. Hansen (unpublished) were among the first who attempted to identify possible reasons for these differences, with experiments conducted during the late 1970's and early 1980's at the Mayfair Piggery, Bendigo, Victoria. The mean growth rate of pigs from 20 to 87.5 kg live weight was about 860 g/day, for animals housed in the boar test sheds, compared with only 675 g/day for pigs of identical breeding, raised in the commercial units. There were substantial differences between the two shed types in both building and pen characteristics. The boar test sheds compared with the commercial units had fewer pigs per building (320 vs 1120), more air space per pig (6.2 vs 1.6 m^3), a greater air inlet per pig (0.17 vs 0.03 m^3), more floor area per pig (0.55 - 2.20 vs 0.37 - 0.55 m^2) and fewer pigs per pen (1 - 4 vs 40). In one experiment, Carr and Hansen replicated the pens from the boar test pens inside pens within the commercial units and measured animal performance. Despite large differences in pen characteristics, the growth rate of pigs from 40 to 50 kg and from 70 to 80 kg live weight, were 715 and 708 g/day for pigs with pens similar to those in the boar test sheds, and were not significantly different from the growth rates of 682 and 719 g/day, respectively, for pigs raised in normal commercial unit pens. These differences in growth rate were related to corresponding differences in feed intake, rather than to differences in the efficiency of feed use, and the depression in feed intake was observed immediately the pigs were transfered from the boar test sheds to the commercial unit. Similar results were obtained by the same research workers from trials conducted at the Menangle piggery in New South Wales. These experiments indicate that the depression in performance is associated primarily with the characteristics of the building, rather than with characteristics of the pens. Possible factors include the social and climatic environment, disease and air quality.

The profitability of pig production enterprises could be increased substantially, particularly for units with the modern lean strains of pigs, if animals in commercial units could achieve growth rates closer to their genetic potential. The aims of this Symposium are to examine current knowledge about factors that may be responsible for depressing the performance of pigs raised in commercial piggeries and to predict, using the AUSPIG decision support software, the consequences of these factors on pig performance and enterprise profitability.

EFFECT OF GROUP SIZE ON THE BEHAVIOUR AND PERFORMANCE OF GROWING PIGS

B.L. Nielsen and A.B. Lawrence

SAC Edinburgh, Genetics and Behavioural Sciences Department, Bush Estate, Penicuik, Midlothian BH26 0QE, Scotland, UK.

Introduction

In the past, genetic selection programs for pigs have been based on measurements from individually-housed animals. The manual weighing of feed offered and feed refusals to obtain information on the intake of individual animals is labour intensive, and the housing method is both expensive and different to that found on most commercial farms, where growing pigs are housed in groups. Also, the selection of pigs in an environment different from that in which they are to be kept commercially, may be responsible for the discrepancy between performance results achieved by pig breeders and those reared in commercial units (Merks, 1989).

The development of computerized feeding systems appears to have solved these problems. Computerized feed intake recording (CFIR) systems allow breeders to measure individual feed intake whilst keeping the animals in a group environment (Young and Lawrence, 1993). However, current CFIR systems generally provide only one feeding space per group of pigs, which may lead to increased competition for access to the feeder, both in comparison to the individually-housed system used by breeders and to the housing situation on the farm, where often more than one feeding space is available. The importance of this competitive behaviour as a source of genotype x environment interaction is at present unclear (Webb, 1989). Pigs, that perform well in a CFIR system, may be behaviourally different from pigs that perform less well, which might result in an indirect selection for certain behavioural traits, such as aggression.

A number of experiments have been carried out with various combinations of group size, feeding space and stocking density, to investigate the effects of social competition on performance and behaviour of growing pigs. Individually-housed pigs generally grow faster than group-housed pigs (Patterson, 1985; Gonyou *et al.*, 1992), although some authors find that pigs kept in groups have a higher feed intake than individually-penned animals, due to an apparent increase in feeding motivation stimulated by other group members (Hsia and Wood-Gush, 1983). Most authors found that increasing group size does not appear to have an adverse effect on performance when the pigs are given ample space and *ad libitum* feeding (Madsen and Nielsen, 1979; Randolph *et al.*, 1981; Kornegay and Notter, 1984). Petherick (1983), suggested accordingly that group size will affect performance adversely only when the amount of total space is below a certain level, or when access to feed is restricted. The latter may be the case with computerized feeders which allow only one pig per group to feed at a time. In an investigation of different group sizes using single-space feeders, Walker (1991) tested groups of 10, 20 and 30 pigs with a constant floor space allowance of 0.6 m^2/pig. He found that pigs kept in groups of ten had a lower daily feed intake but a better feed conversion efficiency than pigs kept in groups of 20 or 30, resulting in no differences in average daily live-weight gain between groups. As expected, the number of pigs queuing to feed counted at hourly intervals increased with increasing group size.

The experiment presented below was designed to investigate the effects of increased competition around a single-space feeder on individual performance and behaviour, by manipulating the number of pigs per feeder. A CFIR system was used to accurately monitor several important feeding behaviour and production variables.

Material and methods

One hundred and fifty male crossbred pigs (Cotswold Pig Development Co. Ltd., Lincoln, UK) were fitted with transponder ear-tags and penned in groups of 5, 10, 15 or 20 (three replicates per treatment) with one single-space computerized feeder (FIRE, Hunday Electronics Ltd, Newcastle, UK) per pen. Each pen had an insulated kennel, sized according to the number of pigs in the pen, and the total space allowance was 1.06 m^2/pig for all groups. Pigs were offered a commercial pelleted grower diet (320 Ultra Grade, Dalgety Agriculture) *ad libitum* for 29 days from 34 ± 3.7 kg (mean ± SD) live weight. All animals were weighed weekly. The computerized feeding system produced a record of each feeder visit consisting of pig identity, time of day, duration and feed intake. An adjustable race leading to the trough prevented more than one animal from entering the feeder at any one time. The animals were exposed to natural light which, during the course of the experiment, gradually increased from 12 to 18 hours. In an attempt to counterbalance partially this change in the light period, artificial lights were switched on at 05:00 h and off at 20:00 h during the whole experimental period. The average temperatures inside and outside the kennels were 16 ± 4.0°C and 11 ± 4.4°C respectively (means ± SD). The data were analysed using analysis of covariance with GENSTAT (Lawes Agricultural Trust, 1987). The model chosen compared groups of 20 to the other group sizes as this gave the best description of the data.

Results

The results are presented in Table 1. The group size in which the pigs were kept influenced all the feeding behaviour variables, with pigs kept in groups of 20 (GS20) making fewer ($P<0.01$) but longer ($P<0.05$) visits to the feeder, than pigs kept in the smaller groups. These two variables did not, however, negate each other, as the pigs kept in GS20 spent less ($P<0.05$) total time in the feeder. Pigs in GS20 also ate more ($P<0.05$) per visit, and they ate faster ($P<0.05$) than pigs kept in smaller groups. There were no differences between groups in daily feed intake, daily live-weight gain and feed conversion ratio, when adjusted for differences in the initial live weight.

Table 1. Mean feeding and production variables for the different group sizes. The means of the three pens per treatment are from days 8 - 28 of the experimental period, and all are adjusted for differences in initial live weight

	Group size				RSD	20 vs rest[1]	
	5	10	15	20		F	Sign.
Feeding variables							
Feeder visits (no/pig/d)	15.9	13.6	13.4	7.1	7.7	18.0	**
Duration of visit (min)	4.28	5.01	4.62	6.91	3.8	7.8	*
Feed intake (g/visit)	96.2	134.5	126.5	214.4	109.3	15.8	*
Feeding rate (g/min)	23.8	26.9	27.0	31.6	7.0	12.4	*
Feeder occupation (min/pig/d)	63.3	61.4	53.5	48.1	15.6	8.9	*
Production variables per pig							
Feed intake[2] (g/d)	1456	1609	1416	1495	488.4	<1	NS
Live-weight gain (g/d)	695	762	714	721	265.6	<1	NS
Feed conversion ratio	2.16	2.13	2.01	2.10	0.324	<1	NS

[1]Comparison of group size 20 with other group sizes; NS, non significant, $P>0.05$; *$P<0.05$; **$P<0.01$. [2]Calculated as the mean of individual daily feed intakes; it is not necessarily equal to the product of number of feeder visits and feed intake per visit presented in the table.

All groups showed two peaks in their daily feeding pattern; a small peak about 08:00 h and a larger peak towards 16:00 h. Differences were found in the feeder occupation shown by the different group sizes over 24 hours. The groups of five barely reached 50% feeder occupation and the groups of ten occupied the feeder for just over 80% only at the afternoon peak. In contrast, the groups of 15 and 20 used the feeder 60 - 100% of the time for almost all of the light period.

Video-recordings of the different group sizes are currently being analysed and the correlations between social behaviour and performance investigated.

Discussion

For all the feeding behaviour variables measured in the current experiment there appear to be a threshold effect, with the pigs kept in groups of 20 differing significantly from pigs kept in groups of 15 or less. The change in feeding behaviour in the groups of 20 (fewer but longer visits, and faster eating) might be expected in pigs facing increased competition for access to feed and appears to represent an adaptation to the constraint placed on their feeding behaviour. This is supported by findings that provision of two single-space feeders to a group of 20 pigs increased the total time spent feeding, from 44 to 51 min/pig/day, compared to one single-spaced feeder (Morrow and Walker, 1991). The constraint on feeding behaviour may consist in part of an unwillingness of the pigs to feed at night, together with a preference of group-housed pigs to feed at the same time, which is expressed by the peaks shown in feeding activity. The lack of differences in performance between the different group sizes show that the pigs in the larger groups were able to adequately compensate for the decrease in trough:animal ratio. Walker (1991) found that the groups of 30 animals occupied the feeder between 80 - 100% at any given time during the first 5 weeks of the experimental period, showing that the pigs were also feeding during the night. This would suggest that although these pigs were able to adapt to the lack of feeding space, they did so by displaying behaviour not normally seen in diurnal animals.

The feeding behaviour results correlate well with those found by de Haer and Merks (1992) using eight pigs per group. They compared these groups to individually-housed animals using a Dutch version of CFIR and found that the individually-kept pigs had more, but shorter, visits to the feeder, and ate less per visit than pigs kept in groups of eight. The results indicate that feeding pattern is not influenced only by group size, but by whether the pig is in a group or not.

Acknowledgements

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EFFECT OF STOCKING ARRANGEMENT ON PIG PERFORMANCE

R.P. Chapple

Purina Mills, Inc., St Louis, MO 63144, USA.

Introduction

Since the inception of intensive pig rearing systems, producers have struggled with defining the optimum stocking arrangement. Considerable research has provided sufficient information to set guidelines and make general recommendations regarding optimal pig density. These recommendations have normally taken the form of minimum or adequate space allocation per animal and account for a recognized reduction in performance as group size increases. However, the negative impact of

antipathetic handling by animal caretakers and providing pigs with barren environments has not generally been considered.

The guidelines for stocking density and minimum group size has served the pig industry well in the past. However, as the competitive nature of animal production continues to escalate, it is essential to understand the reason why commercially-housed animals grow at rates well below their genetic potential. The objectives of this paper are to review recent research related to stocking density, including the impact on eating and activity behaviours, and to provide evidence to suggest a hypothesis for the mechanism controlling the reduced performance observed when pigs are overstocked.

Historical

The negative impact of crowding and large group size has been recognized for a long time (Heitman *et al.*, 1961; Gehlbach *et al.*, 1966). These two groups were among the first to establish maximum stocking intensity without reducing pig performance, and to identify the 'apparently' different effects of group size versus space allocation per animal. Subsequently, many experiments have generated results to fine tune stocking density recommendations. Kornegay and Notter (1984) summarized the information available to that time. Pooling data by live-weight category and adjusting for data source differences by covariance analysis, they developed polynomial regression relationships between either floor space allocation per pig or group size and average daily growth rate (ADG), average feed intake (ADF) and feed conversion ratio (FCR). These equations are listed in Table 1.

Table 1. Equations from Kornegay and Notter (1984) relating floor space allocation and group size to growth criteria

Floor space[1]			Group size[2]	
Weaner period (7.6 to 21.1 kg)				
ADG[3]	= 0.261 + 0.800S - 1.051S^2		= 0.4178 - 0.0037N	
	0.97[5]	(0.001)[6] (0.22)	0.97	(0.01)
ADF[3]	= 0.533 + 1.121S - 1.383S^2		= 0.8317 - 0.0092N	
	0.97	(0.001) (0.36)	0.97	(0.01)
FCR[4]	= 2.081 - 1.733S + 3.253S^2		= 1.9535 - 0.0051N	
	0.88	(0.05) (0.24)	0.94	(0.09)
Grower period (26.6 to 53.5 kg)				
ADG	= 0.489 + 0.520S - 0.281S^2		= 0.6407 - 0.0019N	
	0.93	(0.01) (0.30)	0.43	(0.21)
ADF	= 1.542 + 0.856S - 0.404S^2		= 1.5950 - 0.0025N	
	0.93	(0.05) (0.30)	0.87	(0.50)
FCR	= 3.037 - 0.734S + 0.406S^2		= 2.4974 + 0.0037N	
	0.94	(0.05) (0.31)	0.94	(0.46)
Finisher period (44.1 to 92.3 kg)				
ADG	= 0.398 + 0.704S - 0.340S^2		= 0.7497 - 0.0012N	
	0.69	(0.001) (0.01)	0.82	(0.49)
ADF	= 1.619 + 1.833S - 0.837S^2		= 2.3748 + 0.0032N	
	0.74	(0.001) (0.05)	0.92	(0.40)
FCR	= 3.840 - 0.927S + 0.520S^2		= 3.2182 + 0.0060N	
	0.40	(0.22) (0.32)	0.72	(0.39)

[1]S, space per pig (m^2); [2]N, number of pigs per pen; [3]ADG, ADF have units of kg/pig/d; [4]FCR, ADF/ADG; [5]Equation R^2; [6]P values for the parameter estimate.

The following factors make these equations difficult to interpret and implement:

1. Many quadratic parameter estimates in the floor space equations are not significantly different from zero. This suggests a linear representation is adequate, which casts doubt about the true response surface.

2. All equations have highly significant, positive intercepts, which is impossible because they predict significant growth when either zero space is available or no pigs are present. This is a result of the range in the independent variables used among the data sets (0.08 to 0.32, 0.18 to 0.78 and 0.36 to 0.98 m^2 per pig for the weaner, grower and finisher periods, respectively and 3 to 15 and 5 to 32 pigs per pen for the weaner and combined grower-finisher periods).

3. Apparently, space allocation has a much greater impact on performance than group size. However, many of the data sets used to generate the floor space equations confounded the two components which interact, particularly when space is minimal (Petherick, 1983).

4. Results for group size effect are inconsistent; there was an apparent positive relationship on feed intake during the finisher period, but negative influence during the weaner and grower periods. A similar discrepancy occurred for FCR. It is illogical to expect a different response to group size dependent upon weight.

5. There was a substantial trend for lower R^2 values for all criteria in the floor space equations moving from the weaner to the finisher period, indicating other aspects were resulting in unaccounted variability. Thus the confidence in predicted response is diminished over time.

Most of these problems result from using an empirical approach. Petherick (1983) proposed a better method for establishing space allocation, which was based on spatial requirements for pigs to lay on their sternum or fully recumbent. This description (Area (m^2) = $k*W(kg)^{0.67}$, k = 0.048 in recumbent and k = 0.034 in sternum positions) is weight dependent, but more importantly has physiological significance since pigs use postural changes to broaden their zone of thermal comfort. These results are similar to the value for k (0.039) which can be calculated from the recommendations suggested by Gehlbach *et al.* (1966) almost 30 years ago. More information on the impact of area per pig and group size has been obtained in the 10 years since the report by Kornegay and Notter (1984). Table 2 summarises the general responses observed from some of these experiments. The variability could be explained by the wide range in pig weights and space allocation.

Although stocking density guidelines have been developed from this large amount of research, they have changed little since the first studies of Heitman *et al.* (1961) and Gehlbach *et al.* (1966). In addition, little more is known about the causes of either the observed loss in pig performance from overstocking, or the underlying reasons for such large variability to seemingly similar stocking arrangements.

Behavioural aspects

Little work has been conducted to quantify the performance of individually-housed pigs compared with their counterparts housed in groups. Much of the data has been gathered to compare changes in daily activities of pigs, and to understand the behavioural adjustments pigs make when adapting to penmates, and a dominance hierarchy resulting from differences in group sizes and in area per pig (Randolph *et al.*, 1981; Meunier-Salaun *et al.*, 1987).

Table 2. Generalized performance responses to floor space allocation and group size[1]

Source	ADG	ADF	FCR
Floor space			
Moser *et al.* (1985)	+	NC	-
Yen and Pond (1987)	+	+	NC
Edwards *et al.* (1988)[2]	+	NC	-
Hines *et al.* (1989, 1991)	+	+	-
NRC (1993)	+	+	-
Group size			
McConnell *et al.* (1987)	+	+	-
Petherick *et al.* (1989)[3]	+	+	-

[1]Indicators refer to an improved (+), depressed (-) or no change (NC) in performance for the indicated variable, in response to either increased floor space allowance or smaller group size. [2]Effect on the most severe space restriction only. [3]Effect on the largest group size only (36 vs 18 or 6 pigs/pen).

Hsia and Wood-Gush (1983, 1984) suggested that social facilitation in eating behaviour would induce an apparently satiated pig to consume additional feed, if a hungry pig was placed in an adjacent pen. This response was dependent on social rank, because more dominant pigs ate for longer periods of time and consumed more feed than less dominant pigs. However, these obervations were collected over 10 minute periods and may not be comparable to a group-housed, competitive situation. Baldwin and Meese (1979) demonstrated that, when pigs operantly conditioned to receive feed in reward for pressing a panel, were starved for 24 h then penned in pairs, the dominant pig obtained the most feed. However, when pigs under the same conditions were penned in a group of three, the effect of dominance on intake was abolished. When only one pig in the trio was satiated, the more dominant of the remaining two fasted pigs did the most panel pressing. It was concluded that when pigs are in larger group sizes, social interactions are complex and their response is probably a function of both satiety and dominance.

Spicer and Aherne (1987) demonstrated a reduction in feed intake and growth rate of newly weaned piglets when housed in groups of four, as compared to individually or in pairs. No difference was observed either in the time spent resting/sitting or in total activity time between the group sizes. In contrast, Petherick *et al.* (1989) observed that grower pigs (40 kg) penned in groups of 36 were more active at all times than pigs housed in groups of 6 or 18. Furthermore, pigs in the smallest group settled quicker after activity bouts and showed less agonistic behaviour in the first week of the study. The disparity between these two reports may be explained by the difference in pig age. Spicer and Aherne (1987) demonstrated that piglets spent a greater proportion of the day in active behaviours immediately post-weaning, than at older ages.

New information regarding behavioural modifications to stocking arrangement has come from continuous observation of activity (Walker, 1991; Gonyou *et al.*, 1992; de Haer and Merks, 1992; de Haer and de Vries, 1993). Walker (1991) investigated the effects of penning pigs (37 to 90 kg) in groups of 10, 20 or 30 on growth criteria and eating behaviour using a single-space feeder with solid, protective side walls. Equal floor space per pig was provided for each treatment. In this situation, daily feed consumption for the entire period was greater for pigs housed in groups of 20 or 30 than for those in groups of 10, whereas growth rates were not different. However, there was a highly significant difference in treatment response across time. During the first two weeks of the trial, feed intake and weight gains were depressed in the largest

group. Subsequently, the smallest group consumed less feed and grew more slowly than pigs housed in groups of 20 or 30. This response can be explained by comparing the feeder occupancy times shown in Table 3. Apparently, the pigs housed in groups of 30 required about two weeks to adjust eating habits to feeder unavailability, as evidenced by the 100% feeder occupancy during this period. The results in Table 3 show that as pigs grow, the absolute rate of feed consumption increases, but when expressed per unit of metabolic body weight, it declines (Nienaber *et al.*, 1990). Over the weight range of pigs represented in Table 3, the relative consumption rate calculated from the relationship of Nienaber *et al.* (1990) would fall from about 1.1 to 0.9 g/min/kg$W^{0.75}$, which is equivalent to 19, 23 and 24 g/min for the mid-point weights. These values are lower than those presented in Table 3 for pigs housed in groups of 10, but the pigs used by Nienaber *et al.* (1990) were individually housed. de Haer and de Vries (1993) found that individually-housed pigs consume feed at slower rates than those penned in groups. Nevertheless, the feed consumption rate of pigs grown in groups of 10 (Table 3) increased 50% over time. Pigs housed in groups of 30 consumed feed at a rate twice that observed for pigs penned in groups of 10.

Table 3. Single-space feeder occupancy and calculated feed consumption rates of pigs housed in groups of 10, 20 or 30[1]

	Week	Pigs per pen		
		10	20	30
Time of feeder occupancy (%)	2	66	86	101
	5	50	73	92
	8	45	68	82
Rate of consumption (g/min)	2	21	33	33
	5	27	44	44
	8	34	46	61

[1]Walker (1991). The main effects of group size and time were both significant, $P<0.001$.

Walker (1991), showed that the characteristic biphasic eating pattern of pigs was virtually eliminated during the first two weeks of the trial, for pigs housed in groups of 30. As feeder occupancy declined over time, regardless of group size, the biphasic eating activity returned, with daily eating activity peaks between 0700 - 1100 and 1400 -1800 h. This finding suggests that inherent photoperiodicity may be another key factor determining the pig's overall response in feed consumption to environmental stimuli.

Using single-space feeding stations which allowed instantaneous measurement of feed disappearance, de Haer and Merks (1992) and de Haer and de Vries (1993) showed the effect of group size on eating behaviour. Results from the two studies were similar and those from de Haer and de Vries (1993) are presented in Table 4.

These data demonstrate a dramatic, negative effect of penning pigs in groups rather than individually, depressing feed intake and growth rate by about 7 and 13 %, respectively. Compared to individually-penned pigs, the number of meals consumed daily was halved, intake per meal more than doubled and rate of consumption increased by 20%.

Gonyou *et al.* (1992) and W.H. Gonyou, G.R. Frank and R.P. Chapple (unpublished) also have compared individually-penned pigs to groups of 5, 10 and 15 (Table 5). Growth rate and feed intake were depressed by 6 to 8% for pigs housed in groups, as compared to those housed individually. There was little difference in performance for pigs housed in groups from 5 to 15 per pen. Similar results have been obtained by Patterson (1985), Spicer and Aherne (1987) and Neilsen and

Lawrence (1993). Group-housed pigs are more active and spend less time lying compared with individually-housed animals. Petherick *et al.* (1989) and de Haer and de Vries (1993) also observed greater activity in group-housed pigs which would be expected to increase maintenance energy requirements. The depression in feed intake and increase in maintenance requirements could explain the reduced feed conversion efficiency, reported by Walker (1991) for group-housed pigs. Gonyou and his colleagues (unpublished) showed that diurnal activity patterns were similar for all group sizes, but the larger groups spent more time standing than the smaller groups (Figure 1). This observation suggests greater competitive activity associated with eating, but the competition could be influenced by feeding system and other factors, such as space per animal.

Table 4. Effect of group size on growth performance and feeding behaviour[1]

	Group size		Significance[2]
	1	8	
Growth rate (g/d)	742	642	**
Feed intake (g/d)	2075	1934	NS
Feed intake/meal (g)	104	224	**
N° meals/d	22.9	10.3	**
Feeding time (min/d)	83.2	62.5	**
Rate of consumption (g/min)	26.9	32.4	**

[1]de Haer and de Vries (1993). Note that calculation of a variable from combinations of others (eg; Intake/day=Feeding time x Rate of consumption) may not equal the tabled value. This is a result of the definition of meals as described in the publication. [2]NS, non significant, P>0.05; **P<0.01.

Table 5. Production performance and time budgets of pigs penned individually or in groups of 5, 10 or 15[1]

	Group size				Significance[2]
	1	5	10	15	
Production					
Growth rate (g/d)	988	943	916	936	**
Feed intake (kg/d)	2.99	2.84	2.80	2.84	NS
Feed/gain ratio	3.02	3.02	3.03	3.04	NS
Time budgets (% of total time spent)					
Eating	10.06	9.04	9.92	9.64	NS
Standing, not eating	6.63	8.32	9.10	8.70	**
Lying	83.3	82.6	81.0	81.7	**

[1]Unpublished data from W.H. Gonyou, G.R. Frank and R.P. Chapple; [2]NS, non significant, P>0.05; **P<0.01.

Identical feeders each with two feeding access holes were used in the study of Gonyou and his colleagues (unpublished). Pigs housed in groups of 15 were supplied with two feeders per pen, one half of the pigs in groups of 10 had one and the other half had two feeders, whereas all individually-housed pigs and those in groups of 5 were supplied with only one feeder. Continuous observation of pig behaviour showed that animals consistently choose a particular access hole in a specific feeder and that, in general, pigs avoided eating together. However, pigs in group sizes of 10 or 15 exhibited a lower avoidance index than those in smaller groups, suggesting that when

pigs are hungry they will use another feeder access hole if their preferred one is occupied.

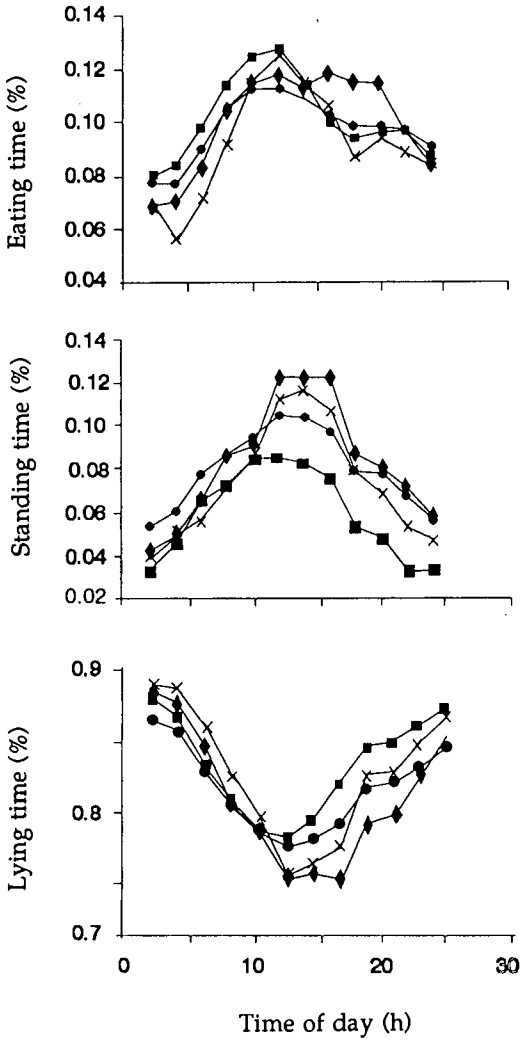

Figure 1. *Percent of time in each activity during 2-hour periods of the day by pigs in different group sizes (■,1; ×,5; ♦,10; •,20 pigs/pen). From H.W. Gonyou, G.R. Frank and R.P. Chapple (unpublished).*

Taken together these reports indicate that: 1) the social interaction between pigs alters substantially the behaviour and performance of pigs housed in groups compared with those housed alone, 2) strong preference by pigs for a particular feeder place is modified to maintain a minimum level of satiety, and 3) group-housed pigs spend a greater time in non-eating, feeding-associated activity than pigs housed individually, which may increase energy expenditure and reduce performance.

Although the observations presented in this section have improved our understanding of the pig's responsiveness to stocking arrangement, they only address the outcome and not the underlying cause. If a resource such as feed, or access to it, is not limiting, why would a pig 'choose' not to consume it up to the point at which their growth potential is realized? However, pigs in groups apparently made this

'choice'. An alternative hypothesis to account for this observation is as follows.

Alternative hypothesis

Experiments at Purina Mills (R.P. Chapple, unpublished) over many years, like those described by Black and Carr (1993), show that pigs housed individually in the research facility, grow on average 16% faster and have a 19% better feed conversion efficiency, than their littermates reared in a commercial production unit. Although many factors differ between the research and production unit, two experiments were conducted to identify the effect of group size alone by housing pigs individually and in groups of 3 and 5. One experiment, over 21 days, was for weaner pigs weighing initially 6.5 kg and the other was for pigs growing from 20 to 100 kg live weight. In the latter trial, a floor space of 1.3, 0.9, 0.8 m^2/pig was allocated, respectively, for animals housed individually and in groups of 3 and 5 pigs.

A significant ($P<0.05$) linear depression in both growth rate and feed intake was observed with increasing group size for the weaner (Figure 2) and grower (Table 6, Obs columns) trials. These results show that the consequences of social behaviour on pig performance are present from weaning and occur once two or more pigs are forced to interact.

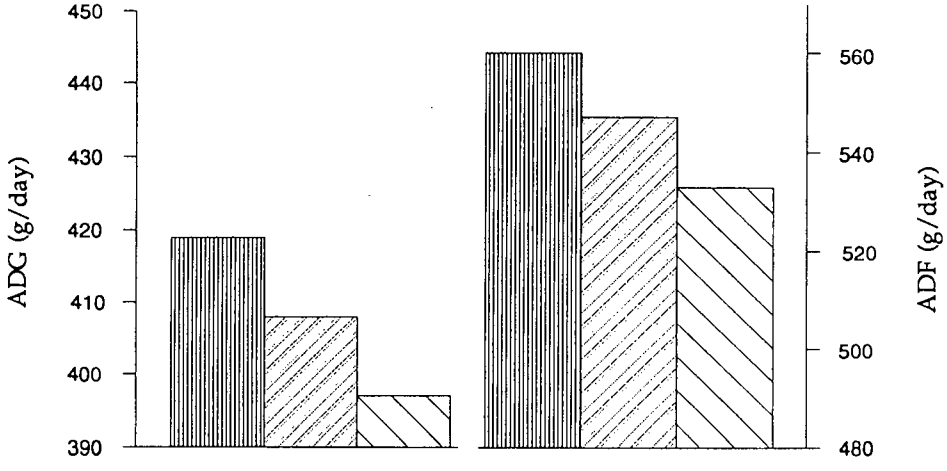

Figure 2. *Effect of group size on weaner pig growth rate and feed intake from 7 to 28 days post-weaning (▥,1; ▨,3; ▧,5 pigs/pen). R.P. Chapple (unpublished).*

The AUSPIG simulation model has been used to help determine the physiological response within the animal that may be responsible for the observed effect of group size. The potential rates of fat and protein deposition, and the relationship between body weight and the partition of metabolisable energy between fat and protein deposition, have been established for the Purina Mills pig genotype. These determined 'genotype factors' were adjusted marginally until the performance of pigs in the grower trial predicted by the AUSPIG model corresponded with that observed for individually-housed pigs (Table 6, AP column). The AUSPIG model was then used to assess the consequences of simply reducing feed intake to that observed as group size was increased to 3 and to 5 pigs. Contrary to the observations, the effect of reducing intake was predicted to result in leaner pigs (Table 6, FI columns). This occurred because the recti-linear relationship between protein deposition and energy intake has a plateau over a substantial range of body weight for the Purina Mills pig genotype.

Table 6. Measured performance and backfat compared with predicted performance and body composition, using the AUSPIG simulation model, for pigs reared individually, or in groups of 3 or 5, from 20 to 100 kg live weight[1]

	Group size[2]							
	1		3			5		
	Obs[3]	AP	Obs	FI	Geno	Obs	FI	Geno
Measured performance								
Gain (kg/d)[4]	0.89	0.89	0.87	0.86	0.86	0.84	0.83	0.83
Feed intake (kg/d)[4]	2.41	2.40	2.30	2.30	2.31	2.19	2.21	2.21
Feed/gain ratio	2.71	2.71	2.66	2.70	2.70	2.64	2.68	2.68
P_2 backfat (mm)	18.7		20.1			21.7		
AUSPIG prediction								
Protein dep (g/d)	-	132	-	129	125	-	127	119
Fat dep (g/d)	-	251	-	234	252	-	217	251
Fat tissue (%)	-	26.5	-	25.7	27.3	-	24.7	28.2

[1]Unpublished data from R.P. Chapple; [2]Pigs/pen; [3]Values under the observed (Obs) columns were measured, all others were predicted from AUSPIG (AP) simulations. Those under FI (feed intake) columns were derived by forcing the predicted feed intake to equal that of the observation. Values under the genotype adjustment columns (Geno) were generated by changing the potential deposition rate of protein and energy so that growth rate, feed intake and fat percentage matched the observed values; [4]Linear depression ($P<0.01$) of observed values with increasing group size.

Thus, a reduction in energy intake resulted in little change in protein deposition, but a substantial reduction in fat deposition. The concept is illustrated in Figure 3, by following the vertical lines labelled 3 and 5 (representing group size) to a point where they intersect the fat and protein deposition lines labelled 'Fat 1' and 'Pro 1', and observing a fall in deposition of fat but no change in protein deposition at the points labelled '1', '3F' and '5F'.

An alternative hypothesis was tested in two more simulations. Instead of assuming a behavioural depression of feed intake, the assumption was made that the capacity of the pig to deposit body tissue declined when it was reared in a group. This was achieved in the AUSPIG model by changing the parameters describing potential protein and energy deposition of the pig. The results of these simulations are tabulated under columns labelled 'Geno' (Table 6). By making these adjustments, all growth performance criteria and body composition compared closely with those observed. The outcome was a 10% reduction in protein deposition rate, but virtually no change in the accumulation rate of body fat. This concept is also illustrated in Figure 3, by following the vertical lines labelled 3 and 5 to a point of intersection with fat deposition lines labelled 'Fat 3' and 'Fat 5', and with protein deposition lines labelled 'Pro 3' and 'Pro 5' and comparing the points labelled '1', '3G' and '5G'. These predictions indicate that the 'stress' of being reared in a group reduces the capacity of the pig to deposit protein, and that this causes a reduction in feed intake and efficiency of feed use.

Concept extension

Indirect evidence that the mechanism suggested above may be correct is supplied from many results collected from Purina Mills on commercially reared pigs for the last 20 years, encompassing several genotypes, management systems, environments and representing over a million pigs. When all results are analysed to

account for energy density of the diet, there is a consistent growth rate of about 740 g/day, which has changed little over time, even though genetic improvements in growth potential of the pigs have occurred. The pigs appear to have adjusted total feed consumption, dependent on energetic density, so that energy intake remained similar. This suggests that the production system may put limits on the capacity of the pig to deposit tissue, even though it can easily consume adequate nutrients to support greater performance.

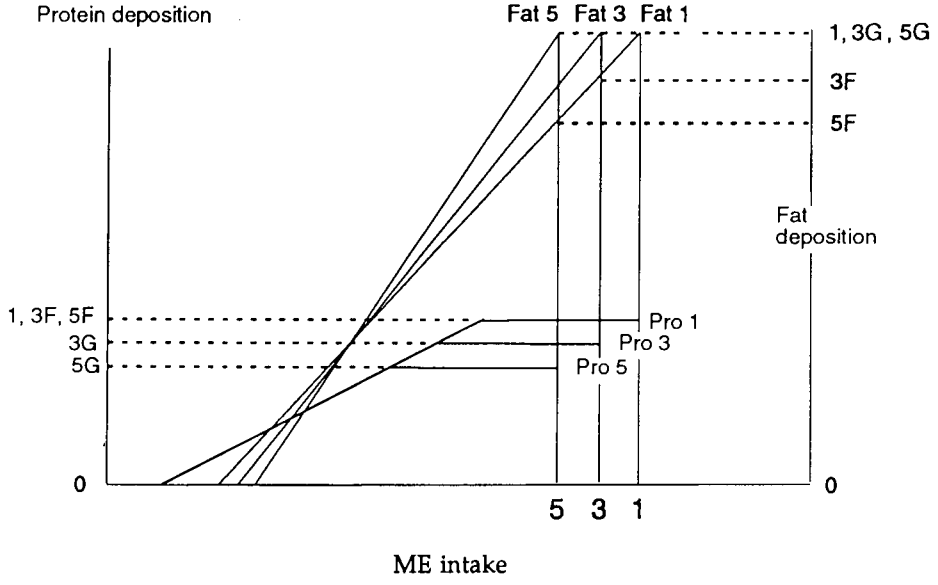

Figure 3. *Schematic representation of the effect of metabolisable energy (ME) intake on protein and fat deposition rates, under two different assumptions of growth response (behavioural feed reduction (F) and genotypic alteration in capacity to deposit tissue (G)), for 1, 3 or 5 pigs per pen.*

Many environmental factors may be stressful to a pig reared in commercial units, but they have not been studied systematically. However, McFarlane *et al.* (1989a,b) have investigated the impact of many mimicked and naturally occurring environmental stressors on growth and body composition of chicks. They evaluated the effect of elevated aerial ammonia, beak trimming, coccidial challenge, electric shock, heat and noise in a complete factorially designed experiment. Protein and fat deposition calculated from the data presented are plotted in Figure 4, against the number of stressors represented in the treatment without regard to its source. The strong linear relationship indicates that these stressors were additive and intensity dependent. Furthermore, the possibility that stress-induced responses may be mediated by a common controlling mechanism is implied. The likelihood is remote indeed that each stressor had separate and unique effects, but could combine in all permutations to be additive. The methodology used by McFarlane *et al.* (1989a,b) will prove to be useful for elucidating the biochemical basis of stress-induced growth reductions in the pig.

If the above hypothesis is correct, the stress in a pig associated with maintaining social order in groups, and that experienced when space is limited, should be mediated through biochemical factors that directs down-regulated tissue growth, lower nutrient requirements and reduce feed intake. Cortisol release is a response to stress and has been shown to be greater following an ACTH challenge (Paterson and Pearce, 1991) and in dexamethasone suppressed, ACTH challenged pigs (Meunier-Salaun *et al.*,

1987) which had been exposed to crowding stress. Cortisol release does reduce protein accretion, but is episodic and has relatively short-term effects. Therefore, it is unlikely to be the sole mediator, but has some role. Porcine somatatropin and the associated group of insulin-like growth factors can be down-regulated, as evidenced by the changes in nutrient partitioning and growth following pharmacological doses of these compounds. The cytokines also represent a large class of compounds which have profound effects on muscle cell and adipocyte metabolism, but relatively little is known about their response to stressors. In addition, tissue specific proteases may be the cellular mediators controlling protein turnover, following a stimulus from circulating messengers, resulting from stress.

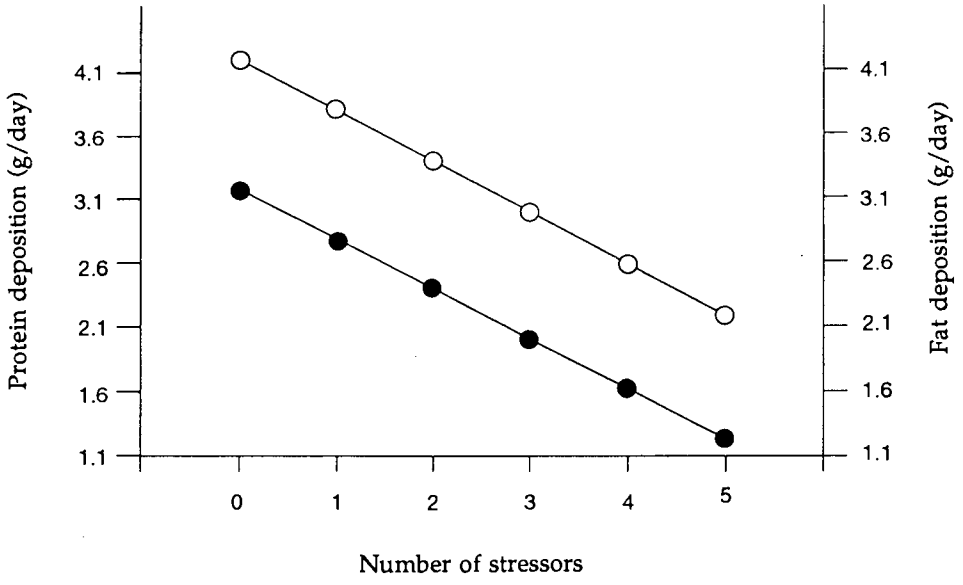

Figure 4. *Protein(o) and fat(•) deposition rates in chicks exposed to multiple, concurrent stressors. Calculated from McFarlane et al. (1989a,b).*

It is likely that both short and long-acting mediators interact to regulate growth and cause appropriate responses to the acute and chronic challenges from environmental stressors. Because the 'realised' growth capacity of pigs reared commercially is so distant from that known to be inherent or 'genetically' possible, intense investigation to elucidate the mechanisms responsible is warranted.

Conclusions

Commercial housing and management systems exert a substantial, negative influence on the productive capability of the pig and has serious consequences on enterprise profitability. Furthermore, potential improvements in performance resulting from conventional breeding, administration of growth regulators such as PST and β-agonists, or manipulation of the genome, will not be realised fully unless the biochemical mechanisms controlling the response in pigs to stressors in a commercial piggery, are better understood. Traditional experiments which measure only whole animal responses to stressors will be of limited value. Studies are required to elucidate the biochemical and physiological control of both muscle and fat deposition, when the pig is confronted with an environmental challenge, of which stocking density is only one.

EFFECTS OF STOCKING ARRANGEMENTS ON RESPIRATORY DISEASE OF PIGS

S.Z. Skirrow

Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.

Introduction

It has long been recognised that many environmental factors affect the prevalence and severity of pig diseases. This is particularly true for respiratory diseases (pneumonia and pleurisy), which are spread not only directly from pig to pig, but also via aerosol droplets. Environmental factors that assist in the transfer of oro-nasal secretions between pigs are therefore likely to increase the transmission of respiratory infections. Among those factors that have been documented as affecting respiratory disease are air quality, ventilation rate, temperature, pen space per pig, air volume per pig, number of pigs per pen and shed section, type of pen wall, floor insulation, dunging facilities, feeder space per pig, and production system (all-in/ all-out; continuous) (Thomas, 1984; Smith, 1991). Most of these factors are inter-related and cannot be taken as separate entities. Considering the effects of stocking arrangements alone on respiratory disease ignores these other factors and the conclusions may be misleading.

Environmental factors and respiratory disease

Lindqvist (1974), in an extensive study into the environmental effects on pig diseases, found that pigs in Swedish herds had a lower incidence of pneumonia if there were less than 500 pigs per shed section, if more than 3 m^3/pig of air space was available and if more than 0.7 m^2/pig of floor space was provided. It was suggested that of all the factors that affected respiratory disease in this study, namely type of production system, number of pigs per section, air volume and floor space per pig, type of manure handling system and access to water, the most important was the type of production system (either continuous or all-in all-out).

The stocking density figures from Sweden are similar to those suggested by Backstrom and Bremer (1978), who stated that pigs with less than 0.5 m^2 of floor space and less than 3 m^3 of air space had a higher frequency of pneumonia. In Norway, Flesja *et al.* (1982) studied the relationship between the environment and disease in 20 herds, and found significantly more pleurisy and severe pneumonia in herds with more than 12 pigs per pen. There was also more pleurisy in herds with less than 3.5 m^3 of air space per pig.

The relationship between respiratory disease and stocking density was investigated in 27 Canadian herds by Wilson *et al.* (1986). Lung scores were measured using the method of Goodwin (1971). Increased herd average lung scores and snout scores were correlated ($P<0.05$) with less floor space per pig. However, there was no correlation between average lung score and growth rate, and some pigs with severe pneumonia at slaughter had good growth rates.

Pointon *et al.* (1985) provided information on the relationship between enzootic pneumonia and environmental conditions in Australian herds. Herds were selected on the basis of pneumonia prevalence at slaughter and divided into high (>70% of pigs with lesions) and low (<30% of pigs with lesions) herds. Herds were also stratified according to size into small (20 - 70 sows) and large (>100 sows) herds. Small, high prevalence herds had significantly more pigs per shed section ($P<0.001$) and per group ($P<0.01$). In addition, more large, high prevalence herds stocked pens ($P<0.05$) and air space ($P<0.05$) more densely. It is difficult to compare stocking densities in this study with those from other studies as pen and air space stocking rates were expressed as kg/m^2 and kg/m^3, respectively.

Respiratory disease and productivity

An experiment illustrating the dramatic effects of environment on respiratory disease and subsequent performance was conducted by Straw (1991). Pigs from a farm with enzootic pneumonia, pleuropneumonia and atrophic rhinitis, were placed in a test station with an improved environment and grown to 100 kg live weight. Improvements to the environment included fewer pigs per pen, more floor space per pig, fewer pigs per feeder, fewer pigs sharing a common airspace, and all-in all-out pig flow. The performance and amount of respiratory disease in the test station pigs was then compared to pigs reared on the home farm. The differences in stocking arrangements, feed conversion efficiency, growth rate and respiratory disease in the two groups of pigs are illustrated in Table 1.

Pigs reared on the test station with an improved environment, had less severe pneumonia than those reared on the home farm, and better growth rates and feed conversion efficiency. This demonstrates that it is not necessary to eliminate respiratory disease or the infectious agent to significantly improve pig performance. The specific components of the improved environment that contributed to the increased performance of the test station pigs were not determined.

Table 1. Stocking arrangements, feed conversion, growth rates and respiratory disease in pigs reared in different environments[1]

	Pigs reared on home farm	Pigs reared in improved environment
Number of pigs	50	50
Initial live weight (kg)	31.1 ± 2.9	31.0 ± 2.9
Space/pig (m^2)		
Grower	0.48	1.11
Finisher	0.60	1.11
N° pigs/feeder space		
Grower	6.0	2.5
Finisher	4.2	2.5
Pigs sharing common air space	650	50
Pig flow	Continuous	All-in/all-out
Feed conversion ratio to 100 kg	4.41	3.31
Growth rate to 100 kg (g/d)	639 ± 131	765 ± 127
Pig with pneumonia at slaughter (%)		
Mild	45.6	67.4
Moderate	28.3	14.0
Severe	26.1	16.6

[1]Straw (1991); data expressed as mean ± SD where applicable.

Estimates have been made of the effects of respiratory disease on growth rate and feed conversion efficiency. Some authors reported an inverse relationship between pneumonia, and growth rate, whereas others found little correlation. Straw *et al.* (1989) reviewed 27 studies on respiratory disease where data were provided on average daily gain and feed conversion efficiency. In 24 comparisons between pigs with enzootic pneumonia and pigs without pneumonia, the estimated regression for feed conversion ratio (FCR) and average daily gain (ADG) was:

> % increase in FCR due to pneumonia = -5.33 + 1.11 (% decrease in ADG due to pneumonia).

Therefore, for every 1% decrease in ADG due to pneumonia, FCR increases by 4%. In these 24 comparisons, the mean decrease in ADG due to enzootic pneumonia

was 17 g/day, and the increase in FCR was 14%. Five studies also examined the severity of pneumonia, and their collective results suggest that for every 10% of lung affected by pneumonia, ADG decreases by 37 g/day.

Most investigations into the effects of stocking density on pig disease have, however, been retrospective on-farm studies, with the amount of respiratory disease at slaughter the outcome or dependent variable. Growth rates have also been calculated and related to the amount of respiratory disease. These studies have an inherent problem in that respiratory disease is a dynamic process, with healing and infection occurring at different times, and perhaps continuously during the pig's life. The amount of pneumonia at slaughter may therefore not correlate well with the amount of pneumonia present during the life of the animal.

Using radiographic studies, Noyes *et al.* (1990) showed that the percentage of pneumonia found at slaughter was minimally related ($r^2 = 0.14$; $P<0.05$) to cumulative lifetime pneumonia. Similarly, live weight at 180 days was not related to the amount of pneumonia at slaughter. However, cumulative lifetime pneumonia was significantly correlated to live weight at 180 days ($r^2 = 0.42$, $P<0.001$), and it was calculated that, for every 1% increase in average lifetime pneumonia, a 1.46 kg decrease in weight from 100 kg at 180 days could be expected.

These findings suggest that it may be difficult to correlate growth rate or any 'risk factor' with the severity of pneumonia at slaughter. However, there is good evidence for a relationship between pneumonia and decreased growth rates and feed conversion efficiency, suggesting that this disease can have a serious economic impact (Straw *et al.*, 1989).

Risk factor studies

French development

A relatively new approach to disease investigation, that takes into account different risk factors and their relationships with each other, has been developed by Madec and Tillon (1985). They used the term ecopathology to describe the technique. Their hypothesis was that the 'performance' of a herd, and the probability of the herd developing disease, could be predicted from the interrelationship between a number of crucial risk factors. It also gave veterinarians a new tool with which to investigate pig disease and production problems, that made biological sense. Not only is disease likely to occur if the disease-producing agent is present, but it is more likely if a certain set of conditions is also met.

Initially, data on numerous possible risk factors were collected from 103 French herds. Statistical techniques were then used to determine the most important risk factors for disease syndromes in pigs. The most important risk factors identified for respiratory disease were:

- air space per pig
- floor space per pig
- number of days with temperature fluctuations greater than 6°C
- average daily minimum temperature
- quality of ventilation
- production system (continuous; all-in/all-out)
- average feed intake at 35 and 50 kg live weight
- respiratory tract lesions on entry to the grower phase
- number of morphological types in the group
- percent of parity one sows in the group's mothers
- presence of antibodies to aujeszky's disease.

These risk factors are not listed in order of importance as they are all considered to interact with each other to predispose pigs to respiratory disease. In addition, the impact of individual risk factors on respiratory disease cannot be determined.

To assess the productivity and respiratory disease level in the herd, a number of outcomes, or health parameters, were also designated:

- the average daily gain
- pneumonia score
- rhinitis score
- pleurisy score
- lung abscess score.

By collecting information on the risk factors in a herd and plotting the interactions of these factors using a computer program called 'Ecopig', an estimate of the relative risk of that herd developing pneumonia can be established. In France and Portugal, this methodology has become an integral part of pig veterinary practice, where the effects of modifying risk factors can be followed by changes in the relative disease risk and health parameters over time (Perestrelo *et al.*, 1990).

Initial Australian study

A study was recently completed in Western Australia that assessed the French methodology and it's validity under Australian conditions (Buddle *et al.*, 1992). Data on the above risk factors and health parameters were collected from 34 batches of pigs from 23 herds (repeat investigations were conducted in 11 herds). Seven batches of pigs originated from enzootic pneumonia-free herds. Summary information on stocking rates, feed intakes, growth rates and respiratory disease are presented in Table 2.

Table 2. Comparison of stocking rate, growth rate, feed intake and respiratory disease in 34 batches of pigs in Western Australian piggeries[1]

	Pneumonia-free[2] (N = 7)	Pneumonia-affected (N = 27)	Significance[3]
Weaners			
Floor space (m^2/pig)	0.44 ± 0.07	0.33 ± 0.13	NS
Air space (m^3/pig)	3.1 ± 2.06	1.8 ± 0.84	*
Growers			
Floor space (m^2/pig)	0.51 ± 0.21	0.57 ± 0.15	NS
Air space (m^3/pig)	3.15 ± 1.31	2.5 ± 1.01	NS
Finishers			
Floor space (m^2/pig)	0.76 ± 0.19	0.75 ± 0.15	NS
Air space (m^3/pig)	3.34 ± 1.08	3.38 ± 1.41	NS
Average daily gain (g/d)	572 ± 33.6	536 ± 40.4	*
Feed conversion ratio[4]	3.33 ± 0.42	3.76 ± 0.75	NS
Feed intake (kg/d)			
At 35 kg	1.53 ± 0.13	1.76 ± 0.36	NS
At 50 kg	2.06 ± 0.30	2.23 ± 0.47	NS
Pneumonia score	0.44 ± .81	16.3 ± 10.9	***
Pleurisy score	1.02 ± 1.78	2.25 ± 2.17	NS
Rhinitis score	2.34 ± 1.36	3.64 ± 2.10	NS

[1]Buddle *et al.* (1992). [2]Data expressed as mean ± SD. [3]NS, non significant, $P>0.05$; *$P<0.05$; ***$P<0.001$. [4]FCR calculated at a mean live weight of 42.5 kg.

The only significant difference in relation to stocking rate was that weaners with more air space per pig had a reduced prevalence of respiratory disease. It is likely that the weaner environment is critical to the development of respiratory disease as pneumonia and pleurisy often first affect pigs as weaners, after maternal immunity has waned, they have been stressed by the weaning process and are mixed with other

pigs. However, as Straw (1991) demonstrated, the grower/finisher environment is also critical, and pigs with respiratory disease as weaners can overcome the problem if good conditions are provided later in life.

There were no significant correlations between stocking density and growth rate, stocking density and pneumonia score, or growth rate and pneumonia score. However, batches without pneumonia tended to have a lower stocking density, higher growth rates and lower feed intakes, and possibly better feed conversion efficiencies.

One of the conclusions from this study was that at least 0.7 m^2/pig of floor space and 3 m^3/pig of air space should be provided during the grower-finisher period for optimum respiratory health (Buddle *et al.*, 1992). This is in agreement with many of the earlier recommendations for optimum stocking densities (Lindqvist, 1974), but is different from the minimum floor space recommendations in the Australian code of practice (Harris and Johnston, 1987), as shown in Table 3. The average area recommended for the grower pig from 20 to 100 kg is therefore 0.50 m^2/pig. This may indicate that the recommended stocking rates need to be reviewed.

Current Australian study

A study is currently underway in Western Australia and South Australia investigating the risk factors for pleurisy in pigs and the effects of pleurisy on growth rates. Information is being collected on many risk factors including stocking density, as well as growth rates and respiratory disease. Although the frequency and severity of pleurisy is the primary interest in this study, levels of pneumonia and pleuropneumonia are also recorded. Preliminary results from 36 batches of pigs in 12 Western Australian herds are presented in Table 4.

Table 3. Minimum recommended Australian stocking rates[1]

Live weight (kg)	Floor area (m^2/pig)
21 - 40	0.32
41 - 60	0.44
61 - 80	0.58
81 - 100	0.65

[1]Harris and Johnston (1987).

Table 4. Stocking density, growth rates and respiratory disease in 36 batches of pigs from 12 piggeries in Western Australia

	Batches without pneumonia[1] (N = 8 from 2 herds)	Batches with pneumonia (N = 28 from 10 herds)	Significance[2]
Weaners			
Floor space (m^2/pig)	0.23 ± 0.07[1]	0.26 ± 0.08	NS
Air space (m^3/pig)	2.13 ± 1.31	1.85 ± 0.72	NS
Grower-finisher			
Floor space (m^2/pig)	0.62 ± 0.11	0.61 ± 0.18	NS
Air space (m^3/pig)	2.85 ± 1.01	3.28 ± 1.46	NS
Prevalence pneumonia (%)	1.34 ± 1.87	69.2 ± 18.9	***
Prevalence pleurisy (%)	3.18 ± 5.13	26.4 ± 14.6	***
Average lung score	0.04 ± 0.06	7.37 ± 5.12	***
Average daily gain (g/d)	562 ± 28.2	519 ± 46.8	*

[1]Data expressed as mean ± SD. [2]NS, non significant, P>0.05; *P<0.05; ***P<0.001.

There were no significant differences between stocking density in batches with and without pneumonia, or correlations between stocking rates, respiratory disease and growth rates. Interestingly, the grower/finishers in the batches without pneumonia were stocked at less than the recommended 3 m^3/pig of air space, which may indicate that in herds without respiratory problems, pigs can be stocked at higher rates without compromising growth rates. Feed conversion efficiency was not measured, and may be adversely affected by increased stocking density, as has been demonstrated in other studies.

Minimising the effects of stocking arrangements on respiratory disease

Minimal disease stock

By either reducing or eliminating respiratory disease from a herd with medication programs such as 'medicated early weaning', or the purchase of 'minimal-disease' stock, it may be possible to reduce the floor and air space allocation in weaner and grower/finisher accommodation without significantly affecting growth rates and feed conversion efficiencies. There is insufficient information currently to determine the highest stocking rates at which herd productivity would be maximised, in herds with and without respiratory disease.

All-in/all-out production systems

Although the advantages of all-in/all-out systems have been established (Clark *et al.*, 1991; Dial *et al.*, 1992), such systems are seldom used in Australia. Perhaps further research and demonstration of these production systems is needed before consultants and producers are convinced of their benefits. In the USA, many weaner, grower and finisher units are now operated as all-in/all-out systems, often on different sites (Dial *et al.*, 1992). Weaners, frequently from a number of sources, are mixed before maternal immunity wanes so they are at less risk of contracting infections.

Reducing stocking density

Although more than 0.7 m^2/pig of floor space and 3 m^3/pig of air space during the grower-finisher phase have been recommended for improved respiratory health, no specific recommendations have been made on the air space volume for weaners. In addition, the stocking rates required to optimise pig throughput per cubic metre of air space, for herds with different prevalence and severity of respiratory disease, are not known.

The number of pigs sharing a common air space appears to be a factor contributing to respiratory disease. Relatively simple shed divisions could be constructed to divide existing buildings into smaller air space volumes. The effectiveness of these smaller rooms, in terms of respiratory health and pig productivity needs confirmation, but such rooms could be used in all-in/all-out systems.

Recommendations for research

The following recommendations for research into the relationship of stocking arrangements and respiratory disease in Australian pig herds are suggested:

1. Determine the relative effects of modifying stocking arrangements on respiratory disease and pig performance by controlling interactions and examining one factor at a time.

2. Investigate the cost-benefits of all-in/all-out production systems in herds with respiratory disease.

3. Determine the economic balance between the efficiency of building use and the

cost of respiratory disease.

4. Determine how the adverse consequences of higher stocking densities can be ameliorated by modifying the interactions between stocking density and the other risk factors.

Conclusions

The frequency and severity of respiratory disease in a herd, and it's subsequent effect on productivity, depends on a complex set of interrelated risk factors. These include the presence of infectious agents, type of production system, level of herd immunity, nutritional status of the herd and the climatic and social environments. Stocking arrangements are likely to be one of the most important risk factors, but it is extremely difficult to elucidate direct cause and effect relationships between respiratory disease and stocking rates due to interactions with other risk factors.

Results from two prospective on-farm Australian studies showed no significant relationship between stocking rates and respiratory disease, possibly due to either the presence or absence of other factors, and because of the dynamic nature of respiratory disease. There are no reports of studies into the effects of different stocking arrangements on levels of respiratory disease, while all other risk factors are controlled.

By improving the environment of pigs with respiratory disease, significant improvements can be made in growth rates, feed conversion efficiency and amount of respiratory disease at slaughter. The effects of respiratory disease can be minimised by employing all-in/all-out production systems, reducing stocking densities to at least 0.7 m^2/pig of floor space and 3 m^3/pig of air space during the grower-finisher phase, and reducing the numbers of pigs per common air space.

COMMERCIAL IMPLICATIONS OF STOCKING ARRANGEMENTS

B.P. Mullan

Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.

Introduction

The major objective of commercial pig production is to maximize profitability. The intensification of pig production has naturally meant a major investment in buildings and, as such, there is a need to maximize return on this investment. Thus, there is often a temptation to maximize throughput by increasing stocking density in the belief that this will ultimately increase profitability. However, the negative effects of overstocking on performance, as detailed in the previous papers of this Symposium, may negate any potential gains.

In the past, it has been difficult to calculate the impact of such management practices on profitability because it is a dynamic process involving a number of interacting factors, most of which are specific for a particular piggery. Fortunately, the pig industry now has at its disposal the AUSPIG simulation model (Black *et al.*, 1986), a sophisticated computer program designed specifically to consider the major factors known to influence a pig's performance and piggery profitability.

The objectives of this paper are to predict the effects a change in stocking density has on pig performance and profitability, and to investigate ways a producer may address a stocking density problem.

Industry situation

The suggested minimum space allowances according to the Australian Code of

Practice for the welfare of pigs (Gardner *et al.*, 1990) are compared to those recorded for 10 piggeries throughout Australia (B.P. Mullan, unpublished) in Figure 1. Most producers are not exceeding the Code of Practice, but there is no assurance that animal performance is not being affected by overstocking. For example, English *et al.* (1988) calculated the space requirement of pigs according to the area they occupied, with preferred body postures, when housed in either a hot or cold environment. According to these recommendations, it is likely that the performance of pigs in the Australian piggeries during summer months could be affected, because of insufficient space for pigs to lie in a fully recumbent position.

For the purpose of this paper, a standard pig enterprise has been defined to represent a strain of pig typical of that in the early 1980's (Herd 1) and another where the genotype is similar to that which the best producers now have as their breeding stock (Herd 2). All other levels of performance and profitability have been kept the same, to facilitate a comparison on the basis of genotype, and are based on PigStats92 (1993) for the 1991/92 financial year. The cost of housing is based on data of G. Cleary and I. Farran (unpublished) and, where there are differences in shed area, the cost associated with depreciation has been adjusted accordingly.

The average net revenue for herds contributing to PigStats92 (1993) was $0.11/kg live weight sold, hence the values for Herd 1 and Herd 2 would approximate the likely range in profitability during that year. The total pen area required for weaners, growers and finishers was similar. Although animals from Herd 2 would be heavier at any given age and, therefore, require additional floor space than those from Herd 1, they were sold 7 days earlier and the fewer number of finisher pens required negates the difference in the total requirement for floor space. The floor areas in Table 1 have been used throughout this paper to represent the situation where floor space per pig is optimal. Herd 2, because of its superior genotype, makes more efficient use of its pen space, producing about 8% more pig meat per m^2.

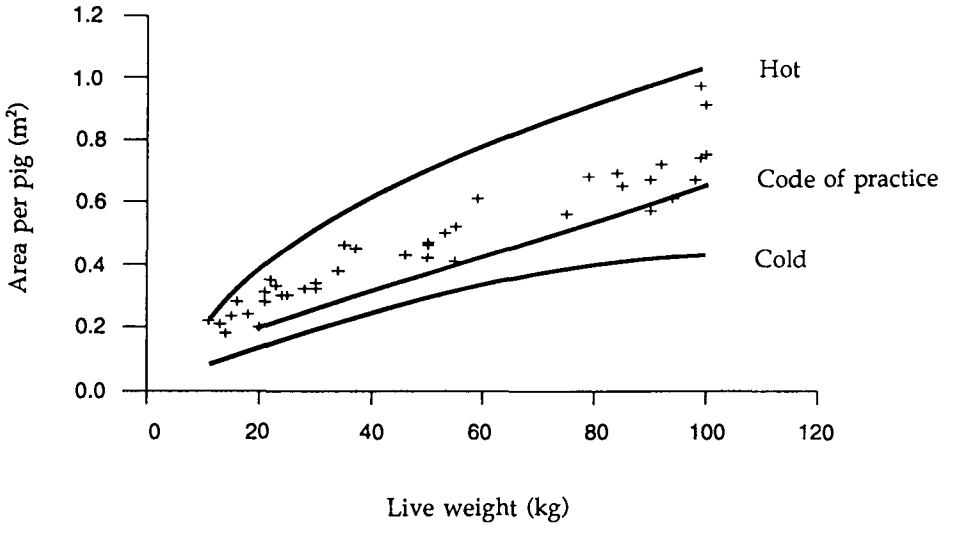

Figure 1. *Space allowances for growing pigs from 10 commercial piggeries (+) compared to that recommended by Australian Code of Practice, and suggested for pigs in either hot or cold environments (English et al., 1988).*

Data on throughput from 18 commercial piggeries in Victoria during 1992

indicates that while the average output per unit of grower space was 420 kg live weight/m^2, a figure similar to that calculated for Herd 1 in Table 1, the range was large (300 to 570; D. Treacy, unpublished). These results imply that, while there are some herds that are overstocked, there are others that are not producing sufficient pig meat from the resources available. However, as is demonstrated by the difference in meat produced by Herd 1 and 2 for the same floor space, some account must be taken of age and live weight at sale when assessing how efficiently a producer is utilizing resources.

Table 1. Base data incorporated into the AUSPIG simulation model for two sample herds, each of 100 breeding sows

Genotype simulation inputs	Herd 1	Herd 2
Typical pig genotype (year)	1980	1990
Pig performance		
Age at sale (d)	164	154
Live weight at sale (kg)	84.9	92.1
Average daily gain (g, birth to sale)	516	597
Depth of backfat at sale (P_2, mm)	13.9	12.4
Pigs in top carcass grade (%)	53	77
Pigs sold/sow/year	18.7	18.7
Grower feed conversion ratio[1]	2.59	2.59
Herd feed conversion ratio[2]	4.21	4.15
Live weight sold (kg/m^2/year)	432	465
Pen design[3]		
Weaner	18 @ 3.3 m^2	18 @ 3.6 m^2
Grower	21 @ 6.0 m^2	21 @ 6.7 m^2
Finisher	21 @ 8.7 m^2	18 @ 9.2 m^2
Total floor area (m^2)	368	371
Area/pig (m^2)		
Weaner	0.25	0.28
Grower	0.46	0.51
Finisher	0.67	0.71
Profit summary ($/year)		
Income[4]	248,157	275,184
Feed costs	135,831	144,260
Other costs	104,347	104,408
Net revenue ($/year)		
Total	7,979	26,517
Per pig sold[5]	4.17	13.85
Per kg live weight sold	0.05	0.15

[1]Live-weight basis. [2]Carcass-weight basis. [3]Assumes a stocking rate of 13 pigs/pen (throughput of 1872 pigs/annum), and pigs enter weaner, grower and finisher accommodation at 29, 68 and 116 days of age, respectively. [4]Average price of $1.52/kg live weight. [5]Includes sale of cull breeding stock.

Effect of stocking density on performance and profitability

Area per pig

The effect on average daily gain of reducing area per pig from 0.67 to 0.40 m^2 for a group of pigs (50 to 90 kg live weight) has been simulated using AUSPIG (Figure 2). The results indicate that there is little impact on growth rate by a short period of overstocking (overstocked for 10 days out of a total occupation time of 49 days with 0.63 m^2/pig) but when pen area is reduced further growth rates decline steadily. The decrease in growth rate is a direct reflection of the change in voluntary feed intake.

This decline in growth rate, when compared to the combined data from six experiments with similar weight animals (Kornegay and Notter, 1984), does not appear to be severe enough in this early period. This suggests that the AUSPIG model, by only assuming an effect on feed intake and not an effect on the efficiency of growth as influenced, for example, by disease, is not penalising animal performance sufficiently in this early period. If this is the case, the financial impact of overstocking is likely to be greater than that predicted later in this paper.

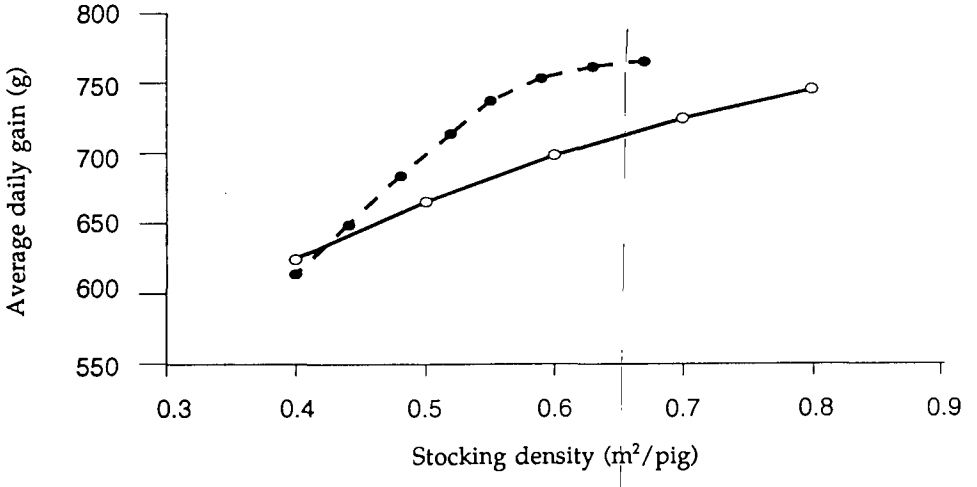

Figure 2. *The effect of area per pig (13 pigs/pen) on average daily gain, as predicted by AUSPIG (•--•) and as reported by Kornegay and Notter (1984; o—o).*

Pigs per pen

The impact of stocking density on performance generally occurs, when for example, 11 pigs are accommodated in a pen designed for only 10 of the same live weight. However, to take account of social interactions between pigs and an increase in the incidence of disease when pigs are overstocked, the effect on performance of a reduction in feed intake *per se* has been simulated using the AUSPIG model.

The paper of Chapple (1993) details the effect of number of pigs per pen on feed intake and performance. These results indicate that the feed intake of animals housed in group sizes typical of commercial pig units, could be only 90% of their potential, even before the effect of overstocking *per se* is considered. In an attempt to calculate the economic cost associated with this reduction in food intake, a number of AUSPIG simulations have been conducted, where the intake of pigs was reduced in incremental amounts for either the whole period from weaning until sale (7 to 90 kg), or just in the finisher period (50 to 90 kg; Figure 3). At no stage were pigs overstocked according to the guidelines of English *et al.* (1988).

Results for Herd 2 (1990 genotype) indicate that a comparatively small reduction in growth rate has a substantial impact on annual net revenue. For example, a 5% reduction in feed intake from weaning to sale results in a 10% decrease in growth rate and a 55% reduction in annual net revenue. The far greater impact on net revenue is due to the low proportion of total costs associated with the breeding herd. Although it is perhaps unlikely for feed intake to be affected over such a long phase of growth, a similar reduction in just the finisher phase still results in net revenue being reduced by approximately 20%.

A reduction in feed intake will also depress the depth of backfat. It could be expected therefore, that there might be financial benefits from a reduction in feed intake for animals of the 1980 genotype (Herd 1) that have poorer gradings at slaughter. Results indicate, however, that while the percentage of animals in the top

grade (P_2<14mm) increases from 42 to 52% when feed intake is reduced by 4% over the period from weaning to sale, this improvement in grading is insufficient to financially compensate for the 7% reduction in carcass weight, and net revenue is reduced by 9%. Chapple (1993) has argued that although feed intake is depressed when pigs are placed in groups compared with when housed individually, the capacity of the pig to deposit body protein is also depressed and the pigs become fatter. If this is the case, no improvement in net revenue would be expected from the fall in feed intake of group-housed pigs.

Commercial situation

Many intensive piggeries were designed and constructed more than 20 years ago and are unlikely to accommodate adequately current levels of production. For example, during the last 20 years there have been major improvements in the number of pigs sold/sow/year, an increase in the growth rate of pigs through improved genetics, nutrition and environment, and an increase in the sale weight at slaughter.

To demonstrate the possible effects of overstocking on commercial pig production, the Herd 2 piggery (Table 1) was simulated assuming a target sale weight of 90 kg live weight and the sale of 18.7 pigs/sow/year. The performance and profitability of this 'piggery' was then compared to one where the size of pens were calculated on levels of performance typical of the 1970's (17.2 pigs sold/sow/year). Therefore, whereas in 1970 pens had been designed to accommodate 11 pigs/pen, those designed in 1990 could accommodate 13 pigs/pen.

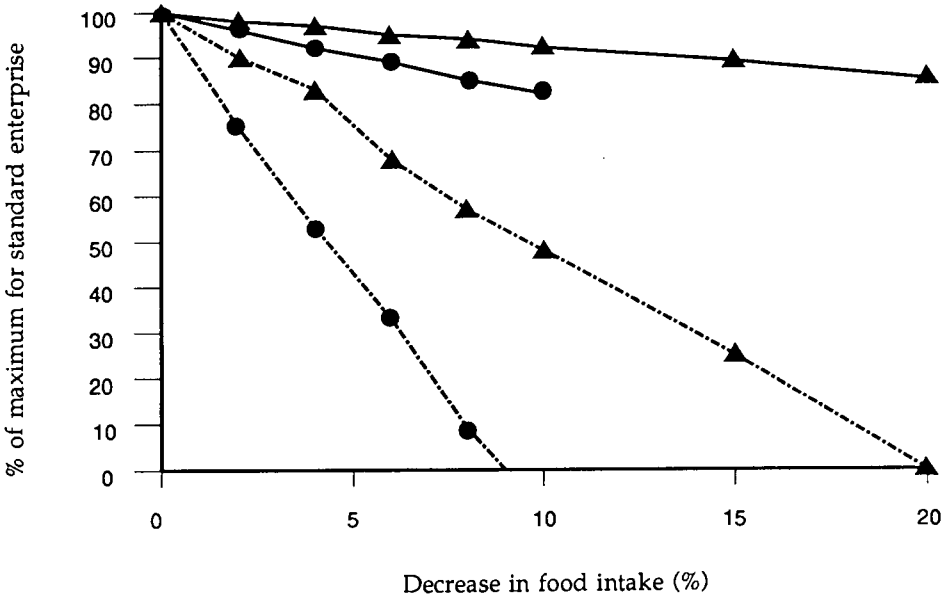

Figure 3. *The effect of a reduction in feed intake, from either 7 to 90 (▾), or from 50 to 90 kg (•), on either growth rate (—), or net revenue (---) for Herd 2.*

Operating a piggery that had been designed to 1970's standards at 1990's levels of productivity (pigs sold/sow/year) clearly leads to overstocking (Table 2). With a target sale weight of 90 kg live weight, pigs were overstocked for approximately half of their total period of occupation. Although this resulted in only a 5% reduction in growth rate from birth to sale, it meant that the target sale weight was not achieved by the time of sale and there was a 30% reduction in net revenue.

In recent years, there has been a steady increase in the sale weight of pigs which is attributable to the improvement in carcass quality and the removal by processors of penalties for heavier weight carcasses. The financial benefits of increasing sale age by one week and taking pigs to a heavier sale weight, under the present grading schedule, are demonstrated in Table 2. When overstocking was not a problem (1990 design), increasing sale weight by approximately 6 kg live weight resulted in a 50% increase in annual net revenue, equivalent to $126/sow. When there was insufficient space available (1970 design), delaying the age at sale by one week resulted in a similar increase in net revenue. This later result, however, may be an overestimate because finisher pigs were overstocked for approximately 75% of the total occupation period. Under these conditions, potential gains in sale weight could be negated by a reduction in performance due to, for example, an increased incidence of disease.

The net revenue/kg live weight sold for those herds contributing to PigStats92 (1993) for 1991/92 was $0.11, equivalent to that for the overstocked situation with a target sale weight of 90 kg live weight (Table 2). This is circumstantial evidence that the full growth potential of the Australian pig herd is not being realised and that one cause is likely to be overstocking. On the other hand, the average area/pig for the 1990 designed piggery in Table 2 (0.5 m^2/pig) is similar to that reported as a herd average by D. Treacy (unpublished).

Table 2. The effect of stocking density, as determined by the year in which a piggery had hypothetically been designed, and age at sale on the performance and profitability of a 100-sow herd

Year of design	1990	1970	1990	1970
Age at sale (d)	154	154	163	163
Area/pig (m^2)				
Weaner[1]	0.28	0.22	0.28	0.22
Grower	0.52	0.39	0.52	0.39
Finisher	0.71	0.55	0.74	0.55
Total grower floor space (m^2)	378	292	385	292
Overstocking[2]				
Weaner	0/39	13/39	0/39	13/39
Grower	0/48	21/48	0/48	21/48
Finisher	1/39	26/39	0/46	34/46
Average daily gain (g)				
Weaner	372	363	372	363
Grower	719	682	719	682
Finisher	912	850	912	839
Birth to sale	598	570	612	578
Live weight at sale (kg)	92.1	87.7	98.5	93.1
Profit summary ($/year)				
Total income	275,184	260,880	297,361	279,055
Total feed costs	144,260	138,131	153,587	146,210
Total other costs	104,408	103,638	104,639	103,802
Net revenue ($/year)				
Total	26,517	19,111	39,135	29,043
Per pig sold	13.85	9.98	20.46	15.18
Per kg live weight sold	0.15	0.12	0.21	0.17

[1]Relates to pen type with 13 pigs/pen. [2]Refers to the proportion of the total period of occupation that the average pig is overstocked.

Throughput vs profitability

To maximize return on facilities, there may be a tendency to overstock grower accommodation, since the cost of grower and finisher accommodation accounts for

approximately 40% of the total capital cost of establishing a piggery (Farran, 1992). Similarly, if a calculation of throughput based on the amount of pig meat produced per unit of area is used as a measure of efficiency, as has been suggested by Kornegay and Notter (1984), then this will encourage producers to overstock.

To investigate the relationship between throughput and profitability, the standard pig enterprise, Herd 2, was used in AUSPIG simulations. When stocking density was at recommended levels, approximately 370m^2 of floor space was required to accommodate pigs from weaning to sale at 92 kg live weight. Several simulations were conducted where this total area was either reduced or increased, thus simulating the impact of an imbalance in shed design and investigating the financial impact of either overstocking or understocking.

The results in Figure 4 confirm that if throughput, as measured by annual live-weight output/m^2, is the criteria used to determine either efficiency or shed area allocated to the grower herd, then increasing stocking rate (a decrease in total grower space) would be recommended. If, however, return on capital, measured as annual net revenue/m^2, is considered, it would be recommended to have only about 90% of the recommended grower space. This, however, does not reflect annual net revenue on a per sow basis, which is only maximized when stocking rate approaches recommended levels. As has been demonstrated earlier in this paper, annual profit/sow is sensitive to an increase in stocking rate.

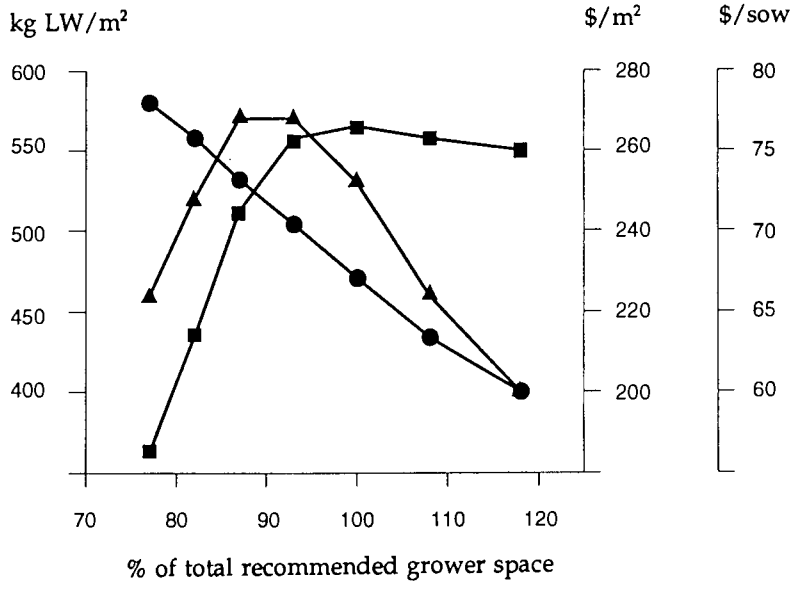

Figure 4. *The effect of total grower space on annual throughput (kg live weight/m^2,•) and on annual net revenue expressed either per unit of space ($/m^2,▲), or per sow ($/sow,■).*

Management strategies to increase profitability

Selection of pigs for sale

Since the problem of overstocking is predominantly related to the finisher stage of growth, altering the selection procedure for sale stock has the potential to alleviate overstocking. For example, Hines *et al.* (1989) reported that when finisher pigs were provided with either 0.56, 0.74, 0.93 or 1.12 m^2 from 60 to 115 kg live weight, growth rate was maximized at only the two largest pen areas and they concluded that 0.93 m^2 was sufficient space for pigs of this weight. However, in a second experiment (Hines *et al.*, 1991) of similar design, individual pigs were removed when they reached 115 kg

live weight and this management procedure reduced stocking rate pressure sufficiently, such that only 0.74 m^2 was required per pig.

To simulate this management strategy, it was assumed that 20% of the grower population had superior growth rates to the average. Under the existing arrangements, all animals were sold at 154 days of age and while the mean sale weight of the 'superior' animals was 93 kg, that for the remainder was 88 kg. Pigs were overstocked under this regimen for 26 of the 39 days during the finisher phase, and for various periods during the weaner and grower phase (see Table 2). Annual net revenue in this instance was \$229/sow, or \$0.14/kg live weight sold.

To significantly reduce stocking density it was necessary to remove the 'superior' pigs two weeks prior to their normal sale age, and while the mean sale weight of the 'average' then increased from 88 to 89 kg, that for the 'superior' was reduced from 96 to 84 kg. Although the problem of overstocking during this pre-sale period was overcome by this practice, annual net revenue declined by 12% (\$199/sow and \$0.12/kg live weight sold). Therefore, the gains made in performance by reducing the number of pigs/pen was insufficient to compensate for the reduction in sale weight of the best pigs, and this result has not taken into account the extra labour required.

A second option is to sell a proportion of pigs at a lighter weight. For example, to overcome the stocking density problems depicted in Table 2 (pigs sold at 154 days of age), it would be necessary to sell approximately 40% of pigs at 50 kg live weight. For there to be no detrimental effect on annual net revenue, the price for these lighter pigs would need to be \$2.11/kg live weight, considerably more than is currently being paid.

Reducing herd size

The number of pigs produced by a piggery is generally determined by the number of farrowing places available, and the stocking rate of the grower/finisher accommodation is often considered to be a secondary issue. If a pig unit is in the situation of having insufficient grower space relative to that of the breeding herd, consideration should be given to reducing the number of breeding sows, thus releasing pressure on the grower accommodation.

To investigate this as a management strategy, the performance of the 1970 designed piggery selling pigs at 154 days of age (Table 2), was considered. Total grower space was kept the same but sow numbers were allowed to change. Reducing sow numbers from 100 to 82 removed the overstocking problem and meant a 5% increase in growth rate from birth to sale. Although profit per pig sold increased there was no significant change in annual net revenue (Table 3). However, if the boar and dry sow accommodation made available by the reduction in sow numbers was then utilised to house finisher pigs, not only could the problem of overstocking be overcome, but sale weight could be increased to 98 kg live weight. This would mean a 55% increase in annual net revenue, despite selling 18% less animals. This strategy depends on there being a market for heavier weight pigs, the genotype being suitable to grow to heavier weights without being penalised for excess backfat, and no account has been taken of any cost of converting dry sow accommodation. However, it does have the additional advantage of removing pressure on farrowing accommodation, such that the length of lactation could be increased and the post-weaning performance of pigs improved.

Design of new facilities

Piggeries have traditionally been designed on the basis that pigs are to be housed according to three live-weight ranges (weaning to 20 kg, 20 to 50 kg, and 50 kg to sale). Assuming that a piggery is designed to meet the needs of pigs at the end of the growth phase, the pig has excess space for a considerable proportion of the time. The total floor space for growers in a 100-sow herd would be approximately 370 m^2 (total of 57 pens) and would involve moving stock approximately every 9 weeks.

Table 3. Predicted effect on performance and profitability, when area for growing pigs is restricted to 1970 production standards, but sow numbers are reduced to alleviate overstocking, and dry sow accommodation is used to house finisher pigs

Number of breeding sows	100	82	82
Total grower pen area (m^2)	292	292	323
Performance			
Age at sale (d)	154	154	163
Live weight at sale (kg)	87.7	92.1	98.5
Average daily gain (g, birth to sale)	570	598	612
Pigs sold/sow/year	18.7	18.7	18.7
Grower feed conversion ratio[1]	2.56	2.59	2.64
Herd feed conversion ratio[2]	4.16	4.15	4.14
Profit summary ($/year)			
Total income	260,880	227,000	243,901
Total feed costs	138,131	119,001	125,956
Total other costs	103,638	88,437	88,216
Net revenue ($/year)			
Total	19,111	19,562	29,728
Per pig sold	9.98	12.39	18.95
Per kg live weight sold	0.12	0.14	0.20

[1]Live-weight basis. [2]Carcass-weight basis.

An alternative is to have a greater range of pen sizes, with the more frequent movement of pigs and less wastage of pen space. For example, if pigs were moved every 3 weeks, the same number of pens would be required, but the range of pen sizes would be doubled and total floor area would be reduced by approximately 10%. Similarly, moving pigs on a fortnightly basis would not change the number of pens, but total floor area would be reduced by a further 5%.

It is possible that potential savings in building costs would be offset by the need for internal gates to facilitate movement of stock and an increase in the cost of labour. The frequent movement of pigs within the same building would also not be appropriate if the all-in/all-out management system for disease control was to be adopted, and it may reduce the degree of environmental control for pigs of different ages. However, there would be greater opportunities to change diets on a more frequent basis, commonly referred to as phase feeding, an increase in animal observation due to more frequent animal handling, and provided pigs are kept in the same group throughout, there should be minimal effect on animal performance.

Another option is to increase the total area for grower pigs by building new facilities. Considering the example outlined in Table 2, with pigs being sold at 154 days of age, an extra 86 m^2 of space is required for the piggery designed in the 1970's to realise the potential increase in annual net revenue of $7,400. Assuming an average cost for grower/finisher accommodation of $250/$m^2$ (Farran, 1992), the required investment of $21,500 would be paid for within 3 years. Although this is a simplistic example of what a producer may do in practice, it does demonstrate the kind of calculation that is required when considering options for future development.

Conclusion

In an attempt to maximize profitability, producers maximize the number of pigs occupying grower accommodation. Invariably the design of grower accommodation has not kept pace with increases in productivity, and hence a majority of producers have stocking rates close to or below the minimum recommended level. While the effects on performance are generally recognised, it has been difficult to calculate the impact this is having on profitability. Furthermore, levels of performance, and hence

profitability, that are considered at close to maximum may in reality be further from an animal's potential then initially realised, and this has important ramifications for the profitability and viability of the pig industry.

SYMPOSIUM CONCLUSIONS

J.L. Black

Pigs reared in commercial production units grow on average between 15 and 25% slower than those housed individually, in either research facilities or boar selection pens. This reduction in performance has a marked effect on piggery profitability. Mullan (1993) has shown that a small depression in growth rate of only 5% from birth to slaughter could result in a depression in net piggery revenue of 30% for each sow.

Many factors associated with both building and pen conditions contribute to this reduction in performance. Social interaction between animals appear to be a major contributor. Chapple (1993) has reported that simply increasing group size from 1 to 5 or 8 pigs per pen, reduces growth rate from 5 to 8%. Other experiments suggest that increasing the number of pigs in a pen from 5 to 20 has little effect on growth rate, but substantially alters the behaviour and activity of the pigs, and can result in a reduction in the efficiency of feed use. The number of feeding spaces per animal appears also to have a major impact on feed intake and performance of pigs housed in groups. There appears to be an interaction between the number of pigs per pen and the floor space per pig. Disease contributes to the reduced performance of pig housed in commercial units, particularly when continuous throughput systems are used. Stocking density, air space per pig, and the number of pigs in a common air space appear to be closely related to the incidence of respiratory disease, and thus to pig performance.

The major effect on performance of increased stocking density and group housing appears to be through a reduction in feed intake. J.R. Carr and B. Hansen (unpublished) observed a strong positive relationship between the number of feeder places per pig, feed intake and performance of individual and commercially-housed animals. However, Chapple (1993) using the AUSPIG model suggested that a reduction in intake alone was not likely to be the primary reason for the reduced performance of pigs housed in groups, compared with those housed individually. He suggested that competitive behaviour and other stressors reduce the capacity of the animal to deposit protein, because pigs housed in groups of 5 were fatter than those housed individually, even though they consumed less feed and grew more slowly. It is important to conduct further research to determine the mechanisms responsible for this decline in protein deposition. Such research may lead to ways of modifying the biology of the pig through gene manipulation, vaccination or other means. However, improvements in the performance of pigs reared in commercial units can be made by reducing competition, through modifying feeder number and design, increasing the air space per pig and reducing the number of pigs in a common air space. Furthermore, the AUSPIG model can be used to investigate the effect on profitability of altering management strategies, such as the number of sows in a piggery, and the selling weights of different classes of pig.

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A REVIEW - DEVELOPING MANAGEMENT STRATEGIES TO REDUCE STRESS IN PIGS: A NEW APPROACH UTILIZING THE BIOLOGICAL COST OF STRESS

G.P. Moberg

Department of Animal Science, University of California, Davis, Davis, CA 95616, USA.

Stress is a part of our lives. We talk about its existence, we worry about its effects, and we frequently go to great efforts to avoid it. Yet, at times we seek stress out, as when we ride a roller coaster. With so much of our energy focused on our own stress, it is not surprising that we readily accept that animals also experience stress in their lives and that they can suffer from its effects. While some of us have a difficult time accepting that animals are capable of suffering from the same emotional stress as we do, others anthropomorphize by attributing to animals a human view of stress. This latter group has had a major influence on the animal welfare movement. Their view of animal stress frequently creates in the mind of society unnecessary expectations for the care of domestic animals. In fact, both views of animal stress are wrong. As we study animal stress, we must view it from the perspective of the animal. While human experiences of stress are a valuable guide in thinking about stress, our views of animal stress must be derived from the experiences of the animal.

As it is for us, stress is part of an animal's life. For the animal stress is not inherently bad nor good. It is simply a biological response that the animal uses to help it cope with threats to its homeostasis, or biological status quo. In spite of our tendency to view stress as bad, we must remember that animals have evolved these defence mechanisms to help them to survive. In most instances the stress response is not bad, but in fact desirable. It is the stress response that helps the animal to survive. If we accept this premise, then the question is why should we be concerned about animal stress? The reason is that there are times when the animal's stress is of such magnitude that there are undesirable effects on the animal's well-being and its welfare is threatened. For those of us involved in domestic animal production, it is these harmful stress responses we must attempt to avoid and if that is not possible, we must develop strategies that help reduce its effects. It is our responsibility to develop management strategies for helping domestic animals cope with stress, just as we have developed management strategies for feeding the animals, breeding them, or housing them.

The purpose of the following discussion will be to propose an approach to developing strategies to manage stress in domestic animal production. However, for us to develop such strategies it is first necessary to understand what constitutes domestic animal stress, especially the cost of stress to the animal. Understanding the cost of stress is not only the key to developing management approaches to protecting animals from undue stress, but may provide a way for us to deal with the growing issues of domestic animal welfare (Moberg, 1992, 1993).

First, we must understand that stress is not easily defined. In spite of everyone recognizing the concept of stress, no single definition of stress has ever been developed (Moberg, 1985a, 1987a). This is because stress, unlike disease, has no specific aetiology or outcome. Individuals differ in how they respond to the same stressful situations. As a result, the term stress has been used in a variety of ways in the literature. In this discussion, I will define stress as the biological response to an event that the individual perceives as a threat to its homeostasis. That event which is perceived as a threat will be defined as the stressor.

Domestic animal stress

Animals evolved stress responses that were necessary for them to survive in the

wild. They developed ways to perceive stressors that might challenge their existence in the wild: predators, environmental extremes, or interaction with peers. They evolved behavioural and physiological responses to help them cope with the stressors of their lives. To escape harm, the rabbit developed the behavioural and physiological mechanisms for flight while the tiger developed the mechanisms for fighting. Each species evolved physiological and behavioural responses that best assured its survival. In the wild, these stress responses were appropriate because in most instances the stress responses are relatively short lived, and the animal needs to muster its biological resources quickly in order to survive. If the animal was successful, the stressor was alleviated or avoided. If the animal was unsuccessful, it perished. As a result of this rapid outcome, the commitment of biological resources, or the biological cost of the stress, was minimal.

With domestication, the animal's options for coping with stress became limited. Confinement prevented an animal from fleeing from a stressor. Under the confines of domestic animal production systems, animals might live in population densities or social groupings that might be undesirable and, as a result, stressful. Under these conditions, the physiological and behavioural mechanisms the animal had evolved for survival in the wild may no longer be appropriate to cope with these stressors. Living with stressors it can no longer avoid and responding to these stressors with stress responses that would normally be of short duration, the domestic animal runs the risk of unduly suffering from stress.

On the other hand, we must keep in mind that domestication for most farm animals began several thousand years ago and, as a result, there has been an ongoing subtle process of selection that has benefited those animals best suited for animal agriculture. Domestication has also eliminated many of the stressors encountered in the wild by protecting the animal from predators, providing adequate nutrition and frequently providing shelter against environmental extremes (Price, 1984).

Yet, we remain concerned about stress in domestic animals because although they have adapted to domestication, they can still suffer from the effects of stress associated with production. Several examples can be found in management practices that are part of pig production. Early weaning of pigs to increase production efficiency can suppress the ability of the immune system to respond to the challenge of pathogens (Blecha *et al.*, 1983). The transportation of pigs has been found to compromise the ability of the pigs to fight disease (Artursson *et al.*, 1989). Pigs raised with limited floor space per animal grow slower and may exhibit greater aggressive behaviour than peers raised in pens where more floor space is available (Kelly *et al.*, 1980; Meunier-Salaun *et al.*, 1987). Reproduction is especially vulnerable to stress as a number of stressors (eg; transportation, social conflict, heat stress, restraint and isolation) have been found to block ovulation, delay the onset of puberty or disrupt the expression of oestrus behaviour in a number of species (Moberg, 1985b, 1987b).

Clearly, domestic animals are still vulnerable to the effects of stress. This vulnerability is becoming heightened by the rapid acceptance of modern intensified production practices, especially in pig production. In spite of the biological advantages that have been realized from the domestication processes, today's animals are facing new stressors for which they have not had time to develop appropriate biological coping mechanisms and, indeed, some of these stresses may be of sufficient magnitude that the animals may never be able to fully adapt. For this reason, we need to carefully examine how our animals cope with stress, before we design our production systems.

The biology of stress

Domestic animals are capable of responding to both internal and external challenges in order to maintain their internal milieu. While internal challenges, such as low blood sugar or changes in ion balance, have an important effect of the individual animal, the primary focus of this discussion will be on the external

challenges. These are the ones that we must concern ourselves with when we develop management systems for our food animals.

External stressors can be divided into three general types: physical stressors, environmental stressors and psychological stressors. For most well managed agricultural systems, physical stressors such as pain occur relatively infrequently. There are times, like castration or slaughter, when such stressors cannot be avoided. These specialized agriculture practices are a part of food animal production and when they do occur, efforts to minimize their effects must be incorporated into an overall management strategy for alleviating stress.

We have long recognized the impact of environmental stressors on domestic animals. These stressors have been especially evident in those northern breeds that have been transplanted to the tropics. In fact, it was concern about environmental stress that resulted in the first concerted efforts to manage stress. As a result, management schemes were developed to provide protection from environmental extremes, as well as other management practices to help alleviate the undesirable effects of the environment. Even today, this still remains an important area of research.

Of the three general categories of stress, psychological stress in animals has proven to be most difficult for us to understand. The problem stems from our inability to make the bridge between human psychology and what the animal experiences. This is because we still lack a sound scientific basis for domestic animal behaviour. Because of this gap in our knowledge, many views of psychological stress in animals have been based on anthropomorphism. This anthropomorphism has especially influenced society's view of animal welfare. Many individuals tend to project their own feelings to the animals by using the logic that 'if I were under those conditions, I would be stressed'. Such an extension of anthropomorphism is dangerous and frequently fails to reflect the animal's perception of the situation. For example, if you put a collar around my neck, attach a leash and take me for a walk, I will be stressed! But, I believe that my dog truly enjoys the experience and looks forward to being taken on a walk as he eagerly awaits me by the door. To eventually counter such misplaced anthropomorphism, we need to develop a better understanding of animal behaviour, especially the behaviour of domestic animals. In comparison to many fields of biological sciences, animal behaviour is still in its infancy and research in this area continues to suffer from a chronic lack of support. This is unfortunate because I believe that animal behaviour remains one of the most fertile fields for providing us a new understanding of animal stress, especially when the study of behaviour is coupled with the physiological responses of the animal. As we intensify domestic animal agricultural practices, the effects of behaviour related stress may have the greatest influence on the psychological welfare of these animals. For this reason, my remarks will primarily be related to the effects of psychological stress, keeping in mind that other types of stressors can compound the effect of psychological stress on the animal's well-being.

There are numerous psychological (sometimes termed behavioural) stressors that domestic animals experience. Examples include crowding, unstable or inappropriate social grouping, frustration, social deprivation, fear, peer intimidation or inability to express normal behaviours. How important such potential stressors are to the animal is not known. Undoubtedly, the impact varies between individuals.

To address these complexities, we must first examine the various components of the stress response. The first step in any stress response is the animal's perception of these threats to its well-being. For an event to be a stressor, the animal must perceive it as a threat. Whether or not the event is actually a threat is unimportant; it is the perception of a threat that is critical to the animal. Monkeys offer us an example of this concept. If you stare at a caged monkey in the zoo, the monkey perceives your stare as a threat, even though it is protected from you by the cage. This response to visual contact is part of a primate response to aggression associated with how they maintain dominance hierarchies in social groups. In this way, the dominant monkeys

intimidate subordinates. As you stare, the monkey will escape from your threat by simply averting its eyes, removing your threat from its perception. Recognition of this behaviour by zoo keepers has provided a useful stress management tool. Visual barriers are placed in cages containing large numbers of monkeys. Subordinate monkeys can move behind the barriers to escape visual contact of their dominant peers, thus lowering stress in the subordinate animals.

Once a stressor is perceived, the animal elicits a series of biological responses to assist it in coping with the stressor. There are three general categories of biological responses available to the animal: behavioural, autonomic and neuroendocrine. These alter the biological responses of the animal in order to provide the biological resources necessary to cope with the stressor.

Of the three types of biological responses to stress, behavioural is the simplest and frequently the most economical response to the stressor. Under ideal conditions, the animal may simply remove itself from the threat. If this is not possible, the animal may express a behavioural response that helps the animal to cope. For example, in the previously discussed behaviour of the subordinate monkeys, a monkey ameliorates the impact of the stressor by averting its eyes. Unfortunately, for many stressors such behavioural coping responses by themselves are not sufficient, especially in domestic animals where confinement may prevent avoidance of the stressor or the full expression of a behaviour.

The response of the autonomic nervous system and the neuroendocrine system to stress come at a greater biological cost to the animal. These systems alter the individual's biological machinery, thereby altering biological function. Activation of the autonomic nervous system alters the function of such diverse biological systems as the cardiovascular system, the secretion of the exocrine glands and the activity of the gastrointestinal system. This impact of the autonomic system on the biology of the individual during stress was recognized by Cannon (1929) who incorporated it into his early views on the 'flight or fight' response to stress. The onset of the autonomic nervous response to stress is rapid and its effects are generally short lived. Because of the brevity of the autonomic response, it is questionable in domestic animals whether the autonomic response during prolonged stress has any long term impact on the well-being of the animal. Although of interest in laboratory studies, the autonomic system response during stress can usually be ignored in domestic animals.

In contrast to the specific and brief effects of the autonomic nervous system, the secretion of hormones by the neuroendocrine system can have a long term and extensive effect on biological function. These hormones modulate virtually every physiological system in the body. The neuroendocrine system regulates metabolism, reproduction, growth and influences either directly or indirectly behaviour and immune competence. The normal function of each of these systems is an indication of well-being. Abnormal function is an indication of the animal's welfare being at risk. For this reason, the hormones secreted by the neuroendocrine system have been the focus of many of the studies on animal stress (Moberg, 1985a).

Selye (1950) was one of the first to understand the impact of stress on the individual. In fact, he was the first to use the term stress. In his writings, he championed the concept of a nonspecific stress response that was common for all stressors. He argued that the nature of the stressor did not matter, the individual always responded with the same biological response. This concept of a nonspecific stress response dominated our view of stress biology until the work of Mason (1968, 1975) demonstrated that different types of stressors elicited markedly different neuroendocrine responses in the same individual. For example, a stressor such as elevated temperature would elicit the secretion of certain hormones while another stressor, like emotional stress, would stimulate the secretion of a different group of hormones. These studies disproved the concept of a nonspecific stress response by clearly demonstrating that individuals respond to different stressors by marshalling different types of biological responses.

The work of Mason still did not fully describe the complexities of the biological

response to stress. Not only do different stressors elicit different biological responses, but different individuals respond differently to the same stressor (see Moberg, 1985a). For example, we have observed in two groups of monkeys, one group raised with dogs as surrogate mothers and the other group raised with inanimate surrogates (in this case hobby horses covered with acrylic fur), that when these animals were exposed to the same stressor, one group would express one combination of behaviour, autonomic and neuroendocrine responses while the second group would express a different combination of responses (Moberg, 1985a). In this example, the nature of biological response to a stressor (ie; pattern of behaviour and physiological responses) was influenced by the animals' early life experiences. We have also found that genetics can influence the biological responses the animal chooses to cope with a particular stressor (Moberg, 1987a). Undoubtedly there are numerous factors that shape the biological response to a stressor; including such variables as genetics, social ranking, previous experience, physiological state, age and sex. The number of variables seems endless, but they must be accounted for in our considerations of the stress response.

When attempting to describe the stress responses of domestic animals, the complexity of these multiple stress responses is obvious, and at times overwhelming. Under the rigidly controlled conditions of the laboratory, these variables are manageable and offer the researcher a rich opportunity to learn more about stress biology. But, in domestic animal production we are under conditions where we frequently have no such knowledge about these variables. Usually we do not know about a pig's early life experiences, the influence of its genes on the stress response or how it views its social rank. As a result, we have no way of predicting which combination of behaviour and physiological responses will be used to cope with the stressor. Further complicating the issue is that domestic animals usually do not face a single stressor at a time. Frequently, they must cope with several stressors simultaneously. For example, during transportation animals may be forced to cope with fear, strange peers, temperature extremes or any number of other threats. Clearly, predicting which combination of physiological and behavioural responses the animal will chose under these conditions is virtually impossible. Likewise, choosing one or two of their biological responses as a measure of stress is questionable.

Anyone confronting these issues is tempted to consider stress as too complicated to understand, let alone develop management schemes to ameliorate its effects. However, the impact of stress on domestic animals is too important to ignore. Animals suffer from stress and this suffering cannot be ignored. As a result, it is necessary to retreat from the classical measures of stress and develop a new view of stress. I believe that this view should be in terms of the effects that stress has on the animal, ie; the biological cost to the animal in coping with the stressor.

Model of animal stress

To develop the concept of a biological cost for stress, it is first necessary to develop a conceptual framework for organizing our discussion of animal stress. The model for animal stress depicted in Figure 1 serves this purpose. Since a detailed argument for the development of this model has been presented elsewhere (Moberg, 1985a), I will emphasize only the points relevant for this discussion.

The stress response can be divided into three general stages. First, there is the perception of a threat to the individual's homeostasis. Second is the animal's response and, finally, the consequences of stress. It is the last stage which determines if an animal is suffering from stress or whether the stress response is merely a brief episode in the animal's life with no impact on its well-being, much like our ride on a roller coaster.

As has been discussed, for the stress response to be initiated the animal must first perceive a threat to its homeostasis. Whether or not a threat truly exists is unimportant, it is the animal's perception of a threat that elicits the stress response.

The central nervous systems perceive the stressor and organizes the pattern behavioural and physiological responses (Figure 1). As has been pointed out, this perception and the pattern of the biological responses is shaped by a number of variables in the animal's life including genetics, previous experience, social rank, and physiological state (Moberg, 1985a).

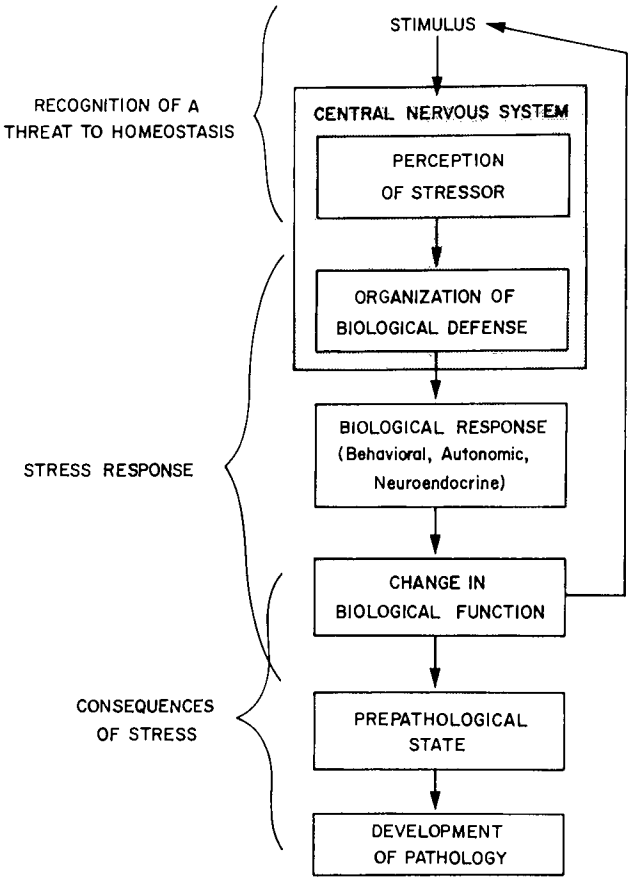

Figure 1. *Model for the biological response of animals during stress (from Moberg, 1985a).*

Regardless of the pattern of biological response the animal uses to cope with the stressor, a change in biological function results. A response by the autonomic nervous system may increase heart rate. The secretion of the stress related hormone, cortisol, will alter glucose metabolism resulting in an increase in the blood concentration of glucose. A behavioural response alters what the animal was doing prior to encountering the stressor. It is these changes in biological function that the animal uses in its attempt to cope with the stressor (Figure 1). Whether beneficial or not in helping the animal to cope, the change in biological function comes at a biological cost to the animal. That is, the change in biological function during stress diverts biological resources from the animal's previous nonstress activities, such as growth or reproduction, in an attempt to provide the animal with the biological resources to assist it in coping with stress.

For most stressors, the stress response is short-lived and the biological cost is negligible. However, during prolonged stress or if the stress is severe, there is a

prolonged, significant change in biological function and the biological cost is great. It is under these stress conditions that the animal enters the next stages of stress: prepathology and pathology (Figure 1). The prepathological state occurs when the stress response alters biological function sufficiently to place the animal at risk for developing pathologies. The most obvious example is infectious disease. The change in biological function occurring during a stress response may suppress the immune system, rendering the animal susceptible to any pathogens present. If the animal becomes ill, it enters the pathological state. For example, shipping fever is associated with transportation stress (Roth, 1985). The longer the animal is stressed, the longer the animal is in the prepathological state and the greater the opportunity for pathology to occur. But, disease is only one type of pathology that occurs during prolonged stress. When metabolism is shifted during stress, growing animals no longer grow normally. Stress can suppress reproduction or may result in the expression of deleterious behaviours. In dealing with stress, we must not restrict our view of pathology to disease, but use the term in the broadest sense of its definition.

From the model of stress (Figure 1), it is evident that the stress response is a highly varied cascade of events. Relying on one or two biological responses as a measure of stress will not provide domestic animal producers with practical ways of managing their animals. Depending on the development of pathologies as a management tool is both impractical and inhumane. Instead, I believe that we need to focus of the change in biological function, or the biological cost, occurring during stress as the key to understanding stress and how to manage it.

Biological cost of stress

It is the biological cost of stress which is truly important to the animal. As I have already indicated, stress is a part of life and is in itself not inherently bad. Most stressors are of short duration and result in no significant biological cost to the animal. It is only when the cost of coping with the stressor is so great that it places the animal into a prepathological state, that we need to be concerned with the effects of stress on the animal. If we focus on the biological cost of stress as a measure of stress, we no longer need to concern ourselves with what types of behavioural or physiological responses the animal uses to cope with the stressor. Whether the animal chooses behaviour, physiological responses or a combination of the two is irrelevant. What is important, is how much this response alters biological function. By this approach, we no longer need to concern ourselves with how such variables an early experience or social rank may shape the nature of the physiological and behavioural responses. We can concern ourselves only with the cost of stress.

The biological cost of stress can also provide us with an insight into a potentially important problem in domestic animals stress, the accumulative effects of subclinical (or subthreshold) stresses (Moberg 1985a, 1992). A subclinical stress response would occur when an individual is exposed to a stressor that elicits a biological response that, by itself, has only a minimal effect on the individual's biological function. Alone, the stress is of no consequence to the animal. In fact, this is exactly what constitutes the typical stress response for most of the stressors that are encountered in life. However, if the individual should be exposed to several such stressors at one time, the accumulative biological cost may prove sufficient to push the animal into a prepathological state, placing its well-being at risk (Moberg, 1992). Alternatively, an animal might experience a sequential series of subclinical stresses, whose total drain on the animal's resources could result in such a significant stress to the animal that a prepathological state would develop. In both examples, the stresses individually would result in no significant biological cost to the animal and would be subclinical in nature. But combined, the cost would be a threat to the animal's well-being.

One of the major problems confronting stress biologists is how to define and measure stress in animals. I believe that one way to solve this problem is to use the biological cost of stress as an indicator of stress (Moberg, 1992). Again, we fall back

on the argument that in domestic animal production, stress is meaningful only when it has a significant impact on the animal's well-being. As has been argued, a meaningful effect on the animal's well-being occurs only when the biological cost is sufficient to induce the development of a prepathological state, rendering the animal vulnerable to a pathology. Therefore, by measuring the development of a prepathological state we would have an indication of an animal experiencing meaningful stress. One example of such an approach might be to determine during a potential stressful event if the suppression of the immune system is occurring. Another approach might be finding that an animal is unable to reproduce because stress is prevented from secreting sufficient luteinizing hormone secretion for ovulation (Moberg, 1987), or that during a stressful event there is a failure to express oestrus behaviour (Ehnert and Moberg, 1991). Comparable measures could be developed for other behaviours, metabolism or growth to provide us an indication of the occurrence of stress. The advantage of this type of a measurement for stress over the classical use of such physiological and behaviour end points as hormones, heart rate, vocalization or stereotypic behaviour is that we no longer need to concern ourselves with individual differences in the type of biological responses. Instead we can focus on whether or not the event had a significant impact on the animal's well-being.

The use of the prepathological state as an indicator of stress has another advantage over the classic biological responses as a measure of stress. We know that the development of prepathology is significant. In contrast, the measurement of the classic behaviour and hormone responses as endpoints is that they may not necessarily be relevant to the animal's well-being or even directly related to the development of a prepathological state (Moberg, 1987; Barnett and Hemsworth, 1990; Rushen, 1991). On the other hand, few would question that an animal rendered vulnerable to the development of pathology is not undergoing a meaningful stress response.

Now, the challenge for researchers is to develop practical, meaningful measures of the prepathological state. With recent advances in immunology, I believe that the impairment of the immune system may prove to be the first area where this will be possible. However, we must develop measures of reproduction, metabolism and behaviour that can be used to indicate an animal has entered a prepathological state. To be practical for domestic animal producers, these measures must be readily applicable to field conditions. This is an important challenge to scientists, but the results will permit us to develop strategies for the management of stress.

Management of stress

I believe that in domestic animal production we must manage stress just as we manage reproduction or nutrition. Stress is a part of domestic animal production and cannot always be avoided. But, it must not be ignored or accepted as just part of doing business. Frequently, producers seek our advice on how to reduce stress in their animals. They are cognizant of its effect on production as evidenced by disease, loss of reproduction or low rates of weight gain. I believe that the answers they seek may be found in developing management strategies that are designed to reduce the cost of stress. Unfortunately, little research has been focused on this topic. Most stress research has been focused on the causes of stress and the biology of stress. Nevertheless, I believe that there are several tactics that may be used to eliminate or ameliorate the effects of stress, when stressors associated with animal production cannot be avoided.

The general strategy should be to keep stress in the subclinical range, that is, of no great biological cost to the animal. Animal behaviour offers one of the most promising approaches to this strategy. The animal stress response is shaped by perceptual and cognitive factors (Moberg, 1985a). As the animal stress model indicates, all stress begins when an animal believes that a threat exists, whether or not the threat truly exists. By capitalizing on our knowledge of animal behaviour, it may be possible to convince the animal that an event is not a threat or to distract the

animal from focusing on the event, thereby reducing the animal's concern about the perceived threat. One such approach to lessening the perception of the threat is the previously discussed example of placing visual barriers in cages housing groups of monkeys, in order to reduce visual contact between dominant and subordinate monkeys. I believe that comparable strategies could be incorporated into pig production practices to remove a perceived threat (McGlone and Curtis, 1985; Barnett *et al.*, 1987). I believe that this is one area of behavioural research that can have a significant impact on pig production, especially in confinement units.

Another behavioural approach is to induce the animal to engage in other ongoing behaviours during a time of stress. Such an approach was tried in pigs by Dantzer and Mormede (1981). They observed that food-deprived pigs subjected to an intermittent feeding schedule exhibited frustration and secreted significant amounts of the stress hormone, cortisol. However if, during the frustration period, the pigs were provided with a chain suspended from the ceiling into their pen, the pigs would chew and pull on the chain and these animals would secrete significantly less cortisol than pigs not provided with access to such adjunctive behaviours. While this work has not been extended to determine if the adjunctive behaviour can also reduce the total biological cost of stress occurring during the frustration test, this approach offers an interesting tactic for stress management and needs to be further studied. It should be remembered that the behavioural response to a stressor probably comes at less of a biological cost to the animal than does the elicitation of physiological stress responses. Thus, a behavioural response may frequently be preferable during a time of unavoidable stress.

An important aspect of the animal stress model is that the very nature of the stress response can be influenced by several modulating factors, such as genetics or early experience. I believe that such modulating factors may be used as tools to ameliorate the stress response of domestic animals. Both genetics and early experience can serve as examples for this approach. In turkeys, it was found that selection for altered stress responses could improve the survival of animals exposed to cold stress (Brown and Nester, 1973). In pigs, it has been noted that stress susceptible strains may show different physiological responses during environmental stress than do non-stress susceptible breeds (Marple *et al.*, 1972). Likewise, an animal's previous experience may influence its biological response to production conditions. In pigs, Hemsworth *et al.* (1981) found that the quality of human handling of young pigs influenced growth, behaviour and blood concentrations of the stress sensitive corticosteroid hormones. Those animals exposed to unpleasant handling treatment were the slowest to grow and showed the greater indication of elevated stress. In domestic animal production, we have only begun to use such modifications of the stress response to alter how our animals cope with stress, but I believe that this area offers one of the most productive areas for future research on stress management.

Even if the stressors can be kept in the subclinical range (ie; no development of a prepathological state), care must be taken not to expose the animals to a series of subclinical stressors whose biological cost accumulates, inducing a prepathological state. Simple precautions can prevent a significant cost of stress. For example, during transportation, pigs are under the greatest stress and experience the greatest mortality if they are loaded just before feeding, or if the pigs are transported during high environmental temperatures (Honkavaara, 1989). Likewise, the longer the time of transportation, the greater the effect on the animals. This latter exemplifies the temporal summation of the cost of stress. By simply separating these potentially stressful conditions, the stress load on the animal is reduced. Many of these additive conditions are obvious to the thoughtful livestock producer, but more work is needed to fully understand the more subtle stressors associated with animal production and their effects of the stress load of the animals.

Finally, some mention should be made about the use of therapeutics to manage stress. The use of tranquillizers is a popular and frequently sought answer for human stress. It is only natural that such an approach would be considered in animal stress.

Tranquillizers have been used in a number of domestic animals, including pigs (Dantzer, 1977). Undoubtedly, there are times when such a strategy may prove useful for dealing with brief stressors that cannot be managed by other means. However, this approach should be used with caution. Many of the tranquillizers in use stimulate many of the same physiological responses (eg; cortisol secretion) that stress does. In such cases, the tranquillizer may result in a biological cost similar or perhaps even greater than that of untreated stress. The use of tranquillizers or other pharmacological interventions should be used only as a last resort and on a case by case basis. We should never entertain the massive use of therapeutics to overcome bad management practices or to replace a sound understanding of the stress biology of our domestic animals.

Summary

Stress, like other areas of animal production, needs to be managed. Stress cannot be simply avoided, because it is part of the everyday life of our animals. They have evolved sophisticated biological responses to help them cope with stress. It is only when stress takes a significant toll on their biological resources that their well-being is threatened and they are at risk of suffering. To prevent such stress, we need to develop management strategies to ameliorate such stress. Such strategies must be based on a sound understanding of the stress biology of the animals. There are several tactics we can use in developing these strategies, including modification of their behaviour, genetics, carefully planning our management practices and the development of a sensitivity toward the biological cost of the events in an animal's life (Moberg, 1993).

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SOW PREFERENCES FOR WET AND DRY CONCRETE FLOORS

G.D. Hutson, M.J. Haskell*, L.G. Dickenson and D.E. Slinger

School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052. *Present address: The Scottish Agricultural College, West Mains Road, Edinburgh EH9 3JZ, UK.

Design criteria for intensive pig housing are usually based on production considerations rather than welfare. However, over the last 15 years ethologists have developed methods for assessing animal preferences. Although controversial (eg; Duncan, 1978; Hutson, 1984) these tests have been used to identify housing features important to the animals. In our own laboratory, we have found that spatial preference shown by a pig able to move freely between different sized pens might be confounded by innocuous factors, such as the location of the feeder and drinker, and whether the animal had been previously confined in one or other of the environments. In order to understand the effect of these variables, in the absence of the space variable, we undertook some baseline studies of environmental preferences. Pigs were offered choices between two environments, one assumed to be neutral - a conventional dry concrete floor, and one assumed to be aversive - a wet concrete floor. The influence of feeding site and confinement on preference was then assessed.

Forty-eight pregnant sows were tested individually in a choice pen consisting of two adjacent 2.4 x 2.4 m pens with a 0.5 m opening between them. The concrete floor of the pen sloped towards a central drain so that either pen could be kept completely wet by an irrigation system, and the other completely dry. Each pen contained a feeder and drinker, and the room temperature was set at 20°C, but could not be controlled precisely and varied within the range 18 - 23°C. Sows were fed in either the wet pen or the dry pen and allowed continuous free access to both pens, or they were confined overnight in one of the pens and allowed 8 h access per day to the other pen. After 2 days experience of this routine, time spent in the dry pen each hour, number of visits to the other pen, and behaviour were recorded over an 8 h period on the test day.

Sows showed a clear preference for dry floors. When fed on the dry side, sows spent most of their time (83.4 ± 2.2%) in the dry pen, compared with 68.8 ± 4.1% when fed on the wet side. However, there was a significant interaction ($P<0.001$) between feeding location and time of day. Sows fed on the wet side quickly changed their pen occupancy from wet to dry side, so that after 2 hours feeding location no longer influenced pen preference. Sows did not sit, kneel or lie on the wet floor, in contrast to the 44.0 ± 3.0% of time spent in these activities on dry floors. Thus, these results confirm that at 20°C, in a windless environment, a wet concrete floor is an aversive environment for the sow. The commercial implications are that floors of confined dry and lactating sows should be self-cleaning or else scraped and not hosed when the temperature is below 20°C.

Confinement had a surprising effect on behaviour. After confinement on the wet floor, sows increased their occupancy of the dry pen from 60.5 ± 6.2% (shown by free access sows, fed on the wet side) to 77.2 ± 4.5% ($P<0.05$), as expected if a wet floor was aversive. However, after confinement on dry floors sows performed more walking behaviour (7.5 ± 2.1 cf. 3.8 ± 1.1%, $P<0.05$) and made more visits to the other pen (15.6 ± 4.5 cf. 5.9 ± 1.1, $P<0.05$). This 'behavioural rebound' effect indicates that normal confinement housing of sows in pens may not satisfy their locomotion requirements.

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PIGLET SURVIVAL IN A CONVENTIONAL CRATE VERSUS AN 'ALTERNATIVE' FARROWING SYSTEM

G.M. Cronin and G.J. Simpson

Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.

Interest in group housing for farrowing sows has increased over the past decade, although piglet mortality levels are generally higher in group compared with conventional-crate systems (eg; Nash, 1992). Sows normally seek isolation at parturition (Jensen, 1986), but little is known about the behaviour and performance of sows and piglets in a group-farrowing situation. The aim of this experiment was to investigate effects of gestation and farrowing/lactation environments on piglet survival.

Data on piglet performance and mortality from 96 primiparous sows (12 replicates of eight sows) were analysed in a 2x2 cross-over design experiment, blocked by replicate. This was used to investigate the effects of gestation accommodation (individual stall vs group pen) and farrowing/lactation accommodation (farrowing crate vs. pair-pen: a pen for two sows with a separate farrowing nest for each sow). Thus there were four treatment combinations, and within each replicate, the data for the two sows per treatment were averaged (ie; experimental unit = 2 sows).

Table 1. Mean number of piglets born per sow, the occurrence of losses and the proportion alive after 8 days in the treatments (un-transformed means)

	Gestat. stall		Gestat. group		Significance[1]		Main effects SED
	Farrowing		Farrowing				
	Crate	Pair-pen	Crate	Pair-pen	Gestat.	Farrow.	
Total born	8.6	8.6	9.6	9.3	NS	NS	0.50
Stillborn	0.5	0.2	0.8	0.5	**	*	0.08[2]
Deaths, day 1-3	0.5	0.7	1.0	0.5	NS	NS	0.13[2]
Deaths, day 4-8	0.0	0.1	0.1	0.4	*	*	0.06[2]
Alive, day 8 (%)	88.4	88.4	80.2	84.9	*	NS	3.10[3]

[1]NS, non significant, P>0.05; * P<0.05; ** P<0.01. [2]$Log_e(1+x)$ transformation. [3]Angular transformation.

All 48 sows in the pair-pen farrowing treatment farrowed in the nest areas. Piglet survival rate to day eight was higher (P<0.05) when sows were individually stalled compared with group housed during gestation. The lower mortality for sows individually stalled in gestation was due to the higher incidence of stillbirths and deaths of piglets in the gestation group/farrowing crate treatment (Table 1).

The results indicate that the farrowing nest area provided for sows in the pair-pen treatment was attractive to sows, and that the piglet survival rate in a non-farrowing crate system was equal to the conventional crate system, at least in early lactation. The finding that piglet survival rate was lowest in the gestation group/farrowing crate treatment, suggests there may be adverse effects on piglet vitality and survival by restricting sows at parturition, which previously had been grouped. Further, since about one half of primiparous sows in Australian herds are housed in groups for gestation and crates for farrowing, it seems that a better understanding of the factors which may contribute to piglet losses in this housing system is required, if piglet survival levels are to improve.

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COMPARISON OF BEHAVIOUR PATTERNS OF SOWS AND LITTERS BEFORE WEANING IN A CONVENTIONAL FARROWING CRATE AND A FARROWING PEN

J.K. Blackshaw, A.W. Blackshaw*, F.J. Thomas and F.W. Newman

Department of Farm Animal Medicine and Production; *Department of Physiology and Pharmacology, University of Queensland, St Lucia, Qld. 4072.

Farrowing crates were introduced in the 1960's in favour of farrowing pens to reduce crushing of the piglets by the sow (Robertson *et at.*, 1966). There is now public concern for the welfare of sows in a farrowing crate, but alternate farrowing systems must improve sow and piglet welfare before they can be adopted. This study was done to assess the behaviours of eight Large White X Landrace sows (parities 3 or more) and litters from birth to weaning, housed in a farrowing crate (600 mm - 800 mm crate in a 2130 mm x 1850 mm pen) compared with the behaviours of eight sows and litter in a farrowing pen (2130 mm x 1850 mm), using data from real time video tapes. Days 1-5 after parturition were examined in detail (Table 1), and data were analysed by ANOVA, t test and chi-square.

Mortality rates for litters in farrowing crates were 14% for the eight sows (born alive, 86; dead, 4; mummified, 2; weaned, 74; mean litter size 10.75 ± 3). All the mortalities were due to crushing in days 1 or 2. The farrowing pen mortalities were 32% of those born alive ($\chi^2_{(1)}$ = 8.551; P<0.01; born alive, 106; dead, 5; mummified, 5; weaned = 72; mean litter size 13.13 ± 2). Of the 34 mortalities, 26 were due to crushing in the first two days, 5 were low viability (under weight), one had severe scours and 2 were of unknown causes.

Table 1. Number of observations of mean frequencies (± SD) of piglet activity in farrowing crates and pens, during 1-5 days after birth per 3h tape

Behaviour	N°	Crate	N°	Pen	Sign.[1]
Active in pen	24	511 ± 51	26	522 ± 48	NS
Resting in pen	24	228 ± 101	26	449 ± 66	NS
Active at udder	24	818 ± 66	26	891 ± 66	NS
Resting at udder	25	1089 ± 149	28	1135 ± 134	NS
Resting under lamp	25	1074 ± 182	26	921 ± 146	NS
Sucking duration (min) (slow and rapid sucking)	24	3.1 ± 0.3	25	1.4 ± 0.3	*

[1]NS, non significant, P>0.05; * P<0.05.

Mortality data suggested that the pen system was more hazardous for piglet welfare than the crate. Piglet behaviour during days 1-5 did not appear to contribute to this difference. Perhaps the sows' activity while lying down (stretching, kicking, shaking or rolling) during days 1-5 (in crate = 18.5 ± 4.3; pen = 36.4 ± 3.1; $t_{(48)}$ = 4.93; P<0.01) is a more likely factor.

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THE INFLUENCE OF ENVIRONMENTAL ENRICHMENT ON PIG GROWTH

H.M. Knowles, G.A. Eldridge and C.I. Ball

Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.

Intensively managed pigs are unaccustomed to being moved, yet handling prior to slaughter can have a marked influence on meat quality (Grandin, 1988). Although Pearce *et al.* (1989) found no effect of handling and environmental enrichment within pen on the growth rate of pigs, there have been concerns that training pigs to handling environments and the moving of pigs from pens could reduce growth rates. This paper reports the influence of handling and changing environments through physical movement, in order to improve handling at the time of slaughter, on the growth rate of finisher pigs.

One hundred and twenty commercial finisher pigs were familiarised with a range of environments and handling facilities. Pigs were allotted to this enriched environment and handling (EE) and control (C) treatments, in a randomised block design experiment (3 blocks x 2 treatments x 2 replicates). The pigs were stratified by live weight into groups of 10 pigs per pen. The EE and C treatment pens were separated by 12 pens housing non-experimental pigs.

Individual pens of animals from the EE treatment were handled twice a week for 30 min by the same stockpersons. During the handling period, the animals were introduced to a succession of environments, including races, pens, scales and lane ways as well as being loaded on to a stock truck. There was no contact between EE and C treatment pigs during the experiment. The C treatment pigs received only minimal human intervention for routine health, food and water checks, similar to that given to non-experimental animals in the finisher shed. The pigs were individually weighed at the start and end of the experiment and the pigs were slaughtered over three consecutive days at the end of the 34 day experimental period. The pigs were fed *ad libitum* from self-feeders; feed consumption was not recorded.

Group means were assessed by analysis of variance. The key results are presented in Table 1. Treatment had no influence on carcass fatness or yield.

Table 1. Influence of environmental enrichment (EE) on growth rate of finisher pigs

	EE	Control	SED	Sign[1].
Initial live weight (kg)	54.9	55.2	0.54	NS
Final live weight (kg)	83.9	81.4	0.81	*
Gain (kg/day)	0.83	0.75	0.03	*
Hot carcass weight (kg)	59.3	58.6	0.84	NS

[1]NS, non significant, $P>0.05$; *$P<0.05$.

The twice-weekly handling and movement of pigs did not detrimentally influence production, but in fact significantly ($P<0.05$) enhanced the growth rate of pigs. Although the reasons for the improved growth rates can only be speculative, there would appear to be an opportunity to accustom finisher pigs to handling for slaughter, without detrimentally reducing growth rate.

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A DRUG THAT REDUCES AGGRESSION IN PIGS - A WELFARE DILEMMA

J.L. Barnett

Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.

Grouping unfamiliar sows and gilts may pose a welfare risk, particularly from injuries due to fighting during the establishment of social hierarchies. Amperozide is an anti-aggression drug, shown to be effective in the young pig (Bjork *et al.*, 1988). In Table 1 and other work by Barnett *et al.* (1993), amperozide significantly reduced the incidence of aggression. However, it also resulted in the elevation of plasma cortisol, suggesting an acute stress response. The magnitude of this acute response resulted in cortisol concentrations that approached the maximum concentrations attained for pigs (see Hennessy *et al.*, 1988) and this finding raises welfare issues that require discussion.

Table 1. The effects of Amperozide on the number of aggressive interactions from 15-90 min, after grouping 4 unfamiliar adult pigs, and the mean cortisol concentration from 90-180 min after grouping (mean {$\log_e(x+1)$} values/pig based on the group of 4 pigs as the unit of measurement and 6 replicates; untransformed data in parentheses)

	Control	Amperozide	Significance[1]	SEM
Aggressive interactions	7.14 (47.0)	2.99 (10.0)	*	1.472
Cortisol (nmol l^{-1})[2]	4.31 (77.8)	5.17 (178.4)	**	0.270

[1]* $P<0.05$; ** $P<0.01$. [2]Mean of 7 values taken at 15 min intervals.

In terms of welfare, it is difficult to interpret the acute stress response following amperozide administration. It is a question of balancing the advantages of reduced aggression against the presence of an acute stress response. While it could be argued that there are no long-term detrimental consequences of an acute stress response unless it occurs at critical periods of the reproductive cycle, the magnitude of an acute stress response is often used to indicate the relative welfare consequences of management practices (eg; Fulkerson and Jamieson, 1982). Thus, it could be argued that a procedure that results in an acute stress response of small magnitude and duration is more acceptable than one that results in a response of large magnitude and duration. Although the duration of the acute stress response in this experiment is not known, it had disappeared within 24 h (mean $\log_e(x+1)$ values were 3.64 and 3.36 nmol l^{-1}, for the Control and Amperozide treatments, respectively; SEM = 0.295). In part, the stress response may be due to injecting Amperozide, which can result in vomiting, although this can be avoided by administering it in the feed (Bjork *et al.*, 1988). However, the consequences of changing the route of administration on adrenal function are not known. Based on the magnitude of the acute stress response, it is suggested that the injection of Amperozide may not be an acceptable procedure to reduce aggression.

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EFFECT OF STRAW ON THE ACTH RESPONSE OF SOWS FED BY AN ELECTRONIC SOW FEEDER

W.A. Clarke, E.S. Batterham and R.J. van Barneveld*

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477. *South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.

Claims that straw bedding improves welfare in sows fed by an Electronic Sow Feeder (ESF) have been largely based on anecdotal evidence (Hunter and Smith, 1991). One indicator of poor animal welfare is the presence of chronic stress. An ACTH challenge offers a physiological method of assessing chronic stress problems (Broom, 1988). By injecting sows with synthetic ACTH, the responsiveness of the adrenal cortex, in terms of the amount of plasma cortisol it produces, can be used as a guide to the welfare status of the animal. When a particular sow is chronically stressed, and is continually producing cortisol, its adrenal gland should have a greater capacity to respond to ACTH than when in an unstressed state. The aim of this experiment was to examine the ACTH responsiveness, in terms of plasma cortisol levels in sows, with or without access to straw.

At three weeks post mating, two groups of 20 Large White sows, parity 1 - 5, were fed by an ESF in a 5.6 m x 10 m pen. In Group 1, the sows spent the first 6 weeks without straw and were then given an ACTH challenge. Straw was provided and the ACTH challenge repeated 3 weeks later. In Group 2, the treatments were the same except that the sows started with access to straw, which was then removed. When used, barley straw at the rate of 2 kg/sow was placed in the lying area daily. In association with each group, a control of five sows was maintained. These sows were kept in individual stalls (⅔ concrete, ⅓ wooden slats), were also given the ACTH challenges, and had no access to straw. A dry sow diet (13 MJ of digestible energy/kg) was given to sows daily at a rate of 2 - 3 kg, depending on body condition. The ACTH challenge involved the intermuscular injection of 75 IU of synthetic ACTH (Synacthen®, Ciba-Geigy Aust. Ltd.) and blood collection 1 h later via tail nicking. Plasma cortisol levels were determined using flouresence polarization on an Abbott's TDX autoanalyser.

Table 1. Plasma cortisol levels (n mol/L) obtained in response to 75 IU ACTH challenge

	Lying area		Housed in stalls	Sign.[1]	SEM
	Concrete	Straw			
Group 1 - Starting on concrete	343	340	338	NS	23.1
Group 2 - Starting on straw	320	293	296	NS	25.0

[1]NS, non significant, P>0.05.

The adrenal responsiveness of the two groups studied were similar and unaffected by the presence or absence of straw (P>0.05). In addition, there was no significant difference (P>0.05) between the cortisol values obtained from sows in stalls, compared to those fed by and ESF. This data suggests that sows fed by an ESF, in the presence or absence of straw bedding, and sows kept in individual stalls, were able to adapt to these environments without evidence of chronic stress, in terms of their response to a dose of synthetic ACTH. Further work on other physiological, as well as behavioural parameters, is necessary to confirm this.

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REDUCING AGGRESSION BETWEEN UNFAMILIAR SOWS USING DIETARY TRYPTOPHAN

W.A. Clarke, R.O. Ball* and R.J. van Barneveld**

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477. *University of Guelph, Guelph, Ontario N1G 2W1, Canada. **South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.

The grouping of unfamiliar sows inevitably leads to aggression as the sows establish a social order. The level of physical injury and stress placed on each sow prompts producers to use individual confinement in preference to group housing methods. This situation appears to be in conflict with consumer preference (Brouns and Edwards, 1992).

Dietary tryptophan has been identified as a potential method of reducing aggression in animals (Adeola and Ball, 1992). Ingestion of large amounts of tryptophan leads to an increase in plasma tryptophan, as demonstrated by Clarke *et al.* (1993), which is then carried to the brain. Here the tryptophan is converted to the neurotransmitter serotonin, which should act as a short term sedative, and thereby reduce aggression between sows. This experiment aimed to establish whether high doses of dietary tryptophan would reduce the aggression between unfamiliar sows, when establishing a social heirarchy.

Twelve groups of five Large White sows, parity 1 - 3, were fed a lactating sow diet *ad libitum* (19.8% crude protein, 14 MJ digestible energy, available lysine 0.55 g/MJ digestible energy and tryptophan 0.22% of available lysine). The sows were held in individual farrowing crates and weaned at 28 days into a 6 m x 5 m pen, with a solid concrete floor and one nipple drinker. Five days prior to weaning 5 g of tryptophan/kg was added to the diet of half of the sow groups. Observations were over the first 3 h post-weaning. The sows were removed from the pen the following morning and were given access to feed and water before being returned to the pen for a further 3 h observation. This was done to avoid behaviours associated with feeding, which lead to aggression not associated with the establishment of the social heirarchy.

Table 1. Effect of dietary tryptophan on aggressive activity between group-housed sows during the 3 h observation periods

Average	Day 1				Day 2			
	Control	Trp	Sign.[1]	SEM	Control	Trp	Sign.[1]	SEM
Aggressive incidents	98	90	NS	15.8	13	9	NS	3.1
Fights	5	5	NS	1.1	0	0	NS	0.0
Duration of fights (sec)	62	44	NS	15.1	0	0	NS	0.0

[1]NS, non significant, P>0.05.

The provision of 5 g of free tryptophan per kg of diet was unable to significantly (P>0.05) reduce aggression between unfamiliar sows when housed together (Table 1). This indicates that the sedative effect of tryptophan was non-existant, or insufficient to overcome the sow's use of aggression to establish a social order.

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A SYMPOSIUM - PORK QUALITY - MEETING CONSUMER'S NEEDS

G.R. Trout

CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.

Symposium introduction

Meeting consumer's needs is of upmost importance in marketing any commodity in today's competitive market. In Australia and other developed countries, today's consumers demand a much higher standard for their food products than they did 20 years ago. This is partly because of the higher standard of living and higher disposable income, but also because of competition from other foods. This is certainly the case with pork which must compete against it's traditional competitors: beef, lamb and chicken. But now it also must compete against other high quality fresh and processed food products, such as fresh seafood, game meat, smoked salmon, gourmet cheeses and pasta, just to name a few.

Hence, pork can no longer be marketed as a commodity but as a food that suits consumers need.

Does Australian pork meet consumers needs? At the present time it is difficult to say. Over the last 20 years there has been enormous changes in the Australian pig industry aimed at increasing the efficiency of production of lean meat. However, it has not been determined if these changes in production practices, which have produced this increased efficiency, have affected the quality of the final product - pork.

This is rather surprising, considering the enormous changes in production and processing practices. Major changes that have occurred include: 1) a change to intensive pig production with the resulting extensive use of antimicrobial agents, 2) production of heavier, leaner pigs, 3) use of entire males, 4) introduction of different breeds, 5) longer transportation distances, and 6) more efficient processing - particularly chilling.

Overseas research indicates that these changes in production and processing can adversely influence many quality attributes (Wood, 1993). Some of the quality attributes affected include: 1) Raw meat- and fat-texture, 2) muscle-muscle and muscle-fat separation, 3) tenderness, 4) juiciness, 5) flavour, 6) processing quality, 7) processing yield, and 8) consumer's perception of the wholesomeness of the product.

The effect of changes in production practices on the quality of Australian pork can be best illustrated by the fact that only about 12% of the pork produced in Australia will meet the quality standards of the Japanese market - one of the major importers of pork. The reason for this low level of acceptability is that 1) 30% of Australian pork is PSE (pale, soft and exudative) (Trout *et al.*, 1991), 2) 15% of Australian pork is DFD (dark, firm and dry) [DFD has a shelf life of two weeks and cannot be shipped to Japan in that time (Shay, 1993)], 3) 50% of the pork produced in Australia is from entire males (at the weight required for the Japanese market 15% of the meat from entires will have boar odour) (Trout, 1993), and 4) 10 - 50% of pigs will react positive to a urine antimicrobial test (Whan, 1993a). Pork with any of these quality defects is not acceptable to the Japanese consumers.

Presumably such variation in quality will also influence the purchasing practices of Australian consumers.

Hence, the objective of this Symposium will be to outline in more detail how changes in production practices have affected pork quality and what the solutions are to these present and any future problems.

PRODUCTION AND PROCESSING PRACTICES TO MEET CONSUMER NEEDS

J.D. Wood

Division of Food Animal Science, School of Veterinary Science, University of Bristol, Langford, Bristol BS18 7DY, UK.

Introduction

To most consumers, high quality infers that high standards have been used for all aspects of the production, processing, packaging and marketing of food. Consumers consider many factors under the heading of quality, as shown in Table 1. The first requirement is for safety which, for meat, implies freedom from potentially harmful ingredients, such as food poisoning organisms and drug residues. This is an area where individual governments and, in Europe, the European Commission (EC), have major responsibilities through legislation.

Table 1. Food quality: the consumer's priorities[1]

	Priority	Main aspects	Examples from animal production
1.	Safety	Microbiology Toxicity	Salmonella Drug residues
2.	Basic properties	Nutrition Composition Function Sensory	Fat content Labelling Roast/microwave Taste/feed
3.	Extra properties	Authenticity Convenience Exotic	Scotch beef Ready meals Kobe beef?
4.	Ethical aspects	Animal welfare	Intensive rearing Slaughtering

[1]Foster and Macrae, 1992.

The second priority for consumers concerns the basic properties of foods which affect its appearance, composition and eating quality (taste). For meat, the important aspects are fatness/leanness and the more common meat quality parameters (Table 2). These vary quite widely, are capable of change using production and processing modifications and will be the main subject of this paper.

Recent years have seen an increase in our understanding of the biological factors which control these aspects of quality and ways to manipulate them. The major biological factors are shown in Table 3.

Manipulation of meat quality

Meat quality is manipulated by changing the levels of the biological factors described in Table 3. This is achieved by changing production and processing inputs and these will now be dealt with in turn.

Table 2. Components of pig meat quality

Eating quality	The lean meat should be tender and juicy. It should have an acceptable level of pork flavour and a low level of abnormal flavours (taints).
Colour	The lean meat should be neither pale nor dark. The fat should be white.
Drip	High levels of drip in the pack or during preparation are undesirable.
Handling characteristics	The tissues should be firm and adhere well together (ie; no fat or muscle separation) during butchery and preparation for cooking.

Table 3. Biological factors controlling pig meat quality

Marbling fat	The lipid deposited in the perimysium between muscle fibre bundles. This reduces shear force during cutting or chewing and increases juiciness.
Collagen	The background strength of the muscle is due to the connective tissue framework. As this ages, stronger intra-molecular linkages develop, which are more difficult to degrade during cooking.
Muscle fibres	A major factor in toughness is the bunching of muscle fibres which occurs during cold-shortening. Also, muscles containing red oxidative fibres tend to be more tender than those containing predominantly white glycolytic fibres.
Androstenone and skatole	The two compounds thought to control taint. Both reach higher concentrations in entire males and skatole is also influenced by diet and management factors.
pH fall	Rapid postmortem pH fall produces pale soft exudative (PSE) meat. A reduced pH fall causes dark firm dry (DFD) meat. These are influenced by breed and pre-slaughter handling.
Stage of tissue development	Pigs which are immature in tissue developemnt exhibit a range of eatures which adversely affect meat quality eg; high water concentration, low lipid content of connective tissue sheaths between muscles.

Genetic effects

Halothane gene

The halothane gene, or ryanodine receptor gene (Fuji *et al.*, 1991) has important effects on meat quality, especially the incidence of pale, soft, exudative (PSE) muscle. Pigs which inherit two copies of this recessive gene (n) show an accelerated rate of muscle glycolysis post-mortem, which results in increased drip loss and the scattering of incident light giving a paler appearance. Most studies agree that the muscle is also tougher when eaten (Bejerholm, 1984).

The halothane gene is closely associated with genes controlling carcass composition and muscle thickness, which are inherited in a normal additive way. Homozygotes for the halothane gene (nn) have inferior meat quality, but also a desirable carcass quality ie; high lean content and thick muscles. The halothane test is commonly used by commercial breeding companies to concentrate nn into one parent line and remove n from the other, so that theoretically the heterozygotes Nn have zero incidence of PSE, but carcasses intermediate in quality between the two parent lines (Jensen, 1981).

However, it is practically difficult to rid NN lines of the gene using the halothane test and in many studies Nn have an important and significant incidence of PSE meat (eg; Murray *et al.*, 1989). A further reason for this is the increased susceptibility to poor pre-slaughter handling of Nn genotypes observed in some studies (Barton-Gade, 1984).

Recently a definitive gene probe has become available for detecting the halothane gene. It should now be possible to guarantee nn and NN breeding lines, so that Nn progeny show advantages in yield without marked disadvantages in quality. An alternative approach is to attempt to remove the halothane gene from breeding lines, whilst still retaining high values for lean content and shape. Success here will depend on the degree to which the halothane gene also controls carcass quality traits.

Marbling fat and the Duroc effect

It is generally accepted that any effects of the fatness of meat on eating quality depend on marbling fat, the lipid formed in the perimysial connective tissue surrounding the muscle fibre bundles. This intramuscular lipid, when extracted in the standard way using diethyl ether, typically constitutes 0.5 - 2.5% of muscle-wet weight in the key loin muscle *m. longissimus*. Values to the lower end of this range (and below) are found in fast-growing lean European-type pigs of 'white' breeding, and to the upper end and above, are found in dark-skinned breeds such as the Duroc and in the fatter pigs reported in the American literature (values in the range 5 - 8% have been reported). Marbling fat has a number of effects on eating quality eg; it reduces the force required to shear myofibrils (the dilution effect) and it aids the separation of fibre bundles during chewing (Wood, 1991). However, there is disagreement on the importance of these effects. In early research conducted in the 1960s and 1970s, positive but sometimes variable associations between marbling fat concentrations and taste panel scores for tenderness, juiciness and flavour were found (reviewed by Wood, 1991). In more recent work, involving samples with lower concentrations of marbling fat, such as are present in modern pigs, studies have also reached different conclusions. Danish and American reports have concluded that 'threshold' values of 2.0% (Bejerholm and Barton-Gade, 1986) or 2.5 - 3.0% total lipid (De Vol *et al.*, 1988) are required for optimal eating quality. Marbling fat had an important and positive influence in both these studies. On the other hand, a Swedish study concluded that there was no difference in eating quality traits between hind loin slices containing 0.8, 1.2, 1.8, 2.2 and 2.6% total lipid (Goransson *et al.*, 1992). In these three studies, total lipid was extracted with chloroform:methanol (2:1) or ether extraction coupled with acid hydrolysis. These procedures extract muscle membrane lipids as well as true 'marbling fat' and produce values approximately 1.2 x the ether extract value.

Extremely low values for marbling fat were reported by Kempster *et al.* (1986)

and Wood *et al.* (1986) in a UK study of pork-weight carcasses (58 kg average). Carcasses with 8mm P_2 fat thickness had on average only 0.55% ether-extractable lipid in *m. longissimus*, the figure increasing to 0.96% at 16mm P_2 (Table 4). In this work, tenderness and especially juiciness increased as P_2 fat thickness and marbling fat increased. The overall correlations between marbling fat and taste panel scores were 0.13, 0.31, 0.17 and 0.22 for tenderness, juiciness, pork flavour liking and overall acceptability, respectively. This does not provide evidence for an overriding role of marbling fat in the regulation of pig meat quality, but it suggests that the industry should be cautious of making reductions below the average figure of 0.8%, currently seen in the UK.

Table 4. Eating quality of loin chops in 58kg pig carcasses differing in fat thickness

	P_2 fat thickness (mm)		Sign.[1]
	8	16	
Consumer panel[2]			
Extrememly or very tender	35	37	**
Extrememly or very juicy	16	23	***
Extremely or very flavourful	35	35	NS
Taste panel[3]			
Tenderness	1.0	1.1	NS
Juiciness	1.1	1.3	**
Flavour	1.5	1.7	NS
Overall acceptability	0.7	1.0	NS
Marbling fat (%)[4]	0.55	0.96	***

[1]NS, non significant, P>0.05; ** P<0.01; *** P<0.001. [2]Tests conducted by Meat and Livestock Commission involving 500 families. Values are percentage of chops in the categories shown (Kempster *et al.*, 1986). [3]Twelve-member Bristol taste panel used the following scores differing in intensity: tenderness, flavour and overall acceptability -7 to +7. Juiciness 0 to 4 (Wood *et al.*, 1986). [4]Diethyl-ether extraction of cores of *m. longissimus* from last rib position (Wood *et al.*, 1986).

Several studies have shown that the heritability of marbling fat is quite high and the correlation between marbling fat and total fat low (Duniec *et al.*, 1961; Hovenier *et al.*, 1992).

The Duroc is an example of a breed with a high concentration of marbling fat in relation to backfat. A recent large-scale study, coordinated by the Meat and Livestock Commission (MLC), showed that as the proportion of Duroc genes increased, so did eating quality, in terms of tenderness (Table 5). This increase was associated with an increase in marbling fat (ether-extractable lipid) and changes in muscle suggestive of an increase in the concentration of red oxidative muscle fibres. The increase of approximately 0.4 scale points in tenderness (1-8 scale), between 0 and 50% Duroc genes (0 indicating all 'white breed' genes), is considered to be detectable to consumers as an important positive effect.

Sex effects

In the UK and in some other countries the practice of castrating male pigs is now considered inappropriate on welfare grounds and in the interests of efficient lean growth. This change has taken place over about 10 years or so and has been an important reason for the continued downward trend in P_2 fat thickness values.

The meat industries of the UK and elsewhere are often critical of meat quality in entires, mainly on the grounds of cooking odours and flavour. Some other complaints

associated with inherent differences in tissue composition have also been made. For example, entires have softer fat than castrates or gilts at the same fat thickness, because of a higher water and lower lipid content and a higher concentration of the polyunsaturated fatty acid linoleic acid (C18:2) (Wood *et al.*, 1989).

Table 5. Effect of Duroc breed on meat quality[1]

	Duroc genes (%)			
	0	25	50	75
Measurements on *m. longissimus*				
Haem pigments (mg/g)	0.61	0.64	0.67	0.67
L* brightness	54.0	53.8	53.3	53.6
a* redness	2.2	2.7	2.9	3.1
Saturation	4.5	5.2	5.4	5.7
Marbling fat (%)	0.70	0.86	1.08	1.27
Scores of trained taste panel (1 - 8)				
Tenderness	4.96	5.03	5.32	5.38
Juiciness	4.09	4.11	4.18	4.38
Flavour	3.88	3.99	3.96	3.98

[1]Meat and Livestock Commission (1992a).

Despite the meat industry belief that eating quality is inferior in entires few, if any, UK studies have shown major differences between entires and other sex types. Results from MLC's First Stotfold Trial are shown in Table 6. Tenderness, juiciness and pork flavour intensity in loin steaks were unaffected by sex. There was, however, a slightly lower pork odour and higher abnormal odour intensity in meat from entires. These differences were not detected in concurrent consumer tests on the same material. Consumers rated pork from the three sexes similar in terms of overall eating satisfaction.

Table 6. Eating quality[1] of roast loin muscle from 420 carcasses of the three sex types, average weight 65kg, as assessed by trained taste panellists[2]

	Entire males	Castrated males	Gilts	Sign.[3]
Tenderness	5.00	4.96	4.94	NS
Juiciness	4.35	4.44	4.26	NS
Pork flavour	4.59	4.55	4.50	NS
Pork odour	3.62^{b}	3.78^{b}	3.84^{c}	*
Abnormal odour	3.80^{b}	3.51^{c}	3.30^{d}	*

[1]Scores 1 - 8 in every case. [2]Adapted from Meat and Livestock Commission (1989). [3]NS, non significant, $P>0.05$; * $P<0.05$; Within rows, means with different superscripts differ ($P<0.05$).

Different conclusions were reached in a French trial designed to evaluate the roles of skatole and androstenone on the eating quality of the different sex types (Table 7). Both compounds have been implicated in lowering the flavour intensity, and increasing the abnormal odour and abnormal flavour ratings of pork, and both reach higher concentrations in entires. In this study, the correlation between androstenone and skatole concentrations was high (0.73). The separate effects of skatole and androstenone were examined and the results examining critical levels of skatole are considered in Table 7. The threshold value of 0.25 ppm skatole distinguishing tainted from untainted carcasses was suggested by Mortensen *et al.*

(1986). The results show more important differences in odour and flavour scores between the male sex types than have been detected in UK work (eg; Table 6), although this was most noticeable in the group with more than 0.25 ppm skatole in backfat. In a small sample (250) of UK pigs, it was estimated that only 3% of males have a skatole value higher than this (Patterson *et al.*, 1990).

There are several reasons why taints could be less of a problem in UK pigs. Firstly, the predominant Large White breed has lower levels of taint compounds than some other breeds (Malmfors and Lundstrom, 1983). Secondly, carcass weights are lower in the UK (taints increase with weight) and thirdly meat tends to be cooked to higher temperatures in the UK than elsewhere. The perception of abnormal odours is much higher at the lower endpoint temperatures used in some other countries (eg; France). Higher temperatures increase pork flavour intensity, which may mask abnormal flavours (Wood *et al.*, 1993b).

Despite the broad associations between odour and flavour scores on the one hand and skatole and androstenone concentrations on the other (Table 7), Bonneau *et al.* (1992) concluded that neither compound could be reliably used as a predictor of taints.

Table 7. Sensory evaluations of meat quality in pork cutlets from castrated males (CM) and entires (EM), having low (L) (≤ 0.25 ppm) or high (H) (> 0.25 ppm) concentrations of skatole in backfat[1]

	CM	EM (L)	EM (H)	Sign.[2]
N° of animals	74	52	22	
Androstenone (ppm)	-	0.44^{b}	1.34^{c}	***
Skatole (ppm)	0.11^{a}	0.13^{a}	0.68^{b}	***
Cooking odour[3]	5.43^{a}	4.02^{b}	2.37^{c}	***
Tenderness[4]	5.45	5.25	5.25	NS
Juiciness[4]	4.77	4.77	4.76	NS
Flavour[4]	5.08^{a}	4.96^{ab}	4.77^{b}	*
Aroma[4]	5.03^{a}	4.86^{ab}	4.58^{b}	**
Preference (%)	56^{a}	44^{b}	42^{b}	***

[1]From Bonneau *et al.* (1992). [2]NS, non significant, P>0.05; * P<0.05; ** P<0.01; *** P<0.001. Within rows, values with different superscripts differ (P<0.05). [3]Scale 0 - 10 (unpleasant to pleasant). [4]Scale 1 - 10 (extremely unsatisfactory to extremely satisfactory).

Feeding effects

Tissue development

As pigs increase in weight, the proportion of fat increases and the carcass tissues become more mature. At a particular weight, fast growing, lean (late maturing) genotypes are low in fat and the fat tissue itself is immature ie; relatively high in water and connective tissue concentration and low in lipid (Wood *et al.*, 1989). The lipid in lean carcasses is also more unsaturated. All these changes in fat tissue contribute to criticisms from butchers of softness and wetness in meat and complaints that excessively lean carcasses do no 'set' for cutting (Table 8). Immature development of fat tissue is also responsible for muscle-muscle and fat-muscle separation.

The solution to these problems is to promote some fat deposition rather than to promote more lean through high protein and lysine concentrations. The problems are also less acute at higher carcass weights (Wood *et al.*, 1986).

Dietary oils

Early work in America (eg; Ellis and Isbell, 1926) showed that changing the fatty acid composition of pig fat and muscle tissues was simply achieved by changing the

type and quantity of oil in the feed. This then has repercussions for the firmness or softness of the tissue since fatty acids vary greatly in fluidity at a certain temperature. It was recognised that manipulating the C18:2 content of tissues was particularly straightforward, since this fatty acid is not synthesised by the pig, or significantly modified before deposition in tissues.

Table 8. Butchers' assessments of meat quality in the loin joint of 58kg carcasses differing in fat thickness[1]

	P_2 (mm)		
	8	12	16
Drip loss (%)	4.8	3.8	3.0
Butchers assessment[2]			
Much too fat	0	4	39
Much too lean	15	1	0
Fat very firm	3	9	24
Fat very soft	10	2	1
Setting: firm or satisfactory	39	72	83
Setting: floppy	60	28	17
Separation: none	4	16	35
Separation: excessive	46	18	11

[1]From Kempster *et al.* (1986). [2]A panel of forty five butchers assessed one hundred carcasses in each fat thickness group. The values are the number of joints in the category shown.

The effects of dietary fatty acids on tissue deposition have received more recent attention, because of trends to increase the energy density of pig diets and utilise a wide variety of fat sources in formulations. There has also been an interest in increasing the polyunsaturated:saturated fatty acid ratio in meat for health reasons. However, modern European pigs are now considerably leaner than the pigs used in the early studies and their fat tissues contain higher base levels of unsaturated fatty acids (eg; typically 13% vs 8% of C18:2). In a 1988 survey, 14% of carcasses in a stratified sample had backfat which was 'very soft' or softer, as determined by a portable penetrometer (Dransfield and Kempster, 1988). The benefits to increased 'healthiness' of feeding high levels of unsaturated fat have therefore to be balanced against the danger of producing unacceptable fat quality.

Studies conducted in the 1980s (eg; Whittington *et al.*, 1986) showed that increasing the C18:2 concentration of pig finisher diets beyond 1.6% resulted in unacceptably soft fat (reviewed by Wood, 1984) and that this effect was exaggerated at low P_2 values. Because P_2 levels have since declined further, this recommendation should now be revised downwards to retain fat quality.

Data from an experiment investigating the effects of breed and feeding level on meat quality were used by Cameron and Enser (1991) to determine the associations between intramuscular fatty acid composition and eating quality traits. The results (Table 9), showed that in general higher concentrations of polyunsaturated fatty acids including C18:2 (but excluding C18:3, linolenic acid) were associated with lower scores for tenderness, juiciness, flavour and overall acceptability, whereas higher concentrations of saturated and monounsaturated fatty acids were associated with higher scores. Lower pork flavour, and higher abnormal flavour scores in meat with high levels of C18:2 and other polyunsaturated fatty acids, is probably explained by increased oxidation and the development of rancidity *in vivo*, post mortem and during cooking (Melton, 1990).

Table 9. Correlations between intramuscular fatty acid composition (% of fatty acids) and eating quality traits in 160 Duroc and halothane-negative British Landrace pigs[1]

	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:4	22:5	22:6
Tenderness	0.14	0,13	0.17	-0.04	0.19	-0.21	0.05	-0.20	-0.23	-0.17
Juiciness	0.15	0.05	0.08	0.04	0.09	-0.06	0.23	-0.20	-0.21	-0.16
Flavour	0.11	0.08	0.21	0.06	0.19	-0.19	0.10	-0.19	-0.23	-0.21
Overall acceptability	0.19	0.12	0.17	0.01	0.19	-0.20	-0.15	-0.26	-0.28	-0.21

[1]Cameron and Enser (1991).

Work by Rhee and colleagues in America found that increasing C18:1 to high levels (>50% of fatty acids in muscle, simultaneously reducing C18:2) was beneficial for eating quality, particularly juiciness and tenderness (Rhee *et al.*, 1990). It is unclear how eating quality could be influenced by fatty acid composition and the effects have not been found by other workers (Shackelford *et al.*, 1990). In the latter study, the pork flavour score was lowest and off-flavours most apparent in pigs fed canola oil, which raised the linolenic acid (C18:3) concentration of muscle lipid from about 1.5 to 3.0%. Off flavours were directly linked to oxidation products of C18:3.

An increased risk of oxidative rancidity and the development of off-flavours in meat also exists when high levels of fish oils are fed. Concentrations of the possibly beneficial (to health) n-3 fatty acids such as C20:5 and 22:6 can be easily raised in pig fat tissues (Irie and Sakimoto, 1992) but levels beyond 1% of the diet have not been recommended because of taint development.

Feeding and system effects on skatole

Work in Scandinavia showed that skatole concentrations could be greatly affected by the farm of origin (Lundstrom *et al.*, 1988) and various possible reasons have been investigated. Dietary effects were implicated because skatole is produced by microbial degradation from tryptophan in the hind gut of the pig. However, studies have shown no correlation between skatole in faeces and fat tissues (Hansen *et al.*, 1992) and voluntary caprophagy did not significantly affect skatole levels in Irish work (Hawe and Walker, 1991).

In Danish work, the feeding of very high levels of peas to pigs (45%) increased skatole levels from 0.09 mg/kg to 0.12 mg/kg on average (Madsen *et al.*, 1990). This was associated with a reduction in the pork flavour score given by taste panellists and a significant reduction in overall acceptability. At the average value of 0.12 mg/kg, a higher proportion of pigs fed peas would have exceeded the 0.25 mg/kg level, suggested by Mortensen *et al.* (1986), as the threshold above which consumers may detect taints.

Other work has implicated dietary fibre as a factor in increased tissue deposition of skatole because of the increased hind gut fermentation which occurs (Hawe *et al.*, 1992). The type of fibre is important and in a study involving workers from Reading and Bristol, levels of molassed sugar beet feed increasing to 30% of the diet, reduced skatole concentrations and increased the overall acceptability score (Wood *et al.*, 1993a). It is not clear how this effect occurred but presumably reduced tryptophan breakdown by bacteria or reduced absorption of skatole from the gut are implicated (Moss *et al.*, 1992).

Recent Danish work has suggested that a large part of the 'farm' effect on skatole concentrations is due to differences in stocking density and faecal contamination (Hansen *et al.*, 1992). Pigs stocked at a high density, whose pens were deliberately kept soiled, had higher concentrations than those stocked less densely in clean pens (Table 10). It is clear from these that a high proportion of pigs in most of the eight groups would have had skatole concentrations above the 0.25 mg/kg

threshold level. Only 3% of entire males had values higher than this in UK studies (Patterson *et al.*, 1990).

Table 10. Effects of stocking rate and faecal contamination on skatole concentration in backfat (spectrophotometric method)[1]

	Skatole (mg/kg)	
	Males	Females
Summer experiment >22°C		
0.6m²/pig, dirty	0.26	0.17
>1.2m²/pig, clean	0.14	0.10
Winter experiment 17°C		
0.6m²/pig, dirty	0.13	0.11
1.2m²/pig, clean	0.08	0.06

[1]Hansen *et al.* (1992).

Vitamin E

Vitamin E is a natural antioxidant and recent work has shown that high levels (200 IU/kg) fed to the pig will reduce the oxidative breakdown of polyunsaturated fatty acids post-mortem (Asghar *et al.*, 1991; Monahan *et al.*, 1992). As shown in the section on dietary oils, this oxidation is a major reason for the undesirable flavour of pig meat high in unsaturated fatty acids.

High levels of vitamin E have also been shown to increase the colour stability and reduce the drip loss from meat. Both these effects are apparently also due to the antioxidant properties of the vitamin (Asghar *et al.*, 1991).

Beta-adrenergic agonists

These feed additives, which mimic the effects of the catecholamine hormones, cause a repartitioning of absorbed nutrients, so that increased lean and reduced fat deposition occurs. However, there are many other effects on the animal, some detrimental to meat quality. In the study described in Table 11, the feeding of the beta-adrenergic agonist, salbutamol, at 3 mg/kg in the diet between 21 and 85kg live weight, reduced P_2 fat thickness by 17%. However, toughness in the major loin muscle *m. longissimus* was increased by 22%. This was associated with changes suggestive of an increase in the proportion of white glycolytic fibres in the muscle ie; haem pigments and colour saturation decreased. The increase in ultimate pH in *m. adductor*, a redder muscle than *longissimus*, was more marked. The causes of the extra toughness of muscles from pigs treated with beta-adrenergic agonists is not clear. There are several suggestions including the shift in muscle fibre types, a reduction in marbling fat, an increase in the proportion of insoluble (heat stable) collagen and a reduced activity of the calpain proteolytic enzyme system, which is responsible for the 'conditioning' effect on tenderness (Wood, 1991).

Feeding level

Results collected in MLC's First Stotfold Trial showed that feeding pigs *ad libitum* rather than at 80% of that level produced more tender meat (Table 12). Subsequent analysis showed that the increased marbling fat concentration was not solely responsible for this increase, the important factor being the increased muscle deposition rate (Warkup and Kempster, 1991). It was suggested that this would have activated the calpain enzyme system to increase post-mortem tenderisation, an effect opposite to that of beta-adrenergic agonists. So far there is no direct evidence that growth rate up to slaughter increases the rate of proteolytic breakdown post-mortem, although other workers have observed a beneficial effect of growth rate on tenderness

(Mottram *et al.*, 1982; Ellis *et al.*, 1990).

Table 11. Effects of the beta-adrenergic agonist salbutamol (Sal, 3 mg/kg in the feed between 32 and 85 kg live weight) on meat quality in pigs[1]

	Control	Sal	Sign.[2]
P_2 fat thickness (mm)	10.5	8.7	***
Ultimate pH in LD[3]	5.52	5.56	**
Ultimate pH in AD[4]	5.76	5.93	***
Lightness[5]	56.1	56.9	NS
Saturation[5]	7.5	5.5	***
Toughness (kg)[5]	4.11	5.04	***
Collagen[5]	3.8	3.3	***
Marbling fat[5]	8.1	8.6	NS
Glycogen[5]	5.4	4.6	NS
Haem pigments[5]	0.82	0.69	***

[1]Warriss *et al.* (1990). [2]NS, non significant, P>0.05; ** P<0.01; *** P<0.001. [3]LD *m. longissimus dorsi.* [4]AD *m. adductor.* [5]Measurements made in LD. All concentrations in mg/g. Glycogen measured 15 min after slaughter, all others at 24 hours.

Table 12. Effects of feed intake on growth and fresh meat quality in pigs[1]

	Ad libitum	Restricted	Sign.[2]
Average daily gain (g)[3]	827	681	*
P_2 fat thickness (mm)	12.8	10.9	*
Marbling fat (%)	0.85	0.75	*
Taste panel scores[4]			
Tenderness	5.2	4.7	*
Juiciness	4.4	4.2	*
Pork flavour intensity	4.5	4.6	NS
Pork odour intensity	3.8	3.7	NS
Abnormal odour intensity	3.6	3.5	NS

[1]Meat and Livestock Commission (1989). [2]NS, non significant, P>0.05; *P<0.05. [3]30 - 80 kg live weight. [4]1 - 8 scores increasing in intensity.

Pre-slaughter and slaughter effects

There is much anecdotal evidence and increasing scientific evidence that the way pigs are handled between the farm and processing plant and in the plant itself has important implications for animal welfare. These same factors affect the incidences of PSE and DFD meat and therefore are also important for meat quality. Pale soft exudative (PSE) meat has been shown to be tougher and drier than normal (Bejerholm, 1984), perhaps because of a lower bound water content, and ultimate pH affects tenderness in a curvilinear fashion, increasing it at low (5.4) and high (7.0) values and reducing it at intermediate values (5.8 - 6.0) (Dransfield *et al.*, 1985).

Danish research has shown important differences in tenderness between abattoirs, associated with different pre-slaughter stunning and processing conditions (Barton-Gade, 1984; Barton-Gade *et al.*, 1987). In the 1984 study, stress resistant genotypes (NN) had a PSE incidence of 0, 8 and 33% in three abattoirs. Heterozygotes for the halothane gene (Nn), however, had PSE incidences of 13, 17 and 33% in the same abattoirs. This is further evidence for a significant, intermediate level of meat quality problems in Nn and suggests important interactions between genotype and

abattoir so far as the level of PSE is concerned.

Processing effects

The most important processing effects concern the way the carcass is chilled and the period of conditioning (ageing).

Chilling, electrical stimulation and pelvic suspension of the carcass

It has been recognised relatively recently, that muscle from pigs with slower rates of glycolysis can suffer from cold shortening toughness, in the same way as beef or lamb (Dransfield and Lockyer, 1985). The effect occurs if the muscle temperature falls below about 10°C within 3 h of slaughter (Dransfield and Lockyer, 1985) whilst sufficient energy reserves are present to induce contraction (indicated by a pH ≥ 6.0).

Rapid chilling is done to reduce evaporative weight loss in the carcass and two approaches are available to allow this whilst avoiding the toughness disadvantage. These are electrical stimulation and pelvic suspension. There is evidence that both will also increase tenderness under normal chilling conditions. Electrical stimulation protects against cold shortening by depleting energy reserves so that severe contraction cannot occur. Pelvic (hip or aitch bone) suspension, on the other hand, achieves the objective by stretching susceptible muscles such as *m. longissimus*.

In a recent trial, eighty pigs (equal numbers of entire males and females) were used to investigate the effects of rapid chilling, electrical stimulation and pelvic carcass suspension on various aspects of meat quality (Taylor *et al.*, 1992). Rapid chilling was at -20°C and continued until the 'deep' *longissimus* temperature reached 10°C (about 3.5 h). Conventionally chilled sides were held at 1°C for 24 h, the storage temperature for rapidly chilled sides following blast freezing. The electrical stimulation parameters were: 700 volts, 12.5 pulses/sec for 90 secs applied 20 min post slaughter. Pelvic suspended sides were also hung for 24 h, from a hook inserted through the *obturator foramen*.

The results (Table 13) show that rapid chilling had little effect on pH fall or drip loss, but reduced the tenderness score. Electrical stimulation increased tenderness in achilles-suspended sides and pelvic suspension was superior to achilles suspension. In this study, both electrical stimulation and pelvic suspension improved tenderness under both chilling regimes (this has not always been the case in other published research eg; see Taylor and Tantikov, 1992) and were particularly important in maintaining tenderness during rapid chilling. Rapid chilling reduced carcass evaporative weight loss by 0.5% on average, in this study, and tended to reduce the drip losses otherwise associated with electrical stimulation. It is therefore apparent that rapid chilling and electrical stimulation are mutually beneficial and should not be used independently in pigs.

Table 13. Effects of chilling rate, electrical stimulation (ES) and suspension method (A, achilles; P, pelvic) on tenderness of pork. Ten pigs in each group (68kg carcass weight)[1]

		A	A-ES	P	P-ES
pH 3h	slow	6.2^{b}	5.7^{a}	6.1^{b}	5.7^{a}
	rapid	6.2^{b}	5.8^{a}	6.2^{b}	5.7^{a}
Drip loss (%)	slow	2.0^{a}	3.5^{ab}	2.1^{a}	4.0^{b}
	rapid	2.3^{ab}	2.8^{ab}	1.7^{a}	3.3^{b}
Tenderness (1 - 8)	slow	3.9^{a}	4.4^{b}	5.1^{c}	4.7^{bc}
	rapid	3.6^{a}	4.1^{bc}	4.0^{b}	4.5^{c}

[1]Taylor *et al.* (1992b). Within rows, means with different superscripts differ ($P<0.05$). For details on treatments see text.

Conditioning

During conditioning, proteolytic enzymes act to break down the myofibrillar structure of muscle and thereby tenderise meat. The extent of the increase in tenderness is greater for lamb and beef than for pork (Koohmaraie *et al.*, 1991) but, nevertheless, is highly significant for pork, as the results in Table 14 show. Pork loin steaks were taken from both sides of six carcasses and stored at 1°C in vacuum packs for either 1 or 24 days. Tenderness was the single aspect of eating quality affected, and the increase (1.2 units on the 1 - 8 scale) is large in comparison with other factors which influence tenderness.

Table 14. Changes in taste panel scores for eating quality between 1 and 24 days conditioning at 1°C in pork loin steaks[1]

	Conditioning period (d)		Sign.[2]
	1	24	
Tenderness	4.07	5.21	***
Juiciness	3.76	3.57	NS
Pork flavour	3.48	3.83	NS
Abnormal flavour	3.56	3.46	NS
Overall liking	3.23	3.53	NS

[1]Wood, Savage, Nute and Richardson (unpublished). Ten trained taste panellists used 1 - 8 scores. [2]NS, non significant, $P>0.05$; *** $P<0.001$.

Enzyme studies show that both the cathepsin and calpain systems are involved in proteolytic breakdown. However, the calpain system seems particularly important and of its component parts, the activity of the protease inhibitor enzyme seems most significant (Koohmaraie *et al.*, 1991). This same enzyme is the one most likely to be affected by changes in production factors eg; growth rate and the feeding of beta-adrenergic agonists (Koohmaraie, 1992).

Blueprints for improved eating quality and quality assurance schemes

Recent research coordinated in the UK by MLC has aimed to provide the pig industry with a Blueprint by which it can improve quality. Research has studied the reasons for variation in eating quality parameters, and provided possible solutions, which can be applied on farms and during processing (Warkup, 1993). So far the MLC Blueprint approach has focused on tenderness and suggested several ways this can be improved, as described in this chapter and summarised in Table 15. At this stage of the program, electrical stimulation is not included because more work is needed to develop this into a workable system in pig plants. Also, pelvic suspension is only recommended for improving the tenderness of leg muscles, whereas recent work shows that the loin is also improved under the slow chilling conditions recommended in the Blueprint (Table 15). The intention is that these guidelines are updated as more information becomes available.

The results available so far suggest that the effects of various Blueprint factors are additive, perhaps because they act on different mechanisms. Results collected by MLC show that the application of the Blueprint significantly improves tenderness over the standard retail pork product (Warkup, 1993).

In the UK, at the present time, a number of 'Farm Assurance' and 'Quality Assurance' schemes for pigs are in operation. In general, the former specify certain standards of welfare, husbandry and feed composition on farms and the latter include some or all of the factors included in the Blueprint program (Table 15). Additional factors such as microbiological quality are also included. The schemes usually involve detailed agreements between producer groups, processors and retailers. Usually feed

and breeding stock are provided by particular companies. Surveillance and monitoring are provided in different ways but must be sufficient to allow 'total quality management' throughout the chain from farm to retail pack.

Table 15. Ways to improve tenderness as specified in MLCs 'Blueprint for Lean and Tender Pork'[1]

Ad libitum feeding from 30 kg live weight
50 - 75% Duroc genes in slaughter progeny[2]
≥ 8 mm P_2 fat thickness
Careful live animal handling and stunning
No PSE
Deep muscle temperature not to fall below 10°C within 3 h of slaughter
Pelvic suspension of sides where legs to be sold as fresh pork
7 - 12 days conditioning depending on product

[1]Meat and Livestock Commission (1992b). [2]Premium product only.

Conclusions

The last few years have seen a major increase in our knowledge of the underlying factors controlling pig meat quality. The first steps towards controlling quality in a meaningful industry-wide fashion have also been made in the UK.

The meat quality improvements described here which result from changes in production and processing practices will invariably add to costs. The use of more Duroc genes or *ad libitum* feeding systems for example, lead to fatter carcasses and less efficient feed use. For the producer to use these new procedures he will expect a higher return in the same way that leaner carcasses receive a higher price per kg than fatter ones. This is an area of intense debate at present involving producers, processors and retailers. Science can help by defining meat quality in objective terms and developing systems which measure the level of quality in each carcass.

FROM FARM TO FACTORY - MEASURING AND MAXIMISING VALUE

D.M. Ferguson and S.V. Myler

CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.

Introduction

Although the operations of a pig producer and pig meat processor are vastly different, they do share one common goal - to efficiently produce as much pig meat with the desired quality as possible. Both are keenly aware of the fact that profitability is directly linked to the degree of success in achieving this goal. Accurate knowledge of what quality characteristics are required by consumers, and being able to objectively quantify them, both on-farm and in the abattoir, are two key elements which influence the degree of success.

The first of these elements has already been dealt with during the course of this Symposium. In this paper, we address how some of these characteristics can be measured in both environments.

Slaughter weight

The weight of a pig at slaughter, not only affects the gross value of its carcass, but also significantly influences total net revenue on-farm and in the abattoir. A study by Whan and Cook (1991) has shown that there is an inverse relationship between slaughter weight and on-farm production and abattoir slaughtering costs. Whilst the maxim, 'big is best' might be desirable from the perspective of production efficiency, there is a downside with respect to meat quality and acceptability. Most notably, larger, heavier carcasses will cool slower and this increases the likelihood of PSE (Pale Soft Exudative) occurring in some muscles of the carcass. The production of heavier entire males will increase the incidence of problems associated with boar odour. Moreover, there is anecdotal evidence that large carcasses present problems with the size of their primal cuts, particularly with middles. Some processors have been critical of large middles because they are often too big for conventional bacon slicing equipment.

Of course, these problems can be minimised by setting limits with respect to carcass weight and imposing price discounts for heavy pigs. However, it is important to be cognisant of the inter-relationships between weight and attributes pertaining to overall quality.

Within the context of this section, it is worthwhile briefly discussing the relative merits of dressing percentage as an index of the quantity of pig meat entering the abattoir. Traditionally, producers have placed considerable value on dressing percentage, in the belief that it was strongly correlated with carcass weight. Unfortunately, in the majority of cases, this is a popular misconception. In general, dressing percentage is an unreliable index of final carcass weight, primarily because it is significantly influenced by several factors. Most notable amongst these include: gut-fill; fatness of the pig; time between farm gate and slaughter; prevailing environmental conditions during transport and lairage; availability of water in lairage and degree of interaction between unfamiliar consignments of pigs. For example, Warriss (1982) and Mayes *et al.* (1988) have shown that pigs fasted for 24 hours will lose between 5 - 6 % of their live weight, but will only be 0.5 - 0.6 kg lighter in carcass weight, compared to similar weight pigs only fasted for 1 hour prior to slaughter. This resulted in a significant difference in mean dressing percentage (1.2 - 2.3 %) between the two groups of pigs. Even between pigs, grown contemporaneously in the same piggery and slaughtered on the same day, dressing percentage can vary by as much as 8% (Ball, 1992).

Carcass composition

Consumers are now far more conscious of the link between diet and health. Consequently, there is a clear preference for less fat in the meat they consume (Kingston *et al.*, 1987; Australia Pork Corporation, 1990; Woodward and Wheelock, 1990). Knowledge of the proportions of fat and lean is therefore essential when determining the breeding potential of an animal, or market value of slaughter stock and their carcasses. Excellent reviews on this subject are given by Kempster *et al.* (1982), Allen (1990) and Fisher (1990).

Traditionally, the simple measurement of backfat depth over the *M. longissimus* in the vicinity of the last ribs has been the most useful index of pig carcass composition. On-farm, this measurement is easily and accurately obtained using pulse-echo ultrasound devices. In the abattoir, backfat depth is measured using the introscope, or the more operationally efficient light reflectance probes (eg; Hennessy Grading Probe - HGP and Fat-O-Meter - FOM). Probes such as the HGP and FOM

utilise the difference in optical properties between tissues to obtain measurements of backfat and also *M. longissimus* depth.

The utilitarian value of backfat measurements is exemplified by the fact that these measurements have been an integral part of carcass classification schemes since the early seventies. Over the last five years, research has centred on quantifying the relationships between combinations of the backfat measurements and others, such as carcass weight and *M. longissimus* depth, with the percentage lean in the carcass. Much of the European work was necessitated by the European Communities decision (EC regulation 3220/84, 1984) to introduce a new pig carcass grading scheme, based on objective estimation of lean percentage, in January, 1989. Measurement techniques were approved for use under this scheme, if they achieved the statistical tolerances of a coefficient of determination (R^2) greater than 0.64, and a standard error of estimate less than 2.50%, over a sample of 120 carcasses representative of the slaughter population. The results of these studies for each member country were reviewed by Walstra (1989) and subsequently updated by Fisher (1990).

Similar studies have been conducted in Sweden (Hansson and Andersson, 1984), Canada (Usbourne *et al.*, 1987) and Australia (Ferguson, 1989; Ferguson *et al.*, 1993). Prediction equations, developed from these studies, are now utilised in commercial abattoirs in each of the countries listed.

Most of the prediction equations in use are based on more than just a single measure of backfat depth. The majority of the countries grading pigs on this basis, utilise equations which comprise of probe measurements taken at two sites on the carcass. The high slaughter rates (> 300/h) in European abattoirs generally preclude the recording of more measurements. At these sites, two fat depths and one measurement of *M. longissimus* depth, are typically recorded.

There is widespread agreement (eg; Kempster *et al.*, 1982; Cook *et al.*, 1989; Ferguson, 1989) that the improvement in predictive accuracy following the addition of a second fat depth and/or *M. longissimus* depth measurement is small. However, measurements of *M. longissimus* depth have been shown to account for advantages in lean percentage at constant fat thickness of pigs with 'blocky' conformation. Hansson and Andersson (1984) showed that at the same fat thickness, carcasses from Hampshire crossbreds had 1.2% more carcass lean and the thickness of the *M. longissimus* was 8.4% greater than carcasses from 'White' breeds. Consequently, predictions based on fat depth alone underestimated the percentage muscle in Hampshire crossbred carcasses. By including muscle depth in the equation, the degree of underestimation was reduced. In contrast, Wood and Robinson (1989) did not confirm this in their study on the prediction of lean content in Large White and Pietrain pigs. Lean content in Pietrain carcasses, known for their superior conformation, was still underestimated by the combination of fat and muscle depth. The work of Branscheid *et al.* (1989) also highlights the problem of predicting lean percentage from FOM measurements of fat and muscle depth in the samples diverse in genotype (Pietrains versus standard 'white' breeds). Despite this evidence, there are no breed specific equations in use, although some countries like the Netherlands also assess conformation as part of their carcass classification system. In Australia, Ferguson (1989) established that there was no genotype bias for the prediction of lean percent, however, there appears to be growing commercial emphasis on the use of the so called 'meatier' genotypes. The impact of these genotypes on the accuracy of commercial prediction equations and, more importantly, meat quality, will warrant research attention in the near future. Genotypes like the Pietrain may offer advantages in lean content, but they also have a well documented history of stress susceptibility and increased predisposition to PSE meat (Brandt, 1991).

By far the greatest debate surrounding the optimal number of measurements for the prediction of pig carcass composition has been stimulated by the development of the Danish Pig Classification Centre (CC). The CC is a fully automated system, which consists of a number of measurement and treatment stations. Full details of the operation of the CC are given by Nielsen and Verwohlt (1989). In the initial version of

the CC, seventeen probes recorded the following measurements on the left side: five fat depths in the hind leg, three fat and three muscle depths in the loin; five fat and five total tissue depths in the belly and four fat depths in the shoulder. An on-board computing system combines thirteen of these measurements with carcass weight to predict lean percentage in the carcass and major primal cuts. In a later development of the CC, the number of probes was reduced to fifteen, and later still to nine through the introduction of neural networks, a form of artificial intelligence controlling measurement quality (Verwohlt and Thrane, 1991).

The results of Luthje *et al.* (1988) help to place some perspective on the predictive advantage of the CC. In a comparison between the CC and a manually operated probe (two sites), the accuracy of the CC (Standard error of estimate [SEE] = 1.63) was moderately better than that provided by probe (SEE = 1.80) for the prediction of lean percentage. However, the CC showed a distinct advantage in accuracy when predicting the lean content in the primal cuts. Although this advantage has been questioned by Dutch workers (Hulsegge *et al.*, 1992). The additional predictive accuracy provided by the CC relative to manual techniques must also be offset against its high cost.

In recent years, there has been a growing interest in the use of non-invasive measurement technologies to estimate composition. Examples of these which have application on-farm or in the abattoir include ultrasound, electromagnetic scanning (EMS) and video image analysis (VIA).

Ultrasound techniques

The first use of pulse-echo ultrasound for livestock evaluation was reported in the late fifties (Stouffer *et al.*, 1959). Since then there have been numerous studies (see reviews by Thwaites, 1984; and Allen, 1990) which have demonstrated the accuracy of ultrasound in measuring carcass traits and estimating composition *in vivo*. Moreover, it is widely recognised as the most practical and cost efficient methods presently available for predicting composition in live animals.

In addition to pulse echo ultrasound, a novel technique based on the measurement of velocity of sound (VOS) has also been successfully used to estimate composition in live animals and carcasses. The technique, developed by British workers (Miles and Fursey, 1977; Miles *et al.*, 1984), is based on the principal that ultrasound travels at different speeds through muscle (1600 m/s) and fat (1430 m/s) tissue. Therefore the time required to travel a known distance through biological tissue, will be directly influenced by the proportions of muscle and fat.

Using this technique, the results to date for the prediction of composition in bulls (Porter *et al.*, 1990; Fursey *et al.*, 1991), live sheep (Miles *et al.*, 1991) and beef carcasses (Miles *et al.*, 1987; Ferguson 1991) have confirmed its accuracy and potential. There is no published data regarding the potential of VOS for live pig or pig carcass evaluation, with the exception of the claim by Newman and Wood (1989), that their preliminary results were as good as those shown in beef carcass studies (eg; Miles *et al.*, 1987).

Another recent innovation by the Danish company SFK-Technology is the ULTRA-FOM. This device is marketed as an ultrasound alternative to light reflectance probes for on-line pig carcass measurement of fat and muscle depth. In 1991, the ULTRA-FOM was approved for use in Denmark under the new EC Pig Carcass Grading Scheme and is currently being assessed for use in England.

Electromagnetic scanning

Electromagnetic scanning (EMS) is based on the principle that muscle is approximately twenty times more conductive than fat tissue, because of its higher water and electrolyte content. When a conductive object such as a carcass is placed in an alternating electromagnetic field, currents will be induced in the carcass causing a loss in energy from the field. The energy absorbed by the carcass is proportional to the quantity and composition of the fat-free mass (ie; muscle).

The original form of the technology, known as the EMME (Electronic Meat Measuring Equipment), was developed around 20 years ago for estimating composition in live pigs. Poor results and variable performance led Mersmann *et al.* (1984) to conclude that the device was of little value for live pig evaluation. Significant improvements to the sensor system were made, and the technology evolved to its present forms, such as the MQ-25, which is now successfully used in boning rooms to monitor the chemical lean content of boxed beef on-line.

Research investigating the ability of EMS to estimate pig carcass composition has been conducted in the United States (Kuei *et al.*, 1989; Forrest *et al.*, 1991) and Australia (Rowland *et al.*, 1991). The results reveal that EMS has a small predictive advantage, relative to the accuracy provided by the combination of standard carcass measurements (eg; carcass weight, probe fat depth and eye-muscle dimensions), for the prediction of lean content (Table 1). However, given that EMS is a process which can be automated, the consistency with which the accuracy is maintained is likely to be higher compared to manual operator dependent probe-based techniques.

Rowland *et al.* (1991) also investigated the operational aspects relevant to the on-line use of EMS and demonstrated that it was applicable for commercial pig carcass evaluation. However, the commercial installation of EMS was costly, estimated by them to be in the order of $350,000 - 400,000. On-line trials of the technology are now being conducted in a commercial pig abattoir in the United States.

Video Image Analysis

In simple terms, video image analysis (VIA) provides rapid and objective means of measuring visual carcass traits. The basic principal of VIA involves firstly digitising the image from a standard video camera into a numerical array of signals which differ in voltage, reflecting the difference in light intensity (Fisher, 1990). The digital representation of the image is then stored in computer memory as an x-y array and reconstructed. Measurements of carcass dimensions and fat distribution are then obtained by applying appropriate software. VIA has been investigated primarily for its application in beef carcass classification, particularly in the United States (Cross *et al.*, 1983), Denmark (Sorensen, 1988) and Australia. The Danish research has given rise to a commercial system known as the Beef Classification Centre (BCC), which is based on the combination of VIA and light reflectance probe. Using a British developed VIA system, Newman and Wood (1989) investigated the applicability of VIA for pig carcass evaluation. By measuring the conformation parameters of area, volume and roundness in relation to carcass length, they assessed the ability of VIA to distinguish between two genotypes (Large White and Pietrain), widely divergent in carcass conformation. Their results showed that these parameters were able to partly explain genotype differences in percentage lean at constant fat depth. These results are encouraging, particularly in view of the commercial emphasis on conformation.

Table 1. Prediction of side muscle weight and percentage based on EMS and HGP measurements[1]

Technique	Muscle weight SD = 3.2 kg		Muscle % SE = 4.5%	
	R^2	SEE	R^2	SEE
EMS[2]	0.94	0.82	0.64	2.77
HGP[3]	0.90	1.02	0.64	2.73

[1](Rowland *et al.*, 1989). [2]Best three variable EMS model. [3]Based on the combination of Hennessy Grading Probe fat depth plus carcass weight.

Determination of factors which influence meat quality

There are two conditions which have the most influence on the quality of pork. These conditions are commonly known as PSE and DFD (dark, firm and dry). PSE meat is the result of a rapid fall in muscle pH post slaughter at high muscle temperature. The major economic losses due to PSE occur mainly through increased drip and cure losses in processed products. DFD meat is caused by a depletion of the muscle glycogen reserves, which inhibits the normal post-slaughter reduction in muscle pH. This condition results in reduced shelf life and in severe cases will affect the uptake of cure in the muscle. The incidence of PSE and DFD in Australia has been reported by Trout (1992) to be 30% and 15%, respectively, with an annual cost of $22.7m to the Australian pig industry (Whan, 1993).

The influence of production and processing factors on meat quality

It is widely acknowledged that PSE and DFD are the result of the interaction between the genotype of the animal and combined stimuli, which occur between the farm gate and the abattoir chiller. The genotype of the animal is important as pigs that carry the porcine stress syndrome (PSS), or halothane gene, in either the heterozygous or homozygous halothane positive forms (Nn, nn), are significantly ($P<0.001$) more susceptible to display poorer meat quality than those pigs without these genes (Barton-Gade and Olsen, 1987). Key pre- and post- slaughter factors which influence the manifestation of these conditions include poor transportation, lairage, handling practices, mixing of unfamiliar pigs, inadequate stunning procedures and an extended time between stunning and chilling. A greater appreciation of the influence of all these causative factors is well documented in review papers by Gregory (1987), Honikel (1987), Warriss (1987) and Tarrant (1989).

Methods for detection of PSE and DFD

A variety of technologies and methods have been assessed for their ability to detect PSE and DFD susceptible pigs. On farm, producers can benefit from several available methods which will allow them to screen their herds for the PSS gene. A method commonly used is the halothane test, where animals are exposed to halothane anaesthesia for a short time (eg; Sather and Murray, 1989). This test has proven to be simple and effective for detecting halothane positive (nn) animals, but unfortunately, the test cannot identify carrier animals which are heterozygous for the gene (Nn). A more comprehensive test which enables all PSS genotypes to be detected is DNA analysis of blood samples (Hughes *et al.*, 1992). Although the test is more reliable, it is more expensive to carry out (approximately $A 60 per pig). Another technique used to detect PSE prone animals is the 'shot biopsy' method reported by Cheah and Cheah (1991). Using this method, a 500mg sample of muscle tissue is taken from the live pig. Meat quality is determined by a combination of measurements of water holding capacity (whc), pH and the amount of Ca^{2+} released after incubation of the muscle sample for 45 minutes at 39°C.

There is no real test for DFD meat on farm, as this condition is the result of depleted muscle glycogen reserves, caused by a prolonged pre-slaughter stress. This condition can be avoided by ensuring that animals are not off feed for longer than 24 hours before slaughter, and the mixing of unfamiliar groups of pigs in lairage be kept to a minimum. In an abattoir environment, there are a number of methods used to detect PSE and DFD meat (see Table 2). These range from pH, colour, whc and conductivity measurements to visual assessments. It is difficult to compare results between countries as very few research methods are standardised. It is for this reason that research was undertaken in Australia to develop methods for the assessment of PSE and DFD under Australian conditions.

There are several important criteria to consider when developing assessment

methods for application in commercial environments. Importantly, the method should be accurate, reliable, practical and cost effective.

Probes such as the HGP and FOM, which were developed to measure fat thickness on the slaughter line, have also been successfully used to assess PSE the day after slaughter. These instruments determine the optical properties of meat by measuring internal light reflectance. Another approach is to measure the internal light scatter, which is the principle used in the Fibre Optic Probe (FOP). The FOP was designed specifically for the determination of PSE/DFD and utilises a light source in the near infra-red (900nm) region. This wavelength is considered necessary to minimise the influence of the haem pigments, as they have maximum absorption in the 500-600nm region, but decreasing absorption for wavelengths greater than 650nm (MacDougall, 1984).

Other instruments, like the conductivity probe, have also been shown to reliably detect PSE in a commercial environment (Schmitten *et al.*, 1987). Whilst probes have been used to detect DFD meat, it is universally accepted that ultimate pH is a more reliable indicator of the DFD condition. In the past, measurement of pH in the abattoir has not been practical because of the use of glass electrodes, which could break an contaminate the carcass. However this has been overcome through the advent of more robust stainless steel electrodes (eg; Sensoptic pH meter).

Table 2. Meat quality evaluation methods recommended for use in Australia[1] and in breeding programs in several European countries[2]

	Australia	UK	Germany	Denmark
Timing of measurement				
Day of slaughter		Yes	Yes	
Day after slaughter	Yes		Yes	Yes
Measurements				
pH	Yes	Yes	Yes	Yes
Colour (light)	Scatter	Scatter	Reflect	Reflect
Visual score			Yes	
Conductivity			Yes	
Measurement sites				
Loin muscle	2 sites	Yes	Yes	Yes
Leg muscle	2 muscles	Yes		Yes
Other muscles			Yes	Yes

[1]Trout (1993) - Australia. [2]Kalweit (1987) - UK, Germany, Denmark.

Timing of measurement

For commercial purposes, it would be desirable to measure meat quality on the slaughter line, at the same time that P_2 and carcass weight are recorded. Accurately assessing PSE and DFD at this time, however, has proven to be difficult. The relationships between quality traits such as drip loss, whc and subjective quality scores, to pH and light reflectance/scatter measurements are not constant and change with time post slaughter. This is because, in the early stages of rigor, many of the quality properties have not been fully expressed biochemically or physically (Kauffman, 1991). Post-mortem decline of whc and pH (Barton-Gade, 1981), and post-mortem development of paleness in muscle (Swatland, 1981) is far from being completed at one hour post mortem.

Early post-mortem detection of the PSE/DFD conditions, using the FOP (MacDougall, 1984; Somers *et al.*, 1985 and Oliver *et al.*, 1991), or reflectance probes and pH measurements taken 45 minutes post slaughter (Barton-Gade 1979, 1980, 1986; Swatland, 1986; Van der Wal *et al.*, 1986, 1987; Fortin and Raymond, 1987; Lundstrom

et al., 1987; and Seidler *et al.*, 1987) are not accurate enough to reliably estimate final meat quality. Reflectance values measured the day after slaughter (Lundstrom *et al.*, 1979; Somers *et al.*, 1985; Oliver *et al.*, 1991 and Trout, 1992) are the most reliable indicators of PSE meat. For DFD, pH measurements taken the day after slaughter are most reliable for detecting DFD meat. Recording meat quality measurements the day after slaughter therefore facilitates a more thorough assessment of meat quality.

Measurement site

Knowing where to measure becomes critical when attempting to determine the meat quality status of a carcass. Most European countries measure in the loin and/or leg muscles, with some also measuring other muscles (refer Table 1). In an attempt to more accurately classify the PSE condition, Australian research has shown the need to measure at two sites in the loin (Myler *et al.*, 1993) and in two leg muscles (*M. semimembranosus* and *M. biceps femoris* - Myler and Trout, 1993). The number of sites chosen were necessary to explain the high degree of meat quality variation that exists between muscles and within muscle of PSE carcasses.

Measuring quality objectively using FOP measurements at these sites, has lead to the development of a system where the expected economic losses (e.g. drip and cure) from a PSE carcass can be estimated. This functional relationship not only provides information to the processor regarding processing quality, but will ultimately provide feedback on meat quality to the producer.

Conclusion

Since the late seventies, carcass weight and fat depth have been the primary determinants of the price paid to the producer. The response by the pig industry to these price signals has been quite dramatic, as evidenced by the increase in average carcass lean content over the period, estimated to be in the order of 8 - 10 % (Ferguson and Eustace, 1991). Apart from price signals, this improvement in carcass composition has also been facilitated through the use of measurement technologies, like ultrasound on-farm, and the introscope and light reflectance probes in the abattoir. It is reasonably clear that in terms of accuracy, cost and practicability, these technologies will continue to serve the industry well at least over the next five years.

In the development of techniques capable of more accurate predictions of carcass composition, research attention will focus on non-invasive measurement technologies, with particular emphasis on automating the measurement process. The integration of complimentary aspects of different measurement technologies, such as the combination of light reflectance probes and VIA, will also receive more attention.

In the future, it is paramount that the industry become more aware of the inter-relationships between the various characteristics which affect overall quality. New breeding practices, such as the exploitation of the halothane gene for increased lean production, or placing too much emphasis on one particular carcass trait (e.g. increased carcass weight) might provide benefits in the short term but could also lead to major problems with meat quality. To prevent this it will be necessary to target meat quality as a breeding goal. This will firstly involve continued control, and preferably elimination, of the halothane gene in breeding herds and secondly monitoring meat quality in the abattoir.

In the immediate future, the FOP and pH measurements have been recommended for use in Australian abattoirs. Application of these techniques will ensure that the increased emphasis on the production of leaner pigs is balanced by objective information on meat quality, thus ensuring the value of our product is maximised.

BOAR ODOUR: IS IT A PROBLEM FOR AUSTRALIAN CONSUMERS?

D.P. Hennessy and S.S. Wan

Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.

Introduction

Entire male pigs have a higher return to pig producers compared to castrates, due primarily to a higher lean-meat content, lower feed requirement and a higher growth rate. The higher lean-meat content in carcasses means that consumers can buy leaner pork and bacon. Castration is also a significant animal welfare issue, which needs to be addressed. However, meat from a small, but significant, percentage (10-15%) of entire males will produce an unpleasant odour during cooking; this odour is often referred to as boar odour or boar taint.

The concerns over animal welfare aspects of castration, and the production advantages of entire males over castrates, are driving many countries to look for alternative methods to surgical castration. The majority of the world's pig producing nations currently castrate male pigs as a method of ensuring an 'odour-free' carcass.

Australia's pig industry moved away from castration of males approximately 20 years ago. The main reasons for this move being the production benefits associated with entire male pigs and the fact that, at the time, it was believed that because of the relatively light weights at which pigs were slaughtered in Australia, the domestic consumer would not discern a problem with 'boar odour'. While many Australians consumers do not find 'boar odour' objectionable, it appears from anecdotal observations that most of the Asian populations, both here and overseas, are discriminate against pork with 'boar odour'.

Because of this problem with boar taint, in recent years there has been an increase in the local demand for 'odour-free' meat by butchers supplying the growing local Asian markets. To this end, many of these butchers will not buy meat from entire boars, because of a fear of complaints from their customers. The demand for 'odour-free' meat has also been increased by the increasing push to export pig meat to Asian countries.

Because of the points outlined above and the progressive increase in slaughter weight of entire males over the last 20 years, 'boar odour' is becoming a significant problem to the Australian pig industry.

Consumer perception of boar odour - What causes it?

Boar odour presents as a distinct unpleasant perspiration, or urine-like smell, when fat or meat from entire mature boars is cooked. This unpleasant odour is usually not detected in meat from either castrated males, sexually immature males or females. In some areas of China, young female pigs are 'castrated' as well as males, in the belief that the gonads of both sexes contribute to an unpleasant taste in the meat (S.H. Zhang, personal communication, 1989).

Not all boar carcasses exhibit boar taint. It is widely accepted that the majority of carcasses from young boars are free of taint when slaughtered at light slaughter weights (50 - 60 kg carcass weight). Furthermore, humans differ in their ability to detect taint. Bonneau *et al.* (1992a) found a poor correlation between objective measures of taint and 'odour score' in 50% of taste panel members. They suggested that this was probably related to the peoples' inability to accurately evaluate odour intensity. Such people probably represent a significant proportion of the general consumer population. Wysocki and Beauchamp (1984) demonstrated a strong genetic link in adult human's perception of androstenone, one of the prime candidates for causing boar odour. Interestingly, only 60% of females and 30% of males could detect an odour, even at high androstenone concentrations.

Given that boar odour exists in some carcasses and can be detected by some consumers, a common approach to eliminate boar odour has been to post-natally castrate male piglets. However, this approach has considerable economic and animal welfare disadvantages. The existence of boar odour has deterred many countries from moving to the production of entire boar meat, although there are greater economic advantages in raising entire boars than castrated male pigs.

Compounds contributing to boar odour

Androstenone

There are two major compounds which have been suggested to be responsible for causing boar odour. The first is the gonadal steroid, 5α-androst-16-en-3-one, or 5α-androstenone (a C_{19}-δ^{16}-steroid), which has been described as having an intense urine-like odour (Patterson, 1968). Marked differences in the carcass level of 5α-androstenone have been reported between castrate males, entire females and entire boars (Schilt *et al.*, 1989), the level in entire males being significantly higher than in castrates or females. Biosynthesis of 5α-androstenone occurs in the Leydig cells of the testes (Brooks and Pearson, 1986) from the precursor molecule, pregnenolone (Kwan *et al.*, 1985). Androstenone is released into the systemic circulation where it is taken up by the salivary glands and adipose tissue.

Storage of androstenone in fat appears to be reversible. Although fat androstenone concentrations decrease following castration, the rate of decrease is rather slow and variable between animals, and does not depend on the rate of 5α-androstenone release from fat to plasma, but is more dependent on the intensity of plasma 5α-androstenone catabolism and elimination (Bonneau *et al.*, 1982). This observation is consistent with the surge in 5α-androstenone production at puberty, which is quickly followed by an increase of fat 5α-androstenone in boars, and the decrease in fat 5α-androstenone levels after castration. Following physical castration of mature boars, the level of 5α-androstenone in peripheral plasma dropped within four days to levels found in female pigs (Andresen, 1975). The apparent half life of fat androstenone was estimated at between 4-14 days (Bonneau *et al.*, 1982).

Plasma 5α-androstenone and the deposition of 5α-androstenone in fatty tissues increased sharply from puberty onwards and was closely related to plasma testosterone concentrations (Andresen, 1976; Louveau *et al.*, 1991). The main function of 5α-androstenone is as a precursor for the production of 5α-androst-16-en-3α-ol and 5α androst-16-en-3β-ol, ie; androstenols, in the salivary glands (Booth *et al.*, 1986). It is suggested that these androstenols and androstenone play physiological roles as pheromones (Booth, 1987). It is known that mature boars, in the presence of oestrous females and unfamiliar boars, produce copious amounts of saliva. The purpose of the salivation is to provide a medium for the release of large amounts of androst-16-ene compounds, which acts as cues to facilitate the mating stance in oestrous females (Booth, 1987). Data from Brennan *et al.* (1986) showed that the androstenols, as well as androstenone, made a significant contribution to the boar odour problem.

The major factors affecting the level of androstenone in fat are the degree of sexual maturity, body weight and genotype. A significant proportion of entire boars do not exhibit an increase in fat androstenone with age, even though fully sexually mature (Bonneau, 1990). This lack of increase may be related to a genetic inability to synthesise androstenone in the testes.

Skatole

The other chemical suggested to be a major contributor to boar odour is skatole (3-methyl-indole). Skatole is formed from the biochemical breakdown of tryptophan by intestinal micro-organisms (Hengemuehle and Yokoyama, 1990), found in the colon (Wilkins, 1990). Skatole is produced in the gut of both sexes. The mechanisms underlying the uptake of skatole into fatty tissues are not well defined and, therefore, its physiological role is not fully understood. Skatole levels are generally higher in the

back-fat of boars than in castrates or gilts (Bonneau *et al.*, 1991). However, the reasons why entire male pigs have significantly higher concentrations of skatole in body tissues, in amounts that cause odour problems, are largely unknown. Testicular steroids have been suggested to be responsible for the uptake of skatole, since entire boars have the highest concentrations of skatole. The differences in skatole level between intact males, castrates and females could be possibly due to influence of hormones on the bacterial production of skatole. The gut micro-flora probably does not differ between sexes, but the differing hormonal patterns might affect the absorption or production of skatole.

It has been suggested that skatole and 5α-androstenone may have synergistic effects. Skatole has been shown to enhance the sensory perception of 5α-androstenone by humans (Lundstrom *et al.*, 1980). Unpleasant odours associated with androstenone can be intensified when high skatole levels are found simultaneously (Bonneau, 1982). One possible suggestion is that 5α-androstenone acts as a carrier molecule for the deposition of skatole in fatty tissues (Singh *et al.*, 1988).

Skatole versus androstenone - Which is the culprit?

The debate over which of these two compounds is the major causative agent is largely unsettled. Some studies claim a higher contribution from skatole, while others claim the fat androstenone level was the more important determinant of boar odour.

Since Squires *et al.* (1992) could not find a significant correlation between levels of skatole in the fat of intact male pigs and the age and live-weight of the animal, the authors suggested that androstenone was a better indicator than skatole. Bonneau *et al.* (1992a) reported a higher correlation between androstenone in fat and odour (r^2=0.68), as assessed by a taste panel, than for skatole and odour (r^2=0.38). This correlation with skatole was substantially lower than that reported by Mortensen (1989) of 0.63, or by Mortensen and Sorensen (1984) of 0.73. Lundstrom *et al.* (1988) reported a significant correlation between both skatole (r^2=0.65) and androstenone (r^2=0.53) and boar odour. In contrast, Judge *et al.* (1988) found a poor and non-significant correlation between either skatole or androstenone and taste panel odour scores. However, in this study the odour intensity scores were low compared to the other studies.

Some of the dilemma may be explained by the ages and degree of sexual maturity of boars in the different studies. For example, in the Danish and Swedish studies, where skatole has been found to be more important, the pigs were slaughtered at a relatively light live weight, and, thus, the fat androstenone levels would have been low due to the relative immaturity of the animals. By comparison, the pigs in the French work of Bonneau were slaughtered at a heavier live weight and thus the relative contribution by skatole may have been lower.

Measurement or prediction of boar odour

Boar odour can be measured subjectively by organoleptic tests, such as the soldering iron method described by Jarmoluk *et al.* (1970), and by taste panels (Malmfors and Lundstrom, 1983). Since boar odour is a subjective description of the smell of pig meat when cooked, it can be difficult to objectively measure and define. However, there are a number of analytical methods that will objectively measure the two compounds, which have been suggested to cause boar odour, namely 5α-androstenone and skatole. Techniques included gas chromatography (De Brabander and Verbeke, 1986; Garcia-Regeuiro and Diaz, 1989; and Porter *et al.*, 1989), gas chromatography/mass spectroscopy (Peleran and Bories, 1985; Schilt *et al.*, 1989), high performance liquid chromatography (Garcia-Regueiro *et al.*, 1986; Lin *et al.*, 1990), colorimetric (Mortensen and Sorensen, 1984; Squires, 1990; Squires *et al.*, 1991), radioimmunoassay (Grinwich *et al.*, 1988) and enzyme-linked-immunoassays (Asghar *et al.*, 1988; Claus *et al.*, 1988; Singh *et al.*, 1988). Using such analytical procedures, the threshold level above which taint is likely to be detected in fresh pork has been

suggested to be 0.5 ppm for 5α-androstenone (Bonneau, 1990); and either 0.2 ppm (Bonneau, 1990; Malmfors *et al.*, 1990) or 0.25 ppm (Squires *et al.*, 1992) for skatole.

In support of their belief that skatole is the major causative agent, the Danes have invested large amounts of money in developing a fully automated on-line method for the measurement of skatole. Pending successful evaluation in two abattoirs, the Danes plan to have the on-line screening system installed in all Danish abattoirs by the end of 1993, thus allowing the Danish pig industry to move to all entire-male production (W.K. Jensen, Danish Meat Research Institute, personal communication).

Production factors known to affect boar odour

Genetic effects

It appears that the fat concentration of both skatole and androstenone differs significantly between breeds. There is also evidence that, within breeds, certain strains differ significantly in the fat concentration of these odorous compounds. For example, the incidence of boar taint has been reported to be higher in the Landrace (Rhodes, 1971; Malmfors and Hansson, 1974) than in the Large White or Yorkshire breeds.

Andresen (1976) demonstrated a significantly higher level of 5α-androstenone and testosterone in the peripheral plasma of boars selected for fatness and low growth rate, compared with boars selected for low back fat and a high growth rate. In a review of the genetics of boar odour, Willeke (1993) recently concluded that selection of boars for the elimination of boar odour could be successful by selecting boars on the basis of low fat concentrations of androstenone, thus suggesting that breeding for low boar odour may offer a practical method of reducing or avoiding boar odour.

Housing, husbandry and diet

Research in Europe being lead by the Danish Meat Research Institute and the National Institute of Animal Science in Denmark is directed towards the manipulation of diet and housing as means of controlling boar odour.

The influence of stocking rate and temperature on faeces deposition and its consequence on skatole concentration in subcutaneous fat was investigated by Hansen *et al.* (1992). It was found that pigs which lay in their faeces in pens with a high stocking rate (0.6 m^2/pig), had higher skatole concentration in subcutaneous fat than pigs kept clean in pens, with a low stocking rate (≥1.2 m^2/pig). Furthermore, it was feasible within one week before slaughter to change the skatole level by changing the stocking rate. The skatole level was significantly higher in subcutaneous fat at higher temperatures in summer, compared with winter, despite the fact that the pigs with high stocking rate in winter were as heavily fouled with faeces, as those in summer.

Since skatole is derived from the metabolic breakdown of tryptophan, it is quite possible that dietary protein and/or fibre could influence the level of skatole in fatty tissues. Lundstrom *et al.* (1991) found that only 2.7% of males selected from a line fed a high-protein diet exceeded the threshold value suggested for skatole (≥0.20 ppm), compared with 23.1% of the males from the low-protein diet line. However, Lundstrom *et al.* (1991) found that there was no difference between lines of males and females fed the high-protein diet.

It has been proposed that the concentration of taint in the carcass can be reduced by adjusting the diet prior to slaughter. For example, feeding pigs an energy-rich, low-fibre diet in the last days before slaughter could limit skatole production, by removing foodstuffs that are known to increase fermentation (Judge *et al.*, 1988). Lundstrom *et al.* (1988) found a higher fat skatole concentration in pigs fed a low nutrient density diet, suggesting that such diets may stimulate hind gut fermentation and thus lead to increased tryptophan metabolism. However, Hawe *et al.* (1992) showed that increasing the level of dietary fibre resulted in an increased elimination of skatole in the faeces. It was also shown that the antibiotic, tylosin, decreased the gut concentration of skatole. However, neither treatment altered the fat skatole level. In

contrast to these results, feeding pigs the commonly used antibacterial agent, virginamyacin, has been shown to lead to a marked reduction in fat skatole levels (W.K. Jensen, personal communication). In an experiment to determine a relationship between skatole intake and deposition of skatole in fatty tissues, Hawe *et al.* (1993) found that infusing skatole into the terminal ileum for three days did not significantly affected the skatole concentrations in subcutaneous fat. They reported a low correlation between skatole output in the faeces and the skatole found in fatty tissue.

Brennan *et al.* (1986) reported that boars which were restrictively fed, from 100 kg to 130 kg live weight, were older at slaughter but had a similar or lower concentration of androstenols, 5α-androstenone and odour intensity compared to those fed *ad libitum* to 130 kg. Bonneau *et al.* (1992b) found that daily treatment of lean genotype boars with recombinant porcine somatotrophin, increased the lean:fat ratio and improved the feed conversion efficiency, with a concomitant decrease in fat androstenone concentrations, but not skatole levels.

Practical methods of controlling boar odour

Since fat androstenone and skatole concentrations are largely dependent on body weight and the degree of sexual maturity, one practical method of controlling boar taint would be to slaughter male pigs at a lighter live weight, as occurs in Britain and Denmark. However, slaughtering pigs at lower weights does not allow producers to take full advantage of the growth efficiency of pigs in the 80 - 120 kg live-weight range and increases killing cost, on a per kg basis.

If the majority of the world's pig producing nations are to move away from castration and if Australia is to move towards significant exports of 'odour-free' meat, a reliable method of predicting or controlling boar odour will be required.

Screening

One method of predicting tainted carcasses is to use various techniques to screen carcasses at slaughter. Since the level of 5α-androstenone and skatole deposition in fat appears to be dependent on the degree of sexual maturity, it has been suggested to sort the carcasses according to the fat skatole and/or 5α-androstenone levels. As mentioned earlier, the Danish Meat Research Institute has developed a rapid on-line colorimetric system to measure skatole equivalents in fat of slaughtered pigs. This method provides a rapid result and allows quick classification of carcasses. The Danes believe that this system will enable their industry to move quickly towards all entire male production, without any loss of product quality, due to increased level of odour in carcasses.

However, Bonneau *et al.* (1992a) found that classification by skatole content was not satisfactory for an accurate determination of odour-free pork meat, that had sensory attributes similar to those of castrate meat. A possible explanation for this difference may be the heavier weight at which the pigs were slaughtered, and hence more advanced stage of sexual maturity, in the French situation.

An alternative classification system was suggested by Bonneau and Russeil (1985) who investigated using the size of the boar's accessory sex glands, the Cowper's (bulbo-urethral) glands, as an estimate of boar odour on the slaughter line. From a practical point of view, it was concluded that the measurement of the Cowper's gland length was a useful pre-screening method for a fast systematic indirect assessment of fat 5α-androstenone in abattoirs. The 'presumably-tainted' carcasses could then be assessed by another more precise measurement of 5α-androstenone content.

Surgical castration

As mentioned earlier on of the most common forms of control of boar odour is castration at an early age.

In Australia, male pig are not castrated and are generally slaughtered at around 90 kg live weight. At this weight, entire male pigs are not fully sexually mature,

hence the mechanism of synthesis of androstenone may not yet be fully developed, and fat androstenone may not have risen to odorous levels. A preliminary survey of slaughtered boars at two Victorian abattoirs, showed that almost every boar had relatively high plasma testosterone concentrations and varying degrees of live spermatozoa in the testes. However, androstenone in fat was only detectable (>0.5 ppm) in about 50% of carcasses (Hennessy, Wan and Azuolas, unpublished data).

Surgical castration, while commonly practiced in many countries, has the distinct disadvantages of reduced growth performance and possible animal welfare concerns. Leaving males entire until a few weeks before slaughter is not a practical option for producers. Thus, the industry in general would benefit from an alternative method of blocking testicular function, without affecting growth performance.

Immunisation - steroids

Immunisation of boars against the aspects of the reproductive system, or against the active components thought to be responsible for boar odour, offers the potential for reducing or controlling boar odour. In practice, however, attempts to block the synthesis of boar odour, by immunising boars against 5α-androstenone, have not been effective. For example, Shenoy *et al.* (1982) immunised pigs against 5α-androstenone. Despite high antibody titres to 5α-androstenone in the immunised pigs, they found little or no effect on boar odour. When organoleptic tests were conducted to compare the meat of immunised and control pigs, it was found that strong boar odour was still present in the meat of the immunised pigs. The failure of the antibodies to prevent the deposition of significant and detectable levels of 5α-androstenone in body tissues may indicate that the tissue receptors may have had a stronger affinity for 5α-androstenone than for the antibody binding site (Daniel *et al.*, 1984).

Williamson *et al.* (1985) used 5α-androst-16-ene, coupled to BSA through the 3 position, and 5α-androstenone coupled to BSA through the 11 position, as immunogens to vaccinate young pigs. The androstene immunogen produced significantly higher antibody titres than the androstenone preparation, although antibody titres to both preparations had declined to relatively low levels prior to slaughter. A significant reduction in fat 5α-androstenone concentration, at bacon weight (90 - 95 kg live weight), was observed in pigs immunised with the 5α-androst-16-ene preparation, but not in pigs immunised with the 5α-androstenone conjugate (Williamson *et al.*, 1985). Neither immunogen was successful in suppressing fat androstenone levels when the pigs were slaughtered at the heavier live weight of 115 - 120 kg. These results highlight the importance of using immunogens, which leave the functional groups unaltered, and in using a vaccination schedule which produces peak or high antibody titres in the weeks just prior to slaughter, when plasma and fat androstenone levels are rising.

Immunisation - Luteinizing hormone releasing hormone (LHRH)

An alternative to immunising against 5α-androstenone has been to immunise boars against LHRH, the peptide hormone which largely drives and controls testicular development and function. A reduction of the LHRH concentration in the hypophysis leads to a reduction of both luteinizing hormone (LH) and follicle simulating hormone (FSH) concentrations in the blood. This in turn will prevent or delay the development of the testes in pre-pubertal animals, while in post-pubertal animals, blocking LH and FSH will suppress testicular function and lead to testicular regression. An effective vaccination against LHRH should be able to block testicular function and thus remove the undesirable boar odour, before the pigs are slaughtered.

There have been several reports in the literature demonstrating that vaccination against LHRH can in fact suppress testicular function and reduce taint levels. For example, Caraty and Bonneau (1986) vaccinated boars at approximately 14 weeks of age with LHRH coupled to bovine serum albumin (BSA) emulsified in Freund's complete adjuvant (FCA), or alumina gel. No specific antibodies were detected in pigs

treated with LHRH-BSA in alumina gel. Significant anti-LHRH titres were observed in the boars treated with FCA. In these animals, fat 5α-androstenone levels were reduced to low levels, similar to those observed in surgically castrated males (Caraty and Bonneau, 1986).

Boars actively immunised against LHRH in FCA (at 12, 18 and 20 weeks of age) showed a decline in LH and testosterone, to non-detectable concentrations. Morphometric examination of the testes revealed reductions in percentage volume of Leydig cells/unit testis, seminiferous tubule diameter and epithelial height and an increased interstitial tissue in LHRH-immunised boars, compared with controls. Histologic evaluation showed severe damage of the seminiferous epithelium, absence of spermatids, incomplete cell associations, disruption of Sertoli cells, formation of multi-nucleated giant cells and a striking reduction in the size of the Leydig cells in the LHRH-immunised animals (Awoniyi *et al.*, 1988).

Immunising against LHRH will thus reduce the synthesis of testosterone to low levels. However, this may also reduce the anabolic effects of testosterone on growth performance and carcass composition. Although, if after vaccination, sufficient testosterone was still secreted, it may allow some anabolic action on growth and carcass composition. This was recently demonstrated by Bonneau and Dufour (1992), who immunised boars against LHRH to study growth performance, carcass composition and fat levels of boar-odour compounds. The LHRH immunised pigs were vaccinated at 29 kg and 89 kg and were slaughtered at 105 kg live weight. None of the 20 immunised boars compared with 63% of the untreated boars had fat 5α-androstenone levels higher than 0.5 ppm. Fat skatole concentrations were not affected by vaccination. Growth performance and carcass characteristics were not adversely affected by vaccination (Bonneau and Dufour, 1992). This demonstrates that anti-LHRH immunisation could be very effective in reducing the levels of boar odour, while having a limited consequences on the performance of the animals.

Recent advances in low reactivity adjuvants, and highly immunogenic LHRH preparations, should result in a practical vaccination regime being commercially available to producers, in the near future. Throughout the world there are several research groups working in conjunction with commercial companies towards this aim.

Summary - Future concerns for Australia

Since most of the young male pigs in Australia are slaughtered at approximately 90 kg live weight, boar odour in pig meat does not appear to be of major concern to the domestic Australian pig industry. If the pig industry wishes to increase exports to SE Asia, China or Japan, boar taint is likely to be a growing problem. Similarly, if the local industry wishes to move towards slaughtering at a heavier live weight (to take advantage of the high relative growth efficiency of entire boars) then boar odour could also become a significant problem in the local market for fresh meat. In either case, vaccination of boars against LHRH at an appropriate stage of production, should be effective in controlling boar taint.

It is highly likely, on the basis of current research by several groups throughout the world, that a practical, cheap and effective method of controlling testicular function in boars, by using an anti-LHRH vaccine, will be available in the near future. Since the level of androstenone, skatole and hence boar odour seem to be closely linked with the degree of sexual maturity, these vaccines will most likely be very effective in controlling the development of boar odour. Using these vaccines, at strategic stages of production, will enable the industry to produce entire male carcasses, of any weight, with confidence that they will be 'odour free'.

Another possible option to be considered, if boar taint does become a significant problem, would be for the pig industry to align itself to international standards in fresh pork meat production, that is free from boar odour. This includes on-line measurements of boar odour, that could be installed at abattoirs, so that carcasses that are tainted strongly could be rejected, before the meat reaches the consumer.

IS THE WHOLESOMENESS OF AUSTRALIAN PORK UNDER THREAT FROM RESIDUES AND DISEASES?

I.B. Stephens and F.D. Shaw*

Department of Primary Industries and Energy, Bureau of Resource Sciences, PO Box 778, Brisbane, Qld. 4001. *CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.

Introduction

Residues of chemicals and veterinary drugs in food animal products are of significant public health and consumer concern. In terms of risks to human health, bacterial contamination of food is far more important than chemical residue contamination. However, there is a perception by the public that the reverse is the case. The issue of controlling residues in food continues to be one of the most publicly visible and controversial challenges facing the food industry. Consumers want zero risk, but fail to understand that nothing in this world is risk-free.

Diseases which are transmissible from animals to man are called zoonoses. Many, but not all, cases of food poisoning in humans arising from the consumption of meat or meat products, are caused by organisms that were originally present in the live animal. Examples of zoonoses associated with pigs include the bacterial infections, colibacillosis, listeriosis, salmonellosis, and yersinosis; the protozoal infection, toxoplasmosis and the parasitic infestations, trichinellosis and sparganosis. In many cases, when these diseases occur in humans it has been as a result of the consumption of raw or undercooked meat. Fortunately, in this country, there are few documented instances of human disease related to the consumption of pig meat. The publicity which would follow even one human mortality or one abortion related to the eating of pork could have a dramatic effect on the pig meat industry.

In today's highly discriminating market, the pig meat industry must maintain the confidence of the consuming public in the safety and nutritional quality of its products. There is a shared responsibility between industry and regulatory authorities for the production of safe and wholesome food, of acceptable quality and price, for the domestic and export markets. Producers and processors must be able to produce and market pork, which stands the test of critical consumer and regulatory scrutiny in domestic and export markets. Moreover, if they are to benefit from their substantial investment in capital expenditure and product promotion, then they must implement production programs that produce pork, which meets consumers expectations.

The objective of this paper is to present an overview of residues and zoonotic diseases, and to provide suggestions as to how the industry should manage the threats presented by these problems.

Residues

Types and groups

One definition of residues is 'the presence of undesirable substances left behind in food'. This definition presents difficulties and is not always helpful. Many foods contain naturally occurring carcinogens and mutagens. At the same time, many foods contain naturally occurring anticarcinogens.

Although certain residues have probably always been present in food, the rapid development of analytical techniques for chemical residues over the last 10 years, has meant that more residues have been detected and their potential health hazards been exposed.

Residues in food can be divided into three general groups:

1. *Naturally present* - are those residues which have always been naturally present

in the environment and consist basically of mineral (heavy metals) and biological residues. Natural biogenic residues, such as mycotoxins and phytotoxins, have always been present in foods. Animals in the wild have either been able to avoid these residues or have developed detoxification systems in the body. Modern agricultural practices, and modifications to the microclimate, have lead to outbreaks of poisonings from these residues.

2. *Caused by man* - are those residues which were not naturally present before the intervention of man. These synthetic compounds can produce residues in animals when administered, for example, antibiotics or by accidental contamination, for example, dioxin.

3. *Secondary residues* - include undesirable or desirable substances that are produced during the treatment and further processing of food, or during the preservation of products. The undesirable group includes the nitrosamines, which arise from nitrite and primary amines in meat during curing, and benzopyrenes from smokehouse procedures.

Another method of classifying residues is as follows:

1. *Homobiotics* - these are substances which occur naturally in the target animal, for example, hormones and vitamins. Some synthetic products used for therapeutic, prophylactic or growth promotion purposes, which add to naturally occurring substances are also classified as homobiotics, for example, steroid growth promotants. The criterion for safety is the extent to which the concentration in edible tissue has been raised above normal.

2. *Xenobiotics* - these are substances not naturally present in the target animal, for example, antibiotics and pesticides.

Specific chemical residues

Growth promotants and repartitioning agents

The increasingly well-documented advantages of porcine growth hormone (pGH), (also called porcine somatotropin (pST)), on growth rates and carcass composition will lead to requests for its routine use in pig production. It will be necessary to assure the public that there will be no adverse effects on human health. The fact that pST is a protein, strongly supports the argument that there would be no adverse effects from ingestion of pork containing traces of the compound. However, the Codex Committee on Residues of Veterinary Drugs in Foods noted that issues unrelated to science, were threatening to affect registration of somatotropins in several countries.

Repartitioning agents, of which the beta-adrenergic agonist clenbuterol is one example, owe their name to their ability to direct energy derived from feed towards the synthesis of proteins, particularly in muscles, to the detriment of fat deposition. The important advantage of these substances, compared with anabolic steroids and growth hormones, is the possibility of administering them with feed. They have been shown to promote rapid growth of lean tissue with little (McKeith, 1993), or no, detrimental effect on meat quality (Thornton and Shorthose, 1989). Although not approved for use in pigs, there is a temptation to incorporate them in feeds. There is one overseas report of collective human food poisoning by clenbuterol residues in veal liver. It is claimed that this is one of the first reports of clinical signs in humans associated with the consumption of food containing drug residues (Pulce *et al.*, 1991). It is important to note that the clenbuterol was not used legally in this case.

Organochlorines

The trade difficulties of 1987, caused by the detection of organochlorine residues in Australian beef exported to the USA, resulted in an extensive residue-testing program, which revealed that the pig industry, as well as the beef cattle industry, had residue problems. Piggeries were quarantined because of dieldrin residues, and attempts were made to develop feeding regimes, which reduced dieldrin concentrations in affected animals (Takken and Mawhinney, 1989). By 1991, the prevalence of unacceptable levels of organochlorine residues in pigs was below 0.1%, which was considerably lower than that found in pigs in most other developed countries (Blackman, 1991).

Oxytetracycline and chlortetracycline

Approximately 10% of the pig urine samples collected from slaughtered animals under the National Antibacterial Residue Minimisation (NARM) program gave positive results to the initial screening test (Nicholls and Stephens, 1992). The majority of these residues were due to oxy- and chlor-tetracyclines, which are widely used in the pig industry. Confirmatory tetracycline assays on muscle samples from these animals were mainly below the maximum residue limit (MRL), because of the high urine to tissue concentration ratio. Problems can arise with export of pig meat to the USA, as their MRL for oxytetracycline is 0.1 mg/kg, compared with Australia's 0.25 mg/kg, and with the use of chlortetracycline, which has a low MRL (0.05 mg/kg).

Sulphonamides

The occurrence of sulphonamide (mainly sulphadimidine) residues in pork has been, and currently is, a problem in many pork-producing countries, and Australia is no exception. In 1990, the prevalence in USA of sulphonamide residues (>0.1 mg/kg) in porker livers was 0.8% (Stephens, 1991a), while in Australia in the same year the National Residue Survey (NRS) indicated a prevalence of 3.2%. However, this value has steadily decreased and, for 1992, was 1.7% (Stephens, unpublished data).

Sulphadimidine is highly resistant to degradation during freezing and cooking procedures, and can be present in detectable amounts in processed pork products, including luncheon meat (Ellerbrook and Steffen, 1991) and salami (Trevisani *et al.*, 1991).

Sulphadimidine is registered for use in pig rations, however, it is illegal to feed these rations to pigs within 15 days of slaughter (the withholding period) for human consumption. In one Australian survey (Nicholls *et al.*, 1993), a failure to observe the withholding period accounted for 38% of the residue violations in pigs. Sulphadimidine is commonly incorporated in medicated feeds at 110 mg/kg (ppm). However, Ashworth *et al.* (1986) found that sulphadimidine above 8 mg/kg in the feed gave concentrations in the muscle greater than the MRL (0.1 mg/kg). Feeds containing sulphadimidine are legitimately present in many feed mills and piggeries, and there is the risk of human error causing these to be fed to finishers rather than weaners or growers. Additionally, sulphadimidine, once introduced into an environment, is difficult to eliminate. Tests at one feed mill in Queensland revealed the presence of the compound in dust from ledges and floors. In Northern Ireland, McCaughey *et al.* (1990) found that producers were frequently not aware of any medication having been incorporated in their feedstuffs. In 1988, of 98 non-medicated finisher ration samples from 91 urine sulphonamide positive farms, 20.4% contained more than 1 mg/kg sulphonamides. Within six months, this had been reduced to 3%, following efforts by feed millers and producers to prevent contamination of non-medicated feeds.

If the pig industry wishes to continue using sulphadimidine, it should consider other forms of administration, for example, in the water or incorporated as granules in the feed, in order to reduce the risk of contamination from the use of the common powdered form.

Zoonotic diseases

The following diseases are, in one sense, of minor importance. There are few documented cases of people in this country being infected with them, as a result of consumption of pork or pork products. However, as they are all capable of causing serious illness, or even death to large numbers of humans, they represent a potential economic threat to the pig industry. The state of scientific knowledge is inadequate to predict the next outbreak of foodborne disease or to eliminate all risks of disease-causing organisms in foods. However, steps can be taken to prevent the contamination of meat with pathogenic organisms and to educate the consumer on the safe handling of meat and meat products. The following list of zoonoses is by no means comprehensive, and includes only those diseases where transmission from animals to man is primarily via the ingestion of food-borne pathogens. Zoonoses such as erysipeloid and leptospirosis, although involving pigs, are considered to be outside the scope of this paper.

1. *Bacterial zoonoses*

Colibacillosis

The unfortunate deaths of four people, together with illness in 500 people, in USA following ingestion of meat containing *Escherichia coli* O157:H7 attracted wide publicity. In one survey in USA, this serotype was found in approximately 1.5% of raw pork samples (Doyle and Schoeni, 1987). However, there is no evidence to date that human food poisoning due to this organism has occurred as a result of the consumption of pig meat. It needs to be emphasised that the cause of the outbreak was due to the consumption of undercooked meat.

Listeriosis

It has been claimed that no other food-borne illness has a higher fatality rate than listeriosis (Robertson *et al.*, 1992). In humans, it commonly affects the central nervous system and, in the case of pregnant women, it may cause abortion or still-birth. The causative organism *Listeria monocytogenes* has been isolated from raw pork (Robertson *et al.*, 1992). Unlike the majority of food-borne pathogens, growth of the organism is not inhibited at refrigeration temperatures; therefore, extended storage time of contaminated, or potentially contaminated foods should be discouraged. Members of the public, particularly pregnant women, should be educated on the potential danger of undercooked meat.

Melioidosis

Although humans are not commonly infected by ingestion of pork, this disease is of some economic importance to the Queensland pig industry, as export restrictions to certain countries are in place because of the disease.

Salmonellosis

Human infections are classically associated with foods of animal origin. Serovars (strains) of the organism which cause food poisoning in man are found in pigs (Murray, 1992) which suggests, but does not prove, that some human infections are related to the consumption of pig meat. Abattoirs have an important role to play in the prevention of this disease. Correct slaughter-floor procedures will ensure minimal contamination of carcasses, while adequate chilling will prevent growth of the organisms (they do not grow at temperatures below 8°C). As with many other food-poisoning organisms, adequate cooking will eliminate the risk of human infection (the organisms are destroyed by temperatures above 55°C).

Streptococcal infection

Streptococcus suis Type 2 has been described as a rare, but serious, zoonotic agent

(Robertson, 1992). The majority of reported cases have involved adults who kept or handled pigs or their meat products, but there is at least one report of a human case following the ingestion of raw pork (Hughes, 1991). The public health dangers from handling meat infected with the organism would appear to be extremely small. The organism is susceptible to heat, surviving for less than two minutes after heating to 60°C.

Yersinosis

Yersina enterocolitica causes enteritis in pigs and an outbreak of food poisoning due to this organism was traced to the eating of raw pork (Barton, 1992). The organism is able to proliferate at 4°C and, thus, the number of bacteria are able to increase in contaminated food during refrigeration. Therefore, where there is a risk of contamination, food should not be stored for lengthy periods, even at refrigeration temperatures (Robins-Browne, 1992).

2. *Parasitic zoonoses*

Sparganosis

Spargana, the second intermediate larval stages of the dog, cat and fox tapeworm *Spirometra erinacei*, frequently occur in skeletal muscles of feral pigs. Human infection with spargana is called sparganosis and normally occurs following ingestion of raw or inadequately cooked tissues containing spargana. The disease in humans is generally mild, with inflammation and pruritis resulting from a subcutaneous nodule. Occasionally, however, there may be serious manifestations with partial paralysis and neurological disorders, as a result of infection of the brain or spinal cord. As the spargana can survive for long periods at refrigeration temperatures, there is a potential public health problem (Stephens *et al.*, 1993). The occurrence of sparganosis might be expected to increase with the increase in popularity of outdoor pig production.

Trichinellosis

One important zoonosis which, fortunately, is not present in Australia, is trichinellosis. *Trichinella spiralis* is a small worm occurring in the intestines of man, pigs and some other mammals. The worm larvae form cysts in the muscles and man becomes infected by eating raw or undercooked pork, containing viable cysts. Heavy human infestations may be fatal, mainly through paralysis of the respiratory muscles. Trichinella infection has never been recorded in domestic animals in Australia (McColl and Butler, 1982). A similar organism, *Trichinella pseudospiralis*, has been found in Tasmanian wildlife but extensive testing of domestic pigs, both in Tasmania and on the mainland, has produced only negative results (Obendorf *et al.*, 1990). It is presently a requirement that all carcasses of horses and wild game pigs intended for export to EC countries be tested for trichinella.

3. *A protozoal zoonosis*

Toxoplasmosis

The protozoal organism, *Toxoplasma gondii*, has been detected in pigs in Australia (Callow, 1984) and thus there is a possibility of human infection from eating raw or inadequately-cooked pork. Viable tissue cysts have been found in muscle meats, up to two and a half years after infection. Because of the role of the cat in the infection of humans with this organism, the feeding of uncooked pork or pig's liver to cats should be avoided. Human toxoplasmosis from eating meat of any species cannot be regarded as a significant problem in this country. However, it may be wise to inform consumers that a risk exists, and of the desirability of heating meat to greater than 70°C for at least 10 minutes (Rothe *et al.*, 1985) to destroy possible infective tissue cysts.

Consumer protection

The consumers' rights to purchase a varied range of foods without residues that might endanger their health is enshrined in various food laws. Consumers heightened interest in health and nutrition has increased concerns over food safety. Whilst animal food products in advanced countries today are probably the safest available, we need to communicate to the consuming public our credibility.

The chemical and drug evaluation and approval process is highly protective against any toxicological effects from residues in the food supply. A thorough evaluation of the absorption, metabolism and excretion of the parent drug and metabolites is undertaken. Toxicological studies are conducted by feeding the parent compound and metabolites to test animals. An acceptable daily intake (ADI) is based on the no effect level (NOEL) of the most sensitive species and further divided by a factor of 100 or more. The maximum residue limit (MRL) or 'tolerance level' is calculated so that the ADI will not be exceeded by the sum of the residues in the human diet from all possible sources. The withholding period (WHP) is calculated as the time required for the residue to reach a safe concentration, as defined by the MRL.

Thus, when any approved medication or feed supplement is used according to the directions, including observing the appropriate withholding period, there is virtually no risk of residues being present at concentrations greater than the MRL. Residues above the MRL may arise as a result of human error or following deliberate misuse of approved or unapproved compounds. Several testing programs exist to ensure that, in these cases, the contaminated product will not reach the consumer. These programs include the Commonwealth government National Residue Survey, NARM, the Queensland government 'flying squad' and screening tests conducted on-site by abattoirs. These programs are valuable in reassuring the consumer of the general status of residues in this country, and minimizing the chance of product containing unacceptable residues reaching the consumer. However, the emphasis on end-product testing must be shifted to residue-preventative programs at the producer level.

Quality assurance

Quality assurance consists of planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. It is a participative management system for the prevention, detection and correction of product defects that would cause customer dissatisfaction. The system is designed to accomplish its objectives at the earliest possible stage of design and manufacture. An important part of this approach is the recognition that quality cannot be inspected into a product, but must be built into it.

In order to encompass the emerging issue and responsibility of residues and bacterial contamination into quality assurance programs, we must combine the elements of risk assessment, problem analysis and decision making. This can be done by the incorporation of the hazard analysis critical control point (HACCP) concept into food quality assurance programs. HACCP is a systematic approach to hazard identification, assessment and control. It offers a rational approach to the control of residues and bacterial contamination and avoids many of the weaknesses inherent in the inspection and end-product testing approach. By directing attention to key factors, the suppliers, producers, processors, regulators and ultimate users of food can be assured that the desired levels of safety and quality are met and maintained. Stephens (1991b) has described the sequential steps involved in the implementation of the HACCP system.

Application of quality assurance programs

Suppliers

Raw product suppliers such as grain growers, protein and mineral/vitamin supplement manufacturers, need to follow good agricultural (GAP) or manufacturing practice (GMP) in order to produce goods to the required quality and specifications. Whilst these suppliers may not need a documented quality assurance program, they should be cognisant of their customers' needs. Similarly veterinarians need to follow a code of practice (COP) as a supplier of drugs for therapeutic, prophylactic and growth promotant use. This role is in the correct dispensing of drugs and instructions for their use, particularly with regard to the withholding period. If the veterinarian prescribes extra-label drugs then he/she is responsible for extra precautions and instructions on their use.

Feed-millers play an important role in modern animal production. Producers are demanding high quality animal feeds at an economical price. Medicated feeds are required to contain the correct drug and quantity, while non-medicated feeds are expected to be clear of drugs. Due to the complicated nature of feed-mill operations, it is essential that quality assurance programs be in place.

Producers

Animal producers are at the hub of producing product uncontaminated by residues. At some time in the future they may even be producing animals free of certain pathogens. Producers who can verify that they can control all aspects of production, via a comprehensive quality assurance program, may enter into cost-effective vendor-certification programs with processors and regulators.

Processors

Processors, such as abattoirs and smallgoods manufacturers, should have quality assurance programs to ensure that product containing residues or bacterial contamination is removed from the food chain. These programs may include quality plans for the production of 'residue-free' product, for example, veal or pork for certain export markets. These programs are based on screening tests at either 100% sampling or acceptance sampling plans for each producer.

Conclusions

There has recently been an increase in public health and consumer awareness of the problem of residues in foods, as a result of modern agricultural methods, increased use of chemicals and veterinary drugs and sophisticated analytical methods. While the need for end-point monitoring of the final product at abattoirs will remain, it is suggested that this be supplemented by preventative programs. Preventative management strategies, based on quality assurance principles at the supplier, producer and processor levels can assure cost-effective production and marketability of food animal products, acceptable to the consumer. Quality assurance programs incorporating the hazard analysis critical control point (HACCP) concept are a rational approach to the identification, monitoring and control of residue hazards.

The pig industry needs to be aware that one, well-publicised outbreak of food poisoning, related to the consumption of pork or pork products, could have dramatic financial consequences for the entire industry. As the majority of food-poisoning organisms are destroyed by adequate cooking, the industry should perhaps consider a comprehensive extension program to educate processors and consumers on the dangers of raw or undercooked pork.

SYMPOSIUM CONCLUSIONS

G.R. Trout

From the papers presented in this Symposium, it is very apparent that many

production and processing factors influence pork quality.

As has been indicated by Jeff Wood, genetics is one factor that has a major influence on quality. The halothane gene, for example, has been shown to increase meat toughness, leanness and level of PSE. Marbling, another heritable trait, greatly influences tenderness and juiciness. This effect of marbling may be compounded with breed, since the Duroc which produces extensive marbling, also produces more tender pork. Sex has also been shown to have an effect on pork quality. Entire males produce fat which is softer than that from females or castrates. Additionally, some entire males produce meat with an offensive sex odour and flavour. Diet can greatly influence quality as well. Fast growing pigs, because of genetics or diet, produce pork which has softer fat and higher incidence of muscle-muscle and fat-fat separation. Inclusion of dietary oils, particularly C18:2 and C18:3, can result in softer fat and oxidised off-flavours. *Ad libitum* feeding, instead of restrictive feeding, produces more tender pork. Use of beta adrenergic agonist in the diet has the potential for increasing lean meat growth but at the expense of tougher meat. Pre-slaughter, slaughter and processing factors also affect meat quality. Many of these factors interact with the stress genotype of the pig to increase the level of PSE. This increases the toughness of the meat and reduces the processing quality. Rapid chilling also increases toughness. This effect can be overcome to some extent by using electrical stimulation or pelvic suspension.

Furthermore, David Hennessy has indicated that boar odour is a problem in slaughter-weight entire males. Both androstenone and skatole are compounds which contribute to boar odour. The relative importance of each has not been determined. Selection of pork with androstenone levels below 0.5 ppm and skatole levels below 0.2 ppm has been suggested as a means of eliminating odour in pork. In practice this approach is not always successful. It has been shown that genetics, diet and animal management practices (eg; stocking density, air quality) influence odour levels in entire males, but do not prevent it. Immunisation has the potential to reduce boar odour levels. Immunisation against androstenone has not been successful, however, immunisation against LHRH has had more success.

Drewe Ferguson and Steve Myler have pointed out that because of improvements in technology, both the yield and quality of meat in a carcass can be measured more reliably. Measuring fat, and fat and muscle depths at two sites on a carcass has become a standardised method for predicting lean-meat yield. Other devices, used singly or in combination, that have greater accuracy than the previous technique include: 1) The Danish classification centre, 2) ultrasound, 3) velocity of sound, 4) electromagnetic scanning, and 5) video image analysis. In measuring pork quality, devices which measure light scattering or conductivity are the most reliable. However, for these techniques to reliably estimate the overall quality of the carcass the measurements must be taken at least 12 hours post mortem and at a minimum of four sites on the carcass.

Frank Shaw and Ian Stephens explained that consumers perception of the wholesomeness of pork has a great influence on the consumers decision to purchase. The known presence of low levels of man-made residues or bacteria and/or parasites has a negative impact on consumers. The potential for contamination by either category of contaminant can be greatly reduced by appropriate quality control programs at all steps of the production and processing chain.

As the result of research, much of which is outlined in this review, we have a much better understanding of production and processing factors which affect pork quality. The real challenge in the next ten years is to build on this knowledge and use it to produce pork which meets consumers needs.

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THE INFLUENCE OF SOME PROCESSING PROCEDURES ON PIG MEAT QUALITY

G.A. Eldridge, C.I. Ball and H.M. Knowles

Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.

The method of handling pigs prior to slaughter has a marked influence on meat quality (Grandin, 1988). Despite the apparent improvements in pig handling facilities, the incidence of pig meat quality defects still remains high (Anonymous, 1992). Consequently, it is suggested that post-slaughter factors, as well as management and handling of the live pig, may influence pig meat quality.

In an experiment, involving 100 pigs from a large commercial farm, pigs were slaughtered over 2 consecutive days. The procedures for handling, lairage, stunning and exsanguination of the pigs were similar on each slaughter day, except that on day 1 the chain between dehairing and removal of the viscera was stopped for 8 mins, because of a problem in the abattoir. Each side of the split carcass was subjected to a different chilling regimen. The right side of the carcass was placed in a standard chiller environment (standard chilling) after being measured for initial pH (pHi) 55-65 mins post-slaughter. This chiller was set to cool the deep-butt temperature to 5°C within 18 hours. The left side of the carcass was chilled at -30°C for 2 h (rapid chilling), immediately after carcass dressing (approximately 30 min) and then placed in the standard chiller adjacent to the right side. Approximately 24 h post-slaughter, a 100 mm chop was removed in the region of the 10/11th rib of each side and was used to measure the surface lightness (Minolta Chromometer, CIE: L* value), ultimate pH (pHu) and 24 h % drip-loss.

Table 1. The influence of day of slaughter and rate of chilling on % drip loss and surface meat colour (L* value)

	Day of slaughter			Rate of chilling		
	Day 1	Day 2	SED[1]	Rapid	Normal	SED[1]
% Drip loss	4.72	3.33	0.307***	3.47	4.67	0.304***
L* value	49.03	46.84	0.421***	47.48	48.55	0.417*

[1]* P<0.05; *** P<0.001.

The day of slaughter and rate of chilling significantly influenced both % drip-loss and meat colour (L* value) (Table 1). Although the meat from pigs slaughtered on day 1 had a significantly lower pHi (5.70 *cf* 6.40; SED = 0.044; P<0.001) than that of pigs slaughtered on day 2, neither day of slaughter nor rate of chilling significantly influenced the pHu of the meat. There were no significant interactions between day of slaughter and rate of chilling (P>0.05).

The rapid chilling of carcasses with potentially high levels of drip may have economic significance, however, there is a risk of toughening of meat through cold-shortening. This experiment also demonstrates that processing delays can result in considerable variation in pig meat quality and it is recommended that, once the animal is stunned, processing continues without interruption between stunning and chilling.

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IMPROVED CARCASS AND BONING ROOM MANAGEMENT TO EXTEND THE SHELF-LIFE OF FRESH PORK

P.R. Widders, K.J. Coates, J.C. Beattie and I.R. Morgan

Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049.

Keeping quality is a barrier to effective marketing of fresh pork. *Pseudomonas species* are the main cause of spoilage of aerobically-stored pork. The aim of this study was to investigate management strategies that limit growth and dissemination of spoilage by *Pseudomonas spp.* during processing of pork.

Environmental, carcass and meat surfaces were surveyed in commercial boning rooms, using the wet-dry swab technique (Morgan *et al.*, 1991). *Pseudomonas spp.* comprised on average 30% of the total microbial count on surfaces. Microbial counts were highest ($>10^3/cm^2$) on carcasses (ham region), cutting boards and the saw table, while other environmental surfaces had low ($<10/cm^2$) counts.

Management strategies that addressed the critical areas of pork processing (carcass storage and boning) were evaluated. Time-temperature integration (TTI) strips were used to monitor the temperature storage history of carcasses. Carcasses (n=61) were tagged with the TTI strips at 3-6 hours after slaughter, then carcass microbial counts and TTI status measured at boning, 18-120 hours after slaughter. There was a significant regression ($P<0.01$) but not correlation ($r=0.33$) of carcass *Pseudomonas* counts on the status of the TTI strip. This confirms that TTI can be used to estimate carcass microbial quality at boning.

In a second study, the contribution of carcass and cutting board contamination to the level of meat contamination, was evaluated. Carcasses with surface counts either greater than or less than $10^4/cm^2$ were boned on cutting boards, that were either cleaned before boning, or that remained in routine use and had high bacterial counts (Table 1). As a result, counts of *Pseudomonas spp.* on meat boned from relatively clean carcasses were significantly lower ($P<0.05$) when boned on cleaned cutting boards compared to 'in-use' boards (Table 1).

These results form the basis for management strategies that can extend and standardise the shelf-life of pork. Time-temperature integration facilitates quality description of carcasses. Appropriate hygiene for cutting surfaces in the boning room will ensure that microbial counts on meat approximate those on the carcass, so that the meat has low levels of spoilage organisms, and therefore a consistent and extended shelf-life.

Table 1. Geometric mean *Pseudomonas* counts (SEM) on carcasses, meat and cutting boards, to determine the effect of management on the microbial quality of pig meat[1]

Board classification	Carcass classification	Board counts	Carcass counts	Meat counts
Cleaned	$<10^4$ (n=38)	0.79^a (0.32)	2.72^a (0.25)	2.77^a (0.24)
In use	$<10^4$ (n=32)	4.55^b (0.21)	2.96^a (0.24)	4.08^b (0.33)
Cleaned	$>10^4$ (n=32)	0.72^a (0.33)	5.04^b (0.25)	4.52^b (0.18)
In use	$>10^4$ (n=36)	4.19^b (0.44)	5.43^b (0.19)	4.77^b (0.18)

[1]Within columns, means with different superscripts differ ($P<0.05$).

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THE USE OF PREDICTIVE MICROBIOLOGY TO IMPROVE THE SHELF-LIFE OF FRESH PORK

K.J. Coates, L. Kamperman*, J.C. Beattie and P.R. Widders

Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049. *Department of Agricultural Science, University of Tasmania, Hobart, Tas. 7001.

Fresh pork has a shelf-life which is limited aerobically by the growth of *Pseudomonas* spoilage organisms on the meat surface. Using current marketing practices, retail managers discard product after one to two days on the shelf. This guarantees the consumer a product with a useful storage life. However, it also means that good products may be wasted. The reason that managers are not able to set a more realistic use-by date is that there is considerable variation in the microbiological quality of carcasses and, consequently in the meat boned from those carcassess (Morgan *et al.*, 1991). Improving the hygiene in boning rooms can increase the shelf-life of fresh pork. However, these gains are lost if carcass microbial quality is not consistently good. The levels of spoilage organisms on carcasses at boning and the subsequent temperature history of the product are the most important influences on meat spoilage.

Predictive microbiology has become a useful tool for food microbiologists. Mathematical formulae are generated to describe the growth of organisms in particular environments. The parameters which have the most effect on spoilage of pork caused by *Pseudomonas spp.* are temperature of storage, pH of meat and initial numbers of bacteria. A model was developed in nutrient broth to describe the growth of *Pseudomonas* spoilage organisms at different temperatures. This equation was derived from the Square Root Model of bacterial growth (Ratkowsky *et al.*, 1982). Using a system of sterile pork meat seeded with spoilage organisms, the generation times for the bacterium on meat at different temperatures was calculated from plate count data and compared to the generation times predicted by the model.

The equation which describes the model is:

$$\sqrt{(1/GT)} = 2.8623 \times 10^{-2} + 4.4893 \times 10^{-3}\ T$$

where GT = Generation Time (mins) and T = Temp (°C)

The predicted generation times for particular temperatures were compared to the generation times calculated from representative experiments. For example, at 4°C, the model predicts a generation time of 460.9 minutes. The generation time calculated from growth on pork was 505.1 minutes.

At the temperature commonly used for retail storage, 4°C, the generation time calculated from the growth of bacteria on meat agreed well with the time predicted by the model. These are preliminary results and further replicates must be carried out at the range of storage temperatures, ie; 0 to 10°C to confirm the accuracy of prediction. It would appear that the model, in conjunction with rapid assays for initial bacterial numbers, may be a useful method for a more accurate estimate of the shelf-life of fresh pork, when the storage temperature history of the product is known.

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EFFECT OF SODIUM LACTATE ON *BROCHOTHRIX THERMOSPHACTA* IN SLICED, VACUUM-PACKAGED DEVON

A. Yang, G.M. Higgs, G.R. Trout and B.J. Shay

CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170.

Although the effect of sodium lactate on suppressing microbial growth and extending shelf-life has been reported in meat products, its effect on specific groups of spoilage organisms, in particular *Brochothrix thermosphacta*, has not been documented. Experiments were therefore undertaken to determine the effect of sodium lactate on *Brochothrix thermosphacta*, a common spoilage organism, in devon, a bologna-type product with a short storage life due to its high pH and high water activity (a_w).

The devon were manufactured with a pH of either 6.4 or 6.0 and contained 56.2% pork trims (90% chemical lean), 23.8% pork back fat, 0.01% sodium nitrite, 2.0% salt, 0.5% spices, 0.3% sodium tripolyphosphate, 17.2% ice and 0%, 0.6%, 1.2%, 1.8% or 2.4% sodium lactate. They were sliced, inoculated with *Brochothrix thermosphacta* culture, vacuum-packaged and stored at 5°C. Vacuum packs were monitored for periods of up to 50 days for microbial growth. Microbial analyses were carried out by macerating 20 g of the devon in 180 ml of sterile 1.25% NaCl solution. Subsequent serial dilutions were made in 0.1% sterile peptone water. Each dilution was spread-plated in duplicate on the surface of the prepoured media of TYSG (Oxoid Tryptone Soya Agar supplemented with 0.2% glucose and 0.2% Oxiod Yeast Extract) for total plate counts and Gardiner's media for the enumeration of *Brochothrix thermosphacta*. The plates were incubated aerobically at 25°C for 72 hours.

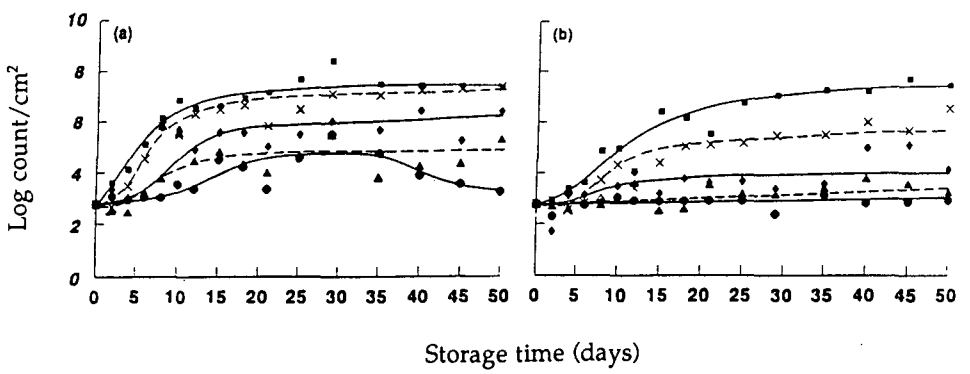

Figure 1. Growth of Brochothrix thermosphacta in devons of pH 6.4 (a) or 6.0 (b) at 5°C with 0% (■—■), 0.6% (x- -x), 1.2% (♦—♦), 1.8% (▲- -▲) and 2.4% (●—●) sodium lactate.

Sodium lactate suppressed the growth of *Brochothrix thermosphacta* and, at the concentrations of 1.2% or higher, the number of these bacteria did not reach spoilage level (log 7/cm^2) after 50 days of storage at 5°C. This antimicrobial effect of sodium lactate appeared to result from both an extended lag phase and a reduced growth rate. At the low pH, 6.0, only the controls reached the spoilage level during the experiment. pH is known to affect the extent of dissociation of an acid and at low pH, a higher proportion of lactic acid is in the undissociated form, which is believed to penetrate the cell and then dissociate to produce acid conditions in the cell, leading to the death of micro-organisms.

These results demonstrate the antimicrobial effect of sodium lactate, and also have practical implications, in that pH appears to play an important role in determining the effectiveness of sodium lactate.

OBJECTIVE ASSESSMENT AND PREDICTION OF QUALITY IN PORK LOINS USING THE FIBRE OPTIC PROBE

S.V. Myler, G.R. Trout, D.G. Taylor* and P.D. Reiser

CSIRO Division of Food Science and Technology, Meat Research Laboratory, PO Box 12, Cannon Hill, Qld. 4170. *Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.

Meat quality in a carcass is commonly assessed by measuring in the loin over the region of the last three ribs. Lundstrom and Malmfors (1985) reported the need to measure at more than one site to get a reliable indication of quality throughout the loin. Our research investigated the use of the fibre optic probe (FOP) to measure quality along the length of the loin, and the prediction of loin quality from a minimum number of sites. For this experiment, 122 pale, soft and exudative (PSE) and 125 normal loins were selected based on FOP measurements. Loins were classed as PSE when the combined drip and cure yield loss was >7%, which equated to an FOP value of ≥45 (Trout, 1992). FOP measurements were taken at 14 anatomically defined sites (6^{th} thoracic to 5^{th} lumbar vertebrae junctions) in the loin. An analysis of the data showed that for normal loins, minimal variation was found in FOP values along the length of the loin, whereas for PSE loins large variation in FOP values was found (Table 1).

Table 1. FOP values (means and SD) at sites 1-14 for PSE and normal loins[1]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PSE	65^a	64^a	60^b	55^c	51^d	47^e	43^f	41^g	39^g	39^g	38^g	38^g	39^g	40^g
SD	13	14	16	16	16	15	14	15	15	15	14	15	15	15
Normal	34^a	34^a	34^a	34^a	33^b	31^c	30^d	30^d	29^d	29^d	29^d	29^d	29^d	30^d
SD	6	6	5	5	5	5	6	6	6	6	5	5	5	5

[1]Within a row, means with the same superscript are not significantly different (P>0.05).

Because of the large and systematic variation of quality shown in PSE loins, it was necessary to measure at least two sites to reliably predict all other site FOP values and hence quality of the loin. Twelve multiple regression equations using two selected sites as predictor variables were developed to predict the FOP values at other sites in the loin. The selected site pair was: site 3 ($8/9^{th}$ thoracic vertebrae) and site 11 (2^{nd} lumbar vertebrae) as this pair had the lowest total sum of squared errors (SSE) compared to other site pairs. The performance of these equations is given in Table 2.

Table 2. Performance of sites 3 and 11 for predicting FOP values at other sites

	1	2	4	5	6	7	8	9	10	12	13	14
R^2	0.86	0.91	0.93	0.90	0.85	0.86	0.87	0.90	0.92	0.92	0.89	0.84
RSD	6.8	5.5	4.3	4.8	5.3	4.6	4.4	3.8	3.4	3.4	4.1	4.6

The results indicate that predictions based on FOP measurements, taken at sites 3 and 11, will give a reliable estimate of overall meat quality (mean of measured and estimated FOP values) for both PSE and normal loins.

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IMMUNISATION AGAINST GONADOTROPHIN RELEASING HORMONE INHIBITS TESTES GROWTH IN YOUNG BOARS

F.R. Dunshea, R.S. Biden, B.A. Moss* and T.E. Trigg*

Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030. *Peptide Technology Limited, Dee Why, NSW 2099.

Testicular development and production of steroids is regulated by the release of gonadotrophins from the pituitary. Gonadotrophin release is in turn regulated by the secretion of gonadotrophin releasing hormone (GnRH) from the hypothalamus. Due to testicular production of steroids, boars with functional testes have leaner carcasses than castrates. However, one testicular steroid, androstenone, accumulates in adipose tissue of post-pubertal boars, giving rise to boar taint. To avoid taint, boars can be either castrated or else kept intact but slaughtered before taint develops. This study examined the effect of immunisation against GnRH on testicular development, plasma testosterone and performance in the boar.

Forty boars were blocked on live weight at seven weeks of age and randomly assigned to one of four treatment groups. Pigs were housed in groups of 10 pigs of similar starting weight and were allowed unlimited access to water and protein adequate rations. Pigs were injected with either saline (CON) or three different GnRH-ovalbumin conjugates (Peptide Technology Limited) at 7, 11 and 15 weeks of age. Blood samples for determination of testosterone concentration were obtained and testes width measured at two weekly intervals and again at slaughter at 85 kg (ca. 20 weeks).

Table 1. Effect of different GnRH vaccines (A, B, C) on growth performance and testes weight, plasma testosterone and backfat of boars at slaughter

	Control	A	B	C	SED	Sign.[1]
Initial weight (kg)	13.0	12.7	12.8	12.8	0.23	NS
Final weight (kg)	86.0	86.0	86.5	87.3	2.69	NS
Live-weight gain (g/d)						
7 - 20 weeks	818	818	806	808	15.3	NS
11 - 20 weeks	908	920	903	902	22.4	NS
15 - 20 weeks	942	954	924	950	26.5	NS
Testes (g)	326^a	45^b	47^b	44^b	24.1	***
Plasma testosterone (pg/ml)	350^a	9^b	22^b	22^b	71.0	***
Backfat at P2 (mm)	15.6^a	20.4^b	20.3^b	20.0^b	1.3	**

[1]NS, non significant, $P>0.05$; ** $P<0.01$; *** $P<0.001$. Within rows, means with different superscripts differ signicantly ($P<0.05$).

Immunisation against GnRH had no effect upon live-weight gain over any stage of growth. However, immunisation against GnRH increased backfat thickness with no differences between vaccines. For the CON boars, there was a linear increase in testicular width with age, whereas there was no increase in testicular width after the secondary vaccination against GnRH. Testes weight at slaughter was decreased by 85% through immunisation against GnRH. From 13 weeks of age (two weeks after secondary vaccination) plasma testosterone started to increase in the control boars, while being barely detectable in the vaccinated boars. Plasma testosterone continued to rise in the control boars, increasing rapidly from about 15 weeks of age (55 kg live weight). In conclusion, immunocastration offers a suitable alternative to surgical castration.

EFFECT OF GENDER ON REGULATION OF INSULIN-LIKE GROWTH FACTORS IN PIGS

P.C. Owens, R.G. Campbell*, G.L. Francis and K.J. Moyse

CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000. *Bunge Meat Industries Ltd, PO Box 78, Corowa, NSW 2646.

Strong, positive relationships have recently been observed between growth rate and the concentrations in blood of insulin-like growth factors (IGF) in young boars (Owens *et al.*, 1992, 1993), indicating that both IGF-I and IGF-II are important regulators of growth in pigs. This was not unexpected for IGF-I, whose expression and secretion are increased by growth hormone (GH), but was surprising in the case of IGF-II because treatment of pigs with GH reduces the amount of IGF-II in blood plasma (Owens *et al.*, 1990). We therefore examined the influence of a different growth determinant, gonadal steroid status, on the levels of IGF-I and -II in blood of pigs.

Two male and one female were selected at weaning from each of 13 litters born on the same day, to pure-bred Large White sows mated with pure-bred Large White boars. One male from each litter was then castrated. These sibling boars, barrows and gilts were thereafter maintained on a complete commercial ration. At 15 weeks of age the animals were individually penned and feed consumption and live weight were recorded weekly until they reached 24 weeks of age. Blood was collected weekly from 12 to 23 weeks of age. Plasma IGF-I and -II were measured by specific assays after elimination of binding protein artefacts by size exclusion high performance liquid chromatography (Owens *et al.*, 1990, 1991).

Boars grew faster ($P<0.001$) than barrows and gilts and their conversion of feed into live-weight gain was superior ($P<0.001$), as expected. Feed consumption of barrows was not different from boars and both ate more than gilts. As observed previously with boars, plasma levels of IGF-II were higher than those of IGF-I in all three groups. Plasma IGF-I levels were highest in boars, whereas IGF-II was highest in barrows and lowest in boars ($P<0.001$).

These results indicate that gender influences growth of pigs through mechanisms that appear to involve expression of IGF-I and repression of IGF-II. Improved lean growth due to treatment with growth hormone also raises IGF-I and lowers IGF-II. Therefore, the relative rates of growth of lean and fat may be determinants of, or be determined by, the relative levels of IGF-I and IGF-II.

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CONTINUOUS 14 DAY INFUSION OF IGF-I OR IGF-II AND GROWTH AND NITROGEN BALANCE OF YOUNG RATS

M.A. Conlon, J.L. Burgoyne*, K. Wright*, S.E. Aplin, P.C. Owens*, F.M. Tomas*, J.C. Wallace and F.J. Ballard*

Department of Biochemistry, University of Adelaide, Adelaide, SA 5000. *CSIRO Division of Human Nutrition, Cooperative Research Centre for Tissue Growth and Repair, Kintore Avenue, Adelaide, SA 5000.

The levels of the anabolic polypeptides Insulin-like Growth Factor-I and -II (IGF-I and IGF-II) in blood increase post-natally in the pig (Owens *et al.*, 1991a) and IGF-I can increase the growth of neonatal pigs (Schoknecht *et al.*, 1993). The IGF's are carried in blood by the IGF Binding Proteins (IGFBP's), predominantly by IGFBP-3. Plasma IGF-I concentrations in young boars correlate strongly with their growth rates following weaning (Owens *et al.*, 1991b), but plasma IGFBP-3 concentrations show an even stronger correlation (P.E. Walton, personal communication). This stronger correlation could be due to the fact that IGFBP-3 carries both IGF-I and IGF-II, and that IGF-II also contributes to post-natal growth of the pig. This study compares the effectiveness of IGF-I and IGF-II in promoting growth and nitrogen balance using the rat as a model.

Female Hooded Wistar rats, of about 100g in live weight, were treated for 14 days with one of the following treatments: vehicle (0.1 M acetic acid), 104 or 260 µg/day recombinant human IGF-I (rech IGF-I), 104, 260 or 650 µg/day recombinant human IGF-II (rech IGF-II). There were six animals per treatment. Treatment was by continuous infusion via a 14 day mini-osmotic pump surgically implanted under the skin. Daily collections of urine and faeces, and daily live weight and feed intake measurements were taken. Animals were fed a high carbohydrate diet containing 18% nitrogen, and were able to feed and drink at will. At the end of the treatment period animals were killed and organs, blood and carcasses were taken for analysis.

Table 1. Effect of IGF's on growth performance (means ± SEM)[1]

Dose (µg/d)	0 Vehicle	104 IGF-I	260 IGF-I	104 IGF-II	260 IGF-II	650 IGF-II
Gain (g/14d)	42.5±1.80	48.17±0.85	52.11±3.08*	41.03±1.60	45.85±3.61	51.53±1.40*
FCE	0.22±0.01	0.24±0.01	0.26±0.01**	0.21±0.01	0.22±0.02	0.26±0.01*

[1]Significance from the vehicle group, *P<0.05; **P<0.01. FCE, feed conversion efficiency.

IGF-II was less potent than IGF-I in affecting growth performance but was nevertheless capable of significant effects. Both IGF's reduced carcass fat content, though not significantly. Carcass protein content, muscle protein breakdown and 14 day nitrogen balance were not significantly affected. Organ and tissue weights, and plasma IGF and IGFBP levels were measured and these will be discussed.

In conclusion, IGF-II can promote the growth of normal rats and may therefore be useful in enhancing the production of pigs.

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EFFECTS OF POTENT INSULIN-LIKE GROWTH FACTOR I ANALOGUES ON PLASMA GLUCOSE AND AMINO ACIDS IN PIGS

P.E. Walton, F.M. Tomas, P.C. Owens, I.K. Priebe, J.L. Burgoyne, G.L. Francis and F.R. Dunshea*

CSIRO Division of Human Nutrition, Co-operative Research Centre for Tissue Growth and Repair, Kintore Ave, Adelaide, SA 5000. *Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030.

Analogues of insulin-like growth factor I (IGF-I), that bind poorly to IGF binding proteins (IGFBP), have been shown to be more potent than IGF-I in stimulating protein synthesis *in vitro* and body weight gain *in vivo* in rats. The objectives of this study were to examine the potencies of these analogues in pigs, by measuring their metabolic effects and by relating these effects to the binding of the analogues to porcine IGFBPs. The IGF-I analogs were provided by GroPep Pty Ltd., Adelaide: (1) IGF-I, (2) des(1-3)IGF-I, (3) R^3IGF-I, (4) Long IGF-I, and (5) Long R^3IGF-I. Bolus doses of 20 and 50 µg/kg body weight of each analogue were administered to male pigs (mean body weight 60.7 ± 1.8 kg) via jugular catheters. Control (vehicle) and insulin (3 µg/kg body weight) treatments were also administered. Blood samples were taken for measurement of plasma glucose and amino acids. All IGF-I analogues caused a dose-dependent decrease in plasma glucose (Table 1), in the following order of potency: Long R^3IGF-I ≈ R^3IGF-I ≈ des(1-3)IGF-I > Long IGF-I > IGF-I.

Table 1. Effects of IGF-I analogues on plasma glucose

Treatment		Depression of plasma glucose (mmol.min/l)	Relative potency (compared to IGF-I)	
			20 µg/kg	50 µg/kg
Control		0	-	-
Insulin	3 µg/kg	112 ± 24.9	33	19
IGF-I	20 µg/kg	22.4 ± 3.9	1.0	-
	50 µg/kg	96.4 ± 13.6	-	1.0
Des(1-3)IGF-I	20 µg/kg	142 ± 33	6.3	-
	50 µg/kg	434 ± 77	-	4.5
R^3IGF-I	20 µg/kg	148 ± 47	6.6	-
	50 µg/kg	414 ± 72	-	4.3
Long IGF-I	20 µg/kg	48.2 ± 25.5	2.2	-
	50 µg/kg	259 ± 60	-	2.7
Long R^3IGF-I	20 µg/kg	196 ± 35	8.8	-
	50 µg/kg	367 ± 99	-	3.9

The IGF-I analogues also reduced plasma alanine, branched-chain amino acids, lysine and threonine in a dose-dependent manner, however, the potency differences were less marked than the effects on plasma glucose. These potent analogues exhibited reduced binding to porcine plasma IGFBPs, and to purified porcine IGFBP-3, in competitive binding assays *in vitro*, in a manner inversely proportional to their biological potency. We conclude that the IGF-I analogues are more potent than IGF-I, due to their reduced binding to porcine IGFBPs, which facilitates a higher effective concentration of IGF to act on target cell receptors.

THE DEVELOPMENT OF SMALL INTESTINAL PEPTIDASES IN SUCKING PIGS

I. Tarvid, P.D. Cranwell, L. Ma and R. Vavala

School of Agriculture, La Trobe University, Bundoora, Vic. 3083.

Peptide hydrolysis in the small intestine is the final stage of protein digestion, and is brought about by the intestinal exopeptidases (dipeptidases and aminopeptidases). This paper reports a study of the postnatal development and the distribution of glycyl-L -leucinedipeptidase and leucineaminopeptidase activities in the small intestine in pigs.

Small intestines from 42 Large White x Landrace sucking pigs, 0 - 30 days of age, 0.6 - 11.5 kg body weight, were divided into 3 equal segments: proximal (P), medial (M) and distal (D). Soluble protein (Lowry *et al.*, 1951), Dipeptidase activity - DP (Tarvid, 1991) and Aminopeptidase activity - LAP (Tarvid and Kushak, 1987) were determined in mucosal homogenates from the mid-point of each segment.

Table 1. Distribution of protein content and enzyme activities in the mucosa of the small intestine of 0 - 30 day-old sucking pigs (Mean ± SEM)

	Newborn n = 10	2 day-old n = 10	10 day-old n = 8	20 day-old n = 8	30 day-old n = 6
Protein (mg/g)					
P	84.7±3.9	86.8±2.7	74.6±2.2	78.2±2.0	83.9±5.8
M	84.4±4.3	89.0±3.5	76.6±2.9	80.7±2.7	91.2±4.5
D	79.1±1.5	86.6±4.6	78.6±3.6	84.9±2.5	94.4±4.5
DP (mmol/g/min)					
P	1.16±0.14	0.96±0.11	0.56±0.05	0.39±0.07	0.56±0.06
M	1.06±0.13	1.01±0.09	0.63±0.06	0.46±0.09	0.63±0.04
D	0.82±0.12	0.93±0.09	1.00±0.08	0.81±0.13	0.90±0.07
LAP (µmol/g/min)					
P	1.26±0.09	1.23±0.09	0.85±0.11	0.92±0.07	0.73±0.13
M	1.45±0.11	1.29±0.10	0.95±0.18	1.04±0.10	0.96±0.15
D	1.42±0.12	1.34±0.13	1.06±0.14	1.29±0.19	1.13±0.24

No significant differences were observed in mucosal protein content at different ages or in different regions of the small intestine. However, at 20 and 30 days protein concentration increased in a proximo-distal direction. Changes in aminopeptidase activity were not clearcut, apart from a decrease in activity in the proximal region at 30 days. There was a definite pattern of development for dipeptidase activity - equal distribution along the small intestine up to 2 days, followed by a decrease in activity in the proximal and medial regions and the development of a proximo-distal gradient, with maximum activity in the distal segment. The high level of DP activity in the distal region of the small intestine is explained by its major role in final oligomer hydrolysis (Corring, 1980) and assimilation of endogenous protein, secreted into the lumen (Skovbjerg, 1981).

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GASTRIC ACID SECRETION IN SUCKING PIGS: NEURAL AND ENDOCRINE RESPONSES

L. Ma, P.D. Cranwell and R. Vavala

School of Agriculture, La Trobe University, Bundoora, Vic. 3083.

The endocrine and paracrine pathways which regulate gastric acid secretion are functional in newborn pigs and undergo further development in the postnatal period (Xu and Cranwell, 1990). To date, no information is available about neural regulation of acid secretion in neonatal pigs, but in neonatal rats it has been reported that the neural cholinergic agonist, carbachol, stimulates acid secretion (Ikezaki and Johnson, 1983). This experiment studied the neural control of acid secretion in sucking pigs.

Gastric perfusion experiments were carried out under anaesthesia in 12 Large White x Landrace sucking pigs, 2 - 21 days of age, 1.6 - 5.0 kg body weight; gastric drainge experiments (15) were carried out in 7 conscious Large White x Landrace sucking pigs, 11 - 31 days of age, 2.8 - 7.8 kg body weight, which were fitted with gastric cannulas. The pigs did not have access to solid food. The surgical, experimental and analytical procedures used have been described by Xu and Cranwell (1990). Gastric secretion was collected during a basal period and during two periods in which secretion was stimulated with intravenous infusions of carbachol (3μg/kg/h) and pentagastrin (4μg/kg/h).

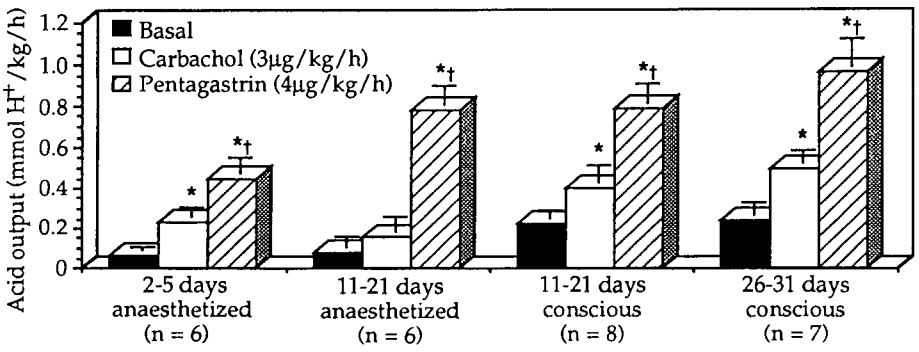

Figure 1. *Basal, and maximal carbachol- and pentagastrin-stimulated acid outputs per unit body weight in anaesthetized and conscious sucking pigs (mean ± SEM). Differences between basal and stimulated* acid outputs, and between carbachol- and pentagastrin- stimulated † acid outputs were significant (P<0.05).*

The results reported here for pentagastrin-stimulated acid secretion are similar to those of Xu and Cranwell (1990). The response to carbachol indicates that neural pathways regulating acid secretion are functional at an early age in the pig. However, in both conscious and anaesthetized pigs the response to carbachol was only 20 - 50% of that to pentagastrin. However, Fujita *et al.* (1980) found that the two secretagogues stimulated similar acid outputs from older pigs prepared with denervated Heidenhain pouches. Comparisons of studies into neural mechanisms controlling gastric function are often confounded if the vagal supply to the stomach has been interrupted.

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MICROBIAL EFFECT ON ILEAL AMINO ACID DIGESTIBILITY

J.S. Kopinski, E.S. Batterham* and K. McGuigan

Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105. *NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.

Cottonseed meal is one of a number of feed ingredients which exhibit discrepancy between availability of amino acids as assessed by ileal digestibility or by slope-ratio assay. The suggested reason for the poor correlation between digestibility and utilization is the adverse effects of processing, in particular heat, which alters the form that the amino acids (in particular lysine) are absorbed, so that digestibility appears to be unaltered, but utilisation is dramatically reduced (van Barneveld *et al.*, 1991). Another explanation for the digestibility/availability difference could lie in the effects of microbial population and activity in the small intestine on ileal amino acid digestibility, where amino acid disappearance at the ileum could be the result of both absorption and microbial catabolism. The relative contribution of each to a digestibility value would be related to the characteristics of the ingredient. Particular dietary ingredients, eg; high fibre protein meals, could create conditions for a substantially increased microbial activity, with a resultant increase in apparent ileal digestibility values for amino acids, which do not reflect actual utilization by the pig. An experiment was carried out to observe the effect of inhibition of microbial activity (with antibiotics) on the ileal digestibility of amino acids from cottonseed meal.

Ten Large White pigs (~21 kg) were fed a sugar-based cottonseed meal diet for 10 days, and then fed the same diet containing chromic oxide as a marker, with or without therapeutic doses of Virginiamycin (150 ppm) and Neomycin sulphate (2000 ppm). After 6 days the ileum (final ~100 cm of the small intestine) and its contents were removed from each pig under anaesthesia prior to euthanasia.

Table 1. Apparent ileal digestibility of amino acids, protein and dry matter in a sugar-based cottonseed meal (CSM) diet, with and without antibiotics (A)

Ingredient	CSM	CSM + A	Sign.[1]	SEM
Lysine	0.50	0.50	NS	0.034
Threonine	0.56	0.55	NS	0.032
Methionine	0.68	0.63	NS	0.028
Protein	0.70	0.68	NS	0.020
Dry Matter	0.76	0.74	NS	0.023

[1]NS, non significant ($P<0.05$).

Preliminary volatile fatty acid results indicated a reduction of microbial activity in the ileum with the use of antibiotics. However, the apparent ileal amino acid and dry matter digestibilities (Table 1) showed no difference between antibiotic treatments ($P>0.05$), indicating that the antibiotics did not affect the microbial action on ileal digestibilities. Alternatively, a change or adaptation of the microbial population may have occurred to nullify the antibiotic effect. The lower than previously published ileal digestibility value of lysine, which may have been a result of over-processing, makes it difficult for conclusions to be drawn from the present study on the influence of microbial activity on ileal amino acid digestibility.

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DEVELOPMENT OF GASTRIC PROTEASE SECRETION IN PIGS

L. Ma, P.D. Cranwell, I. Tarvid and R. Vavala

School of Agriculture, La Trobe University, Bundoora, Vic. 3083.

The three major aspartic proteases secreted by the stomach of the pig are pepsins A and C, and chymosin. Milk-clotting activity (MCA) is highest for chymosin although pepsins A and C have considerable MCA. General proteolytic activity (GPA) is high for pepsins A and C but very weak for chymosin (Sangild *et al.*, 1991). By comparing MCA and GPA measured in gastric secretion from sucking and weaned pigs, one can study the relative development of the different proteases in the stomach.

Gastric perfusion experiments were carried out under anaesthesia in 29 sucking and 5 weaned Large White x Landrace pigs, 2 - 66 days of age, 1.6 - 18.0 kg body weight. Gastric secretion was collected during a 60 minute basal period and during a 60 - 120 minute period in which secretion was stimulated with an intravenous infusion of pentagastrin (4μg/kg/h). In gastric perfusates, MCA and GPA were determined using radial diffusion assays with purified porcine pepsin A as the standard. The procedures used have been described by Sangild *et al.* (1991, 1992).

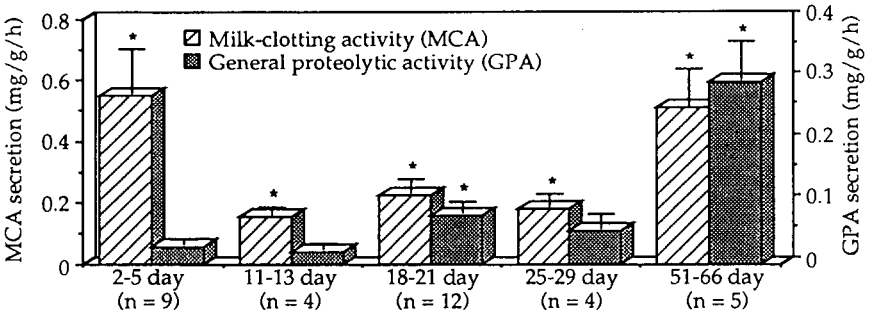

Figure 1. *Maximal pentagastrin-stimulated (4μg/kg/h) MCA and GPA outputs (pepsin A equivalents) per unit stomach weight in anaesthetized, sucking (2 - 29 day-old) and weaned (51 - 66 day-old) pigs (mean ± SEM). Differences between basal (not shown) and stimulated* MCA and GPA outputs, were significant (P<0.05).*

Pentagastrin significantly stimulated secretion of MCA in all sucking and weaned pigs, whereas significant stimulation of GPA secretion occurred only in 18 - 21 and 51 - 66 day-old pigs. The results for sucking pigs are in agreement with those of Sangild *et al.* (1991). In 2 - 5 day-old pigs the ratio between MCA and GPA stimulated secretion was 20:1, indicating that chymosin was the predominant protease. The decrease in the ratio to 8:1 in 11 - 13 day-old pigs, 3:1 in 18 - 29 day-old pigs and 1.7:1 in 51 - 66 day-old pigs, coincided with an increase in GPA secretion, particularly in the oldest pigs. The results indicate that in sucking pigs, chymosin secretion declines with age and GPA secretion is low. In weaned pigs, the marked increase in both GPA and MCA secretion indicates that the pepsins have become the predominant proteases. The mechanisms which control the qualitative and quantitative transition in the gastric proteases are not understood, but they could be related to changes in the nature and composition of the diet (Cranwell, 1985).

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THE DEVELOPMENT OF PANCREATIC PROTEASES IN SUCKING PIGS

I. Tarvid, P.D. Cranwell, L. Ma and R. Vavala

School of Agriculture, La Trobe University, Bundoora, Vic. 3083.

The pancreas produces several enzymes involved in protein digestion, including the endopeptidases trypsin, chymotrypsin and elastase, and the exopeptidases carboxypeptidase A and B. The aim of the present study was to investigate the postnatal development of pancreatic proteases in the sucking pig.

Pancreatic glands were obtained from 42 Large White x Landrace sucking pigs, 0 - 30 days of age, 0.6 - 11.5 kg body weight. Soluble protein was measured in homogenates of pancreatic tissue, and the zymogens underwent autoactivation for 24 - 96 hours at -4°C. Trypsin and chymotrypsin activities were measured using BAEE and BTEE as substrates (Walsh and Wilcox, 1970). Boc-gly-L-leu was used as a substrate in the assay for carboxypeptidase A activity - CPA (Tarvid, 1991), and casein for general proteolytic activity - GPA (Tarvid, 1992). Enzyme activities were expressed as per unit pancreatic weight, per unit protein content and per whole pancreas.

Table 1. Protein content and protease enzyme activities in the pancreatic gland of 0-30 day-old sucking pigs (Mean ± SEM)

	Newborn n=10	2 day-old n=10	10 day-old n=8	20 day-old n=8	30 day-old n=6
Protein (mg/g)	121.2±4.5	118.7±4.6	155.9±3.8*	166.7±5.8	164.6±4.1
(total)	124.8±17.9	291.8±27.7*	830.8±79.0*	1408.0±66.5*	1846.0±106*
Trypsin (/mg wt)	22.2±2.5	19.6±0.9	14.1±1.3*	14.2±2.1	25.5±1.0*
(/mg protein)	182.4±18.5	168.7±12.1	91.3±8.2*	86.8±14.1	155.5±5.7*
(total)	22,2±2.4	48,3±4.5*	74,7±9.7*	117,7±13.8*	284,6±10.2*
Chymotrypsin (/g wt)	5.7±0.3	5.1±0.2	4.2±0.1*	4.5±0.3	4.0±0.4
(/g protein)	46.4±2.4	43.9±3.0	27.1±1.1*	27.5±2.4	24.3±1.9
(total)	5.8±0.9	12.9±1.6*	22.6±2.5*	37.8±2.1*	46.0±6.1
GPA (/g wt)	2.1±0.6	1.7±0.1	4.2±1.1	2.8±0.2	1.7±0.3
(/g protein)	16.9±5.2	15.3±1.9	27.0±7.1	17.1±1.5	10.4±1.8*
(total)	1.9±0.5	4.5±0.5*	22.8±6.4*	24.0±2.3	21.8±3.8
CPA (/g wt)	3.9±0.6	1.6±0.1*	3.9±0.3*	9.5±1.1*	3.8±0.5*
(/g protein)	32.0±5.2	12.4±1.5*	25.0±2.0*	56.2±6.0*	23.3±2.7*
(total)	3.8±0.6	4.1±0.5	21.2±3.3*	79.7±10.3*	43.6±6.5*

*Within rows, values were different from those in the previous column, ($P<0.05$).

Total protein content, and total trypsin, chymotrypsin, GPA and CPA activities increased with age, except for CPA and GPA at 30 days. The highest levels of relative enzyme activities for trypsin and chymotrypsin occurred in newborn unsuckled pigs, the relative activities for both enzymes decreased up to 20 days, followed by a significant increase for trypsin at 30 days. No consistent trends were observed for relative CPA and GPA.

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A SYMPOSIUM - IMPROVING THE UTILIZATION OF AMINO ACIDS BY THE PIG

E.S. Batterham

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.

The overall efficiency of conversion of amino acids in feeds to pig meat is low. For example, in this Proceedings, Barnett *et al.* (1993) reports that only 41-46% of the dietary crude protein was retained by weaner pigs. This low utilization is due to the summation of: 1) inefficient utilization of amino acids by the pig, and 2) unavailability of amino acids in feed sources.

This low utilization is a high cost to the pig industry, as proteins are expensive feed components. It also results in considerable nitrogen being excreted in piggery effluent. In order to improve this efficiency, there is a need to be aware of the factors influencing utilization. Such information is also needed for computer simulation models of the pig, where the model attempts to follow the conversion of feed amino acids into pig meat. It is also needed when attempting to develop strategies to minimise nitrogen pollution from intensive pig production.

This Symposium discusses the progress of research in these areas. It highlights the rapid advances that have been made in our understanding of the changing requirements for amino acids as the pig matures, the limitations in our knowledge on the efficiency by which pigs utilize individual amino acids, the substantial losses in availability of amino acids during processing and the difficulty of detecting these changes. Finally, the potential for developing new techniques for rapidly assessing amino acid availability in feeds is examined.

EFFICIENCY OF AMINO ACID UTILIZATION IN THE PIG

D.H. Baker

Department of Animal Sciences and Division of Nutritional Sciences, University of Illinois, Urbana IL 61801, USA.

Introduction

The pig can be likened to a machine whose purpose is to convert poorly palatable plant-source foodstuffs to highly palatable and nutritious animal-source protein. Pig meat has a high protein quality and is rich in several important micronutrients, including zinc, iron and B-vitamins. An important goal in pig research is to make this machine as efficient as possible, while at the same time minimizing its efflux waste products.

Protein is a costly item in pig diets, so maximizing the efficiency of protein/amino acid utilization is very important. How can one maximize lean meat production with the absolute minimum intake of amino acids? Clearly, diets containing amino acids at minimally required levels (for maximal lean growth) with minimal excesses, is a critically important factor. Using chemically defined diets containing amino acids as the sole source of dietary nitrogen has allowed us to suggest that, with a near perfect amino acid balance, a 15 kg pig is capable of converting 87% of its absorbed nitrogen above maintenance to carcass protein (Chung and Baker, 1992a). This does not mean, however, that each of the 20 amino acids found in dietary protein are utilized at 87% efficiency for protein accretion. Indeed, some amino acids are used more efficiently than others, and understanding the rationale for this 'differential' efficiency is important in applying the concept of an ideal protein to practical pig production (Baker and Chung, 1992).

Ideal protein

Theoretically, an ideal pattern of amino acids should exist for each physiological function, but clearly, the ideal pattern will be different for each function, ie; maintenance, protein accretion, reproduction and lactation. For meat production, amino acid requirements can be separated into that required for protein accretion and that required for maintenance. Moughan (1989) and Fuller (1991) described maintenance as comprising: 1) urinary excretion of unmodified amino acids, 2) use of amino acids as precursors for other essential body metabolites (eg; creatine from arginine and glycine; taurine and glutathione from cysteine, or indirectly from methionine; thyroxin, melanin and catecholamines from tyrosine, or indirectly from phenylalanine; serotonin from tryptophan; nucleic acids and choline from glycine or serine; carnitine from trimethyl lysine; nitrous oxide and polyamines from arginine; carnosine from histidine), 3) amino acids lost from integuments and epidermal structures, 4) obligatory oxidation of amino acids, and 5) amino acids lost from gastrointestinal epithelia (mucous, mucosal cells, digestive enzymes).

Of the total requirement for a given amino acid, protein accretion comprises well over 90% of the need for pigs weighing 10 kg, but as pigs approach slaughter weight, maintenance assumes greater prominence in the total requirement for an amino acid (Fuller *et al.*, 1989; Black and Davies, 1991; Chung and Baker, 1992b, 1992c). Thus, while the ideal ratio of sulfur amino acids (SAA, ie; methionine + cystine) to lysine is 60% for 10 kg pigs (Chung and Baker, 1992a) the ideal ratio for the maintenance component of that requirement is 136% (Fuller *et al.*, 1989). Indeed, in every species where requirements for maintenance have been specifically studied, including studies with humans, the SAA requirement has exceeded the lysine requirement (Baker and Han, 1993). With an increasing contribution from maintenance as an animal grows toward slaughter weight, the ratio of SAA:lysine must increase, probably in a straight-line fashion, as a growing pig advances from 10 kg to 100 kg.

Based upon research with pigs in the weight category 10 to 20 kg, we have proposed a new ideal pattern of amino acids (Chung and Baker, 1992a; Baker and Chung, 1992). For the amino acids that are potentially limiting for pigs (ie; lysine, sulfur amino acids, threonine and tryptophan) our ratios (to lysine) are not greatly different from those proposed most recently by Wang and Fuller (1990), although we feel Wang and Fuller's (1989) original estimate for tryptophan (18%) is correct while their revised estimate (Wang and Fuller, 1990) of 20% is too high. The principal difference between our 'Illinois Ideal Protein' and that proposed by Wang and Fuller (1989, 1990) lies in levels of amino acids that are less likely to be limiting in practical-type diets. Thus, the Rowett group did not include estimates for arginine and histidine, and their levels of leucine, valine and aromatic amino acids are considerably higher than we feel are necessary.

Because the maintenance requirement for lysine is low relative to maintenance requirements for certain other amino acids (eg; threonine and cystine), ideal ratios of amino acids for young weanling pigs (5 to 20 kg) cannot be applied, without adjustment, to older market-type pigs. Our calculations have led to projections of ideal ratios of amino acids for three separate weight categories of pigs (Table 1).

Regarding SAA, there is another important factor that influences efficiency. The portion (wt:wt) of the total SAA requirement for protein accretion that can be furnished by cystine is about 50% (Chung and Baker, 1992c, 1992d), but at least 80% of the maintenance SAA requirement can be furnished by cystine (Baker *et al.*, 1966). Thus, while the optimum methionine:cystine ratio (wt:wt) for 10 kg pigs is 50%, the optimum ratio for 100 kg pigs is probably about 60%. Most feed ingredients used in pig rations contain more cystine than methionine. Giving cystine maximum benefit in meeting the total SAA requirement is therefore important. Moreover, in those situations where cystine is more limiting in a diet than methionine (eg; milk or casein-based diets), excess methionine is only about 80% efficient in supplying cystine metabolically (Graber and Baker, 1971).

Table 1. Ideal pattern of indispensable amino acids for pigs in three separate weight categories[1]

Amino acid	Ideal patterns (%) of lysine		
	5 to 20 kg	20 to 50 kg	50 to 100 kg
Lysine	100	100	100
Threonine	65	67	70
Tryptophan	18	19	20
Methionine	30	30	30
Cystine	30	35	40
Methionine + Cystine	60	65	70
Isoleucine	60	60	60
Valine	68	68	68
Leucine	100	100	100
Phenylalanine + Tyrosine	95	95	95
Arginine	42	36	30
Histidine	32	32	32

[1]From Baker and Chung (1990a).

Because of the complexities cited above for SAA, mistakes are often made in fortifying diets with methionine. An example may help to clarify the confusion. If a diet for 100 kg pigs contains 0.60% bioavailable lysine, and this is assumed to be the desired lysine requirement for the pigs in question, the diet should also contain 0.42% bioavailable SAA (Chung *et al.*, 1989; Chung and Baker, 1992a) consisting of 0.18% methionine (30% of lysine) and 0.24% cystine (40% of lysine). Lets suppose the diet, in fact, contains only 0.16% methionine and 0.20% cystine. The required level of DL-methionine supplementation is 0.07% of the diet and not 0.06% (ie; 0.42% - 0.36%). Thus, to correct the methionine deficiency of 0.02% requires 0.02% methionine, but to correct the cystine deficiency of 0.04% requires 0.05% methionine (0.04 ÷ 0.8). If the hydroxy analog of methionine is used to provide 0.07% methionine activity, 0.08% is needed, assuming the manufacturer's activity value of 88% is correct for pigs (Chung and Baker, 1992e).

In still another SAA dietary scenario, again for 100 kg pigs being fed a diet with 0.60% bioavailable lysine, let's suppose the diet, in fact, contains 0.16% bioavailable methionine and 0.26% bioavailable cystine. Although total SAA in this diet total to 0.42%, the desired level for 100 kg pigs (70% of 0.60 = 0.42%), the diet still requires fortification with 0.02% methionine to make it adequate in **useful** SAA. Hence, in this case the excess cystine (ie; 0.02%) is worthless as a source of SAA, because cystine cannot be converted to methionine.

At first glance, one might assume that a ratio of digestible tryptophan to digestible lysine of 20% for finishing pigs (Table 1) will result in more usage of supplemental tryptophan, which will in turn cause more usage of synthetic lysine. Thus, in US pig production involving simple corn-soyabean meal diets, it is generally assumed that for every two percentage units that dietary protein is lowered (by decreasing soyabean meal at the expense of corn), 0.15% additional crystalline lysine is needed. However, after the first incremental lowering by two percentage units, additional lowering of crude protein requires not only more lysine, but also requires supplemental tryptophan and threonine. Because soyabean meal is rich in tryptophan as well as lysine (tryptophan:lysine ratio = 22%), least-cost formulation schemes call for more soyabean meal rather than less. Thus, at 1992/93 prices, the tryptophan in soyabean meal is considerably less expensive than crystalline tryptophan. As a result, a likely scenario is that no supplemental tryptophan, and less, instead of more, crystalline lysine, will be used in the final least-cost ration.

As evidenced by the tryptophan example described above, least-cost diet

formulation on an ideal protein basis can be influenced significantly by the ratios used. Recent work by Burgoon *et al.* (1992) suggests that starter → grower → finisher tryptophan:lysine ratios of 18 → 19 → 20% are too high. Also, our recent tryptophan work with 15 kg pigs could be interpreted as suggesting that 17% of the digestible lysine as tryptophan is just as effective for young pigs as a ratio of 18% (Han *et al.*, 1993). The point being made here is that whether one uses 18 → 19 → 20%, or instead, 17 → 18 → 19% for a tryptophan:lysine ratio, can have profound effects on diet formulation and, in particular, on quantities as well as sources of both lysine and tryptophan that go into finished pig feeds. Interestingly, the situation could be quite different for barley/wheat-soyabean meal diets such as those used outside the US. Threonine and lysine are the important amino acids in these diets, and threonine unlike tryptophan, is not abundant in soyabean meal (nor in barley or wheat, either). Thus, the threonine:lysine ratio in soyabean meal is 64% which is lower than that prescribed in ideal protein.

Amino acid digestibility

In models of amino acid requirements, interpretation of amino acid digestibility presents problems. Research from Batterham's laboratory (Batterham *et al.*, 1990a; Beech *et al.*, 1991) has shown that digestible lysine, threonine and methionine from soyabean meal are better utilized (ie; after absorption) than digestible lysine, threonine and methionine from certain other (heat processed) feed ingredients such as cottonseed meal. Interestingly, the branched-chain amino acids are not similarly affected. A logical explanation is not obvious for the variable utilization of absorbed lysine, threonine and methionine from one ingredient to another, but this phenomenon represents a confounding problem for those attempting to model amino acid requirements.

Regarding amino acid digestibility, the work of deLange *et al.* (1989) demonstrated that measurement of endogenous amino acid losses from an ileal cannula in pigs fed a protein-free diet accurately estimates endogenous losses of indispensable amino acids, but not losses of dispensable amino acids, or total nitrogen. Thus, when pigs on a protein-free diet were given a complete amino acid mixture intravenously, nitrogen losses from the ileum decreased, and most of the decrease was accounted for by decreased losses of proline and glycine. With free amino acids, the available evidence suggests that the true digestibility of amino acids, both indispensable and dispensable, is essentially 100% (Izquierdo *et al.*, 1988; Han *et al.*, 1990; Chung and Baker, 1992f), although true digestibility measurements of proline and glycine are usually underestimated (Anonymous, 1990).

Efficiency of utilization of absorbed amino acids

The efficiency of amino acid utilization for an individual pig is not the same as for a population of pigs, even if that population is carefully defined by lean growth capacity. A certain quantity of each amino acid is needed for maintenance (ie; zero protein accretion), and those amino acids whose obligatory oxidation rates are low eg; lysine (Aguilar *et al.*, 1972 (under conditions of minimal protein intake); Heger and Frydrych, 1985; Simon *et al.*, 1978; Blemings *et al.*, 1989; Batterham *et al.*, 1990c; Baker, 1991) will have low maintenance requirements, whereas those having high endogenous excretion rates (eg; threonine) or heavy needs for keratoid protein and precursor purposes (eg; cystine) will have high maintenance requirements (Fuller *et al.*, 1989; Fuller, 1991; Chung and Baker, 1992b).

Above maintenance, utilization of most amino acids is probably constant, at least until the first pig in the population being sampled is satiated with regard to its need for maximal protein accretion. At this point (about 90% of maximal protein accretion for the defined population), protein accretion as a function of protein intake becomes curvilinear, increasing at a decreasing rate until zero slope is achieved. Zero slope

occurs when the pig in the population having the highest requirement is satiated.

What does it mean when it is said that the efficiency of lysine utilization above maintenance is 86% to 90% (Batterham *et al.*, 1990a, 1990c; Gahl *et al.*, 1992); or the efficiency for methionine is 72% (Chung and Baker, 1992b). It must mean that there are inefficiencies in uptake of amino acids for protein accretion. Thus, as we force the machine (ie; the pig) to go faster because of more fuel (amino acids) entering the carburettor (protein accretion machinery), we increase protein turnover, with synthesis increasing markedly, and degradation increasing to a lesser extent. Oxidation also likely increases, but this increase is not the obligatory oxidation associated with maintenance, but instead is oxidation associated with amino acid intake above maintenance. If one carefully examines the data of Brookes *et al.* (1972), it is apparent that lysine oxidation (mg/day) increases, but only slightly, as lysine intake above maintenance (but below the level required for maximal accretion) increases. By way of illustration, if we assume that: 1) maximal protein accretion occurs in a growing pig at an intake of 16 g lysine/day, 2) the 'total' lysine requirement is 15.8 g for protein accretion and 0.2 g for maintenance, and 3) of the 15.8 g needed for protein accretion only 13.59 g of lysine (86%) is retained, then at any level of lysine intake above maintenance (and before the inflection point in protein accretion is reached) 86% of that intake is deposited in protein and 14% is lost via oxidation. Clearly, this is what the straight line of Batterham *et al.* (1990c) implies, ie; the slope of lysine retention as a function of (absorbed) lysine intake is 86%. Hence, at 6 g intake above maintenance, 5.16 g lysine is retained and 0.84 g is oxidized; at 12 g intake above maintenance, 10.32 g is retained and 1.68 g is oxidized.

With methionine, the inefficiency of methionine retention as methionine intake above maintenance increases is greater than the inefficiency associated with increased lysine intake above maintenance (Chung and Baker, 1992b). It seems likely that most of the inefficiency of methionine utilization for protein accretion is caused by increased oxidative catabolism of methionine as methionine intake increases. Thus, our data suggest that 28% of the (absorbable) methionine intake above maintenance is lost (mostly to oxidation), exactly double the loss occurring with increased lysine intake above maintenance.

With cyst(e)ine, the situation is considerably more complex because in addition to its high maintenance requirement and the oxidation associated with intake above maintenance, cysteine is an important precursor of other necessary body metabolites (taurine, glutathione, chondroitin sulfate, intestinal metallothionine and cysteine-rich intestinal binding protein). Moreover, it is very probable that the cystine need for synthesis of these compounds increases as cysteine intake above maintenance increases (Chung and Baker, 1990). Clearly, the cystine need of pigs as a percent of lysine must increase as a pig gets older - due to maintenance *vs.* growth considerations. Also, however, it seems likely that the efficiency of cyst(e)ine retention above maintenance will be even lower than that for methionine.

Efficiency-related issues

There are several issues that are germane to the efficiency with which amino acids are utilized by pigs. These are itemized and discussed below.

Frequency of feeding

With amino acid-fortified, intact-protein diets, infrequent meal ingestion (eg; once per day in gestating sows) leads to inefficient use of the free amino acid supplement (Batterham and Murison, 1981; Batterham, 1984). This is logical in that the free amino acid will be absorbed more rapidly than the lysine made available by digestive enzymatic hydrolysis. This 'temporary' excess at the tissue level will result in oxidative losses of the free amino acid, and if the excess is great, some urinary spillage of the amino acid may occur.

Nonessential vs essential amino acids

There is a tendency to focus our attention on the classic 10 essential amino acids (Rose, 1938) and ignore the remaining 10 amino acids that are required for protein synthesis and growth. While these so-called nonessential amino acids can be synthesized in the body from glucose plus nitrogen from the essential amino acids (or ammonia), dietary provision of the 10 nonessential amino acids as such, or as glutamic acid, is far more efficient for protein accretion than is relying on excess essential amino acids to meet this need (Stucki and Harper, 1961; Allen and Baker, 1974). Hence, minimizing excess essential amino acids makes good sense, so long as the nonspecific amino nitrogen component of the diet is sufficient to fully meet the need for nonessential amino acid biosynthesis. In practice, there is seldom, if ever, a deficiency of nonspecific amino nitrogen (largely nonessential amino acids). Instead, excesses generally exist - and such excesses are costly sources of energy. Therefore, minimizing excesses of not only essential amino acids, but of nonessential amino acids as well, is a worthwhile goal.

Effects of excess amino acids on utilization of limiting amino acids

In practice, excesses of amino acids are expensive sources of energy, but the available evidence suggests that the excess amino acids in commercial pig diets do not affect the efficiency with which limiting amino acids are utilized for protein accretion (Sugahara *et al.*, 1969; Southern and Baker, 1982; Cieslak and Benevenga, 1984; Edmonds and Baker, 1987a, 1987b; Edmonds *et al.*, 1987). Greatest excesses in practice occur with leucine, arginine, aromatic amino acids and total nitrogen (ie; the sum of the nonessential amino acids). Oxidative catabolism of these (excess) amino acids yields metabolizable energy (between 14 and 17 kj/g), and it is likely that 99% of the excess amino acids are ultimately catabolized. Thus, only with excess amino acid levels considerably greater than those occurring in practice will urinary spillage of free amino acids occur.

The benefits of the ideal protein concept for diet formulation reside in making maximal use of amino acids for tissue protein synthesis and minimizing their use for energy. The 'cost' of the excess amino acids is not in terms of affecting the efficiency of utilization of the amino acids that are not in excess. The excess amino acids in some diets, however, can result in a reduction in voluntary feed intake (Sugahara *et al.*, 1969). In fact, work with chicks has clearly shown that increments of lysine above the level required to maximize weight gain results in small, but statistically measurable decreases in feed intake (Han and Baker, 1991, 1993). Because weight gain remains constant and feed intake decreases, gain:feed ratio increases, as does protein accretion. But these responses, though significant, are small. It remains for the modeller to ascertain, therefore, whether absolute maximal feed efficiency or absolute minimal body fat deposition is compatible with maximal economic returns to the producer.

Amino acid fortified diets

Why is it that there are limitations in how low one can go in intact protein, even with plentiful amino acid fortification, without sacrificing animal performance. We have done extensive work in this area with chicks fed low protein corn-soyabean meal diets (Edmonds *et al.*, 1985; Han and Baker, 1992) and similar work has been done with pigs (Russell *et al.*, 1986, 1987). In the chick work, when a standard 23% protein corn-soyabean meal diet was modified to 16% protein, no amount or variety of amino acid supplementation could bring the weight gain or feed efficiency back to that achieved with the 23% protein positive-control diet. This was true, whether the protein was lowered by adjusting the ratio of corn:soyabean meal, or by cornstarch dilution of the corn-soyabean meal blend in the 23% protein diet. In young pigs, lower protein amino acid fortified corn-soyabean meal diets result in performance equal to that obtained with a positive-control normal protein corn-soyabean meal diet - so long as the protein reduction does not exceed four percentage units (Russell *et al.*,

1986, 1987). When a 16% protein diet for 30 kg pigs was lowered to 11%, supplementation with lysine, tryptophan, threonine, isoleucine, valine, methionine and glutamic acid restored weight gain to the positive control level, but feed intake was greater in pigs fed the amino acid-fortified 11% protein diet than in those fed the 16% protein control diet. Thus, restoration of feed efficiency was not achieved. It seems that lower protein corn-soyabean meal diets (wherein excess essential amino acids are minimized) often result in greater feed intake as a result of the superior amino acid balance (Baker *et al.*, 1975; Russell *et al.*, 1986, 1987). That feed efficiency often decreases rather than increases suggests that the incremental increase in feed intake may be used primarily for fat rather than protein accretion. Perhaps with genetically superior pigs (ie; high lean growth potential) this would not occur.

Recent unpublished results from our laboratory have used the young chick as a model animal to attack the problem of limitations in amino acid fortification of diets. The results have been encouraging in that an ideal protein system of amino acid fortification (Baker and Chung, 1992) has led to progress. Thus, if soyabean meal is used to provide only 8% crude protein, no essential amino acid is in excess of its required level for maximal protein accretion. If this soyabean meal-dextrose diet is brought to 10% protein equivalent with glutamic acid, one can then fortify (up to ideal levels) the diet with methionine, threonine, lysine, valine and histidine and achieve far better performance, than that achieved by fortifying the diet with these same amino acids, up to levels prescribed by NRC (1984), for chicks fed a 23% crude protein corn-soyabean meal diet. While these results are encouraging, 8% intact protein is probably too low in terms of achieving maximal feed efficiency. Thus, our birds fed the low protein, amino acid-fortified diet overate feed, perhaps in an attempt to meet their protein-amino acid needs. Hence, while we came very close to maximizing weight gain, feed efficiency fell far short of maximum. Clearly, more research is needed in this area to determine if a specific peptide requirement may exist, particularly for poultry.

The chemically defined diet developed for young pigs between 10 and 20 kg body weight (Chung and Baker, 1991) offers a tool to study the problem discussed above. This diet (14.7% protein equivalent) when fed properly allows pigs to perform at levels similar to those of pigs fed a standard 20% protein corn-soyabean meal diet (with 10% dried whey). This offers hope that the restrictions on amino acid fortification of low-protein diets can ultimately be lifted, and the problems cited above can be solved.

AVAILABILITY OF AMINO ACIDS IN FEEDS

E.S. Batterham

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.

The preceding paper dealt with the efficiency of utilization of amino acids by the pig. The utilization of amino acids from feed sources is further reduced, as many are not fully available to the pig. During processing of protein concentrates, the heat used to remove moisture, inactivate anti-nutritional factors and/or extract oil can cause changes to the protein molecule. These changes don't normally affect the determination of total amino acids in the feeds, as the acids used to digest proteins are non specific and can liberate amino acids from unnatural linkages. However, the pig's enzymic digestive system is highly specific and is unable to act on unnatural linkages, thereby rendering the amino acid unavailable.

The problem of amino acid availability has been the subject of considerable research at Wollongbar for a number of years. Due to space constraints, this paper will concentrate on summarising these findings, rather than reporting a more general review of this topic.

Loss of availability of amino acids can be detected by growth assays, where the pig's response to graded levels, of say lysine, in a test protein is compared to the response to graded levels of free (or standard) lysine. Such assays are commonly called slope-ratio assays. Using these assays, the availability of lysine in protein concentrates in Australia has been shown to be a major problem, varying from 34% in cottonseed meal to 108% in ring-dried bloodmeals (Table 1). Of further concern is that the majority of the protein concentrates produced locally had low and often variable availabilities of lysine, ie; meat and bone meals (42-97%), cottonseed meals (27-43%), sunflower meals (60%) and lupin-seed meals (37-74%).

Table 1. Availability of lysine in protein concentrates for growing pigs[1]

Protein concentrate	Availability	
	Mean	Range
Blood meal (ring-dried)	1.08	1.03-1.13
Cottonseed meal	0.34	0.27-0.43
Field peas	0.93	-
Lupin-seed meal	0.55	0.37-0.74
Meat meal and meat and bone meal	0.68	0.42-0.97
Peanut meal	0.57	-
Rapeseed meal	0.87	0.77-0.97
Skim milk powder	0.85	-
Soyabean meal	0.88	0.80-0.98
Sunflower meal	0.60	0.54-0.66

[1]From Batterham (1992).

The limitations of slope-ratio assays are that they are time consuming, expensive, only one amino acid can be assessed at a time, and they have relatively high standard errors. They are therefore not satisfactory for routinely determining amino acid availability. An alternative is the ileal digestibility assay, where the digestibility of amino acids is determined at the terminal ileum. This assay has the advantage that hindgut fermentation is avoided, it requires less resources and all ten essential amino acids can be assessed at the one time. This assay has been used extensively overseas in the development of amino acid feeding standards.

The assumption is made with the ileal digestibility assay that, if an amino acid is digested in the small intestine, then it is absorbed in a form suitable for protein synthesis by the pig. This assumption is not necessarily correct. The problem is illustrated, when a comparison is made between lysine availability and ileal digestibility, in three cottonseed meals and a soyabean meal.

The results (Table 2) indicate that ileal digestibility and lysine availability were similar in soyabean meal, but in the cottonseed meals, ileal digestibility over-estimated availability. Furthermore, formulating diets to similar available lysine levels, utilizing the availability values from cottonseed meal no 2 and the soyabean meal, confirmed that the availability values were suitable for formulating diets (Batterham *et al.*, 1990b).

To further examine the effectiveness of the ileal digestible assay for estimating amino acid availability, a series of experiments was conducted at Wollongbar. Rather than develop individual availability assays for each of the essential amino acids and compare the results with ileal digestibility values, an alternative approach was adopted. Diets were formulated from cottonseed meal, representing a uniform, low quality meal and soyabean meal, a uniform high quality meal, to an equal ileal digestible amino acid content (say lysine) and the utilization of the ileal digestible lysine determined. If all the ileal digestible lysine was in a form suitable for protein synthesis, then similar growth responses and retention of ileal digestible lysine should result. This procedure can be applied to all the essential amino acids by simply re-

formulating the diets to similar ileal digestible levels of, say threonine and assessing threonine utilization. This is much simpler than developing separate slope-ratio assays for each of the essential amino acids for comparative studies.

Table 2. Comparison of ileal digestibility and availability (proportion of total) of lysine in cottonseed and soyabean meals[1]

		Ileal digestibility	Availability
Cottonseed meal No.	1	0.58	0.27
	2	0.68	0.30
	3	0.72	0.29
Soyabean meal		0.89	0.90

[1]From Batterham *et al.* (1990b).

Initially, the ileal digestibility of amino acids in the two protein sources were determined (Batterham *et al.*, 1990a, 1994). Semi-synthetic diets were then formulated, with the test protein as the only protein source in sugar-based diets. This approach avoids any interference of nutrients contributed by the conventional cereal base, and allows a direct determination of the utilization of the test amino acid from a protein concentrate. The diets were supplemented with free amino acids to an approximate 0.30 surplus, to ensure the test amino acid was limiting. An additional two diets were also supplemented with the test amino acid, to verify that it was in fact limiting. The diets were given to growing pigs, at a feeding scale of three times maintenance, over the 20 to 45 kg growth phase. At the completion of the experiment, the protein and amino acid composition of the empty bodies of the pigs was determined.

Lysine

For the lysine experiment, diets were formulated with the cottonseed and soyabean meals as the only source of ileal digestible lysine (0.36 g/MJ digestible energy (DE)) in sugar-based diets.

The results (Table 3), for lysine, indicated that growth performance of the pigs was markedly inferior when given similar levels of ileal digestible lysine from cottonseed meal, relative to soyabean meal. Furthermore, the retention of ileal digestible lysine from cottonseed meal was only 0.36, compared to 0.75 for pigs given soyabean meal. These results show that a considerable proportion of the ileal digestible lysine from cottonseed meal was apparently absorbed in a form/s that was inefficiently utilized by the pig. As such, the ileal digestibility assay over-estimated availability in heat-damaged proteins. This finding supported earlier work of Batterham *et al.* (1990b).

Threonine

Diets were re-formulated with the protein sources as the only source of ileal digestible threonine (0.22 g/MJ DE).

Similar results to lysine were recorded for threonine (Table 3). Growth performance and the retention of ileal digestible threonine were lower for the pigs given cottonseed meal, compared to soyabean meal. The proportion of ileal digestible threonine retained by the pigs was only 0.44 for pigs given cottonseed meal, compared to 0.64 for pigs given soyabean meal.

These results indicate that, as for lysine, a considerable proportion of ileal digestible threonine was apparently absorbed in a form/s that was inefficiently utilized. This indicated that ileal digestible values over-estimated threonine availability in heat-damaged meals.

Table 3. Utilization of ileal digestible amino acids in cottonseed and soyabean meals[1]

	Cottonseed	Soyabean	Significance
Amino acids metabolised in the liver			
Lysine		(0.36 g/MJ DE)	
Gain (g/day)	365	524	*
Protein deposition (g/day)	38	77	*
Lys retained:id lys intake	0.36	0.75	*
Threonine		(0.22 g/MJ DE)	
Gain (g/day)	396	504	*
Protein deposition (g/day)	47	75	*
Thr retained:id thr intake	0.44	0.64	*
Methionine		(0.09 g/MJ DE)	
Gain (g/day)	384	461	*
Protein deposition (g/day)	47	61	*
Met retained:id met intake	0.39	0.47	*
Tryptophan		(0.05 g/MJ DE)	
Expt 1. Gain (g/day)	227	274	NS
Protein deposition (g/day)	37	45	NS
Try retained:id try intake	0.13	0.45	*
		(0.065 g/MJ DE)	
Expt 2. Gain (g/day)	367	411	NS
Protein deposition (g/day)	54	63	NS
Try retained:id try intake	0.46	0.38	NS
Phenylalanine		(0.22 g/MJ DE)	
Gain (g/day)	506	548	*
Protein deposition (g/day)	77	86	NS
Phen retained:id phen intake	0.65	0.75	*
Branched-chain Amino Acids			
Valine		(0.27 g/MJ DE)	
Gain (g/day)	505	508	NS
Protein deposition (g/day)	70	72	NS
Val retained:id val intake	0.58	0.66	*
Isoleucine		(0.23 g/MJ DE)	
Gain (g/day)	533	553	NS
Protein deposition (g/day)	83	91	NS
Iso retained:id iso intake	0.65	0.73	*
Leucine		(0.41 g/MJ DE)	
Gain (g/day)	536	550	NS
Protein deposition (g/day)	77	77	NS
Leu retained:id leu intake	0.70	0.69	NS

[1]From Batterham *et al.* (1990a, 1993a,b), Beech *et al.* (1991), Batterham and Andersen (1994) and unpublished results. Gain (g/day) is on an empty body-weight basis. The first tryptophan experiment was for 28 days only.

Methionine

A level of 0.09 g ileal digestible methionine/MJ DE was used in the methionine experiment. Growth performance and protein deposition was again lower for the pigs given cottonseed meal, compared to soyabean meal (Table 3). However, there was little difference in the retention of ileal digestible methionine in pigs given the two protein sources, although overall retentions were low relative to those recorded with lysine and threonine. Overall the results indicated that ileal digestible values over-estimated methionine availability in heat-damaged meals.

Tryptophan

Two experiments were conducted with tryptophan, the first at 0.05 g and the second at 0.065 g ileal digestible tryptophan/MJ DE. There was considerable variation in pig response, much higher than that experienced with pigs given the other amino acid diets, and the majority of responses were non significant ($P>0.05$). Never-the-less, there were indications that the ileal digestible tryptophan from cottonseed meal was used with slightly less efficiency than that from soyabean meal, especially in the first experiment (Table 3). Overall retention of ileal digestible tryptophan by the pigs was low in both experiments.

These results, together with results from a meat and bone meal (Batterham *et al.*, 1993b) again indicate that the ileal digestibility of tryptophan is not a good indicator of tryptophan availability.

Phenylalanine

Diets were formulated to 0.22 g ileal digestible phenylalanine/MJ DE. The results indicate that ileal digestible phenylalanine was also inefficiently utilized in cottonseed meal, relative to soyabean meal.

Isoleucine, leucine and valine

The results for these three amino acids were contrary to the previous five amino acids, as there were no differences in growth performances and little difference in the retentions of these amino acids in pigs fed the cottonseed or soyabean meal diets (Table 3).

These results indicate that the branched-chain amino acids, isoleucine, leucine and valine, appear less sensitive to heat damage and the ileal digestibility of these amino acids reflects availability. These amino acids differ from the other amino acids, in that they are considered less reactive, and appear less sensitive to the effects of heat (van Barneveld *et al.*, 1994a). They are also metabolized mainly in muscle tissue, whereas the other amino acids are metabolized in the liver. It is possible that, chemically, these amino acids are less susceptible to the effects of heat during processing, or that any changes induced have little or no effect on subsequent protein synthesis in the muscle tissue.

Summary

Amino acids appear to vary in their sensitivity to processing conditions. Lysine, threonine, methionine, tryptophan and phenylalanine are sensitive, and changes in their amino acid profiles appear to occur which do not necessarily effect digestibility, but render the amino acid unavailable for protein synthesis. As a consequence, ileal digestibility over-estimates availability of these amino acids in heat-damaged meals. It was also interesting to note that there were differences in the apparent sensitivity of these amino acids to heat damage. Thus, separate techniques for measuring their availabilities appear warranted.

In contrast, the branched-chain amino acids, isoleucine, leucine and valine,

appeared less sensitive to processing damage and the ileal digestibility assay appears suitable for estimating availability.

There were also large differences in the retention of individual amino acids. For pigs given soyabean meal, retentions varied from 0.75 for lysine to 0.38 for tryptophan. Part of these differences may be due to the use of only a single concentration in the diets and the retention of individual amino acids may vary with level of intake. The differences most probably reflect the different uses of amino acids for maintenance, physiological processes and lean deposition.

Overall, these results indicate that, for the amino acids metabolised predominantly in the liver (lysine, threonine, methionine, tryptophan and phenylalanine) processing damages these amino acids in such a way that, whilst ileal digestibility is little affected, availability is depressed. However, the branched-chain amino acids, valine, isoleucine and leucine, which are metabolised predominantly in the muscle tissue, are largely insensitive to heat processing, and ileal digestibility more closely reflects availability.

Effect of heat on the digestibility, availability and utilization of lysine

It was presumed that the large differences in the utilization of amino acids in cottonseed and soyabean meals were due to the effects of heat used in the processing of these meals. This was confirmed by van Barneveld *et al.* (1994a,b,c,d) when investigating the effect of heat on the digestibility, availability and retention of lysine.

Field peas were used by van Barneveld *et al.* (1994a,b,c,d) as they are not heated prior to use (coarse crushing only). Batches of the field peas were heated in a forced-draught dehydrator to 110°, 135°, 150° and 165°C for 15 minutes.

The initial work examined the effect of heat on the ileal digestibility of amino acids in field peas. The results (Table 4) indicated that the ileal digestibility of lysine improved slightly with heat, then decreased.

Table 4. The effect of heat on the ileal digestibility of lysine (proportion of total)[1]

	Heat treatments				
	0°	110°	135°	150°	165°
Lysine	0.92	0.97	0.92	0.93	0.84

[1]van Barneveld *et al.* (1994a).

Diets were then formulated to an equal ileal digestible lysine content, utilizing the above five treatments and determining the growth performance, protein deposition and retention of ileal digestible lysine of growing pigs. The results (Table 5) indicated that heat depressed growth rate, protein deposition and lysine retained:ileal digestible lysine intake.

Table 5. Growth response and lysine retention in growing pigs given diets formulated to 0.36 g ileal digestible lysine /MJ DE, when the diets were formulated from heat-treated field peas[1]

	Heat treatments				
	0°	110°	135°	150°	165°
Gain (g/day)	498	482	477	450	315
Protein deposition (g/day)	76	69	68	61	36
Lysine retained:ileal digestible lysine intake	0.85	0.65	0.68	0.63	0.45

[1]van Barneveld *et al.* (1994b).

Lysine availability was then determined in the five field peas using a slope-ratio assay. The results in Table 6 show that heat depressed the availability of lysine in all heated batches of field peas.

Table 6. Lysine availability (proportion of total) in field peas subjected to increasing levels of heat[1]

	Heat treatments				
	0°	110°	135°	150°	165°
Availability of lysine	0.96	0.71	0.77	0.56	0.47

[1]van Barneveld *et al.* (1994c).

Overall, the results show that:

- Heat induces changes to lysine which have little effect on ileal digestibility but a marked effect on lysine availability.
- This effect can occur at a very modest heat input - 110° for 15 minutes.
- As such, the ileal digestibility assay overestimates lysine availability in heat-damaged meals.

Originally it was hypothesised (Batterham, 1992) that lysine availability and ileal digestibility would be similar for good quality meals, and, as heat was applied, the reduction in availability would be greater than for ileal digestibility. However, van Barneveld *et al.* (1994c) indicates that this is not the case for field peas (Figure 1). Heat initially improved the ileal digestibility of lysine whilst, at the same time, depressed availability.

These results have substantial implications in the processing of protein concentrates. In many grain legumes, heat is used to inactivate anti-nutritional factors and the ileal digestibility of the processed meals is used to define optimum processing conditions. The results of van Barneveld *et al.* (1994a,b,c,d) indicate that considerable reduction in lysine availability could be occurring, even in mild processing of such meals.

Summary

Overall, these studies indicate that the availability of amino acids from protein concentrates can be severely depressed by the application of heat during processing. Lysine availability varies from approximately 30 to 95% in commercial protein concentrates. The problem is not confined to lysine, and threonine, methionine, tryptophan and phenylalanine are also affected. Furthermore, the majority of protein concentrates produced locally suffer from loss of availability. There is an urgent need for the development of rapid assays, that can be used to assess amino acid availability in feeds for pigs, so that diets can be formulated at least cost, to specified amino acid concentrations, using local protein sources.

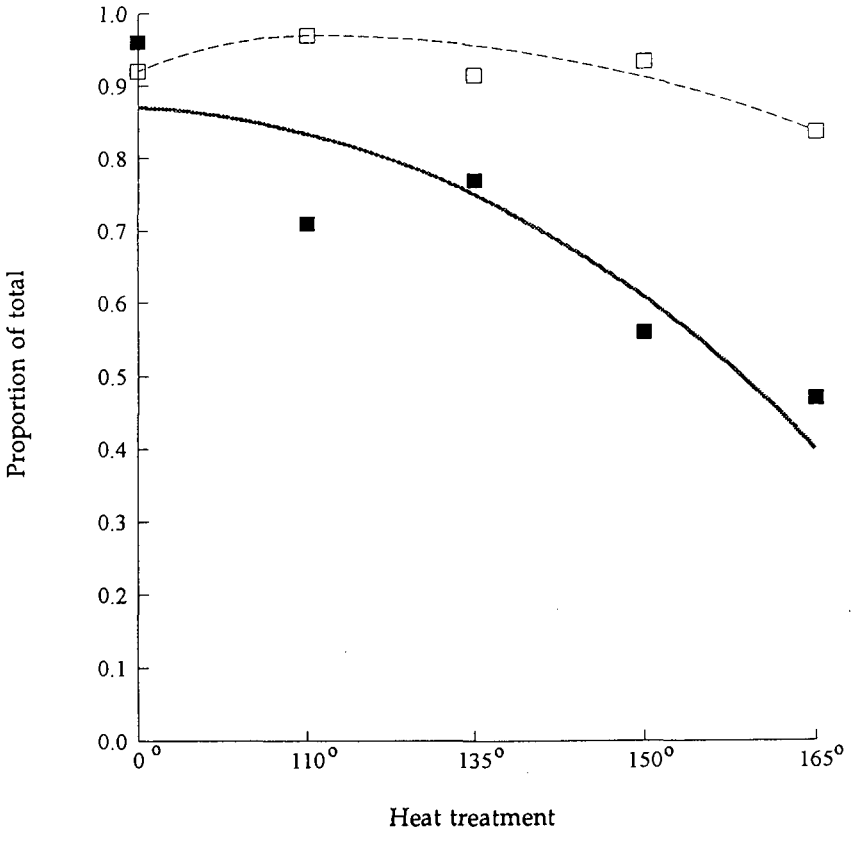

Figure 1. *The relationship between the application of heat and the ileal digestibility (- - -) and availability (——) of lysine in field peas (from van Barneveld et al., 1994c).*

RAPID ASSESSMENT OF AMINO ACID AVAILABILITY FOR GROWING PIGS - DEVELOPMENT AND POTENTIAL

R.J. van Barneveld

South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.

Introduction

The use of amino acid availability estimates in diet formulation helps facilitate accurate matching of the diet to the pigs requirements, for the least possible cost (Batterham *et al.*, 1990). In addition, the use of availability values results in a reduction in nitrogen excretion by the pig thus reducing pollution, ensures more even growth rates and therefore more reliable production, and allows the choice of the most cost-effective ingredients.

Amino acid availability has been defined as that proportion of an amino acid in a diet that is absorbed in a form suitable for utilization by the animal (Batterham, 1980; Sauer and Ozimek, 1986), or similarly, that proportion of an amino acid which is not combined with compounds which interfere with digestion, absorption and metabolism (Low, 1982; Harrison, 1989; Batterham, 1987). Numerous techniques have

been evaluated as a means of estimating amino acid availability, including the slope-ratio analysis of pig, rat and chick growth assays, chemical analysis of proteins, ileal digestibility determination and microbiological techniques. Based on the criteria of speed, efficiency, accuracy and minimal expense, however, a suitable amino acid availability assay for protein concentrates used in pig diets still eludes us.

As shown in the previous paper, the availability of amino acids can vary considerably in vegetable and animal protein meals. Without a rapid amino acid availability assay, we are unable to account for this variability. The significance of this variability is realised if we examine the quantity of some proteins supplied for use in Australian pig diets, the amount of available lysine represented by the range in availability estimates for these proteins (eg; availability estimates for cottonseed meal range from 0.27 - 0.43; if cottonseed meal has a total lysine content of 17.9 g/kg, this range represents 2.9 g available lysine/kg of cottonseed meal) and then attempting to place a dollar value on this amount of available lysine (based on the price of supplying equal amounts of synthetic lysine; Table 1).

Table 1. Estimated value of the lysine that is affected by the differences in lysine availability estimates for five protein sources used in Australian pig diets

	Protein meal				
	Cot	Soya	Rape	Sun	Meat
Quantity for pig diets ('000 t)[1]	1352[2]	100[3]	80[2]	55[3]	475[4]
Mean total lysine (g/kg)[5]	17.9	28.0	18.6	10.9	26.9
Estimate range in availability estimates (%)	16	18	20	11	55
Quantity of available lysine represented by range (t; Range x total lysine x quantity)	386.6	504.0	297.6	65.9	7027.6
Estimated value of available lysine within range (A$ million)[6]	1.99	2.59	1.53	0.34	36.0

Cot, cottonseed; Soya, soyabean; Rape, rapeseed; Sun, sunflower; Meat, meat and bone. [1]Quantity of each protein concentrate available in Australia for use in pig diets. Sources of information: [2]Cargill Oilseeds; [3]Australian Bureau of Statistics; [4]Australian Renderers Association; [5]Standing Committee on Agriculture. [6]Based on cost of A$4,000/t for L-lysine HCl (78% available lysine).

The variation in lysine availability estimates for the five protein sources examined in Table 1 represents approximately 8,300 tonnes of available lysine, with an estimated value of A$42 million. If all other amino acids and protein sources were also considered, this figure would be far greater. The development of a rapid amino acid availability assay is urgently required to allow assessment of all protein sources, prior to inclusion in pigs diets, to account for this variability.

The aim of this paper is to: 1) evaluate existing techniques and their potential to rapidly assess amino acid availability, 2) review current research that may assist the development of a rapid amino acid availability assay, and 3) suggest potential new techniques for the rapid assessment of amino acid availability.

Potential for existing techniques to rapidly assess amino acid availability

Growth assays

1. *Advantages*: Accurate biological assay; true measure of availability by definition.

2. *Disadvantages*: Time consuming; expensive; only one amino acid can be assessed at a time; complex dietary formulations and statistical analysis; standard errors

of the measurements are high.

3. *Future role in amino acid availability assessment*: A standard technique against which others can be compared during the development of a more rapid assay.

The criterion for measuring (as opposed to estimating) amino acid availability is met by applying the slope-ratio analysis (Finney, 1964) to a growth assay with treatments designed to measure the slope of response to an amino acid. Batterham (1992) outlined, in detail, the conditions that need to be addressed when designing a slope-ratio assay and the statistical constraints that must be met before measurements obtained with the slope-ratio analysis can be considered valid.

As mentioned in the previous paper, Batterham *et al.* (1990) conducted a growth assay to measure the applicability of availability measurements for a variety of protein sources, determined using the slope-ratio assay. Diets formulated to equal levels of available lysine produced similar growth responses, regardless of protein source (Table 2). Despite the fact that only one lysine level was used, the retention of lysine was equal, indicating equal utilization. To this end, it can be concluded that the slope-ratio assay can provide an accurate measure of amino acid availability.

Table 2. Growth responses and lysine retentions of pigs fed diets formulated to equal levels of available lysine[1]

Diet N°.....	1 Cot	2 Cot+Lys	3 Cot+Lys +AA	4 Soya	*LSD* P=0.05
Lysine (g/kg)					
Total	8	10.1	10.1	8	
Available	4.9	7	7	7	
Gain (g/d)	541	607	610	631	22
FCE	0.424	0.470	0.479	0.492	0.017
Protein deposited (g/d)	74	90	94	99	5.3
Lysine retained:available lysine intake	0.72	0.57	0.64	0.64	0.038

[1]Batterham *et al.* (1990). AA, amino acids; Cot, cottonseed meal; FCE, feed conversion efficiency; LSD, least significant difference; Lys, lysine.

Apart from the time, expense and complexity associated with the slope-ratio assay, Fuller (1991) suggested a further limitation, based on reports by Sato *et al.* (1987), is that it underestimates the ileal digestibility of amino acids as increments of free amino acid added to the basal diet improve the quality of the dietary protein, whereas increments of amino acid from the test protein do so to a lesser extent, if at all. Fuller (1991) speculated that there may be an exaggerated response to the free amino acid, resulting from the rectification of an amino acid imbalance. This results in a reduction in amino acid availability measurements by up to 0.18 (Sato *et al.*, 1987). This limitation, although an important consideration, could be avoided by attempting to maintain an equal amino acid balance in all diets when formulating for the slope-ratio assay and by restricted feeding at regular (eg; 3 h) intervals.

The above limitations restrict the potential of growth assays with pigs to rapidly assess the availability of amino acids. In addition, comparative availability studies with pigs, rats and chicks have shown little relationship between these three species (Batterham, 1992), and hence the use of faster growing, less expensive pig models is not a viable alternative. Most slope-ratio studies have also been conducted to

determine the availability of lysine in proteins, which is normally the major limiting amino acid in cereal-based diets. Developing suitable basal diets for other amino acids would be more difficult and more expensive than for lysine. Slope-ratio analysis of growth assays, however, will play an important role in the development of a rapid availability assay, as it should be considered as a standard technique against which others can be validated.

Chemical techniques

1. *Advantages:* Rapid; conducted *in vitro*; inexpensive.

2. *Disadvantages:* Overestimates biological availability; usually measure lysine availability only; use highly toxic chemicals (eg; 1-fluoro-2,4-dinitrobenzene).

3. *Future role in amino acid availability assessment:* Limited. May have a role in conjunction with a biological assay.

The majority of chemical techniques used to estimate lysine availability are based on binding the free ε-amino group of lysine with a specific receptor or dye. Carpenter (1960) hypothesised that those lysine units in heat-processed foods that were bound to other groups via their ε-amino group would be unable to *react* with other compounds, such as the carbonyl groups of reducing sugars, and hence were likely to also be nutritionally unavailable. Specific receptors that have been employed include 1-fluoro-2,4-dinitrobenzene (FDNB; Carpenter, 1960; Rao *et al.*, 1963; Roach *et al.*, 1967), trinitrobenzenesulphonic acid (TNBS), O-methyisourea and sodium borohydride (Hurrell and Carpenter, 1974). Hurrell and Carpenter (1975) examined the use of acid azo dyes including Remazol brilliant blue, cresol red and Acid Orange 12. Chemical techniques have the advantage of being rapid and comparatively inexpensive. Most, however, are directed at estimating lysine availability only and these values appear to be significantly greater than biological availability measurements.

The use of FDNB by either the Carpenter (Carpenter, 1960) or Silcock technique (Roach *et al.*, 1967) is widely accepted as the standard *in vitro* assay for monitoring heat damage and lysine availability in proteins. The technique detects a reduction in reactive amino acids with the application of heat (Hurrell and Carpenter, 1974, 1975; Varnish and Carpenter, 1975; Hurrell *et al.*, 1976), but the applicability of these values to pigs is questionable. Batterham (1992) compared the lysine availability in various protein meals, determined using slope-ratio assays with pigs, and by the FDNB direct technique and Silcock lysine technique. There was little agreement between the techniques, with FDNB methods producing consistently higher estimates than those determined by the slope-ratio analysis. Van Barneveld (1993) measured the availability of lysine in raw field peas and field peas heated to 110°, 135°, 150° or 165° using the slope-ratio analysis of pig growth assays and the Silcock lysine technique (Table 3). From these results it is clear that, although the FDNB assay can be used to monitor heat damage in proteins, it is not suitable as a measure of biological amino acid availability for the growing pig.

Davies (1992) examined the relationship between some compounds commonly formed with the application of heat to proteins, and lysine availability. D-lysine, alloisoleucine and lysinoalanine were determined in sixteen commercial protein supplements, on which lysine availability had been measured by slope-ratio assay with pigs, or by chemical dinitrophenylation. It was found that the presence of D-lysine, lysinoalanine and alloisoleucine were not significantly correlated with lysine availability. Davies (1992) concluded that unidentified reactions with lysine apparently produce forms of lysine that are absorbed but not efficiently utilized.

Table 3. Total lysine (g/kg, air-dry basis) and available lysine (g/kg) in raw field peas and field peas heated to 110°, 135°, 150° or 165° determined using the slope-ratio analysis of pig growth assays, or by the Silcock lysine technique[1]

	Heat treatment				
Parameter	0°(Raw)	110°	135°	150°	165°
Total lysine	14.6	15.2	15.2	12.6	8.7
Silcock-reactive lysine	14.6	15.0	14.7	11.2	6.1
Available lysine	14.0	10.8	11.7	7.1	4.1

[1]van Barneveld (1993).

Chemical techniques have largely been applied to determine lysine availability in heated proteins. Current techniques used to measure total amino acids, 'reactive' amino acids and to identify heat-induced compounds, have not been able to be applied to estimate the biological availability of amino acids subjected to some form of heat treatment. Despite this, even if heat-induced bonds and compounds could be identified, quantified and shown to influence availability, it is likely that there would be numerous variations in bond configuration or compound formation, depending on the starting composition of the protein concentrate. As a consequence, the relationship between chemical changes within a protein source and biological availability would be very difficult to establish, limiting the future of chemical techniques as rapid amino acid availability assays. There is a need to identify a suitable biological/animal response for the rapid accurate determination of amino acid availability.

Microbiological techniques

1. *Advantages:* Rapid, biological assay; conducted *in vitro*; more than one amino acid can be assessed simultaneously; inexpensive.

2. *Disadvantages:* Limited validation with pigs.

3. *Future role in amino acid availability assessment:* Cannot be discounted as a rapid assay - further research required.

The use of microbiological assays to estimate amino acid availability and protein quality has been applied for many years. In general, certain microorganisms have a specific requirement for an amino acid. By determining this requirement with standard or free amino acids, the organism can be used to estimate how much of an amino acid is available within a test protein.

In comparison with the direct FDNB technique, Stott and Smith (1966) found that availability estimates obtained using *Tetrahymena pyriformis* and FDNB were highly correlated for meals of high lysine availability, but for meals of low availability the microbiological estimates were significantly lower. Ford (1965) steamed cod fillets at 121° for 24 h and estimated available lysine using FDNB and *Streptococcus durans*. Estimates were 0.62 and 0.37 of the unheated control respectively. Ford and Salter (1966) estimated lysine availability using *Streptococcus durans* in cod fillets heated at 135° for 18 h to be 0.42 of the unheated control compared to 0.59 using FDNB. Batterham (1973) used *Tetrahymena pyriformis W* to estimate the available amino acid content of feeds for pigs. Pig performance was depressed by feeding heat-damaged soyabean meal, however, the addition of free lysine, methionine and tryptophan according to *Tetrahymena* availability estimates, only overcame 0.43 of the effects of heat damage. Batterham (1973) initially speculated that the *Tetrahymena* values were not applicable. Subsequent investigations (Batterham and Murison, 1981) revealed that once-daily feeding resulted in poor utilization of the free amino acids making

interpretation of the previous results difficult. It can be concluded from these studies that microbiological techniques for estimating amino acid availability are more sensitive than the FDNB techniques. Their use in practical diet formulation for growing pigs remains largely uninvestigated, and hence, they can not be discounted as an alternative to the slope-ratio assay.

Ileal digestibility

1. *Advantages:* Rapid biological assay; all amino acids can be assessed simultaneously; inexpensive; estimated means have relatively low standard errors.

2. *Disadvantages:* Overestimates amino acid availability in heated proteins.

3. *Future role in amino acid availability assessment:* Estimation of availability in cereals and unheated proteins, and isoleucine, leucine and valine in heated proteins (E.S. Batterham, personal communication).

The basis for the application of the ileal digestibility assay as an estimate of amino acid availability is the assumption that if an amino acid is not recovered at the terminal ileum, then it has been absorbed in a form suitable for utilization. Some amino acids from heated proteins such as fructoselysine, however, can be digested but are unavailable for use by the pig (Erbersdobler, 1977).

In the previous paper, Batterham compared the availability and ileal digestibility of lysine in cottonseed and soyabean meals for grower/finisher pigs and concluded that for meals of high availability, such as soyabean meal, reduced digestibility appears to be the main reason for reduced availability, but in meals of low availability, such as cottonseed meal, ileal digestibility is not a reliable indicator of lysine availability.

Similarly, van Barneveld (1993) compared the ileal digestibility and availability of lysine in raw and heat-treated field peas for growing pigs to show a much greater reduction in availability than ileal digestibility when heat is applied. This is further evidence to suggest that ileal digestibility is not a reliable indicator of availability in heat-treated meals. Despite this, lysine digestibility values are still widely used when formulating diets containing heated proteins. An estimate of the cost of this practice, in terms of lost production, can be obtained as follows using the AUSPIG computer simulation model.

The lysine digestibility and availability of three commonly used heated proteins are displayed in Table 4. A grower diet and a finisher diet were formulated on a least-cost basis using lysine digestibility values for these heated proteins (Table 4).

If lysine digestibility was equal to lysine availability in heated proteins, the nutrient composition of the formulated diet would support the following pig performance based on an AUSPIG simulation of the Northfield Pig Research Unit piggery:

Daily gain (g/d; 5-77 kg):	665
P2 (mm; at 77 kg):	12.5
FCR:	2.52
Feed costs ($/pig):	35.48
Profit ($/pig):	23.00

Diets containing heated proteins formulated on a digestibility basis are likely to be deficient in a number of amino acids and the amino acid profile will be imbalanced. By substituting availability values for digestibility in these diets and re-simulating pig performance, the consequences of using digestibility values is realised:

Daily gain (g/d; 5-77 kg):	628
P2 (mm; at 77 kg):	13.8
FCR:	2.57
Feed costs ($/pig):	35.98
Profit ($/pig):	20.00

Table 4. Lysine digestibility and availability of heated proteins and dietary inclusion following least-cost formulation using digestibility values

Heated protein	Lysine digestibility (%)	Lysine availability (%)	Inclusion (%)[1]	
			Grower	Finish
Soyabean meal (over-processed)	88	82	2.5	-
Cottonseed meal	72	30	10	5
Meat-and-bone meal	74	52	10	6.5
Dietary digestible lysine (%)			0.80	0.70
DE (MJ/kg)			14.0	14.2

[1]Diets were wheat-based and supplemented with free lysine, methionine, vitamins and minerals, limestone, dicalcium phosphate and tallow.

This simulation reveals that the use of lysine digestibility values for heated proteins could cost this piggery in excess of $3.00 profit per pig. If this was a 150 sow unit, this would mean an $8,000 - 10,000 annual production loss. As well as an increase in feed costs, profits have dwindled due to poorer carcass quality.

The wide range of heated protein sources used in Australian pig diets limits the potential for ileal digestibility assays to rapidly assess amino acid availability. In the interim, the large number of existing measures of ileal digestibility of amino acids in unheated protein sources can be used as estimates of amino acid availability in these proteins.

Simulation models

1. *Advantages:* Rapid, inexpensive.

2. *Disadvantages:* Estimation only; Improvements in accuracy required.

3. *Future role in amino acid availability assessment:* High potential pending a better understanding of the metabolism and utilization of amino acids by growing pigs.

Black and Davies (1987) reported how the AUSPIG computer simulation model could be used to estimate amino acid availability. The model calculates whether sufficient amino acids are available from the feed, to allow the maximum rate of protein deposition for the defined situation, and determines the order in which the essential amino acids would be limiting. When the supply of an amino acid is limiting protein deposition, the model assesses the effect of the deficiency on protein gain, fat deposition and live-weight change (Black *et al.*, 1986). Hence, when used to simulate experiments investigating the effects of increasing intake of either total protein or individual amino acids, the model can provide an assessment of the availability of the most limiting amino acid.

Black and Davies (1987) made comparisons between AUSPIG predictions and experimental observations of amino acid availability. They reported that the availability values estimated using ileal digestibility had to be reduced by 0.25 when lysine was the limiting amino acid in the diet before predictions were similar to

observations. This suggests that either the availability of lysine is lower than estimated or that the metabolic uses and costs of lysine utilization are not fully understood (Batterham, 1987).

Isotopic-labelling of CO_2

1. *Advantages:* Rapid; biological basis; small number of pigs required.

2. *Disadvantages:* Inaccurate; only one amino acid assessed at a time; expensive.

3. *Future role in the assessment of amino acid availability:* There seems little potential for this technique as a rapid amino acid availability assay.

Black and Batterham (1987) proposed a new method for determining amino acid availability in pig diets. The method is based on the fact that when the supply of an amino acid changes from a deficit to an excess, there is a major increase in its oxidation. Hence, if a tracer dose of ^{14}C labelled amino acid is given in the diet, there will be an increase in the proportion of the labelled dose appearing as $^{14}CO_2$ when the amino acid is in excess. The procedure assumes that the labelled amino acid mixes with the free amino acid pool and enters the various metabolic pathways in the same proportion as the unlabelled amino acid entering that pool. The shape of the relationship between $^{14}C0_2$ excretion and amino acid intake will vary depending on amino acid availability. An availability estimate is achieved by regressing the slope of $^{14}C0_2$ excretion when fed a test protein to the slope of $^{14}C0_2$ excretion when fed the amino acid in a free form. Black and Batterham (1987) stated that the amino acid must be supplied in excess of requirement, the concentration of the amino acid in the free pool and the proportion of amino acid following each metabolic pathway must not change substantially with increases in amino acid intake, and the feeding regime must allow full utilization of the free amino acid, for the method to be valid.

Unfortunately, the variability associated with the results have been too great for the assay to give reliable estimates of lysine availability (Ball *et al.*, personal communication).

Development of a rapid amino acid availability assay

It is clear that there is no existing technique that meets the criteria of a rapid amino acid availability assay. Current areas of research, however, may provide the basis for the development of such an assay.

Biochemical understanding of the poor utilization of amino acids from heated proteins

When discussing the need for simple, rapid techniques for assessing amino acid availability, Batterham (1987) stated that "progress to this end will be slow as long as information on the causes of reduced amino acid availability are not fully understood".

Having established the relationship between the digestibility, availability and utilization of lysine from raw and heated field peas, van Barneveld (1993) attempted to determine the fate of poorly utilized lysine from these heated proteins. This study examined the nitrogen (N) balance and urine, serum and plasma composition of growing pigs fed raw field peas and peas heated to 150° or 165°. It was found that there was no significant difference in the proportion of ileal digestible N retained, or the proportion of ileal digestible N excreted in the urine of pigs fed the various pea treatments using N balance techniques (Table 5).

Despite no apparent difference in the proportion of ileal digestible N excreted in the urine and a lower ileal digestible N intake by pigs fed peas heated to 165°, van Barneveld (1993) reported total protein excretion in the urine of these pigs to be 3 - 7 times (depending on estimation technique) the level observed in pigs fed diets containing raw peas. This suggests that a proportion of non-utilizable amino acids in heated field peas may be excreted from the pig via the urine in the form of a peptide

or protein. This is consistent with results of Ford and Shorrock (1971), who reported a three-fold increase in the total urinary excretion of peptide-bond amino acids by rats fed heat-treated cod-fillet protein. Further research is required to examine the capacity of the growing pig to digest and utilize peptides, and the correlation between peptide formation in heated proteins and poor amino acid utilization.

Table 5. Ileal digestible N intake, N retained : ileal digestible N intake and urine N: ileal digestible N intake in growing pigs fed raw and heated field peas[1]

	Heat treatment		
	0°	150°	165°
Ileal digestible N intake (g/day)	31.5	30.4	23.5
N retained:ID N intake	0.67	0.70	0.73
Urine N:ID N intake	0.33	0.30	0.27

[1]van Barneveld (1993).

In addition, Batterham (1992) reported that the branched-chain amino acids isoleucine, leucine and valine appear less sensitive to heat damage than other amino acids. Isoleucine, leucine and valine are primarily metabolized in the muscle rather than the liver (the site of metabolism for most other amino acids) and hence it is possible that any heat induced changes have little or no effect on subsequent protein synthesis in the muscle tissue. To this end, an examination of visceral (gut and liver) metabolism of amino acids may identify reasons for the poor utilization of heated amino acids.

Current research being conducted at the Victorian Institute of Animal Science is addressing some of the above aspects. Objectives of this project include the development of techniques to measure the concentration of small peptides in physiological fluid, so that their contribution to amino acid digestion and absorption can be ascertained, and the application of chronic portal-hepatic preparations (to determine nutrient absorption and hepatic exchanges), and chronic hind-limb cannulations (to determine nutrient exchanges in skeletal muscle; F.R Dunshea, personal communication). This will provide an understanding of the role of visceral and skeletal muscle metabolism in the regulation of growth and development, and may provide basic principles, that can be applied in the development of a rapid amino acid availability assay.

It has been suggested that ileal digestibility determinations with heated proteins are not interpretable (P.J. Moughan and S.M. Rutherfurd, personal communication). During early Maillard reactions, the ε-amino group of lysine is susceptible to binding with reducing sugars to form the biologically unavailable deoxyketosyl lysine. This compound can be hydrolysed to lysine in the presence of strong acids, and hence, conventional total amino acid analysis significantly overestimates the reactive lysine content of the heated protein. Ileal digestibility determinations are further confounded by overestimates of reactive lysine and different digestibilities of reactive lysine and deoxyketosyl lysine.

Moughan and Rutherfurd (personal communication) are attempting to clarify ileal digestibility estimates in heated proteins by developing and applying the guanidination reaction (the conversion of lysine to homoarginine using O-methyisourea) coupled with traditional true ileal digestibility assays with rats and pigs. If successful, results from this work may account for some of the lysine from heated proteins that is apparently absorbed but poorly utilized by growing pigs.

Further research that may be assist the development of a biochemical understanding of heating mechanisms include:

1. The use of isotopically-labelled amino acids within a protein source, that is exposed to heat and then fed to growing pigs. This would allow the fate of heat-treated amino acids to be traced through the various metabolic pools of the pig. The difficulty associated with this approach is obtaining suitable quantities of a protein source with labelled amino acids, and the expense associated with obtaining such a source.

2. Van Barneveld (1993) revealed a high degree of variation associated with the analysis of urine parameters. This variation may be due to interference from brown pigments, consistent with advanced Maillard reactions, that are excreted in the urine. Further research is required to improve the accuracy associated with the analysis of urine from pigs fed heated proteins.

3. Digestibility studies with heated proteins assume that if an amino acid is not recovered at the terminal ileum, then it has been absorbed into the portal blood. It is possible, however, that some heat affected amino acids are being metabolized in the gut wall (Rerat, 1990). Techniques need to be developed to measure the extent of amino acid metabolism in the gut wall of pigs.

4. To date, amino acid digestibility and utilization has largely been considered in isolation. There is a need to improve our knowledge of interactions from other dietary components (eg; non-starch polysaccharides) and their effect on nutrient utilization.

Potential new techniques for the rapid assessment of amino acid availability

In the long term, near infra-red reflectance (NIR) spectrophotometry may have application as a rapid amino acid availability assay, based on the principle that compounds with similar chemical groupings absorb infra-red radiation at characteristic wavelengths. NIR is inexpensive, requires minimal preparation, is accurate when properly calibrated and already forms an integral part of quality control (protein analysis) in many Australian feed mills. Van Leeuwen *et al.* (1991) reported the applicability of NIR analysis for ileal digestibility in feedstuffs. A calibration of the NIR was made based on a wide variety of ingredients, in which digestibility had been previously determined using digesta collection. A high correlation was found between the digestibility values determined using NIR and *in vivo* results. The major limitation to developing NIR analysis for availability estimation is the lack of suitable standards for calibration. It would seem necessary to develop separate calibration curves for individual protein concentrates for lysine, threonine, methionine and tryptophan and this would be a substantial undertaking (Batterham, 1992).

An uninvestigated biological approach to the determination of amino acid availability is the use of tissue culture. Successful culture of viscera and skeletal muscle from pigs is feasible with modern techniques. Utilization of amino acids from the base media of these cultures can then be used as a guide to amino acid metabolism in the respective tissues. Despite being rapid and accurate, this approach is highly specialized and could not be conducted on a routine basis.

Conclusions

Research to date has revealed the benefits of applying amino acid availability values in diet formulations, however, as we lack a suitable rapid amino acid availability assay, their use is currently limited.

Existing techniques that have a future in amino acid availability assessment include the slope-ratio analysis of growth assays, microbiological techniques, ileal digestibility assays and simulation models. In the interim, ileal digestibility values can be applied as estimates of amino acid availability in cereals, unheated proteins and for

the branched-chain amino acids isoleucine, leucine and valine in all proteins. Microbiological techniques lack suitable validation with pigs and appear to have been discounted unnecessarily. The slope-ratio analysis will play a role in the development of a more rapid assay as a standard against which the accuracy of new techniques can be compared.

Current research is addressing a number of areas that may lead to the development of a more rapid amino acid availability assay. These areas include developing an understanding of the biochemical mechanisms associated with the poor utilization of ileal digestible lysine from heated proteins, and more accurate determination of ileal digestibility in heated proteins. If a suitable amino acid availability assay can be developed with a biological basis, more rapid, routine techniques that employ NIR or simulation models may be applied.

Through collaborative research and a thorough understanding of amino acid metabolism in the growing pig, a rapid amino acid availability assay is well within our grasp, and the subsequent benefits are likely to be invaluable to the Australian pig industry.

SYMPOSIUM CONCLUSIONS

E.S. Batterham

As outlined in this Symposium, substantial advances have been made in our understanding of the balance of amino acids required by the pig. It is now possible to accurately specify the amino acid needs, taking into account the changing effects of maintenance as the pig develops. Requirements may also be estimated using computer simulation models, such as AUSPIG, which have the additional advantages of being able to take into account an even wider range of factors influencing needs. Progress is also being made in assessing the efficiency of utilization of amino acids during growth. More work is needed in this area, as at this stage, estimates are only available for lysine and methionine, and there is still uncertainty of the estimates of utilization of these amino acids.

Whilst considerable progress has been made in our knowledge of amino acid requirements, little progress has been made in the development of techniques for rapidly estimating amino acid availability. The availability of lysine (and other amino acids) varies greatly in conventional feed sources, from approximately 30 to 95%. Despite the magnitude of the problem, there is no technique currently available for estimating amino acid availability in feeds.

This problem has developed, in part, due to the emphasis that researchers have placed on developing the ileal digestibility assay. It had been hoped that this assay could be used to predict the availability of all ten essential amino acids. To this extent, considerable progress has been made in the development of feeding standards, based on the apparent ileal digestibility of amino acids. However, as outlined in this Symposium, recent research has shown that this assay over-estimates availability in heat-damaged meals for lysine, threonine, methionine, tryptophan and phenylalanine. It is now evident that separate availability assays are required for these five amino acids for heat-processed protein meals.

Defining the problem is relatively easy, finding solutions will be a real challenge. Much research is needed to determine the biochemical mechanisms whereby amino acid availability is depressed in feed sources. Until this information is available, there will be no real basis for developing new techniques for rapidly predicting amino acid availability in potential feed sources.

Until such techniques are developed, there is little potential to accurately match feed specifications with amino acid requirements of the pig and progress in improving the efficiency of utilization of amino acids in feeds will be retarded.

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THE EFFECTS OF BETAINE ON THE GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FEMALE PIGS

D.J. Cadogan, R.G. Campbell, D. Harrison and A.C. Edwards

Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

The role of betaine in metabolism as a methyl donor is reasonably well understood, and betaine is used commercially in poultry and pig nutrition as a partial replacement for choline chloride. However, Saunderson and Mackinlay (1990) reported a significant reduction in the carcass fat content of chickens offered diets supplemented with betaine. A dose response study, conducted at Bunge Meat Industries, also indicated an effect of betaine on the subcutaneous fat thickness of pigs grown from 55 to 90 kg live weight. The present experiment was conducted to investigate further the effects of betaine on the growth performance and carcass characteristics of female pigs growing from 60 to 103 kg live weight.

Two groups of 20 crossbred female pigs were allocated at 60 kg to the same basal diet (13.5 MJ DE/kg and 0.54 g available lys/MJ DE) supplemented with 0 and 1.25 kg betaine/tonne. The pigs were housed in individual pens, and offered the experimental diets *ad libitum* for a period of at least 35 days, or until each pig approached a live weight of 103 kg. The depth of backfat (P_2), measured using real time ultrasound, was recorded each week. As each pig reached slaughter weight, it was removed from feed and sent for slaughter the following morning. Once sacrificed, head-off, hot carcass weight and depth of subcutaneous fat (P_2), were measured and recorded.

The results (Table 1) showed betaine had no effect on any measure of growth performance or on carcass weight, but reduced depth of backfat by 14.8% (2.6 mm).

Table 1. Effects of offering female pigs a diet supplemented with betaine, from 60 to 103 kg, on growth performance and carcass characteristics

	Betaine (kg/tonne)		SEM	Significance[1]
	0	1.25		
Live-weight gain (g/d)	919	922	21	NS
Feed conversion ratio	3.06	3.01	0.02	NS
Hot carcass weight (kg)	75.0	75.3	0.34	NS
Dressing percentage (%)	72.8	73.4	0.29	NS
Final P_2 (mm)	17.6	15.0	0.49	*

[1]NS, non significant, $P>0.05$; * $P<0.01$.

The weekly results showed that P_2 fat thickness did not differ between treatments until day 21, when pigs offered the diet supplemented with betaine exhibited a 2.2 mm lower P_2 than their control counterparts. The results suggest betaine may be an effective means of manipulating the subcutaneous fat thickness of growing pigs. Whether the reduction in P_2 elicited by betaine is associated with a concomitant reduction in carcass fat, or simply a redistribution of fat, is currently being investigated.

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FORMULATING COMMERCIAL GROWER DIETS USING AUSPIG

B.P. Mullan, G.T. Davies* and M. Charles**

Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030. *DSL Systems Centre, CSIRO Division of Animal Production, Prospect, PO Box 239, Blacktown, NSW 2148. **Berrybank Farm, Ballarat, Vic. 3352.

Commercial diets have traditionally been formulated, using accepted minimum requirements for amino acids, without regard to the specific conditions prevailing on the farm. Simulation models such as AUSPIG (Black *et al.*, 1986) make it possible to account for the complex number of interacting factors which can influence an animal's requirement. The aim of this experiment was to compare the performance of pigs on a 1200 sow commercial piggery, when fed either existing diets or those formulated to AUSPIG specifications.

AUSPIG diets for grower and finisher pigs were formulated to contain the same ingredients and the same level of digestible energy (14.3 and 14.0 MJ DE/kg, respectively) as the diet currently being fed (C). AUSPIG diets were formulated to supply either 90, 105 or 120% of simulated amino acid requirements (90, 105 and 120, respectively) for the mean level of performance in the herd. Entire males (N = 36) commenced the experiment at approximately 66 days of age (24 kg LW) and were housed in groups of 18 during the grower phase (41 days) and groups of nine during the finisher phase (42 days).

Table 1. The performance of pigs fed existing diets or those formulated using AUSPIG

		90	105	120	C	LSD[1]
Av lys/MJ DE	Grower	0.41	0.47	0.53	0.72	
	Finisher	0.39	0.43	0.49	0.55	
Cost of diet ($/t)	Grower	226	240	251	292	
	Finisher	227	230	240	247	
ADG (g)	Grower	544^{a}	559^{a}	583^{b}	612^{c}	20.9
	Finisher	1029^{ab}	1012^{a}	1117^{c}	1069^{bc}	55.5
Slaughter	LW (kg)	89.5^{a}	88.7^{a}	95.2^{b}	94.3^{b}	3.49
	P_2 (mm)	17.0	16.6	17.8	16.8	1.72
Grower + finisher	Feed:gain[2]	2.74	2.70	2.61	2.71	
phase	ADG (g)	789^{a}	788^{a}	853^{b}	843^{b}	41.6
Profit (vs C)	$/pig[2]	+6.08	+7.10	+1.85	0.00	

[1]Within rows, means not followed by a similar superscript differ ($P<0.05$). [2]Calculated on a pen-basis.

Pigs fed the AUSPIG 90 and 105 diets were significantly lighter at slaughter, although there was no difference in depth of backfat (Table 1). AUSPIG diets for the grower and finisher phase had been formulated for pigs weighing 27 and 58 kg, respectively, but since the actual LW at the start of each phase was less than this, then the 105 diet is likely to have been deficient for a greater proportion of pigs in that group than was intended. The results demonstrate how profitability can be increased using AUSPIG to calculate nutrient requirements and, that under the circumstances prevailing at the time, maximizing growth rate was not the most profitable alternative.

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ON-FARM DETERMINATION OF THE UPPER-LIMIT TO BODY PROTEIN DEPOSITION IN GROWING PIGS

P.C.H. Morel, G. Pearson, H. Derix, B. Schutte and P.J. Moughan

Monogastric Research Centre, Massey University, Palmerston North, New Zealand.

The upper-limit to body protein deposition rate (Pd_{max}) is an important constraint on growth in pigs, and is known to be affected by genotype and gender. However, on commercial farms other non-nutritional factors (eg; subclinical disease) can prevent growing pigs from achieving their Pd_{max}. Lack of information on the maximum protein retention achievable on commercial farms (operational Pd_{max}), limits efficient application of pig growth simulation models. This study was to develop a method for estimating operational Pd_{max} for pigs on commercial farms. It was assumed that Pd_{max} is constant during the finishing period, 60 to 85 kg LWT (Whittemore *et al.*, 1988; Jacobson, 1992).

A diet (14.3 MJ DE and 9.4 g digestible lysine per kg air-dry feed) known to be able to support body protein retention of 190 g/day was fed *ad libitum* to pigs from 60 kg live weight (LWT) to slaughter at 85 kg LWT. Backfat thickness was measured on the left side at the last rib, 6.5 cm from the midback (P_2) with ultrasound (US, mm) and on the cold carcass at 85 kg LWT, with a ruler (BF, mm). Total body protein (TBP) was estimated at the beginning and end of the trial using regression equations derived from a whole body composition slaughter experiment, conducted at Massey University with commercial Large White/Landrace (LW/LR) crossbred pigs (Jacobson, 1992):

TBP1 (kg) = 0.590 + 0.190 x LWT - 0.227 x US [n=19 R^2=0.94 RSD=0.766]

TBP2 (kg) = 0.038 + 0.194 x LWT - 0.208 x BF [n=19 R^2=0.95 RSD=0.739]

The study was conducted on three commercial farms. LW/LR crossbred pigs, of the same strain and similar to those investigated in the slaughter experiment, were kept on farms A and C and LW/LR/Hampshire crossbred pigs on farm B. Daily food intakes of the diet were 2985 ± 66, 2486 ± 46 and 2955 ± 77 g/day on farms A, B and C respectively. Estimated operational Pd_{max} values are presented in Table 1.

Table 1. Operational maximum body protein retention (Pd_{max}) for male (M) and female (F) pigs on three commercial farms (Least Square Means ± Standard Errors)

	Farm				Sex		
	A	B	C		F	M	
Number of pigs	37	63	18		56(38)[4]	62(43)[4]	
Pd_{max} (US)[1] (g/day)	-	161±3	149±6	NS[3]	147±5	163±5	*
Pd_{max} (BF)[2] (g/day)	177±5	156±4	143±7	***	148±5	170±5	***

[1] Pd_{max}(US) = (TBP1 at slaughter - TBP1 at 60 kg) / number of days on trial. [2] Pd_{max}(BF) = (TBP2 at slaughter - TBP1 at 60 kg) / number of days on trial. [3] NS, non significant, P>0.05; * P<0.05; *** P<0.001. [4] Pd_{max}(US) data on farm B and C only.

The importance of determinating Pd_{max} on farm is illustrated by the comparison of farms A and C. Pigs of the same genotypic strain eating similar quantities of the same diet showed large differences in Pd_{max}. It is concluded that the developed protocol is potentially useful for determining operational Pd_{max}. More robust prediction equations and independent validation of the method are required.

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THE RELATIONSHIP BETWEEN DAILY ENERGY INTAKE AND PROTEIN DEPOSITION IN PIGS OF DIFFERENT BODY WEIGHTS

P. Bikker, V. Karabinas, M.W.A. Verstegen and R.G. Campbell*

Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands. *Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

Conflicting theories have been published, concerning the effects of body weight and energy intake on protein and lipid deposition (Campbell, 1988). Identification of these effects in the growing pig is essential, both for the development of an appropriate feeding strategy, and for simulating the growth response of the animal to nutrient intake. This experiment was designed to determine the relationships between energy intake, and protein and lipid deposition, as affected by body weight in genetically improved animals.

Fifty-two female pigs of improved genotype were used in this study. Four animals were sacrificed at 20 kg to determine their initial body composition. Twenty-four animals, divided into six groups of four, were fed a protein-adequate diet (CP 19.9%, total lys 0.75 g/MJ DE) from 20 to 45 kg. The respective energy intake levels were *ad libitum*, and 1.7, 2.2, 2.7, 3.2 and 3.7 times maintenance (calculated as 0.475 MJ DE/$kg^{0.75}$). The remaining 24 animals were fed at the same six energy intake levels from 45 to 85 kg. From 20 to 45 kg, these animals had received the same diet at an intake level of 3.7 times maintenance. The animals were sacrificed and body composition (protein and lipid) was determined, at 45 and 85 kg respectively.

Protein deposition increased linearly with increasing energy intake: from 70 to 170 g/d between 20 and 45 kg, and from 80 to 180 g/d between 45 and 85 kg (Figure 1).

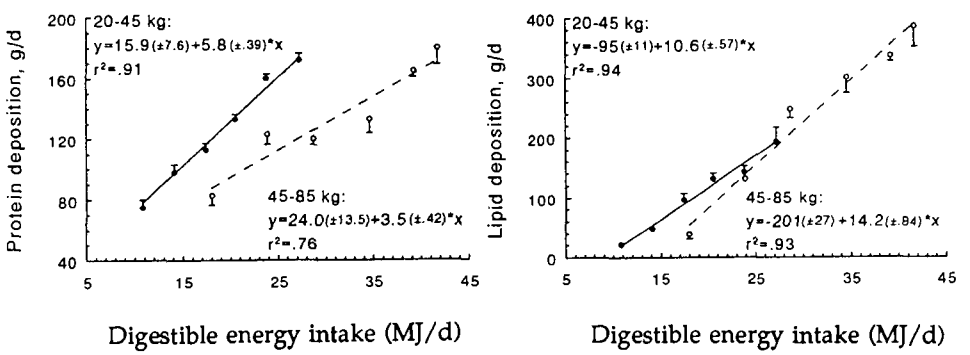

Figure 1. *Relationships between energy intake, and protein and lipid deposition in female pigs from 20 to 45 kg (●---●), and from 45 to 85 kg (o---o).*

It was concluded that for these pigs, the maximum protein deposition lay beyond the limits of feed intake capacity, for both body weight ranges. The slope of the linear relationship between energy intake and protein deposition decreased with increasing body weight. Consequently, between 45 and 85 kg the pigs will deposit twice as much lipid daily as between 20 and 45 kg, given similar rates of protein deposition. As a result, the optimum dietary protein to energy ratio will decrease with increasing body weight.

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GROWTH RESPONSE OF PIGS TO TOTAL DIETARY LYSINE: EFFECTS OF BREED AND SEX

D.N. Singh, J.S. Kopinski and K.C. Williams

Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.

The performance of growing pigs is determined largely by relationships between intake of protein (or lysine in cereal-based diets) and energy. These relationships are influenced by sex and genotype at given live weights (reviewed by Campbell, 1987). Previous studies by McPhee *et al.* (1991) indicated that the total lysine requirement for growth and lean deposition of growing pigs selected from low backfat and control lines was 20 g and 17 g/d respectively, when fed to restrictively. The objective of this study was to investigate the growth response to dietary lysine in growing pigs of both sexes, from two breeds selected for low backfat, when fed *ad libitum*.

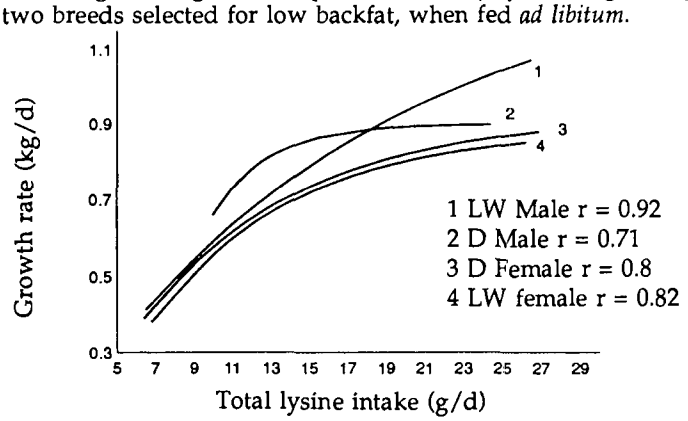

Figure 1. *Growth rate response to total dietary lysine intake.*

A 2x2x8 factorial expt was conducted with 64 individually housed pigs to compare two breeds (Duroc, D; Large White, LW) and two sexes (entire males; females) when offered diets providing eight levels of lysine. Diets in the grower period (25-50 kg) were based on wheat and soyabean and were 14 MJ DE/kg; lysine to DE varied from 0.5 to 0.85 g/MJ. In the finisher period (50-90 kg), diets were 13 MJ DE/kg with barley replacing wheat and the lysine/DE varied from 0.4 to 0.75 g/MJ.

This paper reports preliminary best-fit regression analysis of the data. In the grower period, growth rate improved linearly with lysine intake up to the maximum achieved intake of 20 g/d, irrespective of sex and breed. However, maximum growth rate of LW was better than D (0.89 vs 0.83 ± 0.015 kg/d) even though both breeds had similar feed intakes (2.03 vs 1.91 ± 0.028 kg/d). In the finisher period, growth rate response to lysine intake was curvilinear (Figure 1). Maximum growth rate was achieved by D males with a daily lysine intake of 19 g/d, whereas the LW males were still responding at the maximum achieved intake of 27 g/d. Although neither of the female lines achieved maximum growth, an intake of 27 g/d appeared to be close to the maximum response. Since there was no difference in daily feed intake between sex (2.57 vs 2.42 ± 0.047), or breed (2.47 vs 2.51 ± 0.047), the observed effects on growth rate reflect differences in their respective genetic potential for protein deposition. This data illustrates the need for dietary lysine specifications to be tailored to take account of sex and breed.

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THE PIGLET AS A MODEL ANIMAL IN HUMAN INFANT NUTRITION

A.J. Darragh and P.J. Moughan

Monogastric Research Centre, Massey University, Palmerston North, New Zealand.

Some aspects of nutritional research are difficult or impossible to conduct with humans due to the invasive nature of the techniques employed. Model animals can be used to overcome these difficulties. The model animal, however, must allow valid inter-species comparison. The pig has several characteristics that make it useful for human nutrition research: an omnivorous meal-eating habit, adapts to experimental procedures, is readily available and inexpensive. The piglet has been suggested as an appropriate model for studying infant nutrition (Miller and Ullrey, 1987) and this was confirmed indirectly in a recent comprehensive review (Moughan *et al.*, 1992) of aspects of digestive physiology in suckled human infants and piglets. Given the comparable developmental stage of peak lactation in the dam, the three-week-old piglet showed a close physiological resemblance to the three-month-old human infant. Although comparative information on nutrient uptake in human infants and piglets is limiting, the two species appear to have a similar digestive capacity.

This study compared, under controlled conditions, the faecal digestibility of amino acids in a commercial infant milk formula fed to three-week-old male piglets (mean LWT 3.9 kg) and three-month-old male human infants (mean LWT 6.9 kg). Total faecal output over a ten-day period was collected from piglets and human infants and analysed for amino acids and apparent faecal digestibility coefficients were determined (Table 1).

Table 1. Amino acid digestibility coefficients (%) for a commercial infant milk formula fed to piglets (n=6) and human infants (n=6)(mean ± SEM)

Amino acid	Piglet	Human	SEM	Sign.[1]	Amino acid	Piglet	Human	SEM	Sign.[1]
Lysine	97.6	96.6	0.34	NS	Histidine	97.5	96.7	0.29	NS
Arginine	95.5	94.8	0.56	NS	Threonine	97.6	96.1	0.34	*
Serine	97.5	96.1	0.33	*	Alanine	94.8	93.3	0.59	NS
Valine	96.8	96.8	0.37	NS	Isoleucine	97.2	97.3	0.31	NS
Leucine	97.5	97.5	0.28	NS	Phylalanine	96.3	95.3	0.41	NS

[1]NS, non significant, $P>0.05$; * $P<0.05$.

The digestibility coefficients for most of the essential amino acids examined were not significantly different between species, indicating that piglets and human infants digest amino acids to a similar extent. Faecal measurements are limited, given the high microbial activity in the hind gut, and similar faecal digestibility coefficients may not mean that digestion of protein was quantitatively the same in both species. Evidence from the present study, in conjunction with the observed physiological similarities, however, does give confidence in using the piglet as a model animal for studying aspects of protein digestion in human infants. Work is underway at our Institute, using the piglet as a model, to determine the small intestinal uptake of amino acids from fresh human milk.

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EFFECT OF ENERGY SOURCE ON THE NUTRITIVE VALUE OF *LUPINUS ANGUSTIFOLIUS* (CV. GUNGURRU) FOR GROWING PIGS

G.C. Wigan, E.S. Batterham and D.J. Farrell*

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477. *Department of Biochemistry, Microbiology and Nutrition, University of New England, Armidale, NSW 2350.

In recent studies (Fernandez *et al.*, 1992) growing pigs given sugar-based diets containing lupin-seed meal (lupin), produced superior growth to those given diets containing either dehulled lupin-seed meal (kernel), or soyabean meal (soya). The current experiment was designed to determine whether this response would occur in a more conventional diet, containing wheat as the energy base.

Sixty female pigs were fed six diets (10 pigs per diet) containing either kernel, lupin or soya, with either sugar or wheat as the energy source, over the 20-48 kg growth phase. The sugar-based diets were formulated to contain 0.36 g of apparent ileal digestible lysine per MJ of DE. These pigs were fed 3 hourly, at 3 x maintenance (0.05 $kg^{0.75}$). Isoenergetic (14.2 MJ DE/kg) wheat-based diets were formulated to contain 0.57 g of apparent ileal digestible lysine per MJ of DE and were offered *ad libitum*.

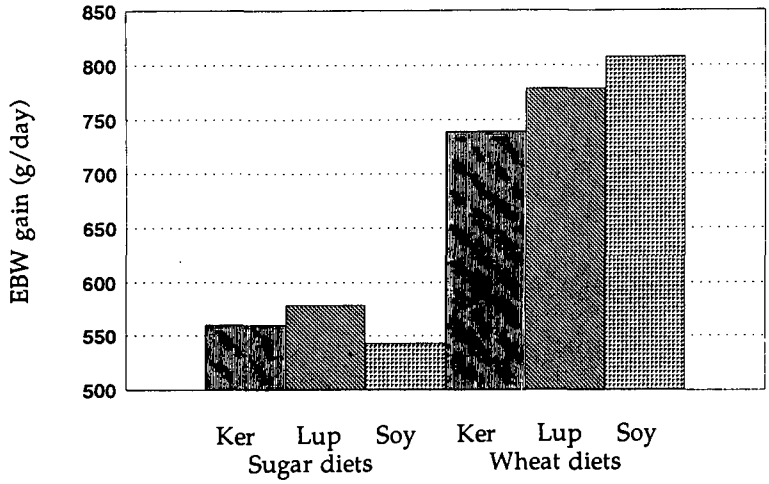

Figure 1. *Empty-body-weight (EBW) gain/day of pigs offered either lupin (Lup), kernel (Ker) or soya (Soy) in sugar- or wheat-based diets.*

There was a significant interaction ($P<0.01$) between diets and energy source for empty-body-weight gain/day. Pigs given the sugar-based diets containing lupin or kernel grew faster than those fed soya, but the reverse occurred with the wheat-based diets. Feed intake of pigs offered the wheat-soya diet was greater (1,825 g/day) than that of pigs offered the wheat-lupin (1,695) or wheat-kernel (1,668) diets ($P<0.001$). There was no significant effect ($P<0.05$) of dehulling the lupins.

This interaction is currently being investigated, and may relate to oligosaccharide composition of the lupins and kernel, interacting with the energy base of the diets.

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THE EFFECT OF A LOW PHOSPHORUS DIET ON GROWTH, BONE CHARACTERISTICS, REPRODUCTIVE PERFORMANCE AND PROGENY OF FEMALE PIGS

N.W. Godfrey, R.W. Payne and H.G. Payne

Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.

Reducing dietary phosphorus (P) levels offers both environmental and economic benefits. This study examined the growth and first parity reproductive performance of female pigs, raised on low P diets in the grower phase, from 21 to 53 kg live weight (LW), and the finisher phase, from 53 to 91 kg LW.

Female pigs (N = 139) were fed diets with low or recommended (ARC, 1981) P levels (3.36 or 6.16 g/kg total P, 1.69 or 4.58 g/kg available P) *ad libitum* during the grower phase and 3.2 times maintenance (ARC, 1981), (3.25 or 4.55 g/kg total P, 1.32 or 2.66 g/kg available P) in the finisher phase. The available P in the diets was calculated from an estimated lupin P availability of 60% and NRC (1988) values for the other ingredients. Diets were based on wheat, barley and lupins, with P supplementation of dicalcium phosphate in the standard diets only. Ground limestone was added to all diets to maintain a Ca:P ratio of 1.25 to 1.29.

Five pigs were selected from each treatment at about 55 kg LW and their P balance monitored in metabolism crates for 7 days, whilst fed the grower diet. After reaching 91 kg, 121 gilts were fed diets formulated to ARC (1981) specifications and exposed to boars until oestrus was detected. Progeny of the sows subsequently mated were monitored to 8 weeks of age.

There were no significant differences ($P>0.05$) in growth rate (648 v 656 g/d), P_2 backfat (15.2 v 15.0 mm), or the feed:gain ratio (2.93 v 2.84) from 21 to 91 kg LW; number of gilts reaching oestrus before 225 days (51/62 v 50/59), number of gilts confirmed pregnant (36/42 v 37/44), total born/litter (10.00 v 10.67), number weaned/litter (8.77 v 8.5), and growth rate of progeny to 8 weeks (290 v 300 g/d) between the low P and standard dietary treatments, respectively. These parameters, and the health status of the animals, were normal for the herd. Bending moment, dry and ash weights, and P and Ca contents of bones determined at 91 kg LW (N = 19), mating (N = 18), 105 days gestation (N = 19) and for progeny at 8 weeks of age (N = 29) were not significantly different ($P>0.05$).

The balance experiment, however, showed significantly lower ($P<0.05$) P output from pigs on the low P diet compared to those on the standard diet (2.99 g/d v 6.76 g/d), whilst the amount retained did not differ between treatments (3.47 v 3.44 g/d).

It was concluded that the low P diets used here were adequate within the constraints of this experiment. However, given the wide range in P availability between different lots of feedstuffs, and the lack of data on males and multiparate reproduction, further information is required before these diets can be recommended.

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HAS PHYTASE A PROTEOLYTIC EFFECT IN DIETS FOR WEANER PIGS?

B.J. Barnett, W.A. Clarke* and E.S. Batterham*

Department of Animal Science, University of New England, Armidale, NSW 2351. *NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477.

It is well documented that the enzyme phytase improves phosphorus digestibility in vegetable sources for grower pigs. What is less clear is whether phytase also has a proteolytic effect. Ketaren *et al.* (1993) reported that phytase improved growth rate and protein deposition in grower pigs. These effects may have been due to an improvement in the phosphorus status of the phosphorus-deficient diets or to a proteolytic effect. Officer and Batterham (1992) also reported that phytase increased the apparent ileal digestibility of amino acids in a diet containing Linola meal for grower pigs. This experiment, conducted at Wollongbar, examined if phytase had a proteolytic effect in a conventional weaner diet, adequate in available phosphorus.

The control diet, containing wheat, soyabean meal, fish meal, meat and bone meal, tallow and L-lysine, was formulated to 15 MJ DE/kg, 0.75 g available lysine/MJ DE and an estimated 0.38 g/kg available phosphorus. Phytase was added at the rate of 1000 FTUs/kg to diet 2 (Natuphos, supplied by Gist-brocades). Both diets were offered *ad libitum* to piglets from weaning at 28 days to 49 days of age. Thirteen pens of six piglets, were allotted per diet. Chromic oxide (2g/kg) was added to the diets on day 46. On day 49, one pig per pen, from 12 pens/diet, was slaughtered for empty-body analysis. Ileal contents were also collected from the last 1.5 m of the small intestine at time of slaughter. It was difficult to collect adequate, representative samples and the ileal digestibility parameters were calculated using results for five pigs for diet 1 and six pigs for diet 2.

Table 1. Effect of phytase supplementation on weaner pig performance

		Control	Phytase	Sign[1]	SEM
Performance:	Feed intake (g/pig/d)	517	501	NS	29.2
	Growth rate (g/d)	344	349	NS	15.2
	Feed conversion ratio	1.49	1.43	NS	0.038
Digestibility:	Dry matter	0.63	0.68	NS	0.020
	Nitrogen	0.66	0.71	*	0.015
	Lysine	0.73	0.77	NS	0.016
Composition:	Protein (g/kg)	0.149	0.150	NS	0.0016
	Gross energy (MJ/kg)	8.0	8.1	NS	0.16
	Crude protein deposited (g/d)	55.3	59.5	NS	4.69
Retention:	Protein retained: protein intake	0.41	0.46	NS	0.025

[1]NS, non significant, P>0.05; *P<0.05.

Phytase had no significant effect on any parameter except nitrogen digestibility (P<0.05), which must be interpreted with some caution, due to the low number of replicates. The results indicate that phytase had a small proteolytic effect, but that this effect was insufficient to improve weaner pig performance.

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FREE AMINO ACID DIETS FOR WEANER PIGS

D.I. Officer, E.S. Batterham and D.J. Farrell*

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477. *Department of Biochemistry, Microbiology and Nutrition, University of New England, Armidale, 2350.

When undertaking amino acid utilization studies, a diet based on free rather than protein-bound amino acids would be advantageous, as it would allow flexibility in dietary formulations, ensure full availability of all amino acids and minimise analytical errors associated with amino acid analyses. Such a diet was developed by Chung and Baker (1992). However, Officer *et al.* (1993) found that growth performance of piglets given this diet was substantially lower than that recorded with a diet containing protein-bound amino acids. Chung and Baker (1992) attempted to minimize chemical reactions within their diet by storing at -20°C and feeding for approximately one hour periods, twice daily. In contrast, Officer *et al.* (1993) stored their diets at room temperature (24.6°C, range = 15-31°C; SD=3.8) for up to 35 days and offered them *ad libitum*. It was possible the lower performance recorded by Officer *et al.* (1993) may have been due to chemical reactions within the diet, during storage. This experiment compared ambient storage (22.3°C, range 13-30°C; SD=2.2) and *ad libitum* feeding with -15°C storage and twice-daily feeding of FAA diets. A diet containing intact proteins (casein/fish/soya (CFS)) and offered *ad libitum*, was used as a control.

The two diets were formulated to 0.84 g available lysine/MJ DE. Half the FAA diet was stored at ambient temperature (13-30°C) for up to 28 days, the remainder at -15°C. The piglets (six per treatment) were allowed to adjust to the experimental treatments from one week post-weaning (35 days of age) until they reached 10 kg live weight. Piglet performance was then assessed between 10 and 20 kg live weight.

Table 1. Effect of storage temperature and feeding regime on piglet performance

Diet Feeding regime Storage temperature	CFS *Ad lib.* 13-30°C	FAA *Ad lib.* 13-30°C	FAA Twice daily -15°C	Sign.[1]	SEM
Days pre-trial	3.5^{a}	7.0^{b}	9.2^{c}	***	0.66
Feed intake (g/d)	1008^{a}	710^{b}	689^{b}	**	51.0
Gain (g/d)	798^{a}	463^{b}	413^{b}	**	41.8
FCR	1.26	1.56	1.69	NS	0.13

[1]NS, non significant, P>0.05; ** P<0.01, *** P<0.001. Within rows, means with different superscripts differ (P<0.05).

Piglets given the FAA diet were slower reaching 10 kg live weight than those given the CFS diet (P<0.05). Performances of piglets given the FAA treatments were mostly inferior to those given the control diet and were unaffected by method of storage or feeding regime (P<0.05).

Chemical reactions between the FAAs and other compounds do not appear to be the reason for the lower piglet performance associated with this diet. Rather, a deficiency of nutrients normally contributed by the intact proteins, appears probable.

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USE OF FREE OR BOUND AMINO ACID MOLECULAR WEIGHTS IN THE DETERMINATION OF AMINO ACID COMPOSITIONS

S.M. Rutherfurd and P.J. Moughan

Monogastric Research Centre, Massey University, Palmerston North, New Zealand.

During amino acid analysis, proteins are hydrolyzed to free amino acids and following separation by HPLC, the moles of each amino acid determined. The amino acids can then be converted to weights based on their respective molecular weights (MW). In making this conversion it is possible to use either the MW of the free amino acid (including the water molecule added during hydrolysis) or the MW of the amino acid as bound in the protein before hydrolysis. Depending on which amino acid MW is used, a 10 - 30% difference in amino acid composition data can result. Table 1 gives an example from our laboratory for bloodmeal of the differences in the amino acid composition generated, depending upon whether free or bound amino acid MWs were used. In bloodmeal, the sum of the amino acids calculated using free MWs was 91.4 g/100 g, while the sum of the amino acids calculated using bound MWs was 78.4 g/100 g, which is a 16% difference. The sum of the free amino acids was similar to crude protein (N x 6.25) yield (90.9 g/100 g), leading to an unrealistic complacency regarding accuracy of the analysis.

Table 1. Amino acid concentration in bloodmeal determined using free or bound amino acid MWs

Amino acid	Amino acid level (g/100g)		Difference (%)
	Free MW	Bound MW	
Threonine	4.72	4.01	17.7
Glycine	3.82	2.90	31.7
Methionine	1.17	1.03	13.6
Valine	7.68	6.50	18.2
Leucine	11.53	9.95	15.9
Phenyalanine	6.19	5.51	12.3
Lysine	8.02	7.03	14.1
Tryptophan	1.13	1.03	9.7
Total for full profile	91.4	78.4	16.5

The crude protein level calculated by N x 6.25 was 90.9 g/100 g.

An informal survey of several Australasian laboratories made in early 1993, showed different groups use different amino acid MWs in determining amino acid composition. Many groups were unaware that there were two ways of calculating the amino acid weights and most did not report the method of calculation used, or as with feed companies, did not have it reported to them.

In nutritional work, it is often satisfactory to use free amino acid MWs, though this is not always the case, and care should be exercised when determining amino acid compositions. In any application where amino acid amounts are compared to intact protein, for example whole body amino acid compositional analysis, or the calculation of amino acid recoveries in relation to determined crude protein, bound amino acid MW's should be used. It is important that researchers be aware of the significance of using different molecular weights (free or bound) in the calculation of amino acid concentrations and that they undertake to report more detailed information on the calculation methods used in deriving amino acid data.

CONDENSED TANNINS IN COMMERCIAL COTTONSEEDS AND IN PROCESSED COTTONSEED PRODUCTS

Feng Yu, T.N. Barry, P.J. Moughan and G.F. Wilson

Monogastric Research Centre, Massey University, Palmerston North, New Zealand.

Recently, condensed tannins (CT) have been detected in commercially produced cottonseed meal (CSM; Terrill *et al.*, 1992). CT are recognized as being antinutritional for the growing pig (Jansman *et al.*, 1993) and may potentially affect the digestibility of nutrients and the excretion of endogenous protein. This study aimed to determine the extractable, protein- and fibre-bound CT fractions in commercial cottonseed and processed CSM.

Whole delinted cotton seeds of 2 commercial varieties were manually separated into kernels and hulls. Representative samples of commercial CSM and cottonseed kernels (from Narrabri only) were taken from the Narrabri and Brisbane plants of Cargill Oilseeds Ltd, Australia (pre-press solvent extraction method). The CT in samples was determined using the 3 stage butanol/HCl method developed by Terrill *et al.* (1992).

CT was not detectable in the pure kernels of the commercial varieties, but was present in the hulls. The extractable CT, protein- and fibre-bound CT fractions in the 2 hull samples comprised 22, 62 and 16% of total CT, respectively (Table 1). Commercial CSM contained CT, with 50-62% being found in the protein-bound fraction and 36-37% in the fibre-bound fraction. On an oil-free DM basis, the amounts of total CT in the Narrabri and Brisbane meals were 1.6 and 0.9% respectively. Industrial cottonseed kernels produced at Narrabri contained very low concentrations of total CT.

Table 1. Content[1] (%DM) of extractable, bound and total condensed tannin (CT) in the hulls of cottonseed varieties and processed Australian cottonseed products

	N° of samples	Dry matter	Extractable	Protein-bound	Fibre-bound	Total CT
Sicala 3-3 hulls	1	91.1	0.47	2.15	0.62	3.24
Siokra 1-4 hulls	1	91.1	1.45	2.84	0.66	4.95
Cottonseed meal N[2]	4	90.5	0.21	0.76	0.54	1.51
Cottonseed meal B[3]	4	91.8	0.01	0.49	0.29	0.79
Cottonseed kernels[2]	2	94.6	0.11	0.07	0.05	0.23

[1]Duplicate means. [2,3]Samples from Narrabri and Brisbane plants, respectively.

An important finding was the presence of a significant quantity of CT in CSM, similar to that found in high tannin sorghum (1.2%, Terrill *et al.*, 1992), which may partly explain the relatively low protein quality of CSM for pigs. The higher CT concentration in the Narrabri meal indicated a difference between the Brisbane and Narrabri plants in the extent of early hull removal. In the present study, a new analytical method was applied, which allows measurement of bound as well as extractable CT. Most CT in CSM is in the bound form, and would not be detected by conventional analysis. The effects of CT on the nutritional value of CSM for pigs is currently under investigation.

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NUTRITIONAL EFFECTS ON THE SITES OF PROTEIN DEPOSITION IN THE BODIES OF GROWING PIGS

P. Bikker, R.J.F. Sasse, M.W.A. Verstegen and R.G. Campbell*

Department of Animal Nutrition, Wageningen Agricultural University, Haagsteeg 4, 6708 PM Wageningen, The Netherlands. *Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

Many experiments have been conducted to develop feeding strategies, aimed at maximizing protein deposition in growing pigs. However, little attention has been given to determining the sites of protein in the body. De Greef and Verstegen (1993) found that at a higher feeding level, a lower percentage of total protein deposited was in the lean tissue. The aim of the present study was to determine the effect of feeding level and nutritional history on the sites of protein deposition in the body.

Two groups of 28 female pigs of improved genotype were fed a protein-adequate diet (CP 19.9%, total lys 0.75 g/MJ DE) from 20 to 45 kg at feeding levels of 2.2 (L) and 3.7 (H) times energy for maintenance (calculated as 0.475 MJ DE/$kg^{0.75}$). At 45 kg, four pigs from each group were sacrificed to determine initial body composition. The remaining 24 animals per group were allocated to six intake levels: 1.7, 2.2, 2.7, 3.2 and 3.7 times maintenance, and *ad libitum*, from 45 to 85 kg. At 85 kg these animals were sacrificed and the bodies were divided into three fractions: organs, lean tissue and 'rest' (non-lean carcass parts). Nitrogen content of these fractions was determined.

Protein deposition between 45 and 85 kg increased linearly from 80 to 185 g/d with increasing feed intake ($P<0.001$) and was not affected by nutritional history (feeding level between 20 and 45 kg) ($P>0.05$).

Table 1. Effect of feeding level between 20 and 45 kg (E145), being 2.2 (L) or 3.7 (H) times maintenance and energy intake between 45 and 85 kg (E185) on percentage of body protein deposition in the carcass (Carcass %) and percentage of carcass protein deposited as lean tissue (Lean %), between 45 and 85 kg body weight

		Energy intake 45 - 85 kg, MJ DE/d								Significance[1]	
	E145	18.2	23.8	29.0	35.1	39.8	43.4	Mean	SEM	E185	E145
Carcass	L	90.5	87.8	85.6	83.5	81.6	81.2	85.0	0.92	***	***
(%)	H	91.8	92.3	89.1	86.7	84.9	88.0	88.8			
Lean	L	66.2	65.2	66.0	64.2	62.2	58.7	63.8	2.06	***	
(%)	H	68.1	70.2	63.2	66.5	60.3	61.9	65.0			

[1]*** $P < 0.001$.

The relative amount of protein deposited in the carcass decreased with increasing energy intake between 45 and 85 kg (E185). In addition, this percentage was lower for the L animals, presumably because at 45 kg these animals had lower organ weights. This was compensated for during the growing period from 45 to 85 kg. The percentage of carcass protein, deposited as lean tissue, also decreased with increasing energy intake (E185). Consequently, the percentage of body protein deposited as lean tissue decreased from about 60% at the lowest energy levels, to about 50% at the highest energy levels. These effects must be considered when feeding strategies are developed or evaluated.

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WHEAT STARCH REDUCES PIGLET PERFORMANCE

D.I. Officer, E.S. Batterham and D.J. Farrell*

NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar, NSW 2477. *Department of Biochemistry, Microbiology and Nutrition, University of New England, Armidale, NSW 2350.

Previous work had found that the performance of piglets, given semi-synthetic diets containing casein, or a completely synthetic diet containing free amino acids (FAA), was less than that recorded with a commercial creep-weaner diet (Officer *et al.*, 1993). The experimental diets contained a mixture of starch, lactose and sucrose as the energy base. This experiment was designed to examine whether one or more of these energy sources affected piglet performance.

A 3 x 3 factorial experiment was conducted using three energy sources (sucrose 620 g/kg; sucrose 470 and lactose 150; sucrose 150, lactose 150 and wheat starch 320) and three sources of amino acids (casein/fish/soya (CFS); casein; FAA) with 5 piglets/treatment. The diets were formulated to 0.84 g available lysine/MJ DE (DE > 15 MJ) by including 15, 30 and 60 g/kg soyabean oil in the CFS, casein and FAA diets respectively. Piglets were weaned at 21 days and offered feed and water *ad libitum*. Growth performance was recorded over the 5-10, 10-20 and 5-20 kg growth phases.

Table 1. Performance of piglets given diets varying in protein and energy source over the 5-10, 10-20 and 5-20 kg growth phases (main effects)

Parameter	Protein source			Energy source			SEM[1]
	CFS	Casein	FAAs	Sucrose	Sucrose Lactose	Sucrose Lactose Starch	
5-10 kg							
Gain (g/d)	318^{a}	264^{b}	215^{c}	273^{x}	282^{x}	241^{y}	8.1
FCR	1.3^{a}	1.5^{b}	1.8^{c}	1.4^{x}	1.5^{x}	1.7^{y}	0.06
10-20 kg							
Gain (g/d)	661^{a}	564^{b}	478^{c}	590	563	550	17.9
FCR	1.3^{a}	1.5^{b}	1.7^{c}	1.5	1.5	1.5	0.05
5-20 kg							
Gain (g/d)	494^{a}	415^{b}	344^{c}	433^{x}	430^{x}	391^{y}	10.7
FCR	1.3^{a}	1.5^{b}	1.7^{c}	1.5	1.5	1.6	0.04

[1]There were no protein by energy source interactions. Within protein or energy sources, line means without a common superscript differ ($P<0.05$).

The results show that wheat starch had a detrimental effect on piglet growth over the 5-10 and 5-20 kg growth phases. Addition of lactose to the sucrose diets produced no improvement in piglet performance. The CFS diets supported superior piglet performance to that of the casein diets, which in turn were superior to the FAA diets. The higher FCR of piglets fed either the FAA or casein diets were partially due to feed wastage. The causes of the poorer performance of piglets given the casein and FAA diets are under investigation.

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GENE MAPPING OF THE PORCINE GENOME USING MICROSATELLITES ASSOCIATED WITH GENES

Muladno, P.R. Le Tissier and C. Moran

Department of Animal Science, University of Sydney, Sydney, NSW 2006.

The mapping of genes controlling economically important traits will ultimately lead to an understanding of the molecular basis of genetic improvement. The main requirement for such mapping is a sufficient number of polymorphic marker loci which are distributed throughout the genome. Microsatellites (Litt and Luty, 1989) have been demonstrated to be highly polymorphic within coding regions of genes in a number of species (for example Love *et al.*, 1990) and have been utilized for gene mapping in domestic animals (Moore *et al.*, 1992). This work presents gene mapping in the pig genome based on microsatellites.

Five microsatellites, within the genes for insulin like growth factor (IGF-1), chorionic gonadotropin alpha polypeptide (CGA), secreted phosphoprotein 1 (SPP-1), tumor necrosis factor beta (TNFB) and diacylglycerol kinase (DAGK), were analysed.

Genomic DNA from 3 - 5 unrelated individuals of 10 different breeds (Meishan, Large White, Landrace, Welsh, Wessex Saddleback, Duroc, Hampshire, Tamworth, Berkshire, Large Black) was amplified by the Polymerase Chain Reaction (PCR). The ^{32}P-labelled PCR products were run on 6% standard polyacrylamide sequencing gels and allelic variants visualized after autoradiography. The sizes of alleles were determined by comparison with the sequence of a common plasmid vector pUC18.

The number of alleles (and observed heterozygosity) for each microsatellite analysed across all breeds are 7 (74%) for IGF-1, 7 (53%) for DAGK, 12 (53%) for SPP-1, 14 (82%) for TNFB, and 18 (77%) for CGA, respectively. The markers have also been used to genotype the PigMap reference families (Haley *et al.*, 1990) showing the Mendelian inheritance of the microsatellites and allowing their placement in the gene map of the pig. Therefore, microsatellites associated with known genes detect a high degree of polymorphism making them useful for both comparative gene mapping and as markers for localizing genes affecting quantitative traits.

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THE INTERNATIONAL PIG GENE MAPPING PROJECT AND THE AUSTRALIAN CONTRIBUTION

C. Moran, P.R. Le Tissier, Muladno, S.C. Brown and F.W. Nicholas

Department of Animal Science, University of Sydney, Sydney, NSW 2006.

A co-ordinated program, named the Pig Gene Mapping Program (PiGMaP), has been underway for three years (Haley *et al.*, 1990). This program has the objective of developing two types of genetic maps: a 20 centiMorgan (cM) linkage map and a physical map. Laboratories from eleven countries, including Australia, are now involved in this program and are cooperating closely. The rationale for the gene mapping program is that, with a 20 cM map, the location of loci affecting quantitative traits can be determined.

The Australian contribution to this program covers three areas: 1) The development of markers which detect polymorphism, for linkage mapping but which can also be used for physical mapping, 2) the development of a database of genes which have been identified in pigs, and 3) the establishment of reference families for quantitative trait loci and collection of data and samples from members of the families.

To date, eight clones for a porcine cosmid library have been mapped by *in situ* hybridisation, analysed for their ability to detect restriction fragment length polymorphisms (RFLPs) and used for linkage mapping in the PiGMaP reference family. Fifteen other RFLPs have been used for linkage mapping in the PiGMaP reference family. Six genes, which contain microsatellite sequences, have been analysed on the PiGMaP reference family and five have been found to detect polymorphism (Muladno *et al.*, 1993). Cosmid clones which contain microsatellites are being analysed by cycle sequencing and primers designed to amplify the region of DNA containing the microsatellite, for the development of more highly polymorphic markers.

The development of a database, Mendelian Inheritance in Pigs (MIP), has progressed to a stage where the database is up-to-date and will be made available to the scientific community via networks. The database contains bibliographic information on all genes identified in pigs, map locations, clone information as well as identifying homologous genes in other mammalian species.

Our contribution to the European PiGMaP program guarantees access to genetic markers produced in the course of producing a framework map which will be available from late 1993. Suitable well spaced markers from throughout the genome will then be analysed on the resource families, produced at Bunge Meat Industries, as part of a project to calculate genetic parameters, and will lead to the identification of quantitative trait loci in economically relevant populations of pigs in Australia.

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A REVIEW - PHYSIOLOGY OF THE UTERUS AND IMPLANTATION

J.K. Findlay

Prince Henry's Institute of Medical Research, PO Box 152, Clayton, Vic. 3168.

Introduction

At the Third Biennial Conference of the Australasian Pig Science Association held in Albury in 1991, A.J. Webb reviewed genetic programs to improve litter size in pigs and concluded that "a limiting factor on genetic improvement must be the negative association of ovulation rate with embryo survival" (Webb, 1991). Dr Webb used the example of the highly prolific Meishan breed in which the advantages appear to stem from improvements in both ovulation rate and embryo survival (Haley *et al.*, 1990). Webb (1991) recommended further research on the physiological basis for fertility and fecundity, particularly the physiological basis for the Meishan advantage.

The purpose of this review is to summarize recent knowledge on endometrial physiology and implantation, where possible citing data from the pig, but also data from other species, where new ideas have evolved which may be applicable to understanding and improving embryo survival of the pig. It is not intended to provide an exhaustive review, but to give examples which illustrate a principle.

Early pregnancy in the pig

Events leading to implantation

The expected length of the oestrous cycle of the pig is 21 days, with 18 to 24 days considered within the normal range and the day of oestrus designated day 0. Ovulation commences 35 to 36 hours after the onset of oestrus and oocytes bearing pronuclei can be found in the oviducts, from 6 - 18 hours after ovulation. The embryo is four cells at about 30 hours and remains at this stage until it enters the uterus, on day three to four. The zona pellucida is lost between days six and eight, then a bilaminar blastocyst forms and by day 10 to 11, the blastocyst begins to expand from an ovoid sac to a tubular to a filamentous blastocyst (days 12 to 14). By day 12, the embryos have distributed themselves along the uterine horn and, in the space of three to four days, have expanded in size from ovoid sacs of about 0.5 to 1 cm diameter to 100 to 200 cm length. The large number of elongated blastocysts can be accommodated in each horn by overlying folds, which grow in the endometrium.

By day 14, local areas of apposition of the trophectoderm and epithelium of the endometrium can be distinguished, followed by the appearance of the trophoblastic areolae and progressively increasing areas of apposition. By days 18 - 22, microvillous interdigitation occurs between the surfaces of the trophectoderm and the endometrial epithelium, and by day 24 chorio-allantoic fusion is complete. Definitive attachment occurs, therefore, around days 18 to 22 in the pig. The outer trophoblastic layer of the blastocyst is non-invasive and there is no pronounced decidual reaction in the stroma, which characterizes implantation in rodents and primates. Placentation in the pig is epitheliochorial, in which uterine penetration does not occur. However, if a pig embryo is transferred to an ectopic site, it invades the tissue, suggesting that the uterus is particularly resistant. Strickland and Richards (1992) believe that inhibition of the plasminogen activator-plasmin system by high levels of plasminogen activator inhibitor in uterine fluid (Mullins *et al.*, 1980) prevents trophoblast invasion in epitheliochorial placentation.

Maternal recognition of pregnancy

The time when an embryo must be present in the uterine lumen, to prevent regression of the corpus luteum, in those species in which implantation does not begin

until after the expected time of regression of the corpus luteum of the cycle, has been called the time of maternal recognition of pregnancy (Short, 1969). In the pig, this is by day 12. Note that this is an endocrine form of recognition, since it pertains to the maintenance of the corpus luteum - there may be other forms such as metabolic and immunologic recognition which will be discussed below.

The recognition of the presence of a blastocyst by the maternal system depends on the stage of development of the blastocyst and its capacity to produce the signals. In the pig, there must be more than four viable embryos present on days 14 or 15 for successful continuation of the function of the corpus luteum (Polge *et al.*, 1966). Furthermore, if one uterine horn contains no embryos pregnancy will not proceed (du Mesnil du Buisson, 1961). This suggests that the quantitative threshold of the embryonic signal to maintain the corpus luteum may be particularly important for reproductive efficiency in the pig. A contributing factor to the quantity of signal will be the synchronous development of embryos with the endometrium around this crucial time.

Maintenance of luteal function

The antiluteolytic and luteotrophic signal produced by the pig blastocyst is oestrogen (Flint *et al.*, 1979). It is proposed that oestrogen synthesized by the trophectoderm acts on the endometrium to prevent the release of prostaglandin $F_{2\alpha}$ into the uterine vein (where it becomes luteolytic), and at the same time, facilitating exocrine release of prostaglandin $F_{2\alpha}$ into the uterine lumen (Bazer *et al.*, 1986).

Aromatization of androgen to oestrogen *in vitro* was first demonstrated in day 12 blastocysts, coinciding with elongation (Flint *et al.*, 1979). Tubular and filamentous blastocysts have relatively high aromatase activity, whereas spherical and ovoid blastocysts have low or no activity. Definitive proof is required that these spherical and ovoid blastocysts can make enough oestrogen between day 10 and 12, when the embryonic endocrine message is first detected by the mother (Dhindsa and Dziuk, 1968).

In summary, the early stages of maternal recognition of pregnancy depend on local effects of oestrogens synthesized by the preimplantation embryo, acting on the processes controlling the distribution of prostaglandins in the endometrium by mechanisms not currently understood. However, as discussed below, new techniques offer novel approaches to answer these questions.

Local regulation in the uterus

The concept of local regulation within the uterus has evolved from several lines of research, some outside the field of uterine physiology and one, ie; maternal recognition of pregnancy, already mentioned. Regulation of uterine function and implantation by local factors could be important, because the presence of the factors may add precision and local specificity to an otherwise indiscriminant stimulation of the tissue by a peripheral hormone. This would allow different cell types within the same tissue to have separate but co-ordinated growth and differentiation under continued stimulation by the same peripheral hormone or hormones.

The idea of an influence of the blastocyst directly on the maternal system, prior to and during implantation, was given substance by Deanesly (1967), who showed in guinea pigs that fertilized eggs have 'a specific capacity to induce changes in the endometrium', a property greater than that of artificial traumatization. The antiluteolytic signal produced by the trophoblast is one example. Work in the 1970's and early 1980's described a number of other influences which the presence of a blastocyst in the preimplantation period has on the endometrium (Findlay, 1983). In the pig, these include a four- to five-fold increase in uterine blood flow on days 12 and 13 (Ford and Christenson, 1979) and increased protein synthesis and protein content of luminal fluid (see Findlay, 1983). Signals to or influences on the maternal system have been easier to define than the maternal influences on growth and expansion of the

blastocyst and expression of the embryonic signals. Recent work described below is beginning to resolve this problem.

Autocrine, paracrine and juxtacrine regulation

Research in cancer biology led to the concept of autocrine and paracrine regulation amongst cells (Sporn and Todaro, 1980). Substances produced by one cell type which can act back on the same cell to regulate its function are called autocrine regulators. Substances which are produced by one cell type and act on a different neighbouring cell type are called paracrine regulators. A feature of these regulators is their local secretion and action. They can mediate or modulate the response of a tissue to stimulation by an endocrine hormone (originating in another organ), leading to localized differentiation and function of cells within that tissue. They can also co-ordinate other functions of cells, such as growth, which may or may not be endocrine dependent. Their actions are highly regulated through expression of the substances and their receptors, and by the presence of binding proteins which can neutralize their biological activity, remove them from the tissue and even metabolize them. In some cases the substance may be secreted and stored in the extracellular matrix (ECM) surrounding the cell, to be released and act when remodelling of the ECM occurs. A more recent concept is the juxtacrine regulation of cells (Massague, 1991), where the growth factor is anchored in the membrane of one cell type and can act via receptors on neighbouring cells.

The first examples of these substances were the cellular growth factors, and cytokines, such as transforming growth factor β(TGFβ) and epidermal growth factor (EGF). It quickly became apparent that these substances and their actions were not only confined to tumours and the immune system, but were also a feature of cellular regulation in many different organs including the uterus.

The endometrium contains a large diversity of cell types, many of which undergo continual morphological and biochemical alterations during the oestrous cycle and pregnancy. Two primary cell types are found within the endometrium, *viz.* epithelial cells on the luminal and glandular surfaces, and stromal cells beneath the basement membrane of the epithelium. Stromal cells are embedded in an ECM rich in collagen fibres and blood vessels lined with endothelial cells (and myoepithelial cells). In addition, there are lymphocytes, macrophages, leukocytes and mast cells, particularly in the mesenchymal layer, but occasionally lymphocytes are also found in the epithelial layer. Interactions among all these cell types within the endometrium is possible by autocrine and paracrine factors (Findlay and Salamonsen, 1991). Of particular importance is the interaction between stromal (mesenchymal) and epithelial cells to control differentiation of the epithelium. Urogenital morphogenesis and cytodifferentiation is specified by mesenchymal cells, which exhibit oestrogen receptor activity and mediate, via paracrine actions, steroid-dependent development of the epithelial cells until such time as the epithelial cells acquire their own steroid receptors (Cunha *et al.*, 1983). Interactions between the trophectoderm of the blastocyst and the endometrial cells is also a form of paracrine control.

Techniques for studying local regulation

There have been major advances in *in vitro* and *in vivo* techniques which have allowed investigations of local regulation in tissues including the endometrium and implantation. Some of these have been applied to the pig.

Immunocytochemical methods have been crucial in identifying the different cell types in the endometrium during the oestrous cycle and pregnancy. This has allowed quantification of cell types with changing hormonal and pathological environments. Immunocytochemistry using antibodies specific to paracrine and autocrine regulators has allowed localization of these peptides to individual cells and the ECM. There are now immunocytochemical methods for localizing protein receptors for oestrogen, progesterone and other factors in individual cell types and observing the changes across the oestrous cycle and pregnancy.

The technique of *in situ* hybridization allows one to identify the cellular sites of expression of messenger RNA (mRNA) coding for many of the local regulators and their receptors. This and analyses of specific mRNAs by other methods, coupled with immunological methods to detect the complementary proteins, allows definitive identification of cellular sites of expression, production and action.

An important advance has been methods to isolate, identify and culture the different cell types and to study the regulation of their function *in vitro* (Findlay *et al.*, 1990). Selective enzymic dispersion of endometrium has been used together with various methods (gradients, sieves, selective plating) of separating individual cells and identifying them by microscopy and immunostaining. A greater understanding of the role of environment of the cell on its capacity to proliferate and differentiate, has led to culture systems in which the cells have morphological and functional properties very similar to those observed *in vivo*. For example, epithelial cells can now be grown *in vitro*, such that they form tight junctions between the cells and become columnar and polarized with distinct apical and basal surfaces. This was achieved mainly be adding an ECM, originally derived from stromal cells, to the culture surface. It is also possible to co-culture epithelial and stromal cells in a dual chamber system, which allows the epithelial cells to retain polarity and the stromal cells to exert an influence from the basolateral side. Similar systems can be used to study blastocyst/endometrial interactions *in vitro*.

Methods have been described to obtain epithelial and stromal cells from porcine endometrium (Zheng *et al.*, 1991), and to study their function *in vitro* (Zheng and Davis, 1991).

A particularly powerful technique is that of homologous recombination of genes in embryonic stem cells, particularly using gene 'knockout' techniques, to obtain transgenic homozygotes which either over or under express a gene of interest. An example of this, to be discussed below in more detail, is the role of leukaemia inhibitory factor in implantation (Stewart *et al.*, 1992). Techniques such as those just described have been used to identify candidate autocrine and paracrine factors involved in endometrial growth, implantation and placental growth.

Proliferation of endometrial cells

Mention has already been made of the growth of the endometrium in the pig to form folds, which accommodate the relatively large number of blastocysts. Such changes are steroid hormone dependent, and until recently it was thought that these steroid-dependent changes would be reflected by the presence of specific receptors in the epithelium cells. More recent data, particularly from primates (Brenner *et al.*, 1990) suggests that the actions of oestradiol and progesterone on epithelial cells are mediated by paracrine factors secreted by neighbouring stromal cells, at least until the epithelial cells acquire a complement of steroid receptors.

The nature of the paracrine regulators involved in endometrial growth have not been properly elucidated, although there are some strong contenders amongst the polypeptide growth factors such as EGF (or TGF_{α}), fibroblast growth factors (FGF) and insulin-like growth factor-I (IGF-I) and its binding proteins (IGFBP).

Epidermal growth factor

There is strong evidence that EGF is involved in the mediation of oestrogen-induced uterine growth (Brigstock *et al.*, 1989; Pollard, 1990). EGF is a 53 amino acid polypeptide with well documented mitogenic and differentiating properties. Both the growth factor and its receptor (a homologue of the *v erb B* oncogene) are present in the uterus at the RNA and protein level and EGF stimulates proliferation of mouse and rabbit endometrial cells *in vitro*. Oestrogen is believed to stimulate cleavage of EGF from a larger precursor molecule, as well as stimulating expression of the EGF receptor, resulting in an autocrine loop for EGF on epithelial cells in rodents (Di Augustine *et al.*, 1988; Huet-Hudson *et al.*, 1990). Similar effects of EGF do not appear

to have been reported in the pig but would be worthwhile investigating in view of the growth of the uterus in pregnancy.

Heparin-binding fibroblast growth factors

Uterine tissues and flushings from pigs contain both basic and acidic FGF-like proteins (Brigstock *et al.*, 1989). These proteins probably represent microheterogeneous forms of FGF. The origin of these proteins is uncertain particularly because the FGF-like proteins do not possess the signal peptide needed for secretion by the cell. The FGF-like material in the pig uterus could be of embryonic origin or leaked by endometrial cells.

Two aspects of FGF physiology are of interest. The first concerns the role of heparan sulphate proteoglycans on the cell surface, which facilitates access of FGF to its receptors (Raprager *et al.*, 1991). These proteoglycans can be found on the basal lamina of the endometrium (Aplin *et al.*, 1988) but it is not known if FGF-like proteins act in this way in the endometrium. The second concerns the association of FGF with the ECM. Heparinase and other ECM-degrading enzymes are found in the endometrium and are tightly regulated by steroid hormones and cytokines, such as TGF_{β}. The release of FGF in this way could allow targetted access of FGF to receptors in the vicinity of implantation and areas of uterine growth.

Insulin-like growth factor-I and II

The IGF-I and II were first identified as circulating mediators of the action of growth hormone. Subsequently they were shown to be highly expressed in many tissues, especially the ovary and uterus (Murphy and Ballejo, 1994). IGF-I is a mitogen which has the ability to potentiate other mitogens such as EGF and platelet-derived growth factor. It is a 70 residue polypeptide which has sequence homology with insulin.

IGF-I protein is present in uterine lumenal fluid, endometrium and the blastocyst of pigs (Letcher *et al.*, 1989; Simmen *et al.*, 1990, 1992). The concentrations of IGF-I in uterine fluid were greater in pregnant than non-pregnant horns, lowest on day 8 and highest on day 12 of pregnancy, coincident with maximum growth of the blastocyst and endometrium. The fluid contents then declined by day 14. The mRNA for IGF-I is also present in endometrium and was highest on day 12, in both the pregnant and non-pregnant sow (Geisert *et al.*, 1991; Simmen *et al.*, 1992). IGF-I binding sites are present on the endometrium but do not change in pregnancy (Hofig *et al.*, 1991). Oestradiol induced expression of IGF-I in porcine endometrium, and progesterone treatment of oestradiol-primed gilts reduced uterine IGF-I mRNA levels, while an increase was seen in mature ovariectomized gilts given progesterone within four days of castration (Simmen *et al.*, 1990).

The biological actions of IGF-I and II are modulated by the presence of a family of binding proteins (IGFBP), of which there are currently five (Shimasaki *et al.*, 1991). The mRNA for IGFBP-2 has been identified in both epithelial and stromal cells of the pig endometrium and was lowest on day 10 of cyclic and pregnant gilts (Simmen *et al.*, 1992).

Of particular interest was a study of IGF mRNAs in two breeds of pigs that exhibit different levels of prolificacy (Simmen *et al.*, 1992). The endometrium from the Large White breed with high conceptus mortality had higher levels of IGF-II and IGFBP-2 mRNAs on day 12, than did endometrium from the Meishan breed with low conceptus mortality. Expression of IGF-I mRNA was higher in endometria of Meishan than Large White gilts on day 12. The authors concluded that the correlation of relative ratios of IGF mRNAs with prolificacy during the critical period of maternal recognition of pregnancy, coupled with the stage-specific expression of the mRNAs, suggests an important role for IGFs in conceptus and foetal development. Obviously, more research is needed on the control of expression of IGFs and their binding proteins in pig endometrium, particularly in relation to the role of steroids and other local regulators from the endometrium and blastocysts.

Prolactin receptors

During gestation, pigs have constant circulating levels of prolactin and lack decidual prolactin and placental lactogens. The effects of prolactin on uterine physiology are modulated by changes in lactogenic receptors present on endometrial membranes (Young and Bazer, 1989; Young *et al.*, 1990). In cyclic gilts, the levels of lactogenic receptor remain constant between days 8 and 15, whereas in pregnant gilts, the levels increase on day 12 and remain elevated between days 14 and 30. This increase was shown to be reproduced in non-pregnant gilts by treating them with oestradiol, suggesting that in pregnancy, oestrogen originating from the blastocyst could control the endometrial response to prolactin in the pig.

Regulation of implantation

Local regulation of the process of implantation has been difficult to study but with recent advances in technique described above, it is now possible to address this question. Much of the work done so far has been in rodents, and a particularly interesting example is the role of leukaemia inhibitory factor (LIF).

LIF is a 45 to 56 kilodalton glycoprotein which has multiple activities as a cytokine. These include the acute-phase response in hepatocytes, regulation of differentiation and proliferation of certain haematopoietic cell lines, remodelling bone and inhibiting differentiation of embryonic stem cells (see Bhatt *et al.*, 1991). It has now been shown that uterine expression of LIF protein occurs in the stromal cells of mice, which increased transiently on day 4 just prior to implantation. This expression of LIF was independent of the blastocyst, because it also occurs at an equivalent time in pseudopregnant mice. In experimentally delayed implantation, transient LIF expression is also delayed and is induced by oestradiol (Bhatt *et al.*, 1991). This suggested a role for LIF in implantation, but did not prove it. It was shown subsequently, that transient expression of LIF was essential for implantation in mice by using female mice lacking a functional LIF gene as a result of 'gene knockout' in embryonic stem cells (Stewart *et al.*, 1992). These females conceived but the blastocysts failed to implant and develop. The blastocysts were viable because they implanted and developed to term when transferred to wild-type pseudopregnant recipients.

It has been suggested that maternal LIF acts during the initiation of implantation in mice, by inducing a change in the uterine epithelium that favours blastocyst attachment or invasion (Strickland and Richards, 1992). Similar studies in the pig have not been reported.

Placental growth at and after implantation

The speculation that local regulators may be involved in growth of the conceptus was first made over seventy years ago (Corner, 1921). The uterine secretions or histotrophe produced by endometrial glands were thought to carry the factors responsible (Amoroso, 1952). These secretions almost certainly contain growth factors which directly influence the growth of the embryo and its membranes, and could also include cytokines involved in regulation of immunological reactions against the semi-allogeneic embryo. One prime candidate as a uterine growth factor with these properties are the colony stimulating factors (CSFs) (Pollard, 1990). Others include retinol binding proteins and uteroferrin.

Colony stimulating factors

CSF-I is a homodimeric glycoprotein growth factor originally purified as a lineage specific growth factor for mononuclear phagocytes, which facilitated their survival, differentiation and proliferation (see Pollard, 1990). The receptor for CSF-I is a transmembrane tyrosine kinase, now known as a product of the *c-fms* proto-oncogene. A role for CSF-I in regulating placental development during pregnancy is suggested by the temporal relationship of CSF-I in the uterus and the identification of

its receptor mRNA in placenta and on trophoblast. Oestradiol and progesterone appear to regulate synthesis of CSF-I in the uterus, by induction of its mRNA in epithelial cells. This production is low in early pregnancy, but increases with advancing pregnancy, consistent with a role of CSF-I in placental and fetal growth. More definitive evidence of the role of CSF-I in early pregnancy comes from a study of osteopetrotic (*op/op*) mutant mice (Pollard *et al.*, 1991). These mice have a mutation in the gene encoding CSF-I, which causes a frameshift in the readout, and as a consequence, premature termination of translation. Mice with the *op/op* deficiency do not implant embryos. This is a maternal defect, which can be partially overcome when *op/op* females are mated with either wild-type or *op/+* males, suggesting compensation can occur for the lack of maternal CSF-I.

The involvement of CSF-I in implantation and placental growth is a good example of the involvement of factors, originally defined by their roles in the immune system, having different paracrine actions in the uterus. To the author's knowledge, the role of CSF-I in the pig uterus has not been reported.

Retinol-binding proteins

A family of retinol-binding proteins (RBP), distinct from the serum form, is secreted by the uterine endometrium of the pig (Clawitter *et al.*, 1990). At least four relatively acidic proteins, of molecular weight about 22 kilodaltons, were found in uterine flushings of pseudopregnant pigs. The concentrations of retinol and RBP were low in uterine flushings obtained on days 10-12 of the oestrous cycle and from pregnant gilts in which conceptuses had not elongated, but were elevated seven- to eight-fold when filamentous conceptuses were present (Trout *et al.*, 1992). The RBP in uterine flushings was increased in ovariectomized gilts in response to progesterone (Clawitter *et al.*, 1990), and the RBP mRNA was increased in the endometrium of ovariectomized gilts given steroid replacement to mimic early pregnancy (Trout *et al.*, 1992). The RBP mRNA was also enhanced approximately 12-fold in the endometrium of pregnant and pseudopregnant gilts, compared with non-pregnant controls on day 13 (Trout *et al.*, 1992).

These RBP appear to form part of the uterine histotrophe, thought to be essential for the metabolic requirements of the conceptuses in pregnancy.

Uteroferrin

Uteroferrin is a progesterone-induced, iron binding glycoprotein of 35 kilodalton molecular weight. It is secreted by the glandular epithelium of the pig endometrium and has acid phosphatase activity (see Baumbach *et al.*, 1991). Evidence based on studies using labelled uteroferrin suggest that preimplantation pig blastocysts actively take up uteroferrin by endocytosis from the glandular secretions *in vitro* (Baumbach *et al.*, 1990). Although it is thought that uteroferrin represents another important component of the histotrophe required by the growing blastocyst, the need for its exocytosis is not clear.

Recently, a group of antigenically-related, basic glycoproteins were found to be associated with uteroferrin (Malathy *et al.*, 1990). These proteins are produced by the porcine endometrium, under the influence of progesterone, and share many biosynthetic and structural features with the uterine 'milk' proteins found in sheep. The function(s) of these proteins remains obscure.

Conclusions

The evidence supports the concept of paracrine and autocrine regulation of the uterus and early pregnancy. The uterus and conceptus are both rich sources of growth factors and hormones which can have local regulatory actions, and in the case of the uterus, production of the growth factors is largely regulated by oestradiol and progesterone. Much less is known about regulation of production of factors produced by the conceptus.

It is also evident from this review that with a few exceptions, relatively little has been done to explore autocrine and paracrine regulation in the pig endometrium. After an intensive search revealed that the antiluteolytic factor produced by the pig blastocyst was oestrogen, the research emphasis moved more away from pigs to other domestic species, such as sheep and cattle. Recent interest in endometrial IGF and IGFBP and proteins in uterine flushings of pigs suggest a redress in this balance. Obviously, there are now a number of candidates to be explored in relation to embryo growth and survival in pigs of different strains and breeds, and in different nutritional and physiological situations. It is in this way that the physiological basis for fertility and fecundity at the uterine level, and the advantages of highly prolific strains, such as the Meishan, will be elucidated.

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MALE CONCEPTUSES GROW FASTER THAN FEMALES EVEN IN VERY EARLY STAGES OF PORCINE GESTATION

G. Cassar, W.A. King* and G.J. King

Department of Animal and Poultry Science; *Biomedical Sciences, University of Guelph, Guelph, Ontario N1G 2W1, Canada.

Pig conceptuses show considerable size diversity by day 11 when they enter a phase of rapid growth (Anderson, 1978) and begin placentation (Keys and King, 1991). Since most early embryonic mortality occurs by this time (Lambert *et al.*, 1991), with asynchrony suspected as an important contributing factor, and some suggestion that smaller specimens are disadvantaged, possible relationships between size, sex and survival to day 11 were investigated, to determine if this might suggest any mechanism influencing prolificacy.

Gilts were inseminated with pooled semen 24 h after detection of second oestrus (Day 0) and slaughtered 9, 10 or 11 days later. Numbers of corpora lutea and conceptuses were recorded with the latter all photographed under low magnification (6X). Conceptus outlines (n = 899 from 82 litters) were traced on a digitized tablet interfaced with a computer program to assess surface area for calculating size and variability within and between litters.

The proportion of corpora lutea represented by viable conceptuses on days 9 (76.5 ± 3.5%), 10 (79.7 ± 3.6%) and 11 (76.2 ± 3.6%) were similar ($P>0.05$). Between these days mean conceptus area increased from 1.06 ± 1.16 to 21.84 ± 1.41 mm^2 ($P<0.01$) and variance from 0.42 ± 0.56 to 9.47 ± 0.68 mm^2 ($P<0.05$), but greater size diversity on Day 11 was not associated with altered survival.

Day 11 conceptuses (n = 214 from 19 litters) were karyotyped to investigate sex and development relationships. Individuals within each litter were partitioned into small, medium or large groups by three equal divisions of the size, cultured in medium 199 with 1% colcemid and 20% FCS for 4 h, fixed on slides and stained with 4% Giemsa. Sex was determined by presence or absence of the Y-chromosome in at least two metaphase spreads from each specimen.

Overall sex ratio for 125 successfully karyotyped conceptuses approximated 1:1, but ratio of females to males was 42:9 in small, 12:10 in medium and 14:38 in larger sized groups. Logistic analysis indicated more females in smaller and males in larger sized groups ($P<0.01$). Proportion of specimens whose sex could not be successfully determined did not differ between groups ($P>0.05$).

Results showed that male conceptuses grow faster than females during the period between hatching from the zona pellucida and commencement of attachment to the uterine lining, so genetic sex is certainly a contributing factor to developmental diversity in preattachment porcine embryos. Whether this difference results from hyperplastic or hypertrophic growth is still unresolved and any potential application in reducing embryonic mortality is questionable. However, since sex ratio at birth is about equal and there is no evidence of selective loss of males later in gestation, the results indicate that bigger is not necessarily better at this critical stage of gestation.

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A ROLE FOR LH PULSES IN THE ESTABLISHMENT OF PREGNANCY?

B.G. Easton, R.J. Love, G. Evans* and C. Klupiec*

Department of Animal Health, University of Sydney, Camden, NSW 2570. *Department of Animal Science, University of Sydney, Sydney, NSW 2006.

Delayed returns to oestrus, indicating early pregnancy failure, are considered a major component of seasonal infertility (Love *et al.*, 1993). A seasonal change in luteinising hormone (LH) production could be responsible for these pregnancy failures. Little is known about the nature and timing of onset of the LH requirement for the establishment of pregnancy in pigs. Hypophysial stalk transection on the day after mating (Anderson *et al.*, 1966) or treatment with anti-ovine LH rabbit serum (Spies *et al.*, 1967) result in atrophy of corpora lutea and complete embryo loss in pregnant animals. Synthetic LHRH agonists have been used to modulate LH secretion in other species (McNeilly and Fraser, 1987); in this experiment we used an LHRH agonist to investigate the LH requirement for the establishment of pregnancy in pigs.

Four gilts were implanted with slow release implants of the LHRH agonist *Zoledex* (ICI 118,630; 3.6 mg) on the day of standing oestrus and were mated that day (day 0) and again 24 hours later. A second group of four non-implanted gilts were mated at the same time. Blood samples were taken via jugular cannulae daily from day 7 until day 42. On days 15 and 22 samples were taken every 15 minutes for six hours. Daily blood samples were also taken from a group of four unmated non-implanted gilts for the duration of one oestrous cycle. Plasma concentrations of LH and progesterone were measured by radioimmunoassay.

The LH 'window' bleed on day 15 showed that the LH pulses seen in the mated non-implanted gilts (1.25 ± 0.25 pulses per 6h) were eliminated in the LHRH implanted gilts, although the mean LH concentration did not differ significantly (1.00 ± 0.01 vs 0.88 ± 0.09 respectively; P=0.2). In all three groups, progesterone reached similar concentrations on days 8 - 13 (mated LHRH implanted, 15.5 ± 1.17; mated non-implanted, 13.8 ± 1.09; unmated non-implanted, 13.5 ± 1.41). In three of the four non-implanted mated gilts, high progesterone was maintained throughout the experiment, indicating that corpora lutea and pregnancy were maintained; in the fourth gilt the concentration of progesterone fell between days 16 - 21 and she returned to oestrus. In the four LHRH implanted gilts, progesterone declined between day 13 and day 21; one implanted gilt was seen to abort on day 21. In the unmated non-implanted gilts, progesterone declined in a similar way to the implanted mated gilts.

These results demonstrate that LHRH agonist treatment in the pig eliminates LH pulses, without significantly affecting mean LH, or luteal phase progesterone, a comparable effect to that seen in sheep (McNeilly and Frazer, 1987). However, treatment with LHRH agonist compromised the establishment of pregnancy. In at least one of the four LHRH implanted gilt's, embryos apparently developed normally, indicating that regression of the corpora lutea is responsible for the pregnancy failures. This suggests that pulses of LH, rather than simply a basal level of LH, are required for sustaining the corpora lutea of pregnancy.

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AD LIBITUM FEEDING OF MATED SOWS IMPROVES FERTILITY DURING SUMMER AND AUTUMN

R.J. Love, C. Klupiec*, E.J. Thornton and G. Evans**

Department of Animal Health, University of Sydney, Camden, NSW 2570. *Department of Animal Science, University of Sydney, Sydney, NSW 2006. **Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

High plasma melatonin levels in pregnant sows in summer (Peacock *et al.*, 1991) and adverse effects of constant-release melatonin implants on sow fertility in summer and autumn (Love *et al.*, 1993) suggest a causal relationship between elevated melatonin levels and seasonal infertility. Recent work indicated that plasma melatonin levels in prepubertal gilts were elevated by feed restriction under artificial long, but not short days (Klupiec *et al.*, 1992). Sows are normally feed restricted during early pregnancy. As a result of these findings, field trials are being conducted to examine the effect of feeding level on fertility of sows in different seasons. The results of the summer-autumn (February-March) trial are reported here.

Sows were fed *ad libitum* between farrowing and mating. Sows mated in each week were housed in four pens (22-23 sows/25m^2) and floor-fed, once daily. Sows in two pens were fed 22 MJ/sow/day for two weeks, 27 MJ/sow/day for two weeks then 34 MJ/sow/day until farrowing (restricted group). The remaining sows were fed *ad libitum* (approximately 44 MJ/sow/day) for four weeks, then 34 MJ/sow/day (*ad libitum* group). All sows not returning to oestrus were pregnancy tested by ultrasound seven weeks post-mating. The pregnancy rates are shown in Table 1.

Table 1. Pregnancy rates (%) seven weeks post-mating in sows fed at various levels during early gestation in summer-autumn (numbers of animals in brackets)

Week mated	Restricted group	*Ad lib.* group	Sign.[1]
7	56.1 (23/41)	86.0 (37/43)	**
9	43.2 (19/44)	78.3 (39/46)	***
10	63.0 (29/46)	67.4 (29/43)	NS
11	63.0 (29/46)	87.0 (40/46)	**
Total	56.5 (100/177)	79.8 (142/178)	***

[1]NS, non significant, P>0.05; ** P<0.01; *** P<0.001.

The results indicate that *ad libitum* feeding of group-housed mated sows significantly improves fertility compared with restricted feeding. The influence of season on this association between feed intake and fertility is being investigated by a similar field trial during winter. Data from previous years for this piggery suggest this level of feed restriction will not adversely affect fertility in other seasons. It appears that high level feeding of grouped sows during early gestation in summer-autumn offers a simple strategy for mitigating the reduction in fertility often encountered at this time.

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LIMITATIONS OF A DIRECT RADIOIMMUNOASSAY FOR MEASUREMENT OF MELATONIN IN PIG PLASMA

C. Klupiec, G. Evans, R.J. Love* and D.J. Kennaway**

Department of Animal Science, University of Sydney, Sydney, NSW 2006. *Department of Animal Health, University of Sydney, Camden, NSW 2570. **Department of Obstetrics and Gynaecology, Medical School, University of Adelaide, Adelaide, SA 5000.

A previous study indicated a significant increase in plasma melatonin, as measured by radioimmunoassay (RIA), in prepubertal gilts fed at 60% *ad libitum* intake, compared with *ad libitum* feeding under artificial long days, but not short days (Klupiec *et al.*, 1992). The magnitude of the increase in the long-day group prompted analysis of selected samples in another laboratory, using a different RIA, to confirm these results.

Plasma melatonin was initially determined by a direct RIA, modified from the technique of Webley *et al.* (1985), using an antibody obtained from Stockgrand Ltd and solid phase, second-antibody separation (present assay). A group of these samples, selected from long-day gilts on *ad libitum* and restricted feed intake, was then analyzed by the method of Earl *et al.* (1985), with and without the extraction step, using a different antibody (G280) and charcoal separation (comparison assay). Mean melatonin levels for the same groups of samples measured using each assay are given in Table 1.

Table 1. Mean (±SE) plasma melatonin (pg/ml) in prepubertal gilts under artificial long days, on *ad libitum versus* restricted feed intake, measured by different RIAs

	Present assay	Comparison assay	
	Direct	Direct	Extraction
Ad libitum (17 samples)	21.3 ± 3.5	17.8 ± 1.5	15.1 ± 1.0
Restricted (17 samples)	233.0 ± 40	15.8 ± 1.0	16.0 ± 1.0
Significance[1]	**	NS	NS

[1]NS, non significant, $P>0.05$; ** $P<0.01$.

In contrast to the present assay, no significant difference was detected between samples from *ad libitum* fed and restricted gilts when assayed using the comparison assay (direct or extraction). The results of the different direct assays indicate that specific binding of melatonin tracer with a binding protein is not the cause of this discrepancy. High levels of melatonin (>100 pg/ml) were subsequently detected in pooled plasma from long-day restricted gilts in the present assay, using either the charcoal or second-antibody separation system. The possibilities of cross-reaction of the antiserum, used in the present assay, with high circulating levels of other compounds, or interference with tracer-antibody binding, due to non-specific plasma effects, are under investigation.

Alteration of plasma constituents in gilts by feed restriction under long daylengths impairs the accuracy of detection of melatonin by the direct RIA, used in our laboratory. Identification of the cause of this interference is important in terms of the potential physiological significance of feeding/photoperiod interactions in pigs.

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THE EFFECT OF LIMITING THE NUMBER OF MATINGS ON THE REPRODUCTIVE PERFORMANCE OF WEANED SOWS

A.M. Paterson and B.P. Mullan

Department of Agriculture, Animal Industries Division, Baron-Hay Court, South Perth, WA 6151.

It is current practice to mate sows at least twice at their first oestrus after weaning. Recently, it has been suggested that mating sows only once may reduce costs without affecting performance. However, the scientific validity of the data on which this claim is based is open to debate. In this experiment, we investigated the effect on reproductive performance of single vs double mating, using planned comparisons, made under well controlled conditions, with adequate numbers of animals. The AUSPIG simulation model was used to estimate the impact of mating strategy on profitability.

In February/March 1993, all sows which showed oestrus within 14 days of weaning in a large commercial piggery were allocated among three treatments:

Treatment 1. Double mating - first when detected, second 24 h later.

Treatment 2. Single mating when first detected in oestrus.

Treatment 3. Single mating 24 h after first detected in oestrus.

Sows were allocated to treatments at weaning. Those allocated to Treatment 1 which did not stand for a second mating (n=30) were excluded from the study. Over 90% of the sows in each group were mated within 8 days of weaning. The AUSPIG simulations used the piggery standards for litters/year, mortality, growth rate, carcass characteristics and marketing policy. It was assumed that single mating increased the boar:sow ratio from 1:20 to 1:33, and that the piggery was fully stocked. If the floor space previously used for boars was used for grower/finishers, average slaughter weight could be increased by 4 kg.

Table 1. The effect of number of matings on reproductive performance

	Matings			Sign.[1]	SEM
	Double	Single	Single - 24 h		
Number farrowed	104	154	121		
Average parity	3.5	3.6	3.6		
Farrowing rate (%)	86.7	85.1	84.6	NS	
Born alive/litter	11.1[a]	10.2[b]	10.2[b]	*	0.26

[1]NS, non significant, P>0.05; * P<0.05. Means with different superscripts differ (P<0.05).

The double-mated sows had more (P<0.05) pigs per litter than either of the groups of sows, which were mated only once. Among the single mated sows, litter size was the same regardless of when the mating took place. There was no significant effect of treatment on farrowing rate (P>0.05).

AUSPIG analysis indicated that single mating reduced net revenue from $286/sow/year to $174/sow/year. If the resources saved by single mating were used to increase slaughter weight, a decrease of 0.6 pigs/litter could be sustained before net revenue was adversely affected. In this scenario, the observed fall in performance would have reduced net revenue to $234/sow/year.

The data presented here show that single mating can reduce reproductive performance and profitability. It is recommended that if producers are considering adopting single mating, then they should proceed with extreme caution.

THE ROLE OF BOAR CONTACT FREQUENCY IN MODIFYING THE EFFICACY OF THE 'BOAR EFFECT'

P.E. Hughes

School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.

All previous studies on the boar effect have assumed that daily contact with a boar will maximise the level of gilt puberty stimulation. However, in rodent species, male contact frequencies of greater than once daily are known to be more stimulatory to the prepubertal female than is a single daily period of male contact. The present studies were, therefore, conducted to examine the effects of allowing gilts boar contact at frequencies greater than and less than once daily, on the efficacy of the boar effect.

Sixty four Large White/Landrace crossbred gilts were allocated to treatment (n = 16/treatment) in each of two experiments in this study. The two experiments compared the effects on puberty attainment of exposing gilts to boar contact either on alternate days (AD), daily (D) or twice daily (2D) in Experiment 1, and daily (D), twice daily (2D) or three times daily (3D) in Experiment 2. In each experiment, puberty attainment by gilts in the boar exposure regimes was compared with puberty attainment in a non-boar exposed control group of gilts. The two boars used for boar exposure in both experiments were mature (>12 months of age) and were used on alternate days. Boar exposure began at a mean gilt age of 160 days and continued for 60 days. The duration of boar contact was for 20 minutes/exposure period in Experiment 1, and for 60, 30 and 20 minutes/exposure period respectively for treatments D, 2D and 3D in Experiment 2. Experiment 1 commenced treatments in the summer while Experiment 2 began in winter. All boar exposure regimes significantly increased the proportion of gilts attaining puberty within 60 days of the commencement of treatments ($P<0.05$), compared with control gilts in both experiments. Both the mean days taken to reach puberty following the imposition of treatments, and mean gilt age at puberty, were significantly reduced by increasing boar contact frequency in both experiments. In Experiment 1, twice daily boar contact resulted in a significantly higher proportion of gilts reaching puberty in the first 20 days of treatment, than for either daily or alternate day boar contact.

Table 1. The effects of treatment on gilt puberty attainment (Experiments 1 and 2)

			Treatment[1]				
			C*	AD	D	2D	3D
Days to puberty:	Expt. 1	- Mean	-	34.9[a]	26.9[a]	12.9[b]	-
		- SEM	-	3.2	4.3	2.4	-
	Expt. 2	- Mean	-	-	27.8[ab]	35.4[a]	17.8[b]
		- SEM	-	-	5.0	4.2	4.0

* No control gilts reached puberty within the 60 day experimental period. [1]Within rows, means with different superscripts differ ($P<0.05$).

It is concluded that: 1) daily boar exposure does not maximise the pubertal response of the gilt to the boar effect, and 2) maximal gilt response may be achieved by more frequent boar exposure regimes, but the actual frequency required is dependent on season.

EFFECT OF FEEDING LEVEL ON EARLY REPRODUCTIVE DEVELOPMENT OF GILTS

J.B. Gaughan, G. McL. Dryden and R.D.A. Cameron*

Department of Animal Production, University of Queensland, Gatton College, Lawes, Qld. 4343.
*Department of Farm Animal Medicine and Production, University of Queensland, St Lucia, Qld. 4072.

Early sexual maturity of gilts may increase herd productivity. Selection of early maturing types has given variable results in the age of puberty of their offspring. Beltranena *et al.* (1991) has shown that although body composition is unlikely to influence puberty attainment, nutritional intake may. This study investigates the influence of different feeding regimes on early reproductive development of gilts.

Forty five Large White gilts (15 littermate triads) selected at 56 ± 2 days of age, with a mean live weight 16.4 kg, were housed in individual pens and were offered a wheat-based diet consisting of 14.12 MJ DE, 9.2 g available lysine and 160 g crude protein per kg. The litter mates were randomly selected and allocated to one of three feeding levels. Level 1 (L) were offered 1.25 kg day^{-1} from 56 to 112 days of age after which it was increased to 1.45 kg day^{-1}. Level 2 (M) were offered 1.80 kg day^{-1} while level 3 (H) were fed *ad libitum*. Oestrus activity was monitored from 145 days of age. From 160 ± 2 days of age gilts had daily contact with a mature boar. The gilts were slaughtered at 176 ± 4 days of age and reproductive tracts were removed and examined.

Table 1. The effect of feeding level on growth and reproductive parameters in gilts

	L	M	H	SEM
Number of gilts	14	15	14	
Live weight (kg)	98.0	99.8	103.9	7.4
Gain (g/day)	701	712	776	0.03
Backfat (mm)	15.3	18.3	18.5	6.5
Weight of reproductive tract (g)	261	325	389	184.8
Weight of ovaries (g)	7.7	9.0	7.4	2.7
Number of follicles	12.8	11.4	11.3	8.1
Puberty attainment	3	4	9	0.46

Data presented in Table 1 shows that feeding level had a non significant ($P>0.05$) effect on weight gain and backfat indicating that the potential for growth was not restricted by intake up to 176 days of age. This may be due to a faster rate of passage through the digestive system in the H gilts, resulting in a reduction in nutrient uptake. There was a significant difference in puberty attainment between L and H ($P>0.05$) and M and H ($P>0.05$). However, four of the nine H gilts had a silent heat, as detected on examination of ovaries at slaughter; a similar result was a reported by Newton and Mahan (1992). Examination of ovaries at slaughter suggested that five H, six M and four L gilts would have ovulated in 2 - 5 days time. The number of follicles, average daily gain, weight of reproductive tract and ovaries were not significantly effected by treatment. Litter mates tended to have similar reproductive development irrespective of treatment, which implies a strong genetic influence. There is probably little advantage to be gained from the *ad libitum* feeding of gilts to improve reproductive development.

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THE INFLUENCE OF BOAR LIBIDO ON THE EFFICACY OF THE 'BOAR EFFECT'

P.E. Hughes

School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052.

Much of the variation in the pubertal response of gilts to boar contact is thought to be due to the level of stimulation provided by the boar (ie; his stimulus value). Indeed, it has been known for some time that the boar's age influences his ability to stimulate puberty in young gilts (Kirkwood and Hughes, 1981; Zimmerman and Kopf, 1986). More recently it has been suggested that considerable variation exists in the stimulus value of mature boars aged 10 months and above (Hughes *et al.*, 1990). The present study was therefore designed to investigate the effect of boar 'libido' on puberty attainment in gilts.

Eighty one Large White/Landrace crossbred gilts were used in three replicates in this study. These gilts were allocated to one of three treatments, these being: 1) control - no boar contact, 2) daily exposure to a low libido boar, and () daily exposure to a high libido boar. All treatments began at a mean gilt age of 160 days and continued for 60 days. The four Large White 'libido' boars used in each replicate of this study were at least 12 months of age. They were designated as high or low on the basis of their sexual behaviour in three 15 minute mating tests, conducted when the boars were 9-10 months of age. The variables measured for this assessment were total number of copulations achieved (5.8 ± 0.48 vs 2.7 ± 0.42 for high and low boars respectively) and mean times to first mount an oestrous female (25.2 ± 8.05 vs 84.5 ± 15.60 for high and low boars respectively). Results show that gilt exposure to a high libido boar stimulated puberty at a significantly earlier age than did exposure to a low libido boar (179.6 vs 194.1 days, $P<0.05$; Table 1).

Table 1. The effects of boar libido on gilt puberty attainment

	Treatment[1]		
	Control	Low libido	High libido
Proportion pubertal by:			
Day 20	0.00[a]	0.19[b]	0.59[c]
Day 60	0.35[a]	0.88[b]	0.89[b]
Days to gilt puberty:			
Mean	48.1[a]	33.7[b]	19.4[c]
SEM	3.0	3.6	2.9

[1]Within rows, proportions/ means with different superscripts differ ($P<0.05$).

These data demonstrate that differences in the stimulus value of mature boars to prepubertal gilts do occur. The causes of these differences remain to be identified, although the present results suggest/implicate the sexual motivation of the boar.

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LEPTOSPIRES OF SEROVAR *BRATISLAVA* AS A POSSIBLE PATHOGEN IN AUSTRALIAN PIGS

R.J. Chappel, M.L. Billinghurst, S.S. Wan, D.P. Hennessy, W.A. Ellis* and B. Adler**

Department of Agriculture, Victorian Institute of Animal Science, Attwood, Vic. 3049. *Department of Agriculture, Veterinary Sciences Division, Stormont, Belfast BT4 3SD, Northern Ireland. **Department of Microbiology, Monash University, Clayton, Vic. 3168.

Leptospiral infection among Australian pigs is usually attributed to *Leptospira interrogans* serovar *pomona* and to *L. borgpetersenii* serovar *tarassovi*. *L. interrogans* serovar *bratislava* infects pigs in Europe and North America, and has been associated with abortions and stillbirths. Serovar *bratislava* has yet to be isolated in Australia, but there is emerging evidence that it is widespread.

Preliminary studies (Chappel *et al.*, 1992) of microscopic agglutination test (MAT) titres to *bratislava* have been extended. Sera were obtained from 522 pigs slaughtered in Victorian abattoirs, of which 329 pigs originated from 126 individually-identified herds in Victoria, New South Wales and South Australia. Of these, 56 (11%) had MAT titres of ≥256 to *bratislava*, and these titres were obtained from 32 (25%) of the identified herds. The comparable figures for titres of ≥256 to *pomona* were 20 (4%) sera, and six (5%) identified herds.

Morphologically-identified leptospires were visualised by immunofluorescent staining, using a genus-specific antiserum against *Leptospira*, in uterus or kidney of sows culled for infertility from one herd and of grower pigs with titres to *bratislava* in two other herds, and in kidney and lung of stillborn piglets from two further herds. All these herds were free of serovar *pomona*, as indicated by serological testing.

Sera from 258 breeding gilts and sows from two farms were tested by the MAT for serovar *bratislava*. On the first farm, titres were significantly lower in pigs mated during the summer/autumn season of reduced fertility. On the second farm, titres were significantly lower in infertile pigs than in pregnant animals. Infertile animals mated in summer/autumn in these herds showed an inverse relationship between basal serum cortisol concentrations and *bratislava* titres. These results suggest that serovar *bratislava* may have a role in seasonal infertility in some herds. Possibly stress can inhibit the antibody response of some pigs to serovar *bratislava* making them susceptible to reproductive losses.

Culture of serovar *bratislava* has been attempted from tissues of adult, stillborn and newborn pigs from 22 herds, using Tween 40/80 medium and EMJH medium containing 0.4% heat-inactivated rabbit serum (Ellis *et al.*, 1985; Bolin *et al.*, 1991). All cultures were negative.

Work with serovar *bratislava* is difficult because it is much less immunogenic than serovar *pomona* and because it is notoriously fastidious in its growth requirements (Bolin *et al.*, 1991). Nevertheless, further studies are needed to unambiguously confirm infection of Australian pigs with *bratislava*, and to determine any link between this organism and reproductive performance.

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DIETARY MANIPULATION OF SWINE DYSENTERY

P.M. Siba, D.W. Pethick, K.A. Nairn*, and D.J. Hampson

School of Veterinary Studies, Murdoch University, Murdoch, WA 6150. *Milne Feeds, Welshpool, WA 6106.

Swine dysentery is the most economically-significant endemic disease affecting the Australian pig industry (Cutler and Gardner, 1988). The condition is a mucohaemorrhagic colitis, which results from infection with the anaerobic spirochaetal bacterium, *Serpulina hyodysenteriae*. Disease is mainly seen in grower pigs, which may suffer severe loss of production. Despite there being serological evidence that the infection is common in Australia (Mhoma *et al.*, 1992), severe disease is not reported frequently. A virulent strain of the bacterium has also been isolated from a herd that appeared to be free of clinical swine dysentery (Hampson *et al.*, 1992). The reason for lack of disease in this herd was not clear.

It has been suggested that fermentable diets which result in acidic conditions in the large intestine may inhibit the growth of *S. hyodysenteriae*, and prevent the development of disease (Prohaszka and Lukacs, 1984). We tested the effect of pH on growth of *S. hyodysenteriae* in a chemostat; a pH of 6.0 was shown to be inhibitory, while the organism grew vigorously in the same medium at pH 6.85.

In an attempt to obtain similar pH values in the large intestine, we fed groups of pigs either a highly fermentable unpelleted commercial diet, based on wheat and lupins (15%), or an experimental diet based on cooked rice and animal proteins. As a result of fermentation, the mean (± SEM) pH of caecal contents in pigs (n = 7) on the wheat/lupin diet was 5.37 (± 0.03), and was 6.54 (± 0.12) in pigs (n = 6) on the readily-digestible rice diet.

We then used cultures of *S. hyodysenteriae* to orally challenge eight pigs fed one or the other of these two diets. The two groups were mixed for four hours each day in the week following the first signs of disease, to increase the opportunity for transmission of infection. Pigs in both groups developed antibody titres to *S. hyodysenteriae*, but, unexpectedly, only the four fed the wheat/lupin diet developed swine dysentery. The presence of acidic conditions in the large intestine therefore did not protect these pigs from swine dysentery. The rice diet was, however, protective. Pigs on this diet also had much smaller and less well-developed large intestines than did those on the wheat/lupin diet. Mean weight of the large intestine and its contents as a percentage of total body weight for the pigs on the wheat/lupin diet was 4.50 (± 0.24), compared to 1.76 (± 0.10) for pigs on the rice diet. Since there is evidence that *S. hyodysenteriae* requires the activity of other anaerobic bacteria to colonise the porcine large intestine and to cause lesions (Whipp *et al.*, 1979), we postulate that the large intestinal flora altered in pigs fed the highly-digestible rice diet, and hence they were less susceptible to disease.

In conclusion, the expression of swine dysentery can be manipulated by dietary means. This may explain some of the clinical variability of the disease that is seen in the field.

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MANAGEMENT PRACTICES LIKELY TO BE ASSOCIATED WITH POST-WEANING COLIBACILLOSIS

B. Walker

NSW Agriculture, PO Box 546, Gunnedah, NSW 2380.

This paper reports on feeding and management practices likely to affect the incidence of post-weaning colibacillosis. Results are drawn from a survey sent to 400 producers with more than 20 sows, selected at random from the NSW Swine Brands Register. One hundred and twenty one replies were received.

Producers were asked about creep feeding, source and pH of water, pen hygiene, creep and weaner house heating, and type of weaner accommodation. Differences in responses were then analysed by Chi-Squared test, depending on whether or not the producer stated that he had a problem with weaner scours.

Producers were asked to indicate cleaning method(s) and cleaning frequency used, from a number of listed options. Producers who hosed farrowing pens regularly reported a significantly lower incidence of scours ($P = 0.028$), than those not hosing out, which goes against the usual dogma that farrowing crates should be kept dry. (The survey did not determine whether the whole pen was hosed, or just the area behind the sow). There was a tendency ($P = 0.126$) for a higher scouring incidence if dung was shovelled out only.

In this survey, producers who provided heating in the creep area reported a significantly higher incidence of scour problems ($P = 0.047$ Fisher exact). However, this result may have occurred because those with a scour problem subsequently added a heat source. Also, no question was asked to determine what range of temperature occurred in the shed. No relationship was demonstrated between the incidence of scours and whether or not an enclosed creep area was provided.

There was no significant difference in the weaning age in the problem (30.04 + 8.28 days) and non-problem groups (30.72 + 7.69 days).

The source of water supply was not significant. There was a tendency for problems with scours if the pH of the water was not neutral (scour problem in 3 out of 4 (75%) with acid, 5 out of 19 (26%) with neutral, and 6 out of 14 (43%) with alkaline water). Although not significant, due to small numbers of producers who knew the pH of their water (31% of respondents), this may be a factor worth investigating.

Another section of this survey, covering treatment and control measures used against colibacillosis, was reported by Walker (1993).

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VARIABILITY OF METABOLITE CONCENTRATIONS IN THE PLASMA OF PIGLETS OVER THE SUCKLING PERIOD

M.J. Thompson, C.M. Wakeford and P.E. Hartmann

Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.

This preliminary study was performed to investigate the variation in the concentrations of various metabolites in the blood plasma of piglets during the suckling period. The metabolites chosen were associated with carbohydrate and fat metabolism. Blood (60µl) was obtained by pricking the ear veins of the piglets. Concentrations were determined using either bioluminescent or spectrophotometric assays as described by Arthur *et al.* (1989), on small samples (20µl) of blood plasma. The day of farrowing was taken as day 1. All piglets were either Landrace, Large White or Landrace x Large White cross breeds.

Significant changes were observed in the concentrations of monosaccharides over the first two days; with glucose increasing ($P<0.05$) and galactose and fructose decreasing ($P<0.05$ and $P<0.01$, respectively). Milk lactose was discounted as the source of variation in glucose and galactose, as the piglets were denied access to the sow for 45 min prior to blood collection, except for day 1 piglets and they were sampled prior to first suckling. The concentration of β-hydroxybutyrate (β-OH-but) showed no significant change during the suckling period. Plasma concentrations of glucose-1-phosphate (G1P) were significantly correlated ($P<0.001$) to glucose-6-phosphate (G6P) and the concentrations of G1P were higher than those for G6P, throughout. Although concentrations of G1P tended to increase with age, differences between values at various ages were not significant. In contrast, there was significant increase ($P<0.001$) in G6P concentrations on day 7, above those on days 1 and 2.

Table 1. Metabolite concentrations in the plasma of piglets

Day of age	1	2	7	10	15	17	19	21
Glucose	3.0	4.7	4.0	4.4	4.5	4.1	5.0	4.0
(mM)	±0.8	±0.7	±0.8	±0.3	±0.7	±0.9	±0.7	±0.4
Galactose	186	56	13	23	11	17	21	11
(µM)	±94.2	±24.1	±11.1	±13.1	±3.1	±9.8	±17.5	±4.3
Fructose	1855	230	21	12	15	8	10	6
(µM)	±621	±200	±7	±12	±11	±7	±2	±5
β-OH-but	7.4	12.0	12.6	9.7	8.8	5.7	8.2	12.4
(µM)	±3.5	±2.7	±7.2	±3.8	±3.8	±0.9	±4.2	±12.4
G1P	2.7	2.9	1.9	3.9	2.8	3.0	4.0	3.5
(µM)	±0.3	±0.2	±0.4	±1	±0.4	±0.7	±2	±0.9
G6P	0.5	0.4	1.1	1.5	1.1	1.2	1.5	1.7
(µM)	±0.2	0.1	±0.3	±0.4	±0.2	±0.5	±0.7	±0.5

Values are given as mean ± SD where n = 4 for all ages except day 15 where n = 5.

Large variations occurred in the concentrations of all metabolites during the suckling period. The significance of this variation and its relationship to the growth and development in the suckling piglet, requires further investigation.

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TRENDS IN CHRONIC RESPIRATORY DISEASE ACROSS THE AUSTRALIAN PIG INDUSTRY

A.M. Pointon, M. Moore and C. Cargill

South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.

Disease prevalence information, obtained from monitoring production limiting diseases at slaughter (Pointon *et al.*, 1992a), creates the opportunity to examine disease trends across industry. Chronic respiratory disease (CRD), comprised principally of enzootic pneumonia and complicated by *Pasteurella* infection, can readily be assessed at slaughter due to the persistence of lesions. These herd prevalence reports are particularly important to producers wishing to assess the contribution of respiratory disease to poor growth and the effectiveness of disease control strategies. This paper collates results of herd slaughter checks during 1988-1992 and reports the effect of herd size on the prevalence of CRD. The likely impact of the national trend to increasing herd size is examined in view of these findings.

The prevalence of CRD within herds is highly dependent on herd size ($P<0.01$) (Pointon *et al.*, 1992b) ie; within herd prevalence increases as herd size increases. Slaughter surveillance data from 1988 to 1992 indicate that the prevalence of CRD has remained relatively constant in South Australia (Figure 1) ie; 39 - 48% of all pigs monitored in affected herds each year had CRD lesions at slaughter. During this period the herd size profile of monitored herds remained relatively stable, even though Australian Bureau of Statistics indicate an increase in average herd size nationally (the number of herds declined by 31% while sow numbers declined by 10%).

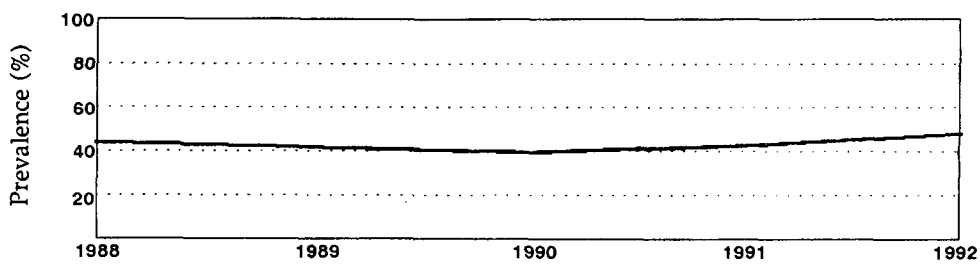

Figure 1. *Prevalence of chronic respiratory disease at slaughter in SA. Data represents all inspected pigs from chronic respiratory disease positive herds.*

There are two important implications of these findings: 1) Intervention to control CRD has not had a serious impact on prevalence. The cost of medication required to maintain herd growth performance in the face of CRD was found to be \$2 and \$5/pig marketed from two herds with a prevalence of lesions at slaughter of 35% and 80%, respectively, and 2) An increase in overall prevalence and, therefore, cost of control, may be predicted due to the trend towards increasing herd size.

Considerable challenge and opportunity exists for producers to reduce the cost of production, by maintaining better environment conditions, through the installation of automatic control equipment, or moving to respiratory disease free stock.

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STUDIES ON PORCINE PLEUROPNEUMONIA - AN UPDATE

P.J. Blackall, G.J. Storie and J.L. Pahoff

Queensland Department of Primary Industries, Animal Research Institute, Yeerongpilly, Qld. 4105.

Porcine pleuropneumonia is a serious, often fatal respiratory disease of pigs, caused by the bacterium *Actinobacillus pleuropneumoniae* (previously known as *Haemophilus pleuropneumonia*).

In previous work we have performed some basic characterisation of the disease causing agent (Eaves and Blackall, 1988; Eaves *et al.*, 1989; Rogers *et al.*, 1990). In this paper we report on our recent work, which has involved continued characterisation studies plus the evaluation of vaccines against the disease.

A total of 352 haemophili isolated from pigs in all mainland Australian states were studied. The majority of the isolates were identified as *A. pleuropneumoniae* (296 isolates) or *Haemophilus parasuis* (42 isolates). A small number of isolates were identified as members of unclassified bacteria known as *Haemophilus* Taxon 'minor group' (12 isolates) and *Haemophilus* Taxon D (two isolates).

The 296 isolates of *A. pleuropneumoniae* identified in the characterisation study were serotyped. Of these, only 156 could be assigned confidently to one of 12 recognized serovars. The occurrence of the various serovars amongst these 156 isolates was as follows: serovar 1 - 85 isolates, serovar 2 - 4 isolates, serovar 3 - 2 isolates, serovar 5 - 10 isolates, serovar 7 - 51 isolates, serovar 11 - 2 isolates and serovar 12 - 2 isolates. Of the remaining 140 isolates, 91 gave cross-reactions with serovars 3 and 6 while 49 gave no reaction with any of the antisera.

All the vaccines examined in this study were based on killed cells of *A. pleuropneumoniae* serovar 1 and all challenges were homologous. Initially, we examined four different adjuvants for their efficacy. A simple mineral oil emulsion was very effective, but caused unacceptable tissue reactions, while an aluminium hydroxide gel did not come adverse reactions, but did not stimulate a good protective response. The other two adjuvants evaluated, one produced by Auspharm and the other by the Victorian Department of Agriculture (DARA), did not cause adverse tissue reactions and were effective under our conditions of trial. We selected the DARA adjuvant for the next stage of the work.

Using this selected adjuvant, the effect of varying the antigen component (*A. pleuropneumoniae*) was evaluated. Several different methods of growing the antigen were evaluated, without demonstrating any significant improvement. The most effective antigen component was found to consist of killed whole cells that were supplemented with concentrated supernatant from the growth medium. Vaccines based on this antigen preparation, combined with the selected adjuvant, were able to give very high levels of protection against a severe challenge from a virulent strain of *A. pleuropneumoniae*. Vaccinated pigs showed no clinical signs, had no lung damage and the respiratory tract was free of the challenge organism. In contrast, unvaccinated pigs showed severe clinical signs (one of five pigs dying from the disease), had severe lung damage (average of 54% of the lung affected) and were heavily colonised by the challenge organism.

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THE EFFECT OF LUNG DAMAGE DUE TO PLEUROPNEUMONIA CHALLENGE ON ENERGY EXPENDITURE OF GROWING PIGS

H.J. Bray, L.R. Giles, K.H. Walker*, J.M. Gooden and J.L. Black**

Department of Animal Science, University of Sydney, Camden, NSW 2570. *NSW Agriculture, Elizabeth Macarthur Agricultural Institute, PMB 8, Camden, NSW 2570. **CSIRO Division of Animal Production, Prospect, PO Box 239, Blacktown, NSW 2148.

Although a relationship exists between the long-term effects of pleuropneumonia and a depression in voluntary food intake (VFI) and food efficiency of growing pigs, the mechanisms by which performance is reduced during the acute phase are unclear. This study examined the effect of lung damage (LD), due to challenge with serotype 1 of *Actinobacillus pleuropneumoniae* (App), on VFI and oxygen consumption (VO_2).

Seven specific-pathogen-free female pigs (mean live weight, 80 kg) were fed *ad libitum* a pelleted commercial diet containing 12.6 MJ DE/kg and housed at 22°C in individual metabolism crates. The pigs were surgically prepared for the continuous measurement of VO_2 (Giles *et al.*, 1990). All pigs returned to pre-surgery VFI within 3-5 days. Two weeks after surgery, VFI and VO_2 were measured for a control period of 1-3 days. Each pig was challenged via intra-bronchial inoculation of App into the right lung, with inoculation doses ranging from 10^5 to 10^9 colony forming units. VFI and VO_2 measurements continued until post-mortem 6 days after inoculation. The right lungs were isolated and perfused with fixative and LD was assessed from image analysis of serial lung slices. The daily results (mean ± SEM) for VFI and VO_2 for all seven pigs during the control period were 2640 ± 93.0 g/day and 403.4 ± 22.77 ml/min respectively.

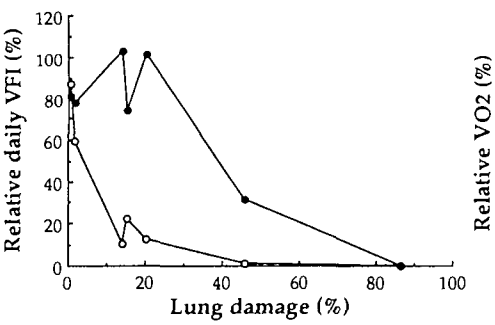

Figure 1. Relative VFI at day 2 0–0, and day 6 ●—●, related to lung damage to the right lung at day 6 post-inoculation with A. pleuropneumoniae in each of 7 pigs. Pre-inoculation VFI for each pig = 100%.

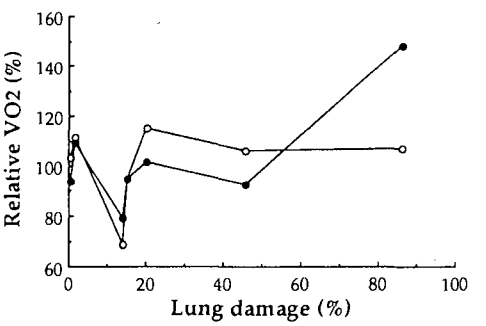

Figure 2. Relative VO_2 at day 2 0–0, and day 6 ●—●, related to lung damage to the right lung at day 6 post-inoculation with A. pleuropneumoniae in each of 7 pigs. Pre-inoculation VO_2 for each pig = 100%.

At day 2, VO_2 was greater than pre-inoculation values in all but one pig, despite a decline in VFI. By day 6, five pigs with less than 20% LD returned to pre-inoculation VFI and VO_2. Two pigs with more than 20% LD at day 6, however, maintained or actually increased VO_2, despite reduced VFI. These results indicate an increase in maintenance energy requirements during the acute phase of pleuropneumonia.

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AUTOMATED CONTROL OF PIGGERY ENVIRONMENTS

N.K. Masterman, R.J. van Barneveld and A.M. Pointon

South Australian Research and Development Institute, Northfield Pig Research Unit, GPO Box 1671, Adelaide, SA 5001.

It is estimated that sub-optimal environments cost the Australian pig industry in excess of $50 million annually (Bolla and Wright, 1985). Exaggerated feed costs, reduced growth rates, poor pig health and infertility are some of the detrimental effects caused by sub-optimal environments. Automatic control systems (ACS), that primarily monitor and adjust for temperature and ventilation on a 24h/day basis, can be used to limit losses.

Four systems exist in automatically controlling piggery environments, namely; 1) *electromechanical,* using hardwired electrical devices, such as thermostat, timer and relays, 2) *micro-computer,* where control equations are preprogrammed into the processor memory, 3) *personal computer,* that addresses and communicates to remote interface modules, and 4) *programmable logic controller,* an electronic device programmed via a hand-held panel.

A survey of 34 South Australian piggeries (28 - 2,200 sows) was conducted to assess current trends in environmental control (Table 1). Farms were randomly selected within herd size categories to ensure a proportional distribution across the range of piggery sizes.

Table 1. Extent of automated environmental control in 34 South Australian piggeries

Environmental parameter	Accommodation type				
	Dry sow	Farrowing	Weaner	Grower	Finisher
Ventilation					
Manual control	92%	76%[1]	64%	82%	85%
Automatic control	-	32%[1]	41%	17%	20%
Heating					
Manual control	-	60%	11%[2]	-	-
Automatic control	-	40%	37%	-	-
Cooling					
Manual control	15%	30%	4%	12%	14%
Automatic control	11%	23%	11%	25%	25%

[1]>100%; two methods of control (eg; automatically controlled poly-duct fan in a manually controlled, naturally ventilated shed) on one or more farms. [2]A further 24% utilised weaner kennels for heat conservation.

The prominence of manually controlled shed environments was revealed by the survey, and that existing ACS have predominantly been installed in farrowing and weaner sheds. ACS are poorly utilised in the grower/finisher and lactating sow environments, which have been associated with major losses within the Australian pig industry. The adoption of ACS has been slow, because of initial installation expenses, concerns of reliability and blase' attitudes.

The new generation of integrated ACS offer the advantage over single, task specific units, by controlling many environmental parameters from a central processing unit. Benefits include flexibility, cost effectiveness, fail-safes and data acquisition.

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THE IMPORTANCE OF MANURE CHARACTERISTICS IN THE DESIGN OF ANAEROBIC PONDS FOR TREATING PIG WASTES

K. Casey

Queensland Department of Primary Industries, Agricultural Engineering Section, Toowoomba, Qld. 4350.

Outline of problem: Effluent management is a major problem facing the pig industry in today's environmentally conscious world. Anaerobic ponds are commonly used by many piggeries for the primary treatment of their effluent. Design of anaerobic ponds should be based on a loading rate of organic material per unit volume. This can be expressed in terms of either daily biological oxygen demand (BOD) or daily volatile solids (VS) loading per unit volume. Anaerobic ponds for treating pig wastes in Australia are designed with either simplistic design rules (eg; $4m^3$/pig), or on the basis of VS or BOD loading rate. The application rate of effluent to land is determined by its land limiting constituent (LLC), which is commonly one of the nutrients (N, P, K).

These design methods rely on having access to data on the characteristics of effluent from the piggery, or reliable generic pig manure characteristics. Pig manure characteristics have been summarised in a number of design publications (ASAE, 1991; MWPS, 1985; USDA-SCS, 1975). This data has been obtained from measurements of manure characteristics in experiments under widely varying conditions over a considerable period of time. Barth (1985) proposed an approach utilizing digestibility approximations of manure production (DAMP). This model utilizes knowledge of feed component digestibility for given specie to predict manure characteristics.

Methods used: The loading rate for a number of parameters of an anaerobic lagoon treating the wastes from a 100 sow piggery was estimated from several design guides. These values were compared and found to vary significantly.

Statement of results: Comparisons of predicted manure output characteristics of a one hundred sow unit showed that there were significant differences in the value of parameters such as VS and nutrient levels generated from the various design sources. Manure mass calculated from ASAE data was 41% greater than that predicted by DAMP analysis, while VS mass was 80% greater when calculated from ASAE data. The mass of phosphorus in the manure predicted from USDA-SCS and MWPS data was approximately 60% more than that predicted by the DAMP model, but 27% less than that predicted from ASAE data.

An anaerobic pond designed using DAMP VS data would be heavily overloaded if the ASAE values were correct, this overloading would mean higher odour levels and more rapid accumulation of sludge. A land disposal area designed using DAMP phosphorus data would be loaded at an unsustainable level if MWPS or ASAE data proved correct.

Conclusions from the work: 1) Large differences exist between loading rates calculated using different reference sources. 2) Manure properties based on overseas data have limited applicability in Australia due to different diet, genetics and housing practices. 3) A better method of manure characteristics and hence predicting loading rate is required; an enhanced DAMP method may provide this.

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A MARSUPIAL MODEL TO STUDY MECHANISMS FOR ALTERING MILK COMPOSITION AND YIELD IN THE SOW

P.H. Bird, K.A.K. Hendry*, K.R. Nicholas and C.J. Wilde*

CSIRO Division of Wildlife and Ecology, PO Box 84, Lyneham, ACT 2602. *Hannah Research Institute, Ayr, Scotland KA6 5HL, UK.

Sucking piglets do not necessarily grow at their full potential during lactation (Cranwell and Moughan, 1989). Indeed, Etienne and Noblet (1993) suggest that the protein:energy ratio in sow's milk is low compared to the nutrient requirement for maximal growth. Nutritional and endocrine manipulation of lactating sows does not appear to significantly alter milk production and composition. However, local intramammary mechanisms that have been identified in several mammals can alter milk secretion acutely, and mammary gland development in the long term. In contrast to the sow, the tammar wallaby progressively alters the production and composition of milk during lactation. Therefore, understanding the factors controlling these processes in the tammar offers the opportunity to radically alter milk secretion in the sow.

At mid-lactation of the tammar, milk yield and protein content increases. These changes precede an exponential increase in the rate of growth of the young. The tammar also can provide a small volume of dilute milk for a newborn pouch young from one gland, and greater amounts of concentrated milk from another more developed gland for a young at heel; a phenomenon termed asynchronous concurrent lactation (ACL). This confirms that mechanisms intrinsic to the individual mammary glands are important for controlling changes in the rate of milk production and milk composition.

The changes in milk protein synthesis in the tammar which lead to altered milk protein content have been studied by examining the control of the genes which code for α-lactalbumin (α-lac), β-lactoglobulin (β-lac), α-casein (α-cas) and β-casein (β-cas). All these genes are induced in a coordinate fashion at parturition, although the hormonal requirements for the expression of the individual genes *in vitro* requires different combinations of insulin, cortisol and prolactin. However, at mid-lactation the level of expression changes non-coordinately: β-lac and β-cas increase significantly, whereas that for both α-cas and α-lac remain unchanged. Furthermore, the gene for a novel whey protein named late lactation protein is induced. The level of expression of the developmentally-regulated milk protein genes observed during lactation was reflected in the individual mammary glands of ACL tammars. These data support the concept that local intramammary factors, in addition to endocrine influences, must operate to account for this differential regulation of milk protein gene expression, and milk protein content, during established lactation.

We have identified two different factors secreted in the whey component of tammar milk which alter milk secretion. The first factor inhibits milk protein secretion *in vitro* in mammary epithelial cells from lactating mice and appears to be similar to a factor isolated from other species. The second factor appears to stimulate milk protein synthesis. Therefore, we suggest that the interrelationship between two such factors is likely to play a central role in altering milk production, and potentially, milk protein composition. Thus, the tammar's unique lactational strategy may arise, at least in part, from adaptation of a mechanism shared by most if not all mammals. An understanding of the mechanism of control of these changes in the tammar offers the potential of manipulating sow lactation to meet the nutritional requirements for maximal growth of the piglet.

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PRELIMINARY EXAMINATION OF SOW'S MILK BY NUCLEAR MAGNETIC RESONANCE

M.F. Comber and P.E. Hartmann

Department of Biochemistry, University of Western Australia, Nedlands, WA 6009.

The application of nuclear magnetic resonance (NMR) to biological materials has proved of particular interest in recent years (Belton and Lyster, 1991). The aim of this study was to use phosphorus NMR (^{31}P NMR) spectroscopy to detect new phosphorylated compounds in sow milk. These compounds may arise as a result of the metabolic processes involved in milk synthesis, or to provide a specific benefit to the developing piglet. For example, some phosphorylated compounds are believed to play a vital role in establishing the microflora in the bowel of the young piglet (Uauy, 1989). Although ^{31}P NMR has been employed to analyse the milks of other species it has not previously been used for sow milk.

We obtained ^{31}P NMR spectra of five times concentrated defatted, deproteinized sow milk at 121 MHz on a Brucker AM-300 instrument. Although some phosphorylated compounds were already known to occur in sow milk (G6P, UDP-gal and UDP-glu) we identified eight new ones (Table 1) by reference to internal spikes.

Table 1. Phosphorylated compounds detected in established sow's milk by ^{31}P NMR

Chemical shift (δ)[1]	Metabolite	NMR (μM)	Known (μM)(±SD)
+5.07	Glucose-6-phosphate	40	63.0 (±21.3)[2]
+4.39	3-Phosphoglyceric acid	5000	-
+4.35	Phosphorylethanolamine	4500	-
+4.29	Inosine-5'-monophosphate	1.2	-
+4.21	Uridine-5'-monophosphate	680	1008 (±265)[2]
+3.03	Dihydroxyacetone phosphate	15.0	-
+2.62	N-Acetyl-D-glucosamine-1-phosphate	0.35	-
+1.03	Glycerophosphorylethanolamine	0.25	-
+0.496	Glycerophosphorylcholine	2.5	-
-2.512	Phosphocreatine	350	-
-10.50 & -11.98	Uridine-5'-diphospho-galactose	350	635 (±173)[2]
-10.63 & -12.24	Uridine-5'-diphospho-glucose	120	296 (±95)[2]

[1]Diagnostic signal confirmed by internal spike. [2]Atwood (1993) (enzymatic assay).

Phosphorus NMR analysis has detected eight metabolites not previously reported to be present in sow milk. Since these metabolites have a molecular weight less than 300 daltons, it is probable that they pass from the cell cytosol, through the Golgi vesicles, into milk.

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THE EFFECT OF EXOGENOUS PROLACTIN ON THE LACTATION PERFORMANCE OF FIRST-LITTER SOWS

R.H. King*, J.E. Pettigrew, J.P. McNamara, T. Henderson and M. Hathaway**

Department of Animal Science, University of Minnesota, St Paul, MN 55108, USA. (Present Addresses: *Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030. **Department of Animal Science, Washington State University, Pullman, WA 99164-6320, USA).

Prolactin appears to play a major role in the hormonal control of mammary gland growth, initiation of lactation and maintenance of milk secretion (Cowie *et al.*, 1980). The aim of the present experiment was to investigate the effect of exogenous porcine prolactin (pPRL) on mammogenesis and milk production in first-litter sows, in which mammary development may have been impaired by dietary protein restriction during the preceding pregnancy (Head and Williams, 1991).

Eight gilts received a diet containing 179 g CP/kg (ADEQ) while another 16 gilts were given a diet containing a similar DE content but only 80 g CP/kg (DEF) throughout pregnancy. Gilts given the protein-deficient diet were injected with either 15 mg pPRL (n=8) or excipient (n=8) i.m. twice daily at 0800 h and 2000 h between d 102 of pregnancy and weaning at day 22 of lactation. Mammary biopsies were obtained from each animal on d 71 and 108 of pregnancy for determination of DNA and RNA content. Samples of colostrum were manually collected from sows and milk yield was estimated between day five and eight and between d 19 and 22 of lactation by the deuterium oxide dilution technique.

Table 1. The effects of dietary protein intake during pregnancy and exogenous pPRL on nucleic acid concentrations of mammary tissue and milk production[1]

	Nucleic acid concentration (mg/g)				Milk yield (kg/d)		Colostrum (g/kg)	
	d71		d108					
Treatment	DNA	RNA	DNA	RNA	d5-8	d19-22	Protein	Fat
ADEQ	0.59	0.68	1.20	3.64	9.21^{a}	10.62^{a}	180^{a}	30^{b}
DEF	0.38	0.48	1.07	3.15	8.36^{ab}	10.74^{a}	164^{a}	47^{b}
DEF+pPRL	0.63	0.80	1.12	3.24	6.98^{b}	8.22^{b}	104^{b}	127^{a}
SEM	0.22	0.36	0.39	1.47	0.98	1.08	21	18

[1]Within columns, means with different superscripts differ ($P<0.05$).

The nucleic acid concentrations in tissue biopsies were unaffected by dietary protein and pPRL. Milk yield during both periods of lactation was unaffected by dietary protein during the preceding lactation, but administration of pPRL reduced milk yield. The altered composition of colostrum from pPRL-treated sows indicated a more advanced stage of lactogenesis. Administration of exogenous pPRL to protein restricted gilts during pregnancy, and throughout lactation, seemed to initiate lactogenesis early but reduce subsequent milk yield during established lactation.

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THE EFFECTS OF DIETARY PROTEIN ON THE LACTATION PERFORMANCE OF FIRST-LITTER SOWS

S.M. Tritton, R.H. King*, R.G. Campbell and A.C. Edwards****

Rhône-Poulenc Animal Nutrition, 19-23 Paramount Rd., West Footscray, Vic. 3012. *Department of Agriculture, Victorian Institute of Animal Science, Werribee, Vic. 3030. **Bunge Meat Industries, PO Box 78, Corowa, NSW 2646.

Recent work by King *et al.* (1993), indicates quite marked differences in the level of dietary crude protein (CP) needed to support maximal nitrogen conservation and lactational performance in first-litter sows. Nitrogen conservation reached a plateau at dietary CP levels greater than 203 g CP/kg, whereas yield and composition of milk appeared to reach maximum levels at between 135 and 168 g CP/kg. The present experiment was conducted to further investigate the effects of dietary CP on the lactational performance and subsequent fertility of first-litter sows, in a commercial piggery.

One hundred and thirty four first-cross hybrid gilts, with an average post partum live weight and backfat thickness (mean of P_1 and P_2) of 175 (± 1.8) kg and 24.6 (± 0.4) mm, respectively, were allocated to one of five diets, ranging in dietary CP content from 149 to 249 g/kg, (6.2 to 15.1 g total lysine/kg and 5.1 to 13.3 g available lysine/kg) respectively. All diets contained 14.3 MJ DE/kg and were offered *ad libitum* during a 23 (± 0.25) day lactation. At day 2 litter size was averaged to 10.0 (± 0.08) piglets/litter. Piglets were weighed at days 2, 14 and at weaning. The experiment ran from October to December.

Table 1. The effect of dietary protein on the lactation performance of first-litter sows

	Dietary protein (g/kg)					Significance[1]		SED
	149	171	195	225	249	Lin	Quad	
Feed intake (kg/d)	4.54	4.45	4.21	4.64	4.50	NS	NS	0.26
Sow weigh loss (kg)	26.6	26.2	26.2	23.7	22.0	NS	NS	4.8
Sow backfat loss (mm)	2.5^{a}	3.6^{ab}	4.5^{b}	4.2^{b}	4.0^{ab}	***	*	0.8
Piglet growth rate (g/d)	187^{a}	213^{bc}	205^{ab}	231^{c}	210^{b}	***	*	10.0

[1]NS, non significant, P>0.05; * P < 0.05; *** P < 0.001. Within rows, means with different superscripts differ (P<0.05).

Dietary CP content had no effect on voluntary feed intake or the interval from weaning to remating (8.5 ± 0.6 days). Piglets sucking sows offered the diet of lowest dietary CP content grew significantly slower than those reared on sows offered the higher levels of dietary CP. There were significant curvilinear relationships between dietary CP content and both the loss of backfat by sows and piglet growth rate. Low dietary CP content was also associated with less backfat loss and as body weight losses were similar between treatments, the likelihood of greater body protein losses during lactation. These results show that lactating first-litter sows required diets containing at least 8.4 g lysine/kg and 171 g CP/kg (equivalent to daily intakes of 37 g lysine and 760 g CP) to maximise lactation performance.

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A SYMPOSIUM - OUTDOOR PIG PRODUCTION

M.R. Cowan

Department of Primary Industry and Fisheries, PO Box 46, Kings Meadows, Tas. 7249.

Symposium introduction

The housing of pigs outdoors appears to offer solutions to many of the problems facing the Australian pig industry. These include the increasing costs of establishing and maintaining conventional units, which provide only constant or reducing levels of profit margin and the possibility of increasing attention from the community, regarding the housing and production systems in use.

The outdoor housing of pigs in Australia has generally been left to either specialist enthusiasts or low input/low output operations. The more progressive outdoor producers have adopted practices from the UK, where a significant proportion of the industry is moving outdoors, in response to pressure from pending welfare legislation, the high establishment and operating expenses of intensive units, changing farming practices, new attitudes from stock attendants, differing enterprise profitabilities and market opportunities. Many of these factors are present in Australia to varying degrees.

Pigs produced or housed outdoors have variously been called 'free range', 'paddock reared', 'extensive' and 'green'. The extent to which pigs are kept outdoors during the production cycle varies, from sows outside during gestation only, to full production of bacon pigs housed outdoors. Traditional outdoor systems have weaned pigs at up to 8 weeks of age. However, units are now weaning at ages and weights comparable with indoor herds, ie; seven kilograms at around 21 to 25 days of age.

Grow out from weaning may occur in either conventional grow-out systems, or straw-based weaner systems combined with conventional or outdoor finisher systems. Until there is more information on the economics of finishing pigs to bacon or pork in outdoor systems, the number of pigs produced in this way will be limited. Outdoor 'feedlotting' may, however, be an alternative low-cost system, if the resulting carcasses are acceptable.

Outdoor production systems are not new. Pigs have been kept outside ever since the pig was first domesticated. Many 'cottager' type sties were similar to the straw-based weaner sheds used now. Many of the pioneers of outdoor systems were driven by the philosophy of minimising inputs, particularly capital. This was to avoid the treadmill of chasing the higher productivity required by high input systems, given constant or only marginal increases in return/unit produced.

Apart from the financial pressures on conventional units, there have been changes in public attitudes towards the way in which food is produced and the right to confine farm animals. These changing attitudes have lead to support for legislation which restricts farming practices, for example, the banning of stall and tethering systems in the UK and have resulted in what is often termed 'green consumerism'. These attitudes are therefore producing changes driven from both the market place, legislation, and from those operating the production systems and are increasingly apparent in Australia, albeit to a lesser degree.

Not only in the UK, but also in Australia, advances in equipment have simplified the practical layout and operation of outdoor units. Electric fencing systems have been simplified and are effective over long distances. Posts and insulators are cheap and easy to use. Solar and wind powered recharging systems allow battery-operated fence units that can remove the necessity of siting units near power sources. Water can now be quickly and easily laid on using polythene pipe systems, with simple couplings and joints. To counter extremes of temperature, pipes can be mole ploughed into the ground.

Four and six wheel drive motorbikes have revolutionised the movement of

people and materials around outdoor units. These all-terrain vehicles can transport substantial weights and have alleviated much of the heavy carrying work on outside units, with reduced damage done to soil surface and structure, particularly during winter.

Traditional outdoor stock has been either purebred, or lines based on breeds such as Saddleback and Berkshire, with good mothering ability and a reputation for hardiness. Unfortunately, this hardiness was associated with high fat levels resulting in progeny carcasses with higher P_2 levels. These problems have been largely overcome with the introduction of specialised dam and sire lines.

Experience in Tasmania with pigs kept under outdoor, compared with indoor conditions, suggests no additional health problems, particularly with regard to pneumonia. In fact, pigs reared outdoors have a reputation for robustness and ease of adaption to new environments.

Perhaps the most significant innovation associated with outdoor production systems has been the introduction of radial units layout and variations thereof. These systems are based around a central circular handling yard, from which segment-shaped paddocks radiate. Two laneways at opposite sides of the yard provide access to the edge of the circular layout. These systems have improved labour productivity on outdoor units, where higher levels of labour were required for stock handling. Radial systems allow one stockperson to manage and handle up to 300 sows to weaning, with assistance only required during the weaning of piglets.

Until around 1990, outdoor units had been laid out with paddocks adjacent to central laneways, not unlike an indoor dry-sow shed with pens off a central feed passage. Where permanent or semi-permanent sites have been set up, the fences have been timber posts with wire mesh. The most significant features about paddock and laneway systems have been the time required to get around the unit carrying out routine feeding, the difficulty of moving stock and the effects of heavy traffic on laneways particularly after rain. Conversely, radial systems allow relatively easy movement of stock, feed and rotation of units to new sites.

The largest radial system in Australia has been established by Mr Geoff Terry, of Dairy Plains, in northern Tasmania. Mr Terry studied these units in the UK, while taking up the 1990 Department of Primary Industry and Fisheries Overseas Travel Award. On his return to Tasmania, Mr Terry set up his first radial unit in October 1991. He has since converted his conventional paddock system to three, 300 sow units.

This Symposium provides an overview from a consultant, Mr John Riley, of the factors affecting production outside, with particular reference to the UK experience, and from Mr Geoff Terry, the benefits of his experience in operating a large scale, outdoor operation. Mr Riley's paper indicates that outdoor pig production has gone through a significant development phase, and is not just a new innovation, and Mr Terry stresses the 'people' aspect of outdoor systems.

A REVIEW OF OUTDOOR PIG PRODUCTION

J.E. Riley

JCR Associates International, "Warreners", Mail Service 150, Pittsworth, Qld. 4356.

Reading the popular press, particularly the UK press, a city dweller would conclude that 'Outdoor' pig production is a revolutionary system invented in the last five years.

Nothing could be further from the truth. According to legend, the running of large herds of pigs in the forests of Europe can be traced back to the ninth century BC and the rights and privileges of pannaging (grazing pigs on common land) were debated in the Doomesday Book, 1086. The privileges of pannaging still apply to this day in the New Forest of Southern England.

The system is not unique to the UK. Since the arrival of the First Fleet, the Australian feral 'range' herd has expanded to about 600,000 pigs (so I am told). It is now a valuable revenue earner with exports to Europe exceeding the value of imports of Canadian pig meat (Ransley, R.; APC, 1992, personal communication).

The last five years in the UK has seen the number of breeding sows kept outdoors, for all or the greater part of their production cycle, increase from 8% to about 25% of the national breeding herd of 780,000 head in 1992. The upsurge in interest in the UK is due to a number of factors including:

1. A changing public attitude to agriculture and the environment
2. A change in consumer perceptions and tastes
3. A change in Government support to agriculture.

The result is a determined effort to reduce the cost to the taxpayer of the Common Agricultural Policy (CAP) and the introduction of legislation to improve the environment and animal welfare.

UK Government Policy

The policy statements published in a white paper "The Common Inheritance" (Great Britain, 1990) includes:

1. An integration of Agricultural and Environment policies in the EC
2. Increased powers over the siting, design and appearance of farm buildings
3. Codes of good Agricultural Practice to stop the pollution of soil, air and water
4. Encouragement of organic farming.

Why outdoor sows?

Legislation to achieve these objectives and regulations introduced regarding animal welfare and dry-sow housing in particular, have increased the costs of and limited the opportunities for intensive pig production. Those with investment in the industry, the breeding companies, the feed manufacturers, the processors, the retailers and the primary producers have, therefore, been forced to re-examine the merit of outdoor sows.

The roadnight system

In the south of England, outdoor pig production has been practised on free draining chalk and sand lands since the end of the war in 1945. Herds of 300-400 sows were run on two-three year grass leys that served as a break crop on the larger often tenanted holdings. A doyen of the practice was Richard Roadnight of Watlington, Oxfordshire, who mated Saddleback (later Landrace cross Saddleback, the Britwell Blue) sows to Large White boars. The sows were farrowed twice a year, in March and September. The progeny was sold as 10-12 week old stores for finishing on swill or dairy by-products.

Problems

For the less than totally committed, results were disappointing. Low output, 10-12 weaners per sow per year, high feed wastage (at least the birds thrived), losses to predators (four and two legged species) and a rapidly declining market for the coloured pig produced, limited the uptake of the system.

The breakthrough

The accelerated political and economic pressures experienced by the pig industry in the 1980's coincided with two developments that made outdoor pigs, once again, a

potentially viable system. First, the three weeks weaning of piglets with no previous access to creep feed. This practice reduced feed usage (particularly feed wastage) and reduced the loss of condition in lactating sows, thereby improving subsequent re-breeding. It also allowed the sow and litter to be maintained as a single unit, so reducing piglet losses and greatly assisting management control. Second, the development by the breeding companies of dam and sire lines producing progeny that met market requirements and in some instances attracted a premium. In addition, the increased availability of high density diets, in cob or large pellet form, reduced feed wastage and improvements in electric fencing methods aided stock control.

The key factors

The components of successful outdoor pig production (Riley, 1992) are:

1. Stocking rate
2. Farrowing rate
3. Litter size
4. Survival rate
5. Variable costs
6. Staff motivation.

1. *Stocking rate*

Stocking rate will be determined by soil type, topography, rainfall and degree of exposure. On the free draining soils of southern England, a 600 sow herd requires about 36 hectares, when part of a crop rotation. On heavier soil in higher rainfall areas, stocking rates will be lower, with less pigs produced per hectare and higher variable costs, such as rent, fuel, fencing, etc.

2. *Farrowing rate*

The farrowing rate or number of litters produced per sow per annum is affected by many factors, the most important being:

i) Feed levels
ii) Temperature
iii) Photo period.

Feed levels

On a 3,000 sow unit, Wheeler (1987) investigated the effect of feed allocation per sow per year on weaning to service interval and litter size in a 1,000 sow group. Increasing feed allocation from 1.07 tonnes/sow/year to 1.24 tonnes/sow/year over a six-year period, during which management practices were kept as standard as possible, increased litters produced by 0.075 per sow per annum per additional 50 kg of feed.

Temperature and photo period

Summer infertility and autumn abortion are problems experienced by all outdoor pig producers who keep records (for the remainder, ignorance is bliss). In the UK, there is normally a drop of about 10% in conception rate in summer compared with other seasons of the year. In warmer climates, the problems are considerably greater. A herd that I have worked with in South Africa recorded a conception rate of 81.2% to winter falling to 68.3% for summer services. Wrathall (1990) reports that in Southern Europe farrowing rate to summer services can fall to 70% when, for the rest of the year, 85 - 90% is the norm. The reduction in subsequent farrowing rate is due to a sharp increase in irregular returns, sows not in pig and abortions. The results indicate that summer infertility is not just a boar problem, but that the female also plays a role. A current investigation involving Thames Valley Pigs (a producer-marketing group),

Oxford University, Agricultural and Food Research Council, ADAS and MAFF (1993) will hopefully increase our understanding of the problem.

Photo period is a major component of reproductive failure. While the European wild pig is anoestrus from June to December (Mauget and Boissin, 1987), Wrathall (1990) showed that declining day length in late summer increased the rate of reproductive failure in the UK. Both workers reported that the problem was reduced by increased feed supplies. Wheeler (1987) reported a decline in fertility of 7.6% over the full period of photo period decline, when the rate of decline in photo period was 30 minutes per week. When feed levels were increased in the following two years, overall herd fertility increased by 2.5%, but the rate of fall due to photo period remained at 7.6%.

In the UK, extremes of both low and high temperatures have adverse effects on reproductive performance. In temperatures around freezing point, inadequate feed intake and reduced social interaction results in reduced conception rate. In periods of high temperature that occasionally are experienced in the UK, depressed performance results. At temperatures above 35°C, Einarsson and Larsson (1982) and Cameron (1987) report changes in the morphological characteristics of semen whilst Buddle and Hawkins (1984) and Paterson and Pett (1987) suggest that high ambient temperature before and after mating could adversely affect the reproductive physiology of both the sow and the boar.

3. *Litter size*

The main factors influencing litter size are genotype (van der Steen, 1992), service management and feed levels. The use of dam lines selected for the following attributes is widely accepted in the UK:

i) Robust and docile
ii) Territorial instinct
iii) Maternal ability
iv) High piglet birthweight
v) Fast growth
vi) Fat cover to maintain body condition.

The crossbred dam line, which increasingly includes some Duroc genes, gives the full benefits of heterosis lifting weight of pigs weaned by 20 - 25% (Webb, 1991). The use of a crossbred terminal boar that meets the following criteria:

i) Hardy and active
ii) High libido
iii) Fast growth
iv) High lean content
v) White skin colour
vi) Selected and managed as a group

will increase mating performance and conception rate by 15-20% (Webb, 1991).

Under-feeding will reduce litter size and survival rate. In Wheeler's (1987) investigation referred to earlier, a 50 kg/sow/year increase in feed allocation resulted in an extra 0.17 pigs per litter. In the outdoor system, service management is basically left to nature, with three boars that have been reared together running with 10 - 12 gilts or sows. The performance of gilts can be improved by the introduction of vasectomized boars, six to eight weeks before planned mating date. With most replacement animals normally being purchased at about 40 kg, to allow acclimatization, the use of vasectomized boars is a widely adopted technique.

4. *Survival rate*

Hut design and temperature have greatest influence on piglet survival rate. In

the UK, little work has been carried out on hut design, the half round arc has been used by all. The NAC (1992) have recently established an outdoor unit and a comparison of hut design will be one of their priorities. Records from Soetvelde farms in South Africa indicated an 89% survival rate for the British round arc, 87% for an A-frame and 85% for an A-frame with floor. Extremes of temperature will reduce survival rate. At low temperature chilling, starvation and over laying increase piglet losses, whilst at high temperatures, over lying can become a serious problem as the piglets attempt to lose heat through contact with their dams, who have access to wallows.

5. *Variable costs*

There is the opportunity to keep costs to the minimum and thus avoid the technology treadmill upon which many indoor units find themselves, chasing higher production to finance higher fixed costs. The system is a low-cost system in which variable costs, such as repairs and power and capital costs such as machinery are kept to an absolute minimum. In addition, on the mixed farm opportunities for the reduction in costs of following crops, particularly fertilizer costs, must be fully exploited to maintain the viability of the total farm business.

6. *Staff motivation*

The key to successful outdoor pig production is staff motivation. In intensive units, the control of resources is relatively simple and the needs of the individual pig is relatively easy to satisfy. On outdoor units, the staff must operate in an ever changing climate and they require skills not necessarily possessed by even the successful indoor operative. For the manager, staff motivation skills are of a higher priority than pig husbandry knowledge.

Outdoor v indoor

The performance of outdoor units now approaches that achieved on indoor units (Table 1).

Table 1. Outdoor versus indoor[1]

	Outdoor	Indoor
Litters per sow per annum	2.22	2.24
Born alive	10.57	10.79
Mortality (%)	11.80	12.10
Pigs reared	20.70	21.30
Sow feed per annum (tonnes)	1.37	1.20

[1]MLC (1992).

In the UK, the attraction of the system is the higher return on capital invested. The cost of establishing a 300 sow unit, weaning at three weeks, is in the order of $1,100 - $1,600 per sow outdoors and $2,200 - $3,200 indoors. The Cambridge University Pig Management Scheme Report (Ridgeon, 1992) indicates a return on capital of 41.5% and 26.6%, respectively, in the 12 months ending September 1991. In Australia, the comparative costs are of the order of $530/sow for outdoor herds compared with $3,200/sow for indoors (Farran, 1992).

Opportunities in Australia

The climate here is less suitable to the system than areas such as Canada and the

USA, since high temperatures are a greater problem for the outdoor sow than low temperatures. However, the system is practised successfully in Tasmania, with recent adopters in Victoria, New South Wales, South Australia and Western Australia.

In other areas the climate will limit the uptake of the system as practised in the UK. However, there could be opportunities for the system, modified in one of the following ways:

1. Farrowing large groups twice a year, in March and September. A four-week weaning system would avoid excessive weight loss in lactation and increase conception rate.

2. A once-bred gilt system based on September farrowing and three-four week weaning.

3. A small unit complimenting an existing intensive unit. Such a unit would only operate in the winter months taking the pressure off housing allowing resting, cleaning and refurbishing and result in a boost in performance.

Conclusion

Outdoor pig production can, in a mild climate, be as profitable as intensive systems. The development of the system in Australia will be limited to Tasmania and the southern States, where climate should have less influence on sow productivity.

OUTDOOR PIGS

G.J. Terry

"Juniper Lea", Deloraine, Tas. 7304.

Since leaving school in 1971 my interest in outside pig production has gradually grown. Starting with eight Berkshire sows and a Landrace boar, I used old water tanks cut in half for farrowing sheds and grew the progeny out as porkers in the shearing shed. Most of the local dairy farmers had a few sows in those days and I supplied them with breeding stock. In 1978, the shearers almost refused to shear the sheep in the shearing shed so it was either build a piggery or get out of pigs altogether.

I enjoyed working with pigs and wanted to continue with them. I toured the mainland looking for what I considered to be a practical piggery to build. At the same time I had written a letter to a friend in England telling of my intention to build a piggery. Some months passed until a tape came from our friend in England who had taped a conversation with a person who he called 'one of the high flyers' in the British pig world. His words were 'it's not the plans you are after, it is the thinking behind them that you want, come and have a look'. This sounded a very eccentric thing to do, having never travelled before. But one month in England completely changed my thinking on pig raising in Tasmania. One of the major factors I learnt was that the climate in southern England was more applicable to Tasmania than was the climate of mainland Australia. This meant different shed designs were needed to those being used on the mainland, to suit the Tasmanian climate.

On my return I built a 100 sow piggery with all the sows outside, this time using specialized farrowing huts, with guards on the front to stop little piglets getting out until they were about one week old. We built a controlled environment three-week weaner shed and four 'Trobridge' type mono-pitch buildings to accommodate the progeny of the 100 sows. As years passed, more sows were kept and we went on building the same way until we had about 500 sows. During this time we installed a computerised liquid feeding system for the growing pigs.

In 1991 I won the Tasmanian Department of Primary Industry Overseas Travel award. My subject was extensive pig management, welfare and the environment. Again this trip enlightened my thinking on outside pig production. Because of the increased pressures on the British producer, both from welfare and economics, there has been and will be big changes there in the way pigs are produced and marketed. It will be sooner, rather than later, that these trends will come to this country.

My aim after this overseas trip was to produce a better pig at a cheaper price. Although there is some fine tuning to be done, I believe we are on the right path to this goal. We have expanded our operation to 900 sows, divided into three x 300 sow units, with one man responsible from conception to weaning at three weeks of age on each of the 300 sow units.

At weaning, approximately 60% of the pigs are put in the conventional flat deck housing, in controlled environment sheds, and the balance are put out on barley straw, in mono-pitch portable kennels similar to Cosi Kennels, a UK design. These kennels have flaps on the front, to retain piglet warmth, and hurdles at the front form a strawed yard, that can be expanded as the pigs grow. *Ad libitum* feeders are placed at the rear of the kennel. The pigs stay in these kennels from three to 10 weeks of age.

From the kennels they continue outside in mobs of 200 with two self feeders in each of the paddocks. They are housed in 2.7 m x 3.9 m half round grower huts, 20/hut. We use a radial layout similar to that used for the breeding stock, with triangular paddocks radiating off a central circular handling yard, with access to laneways and loading ramps. Each segment of approximately 0.5 hectares holds 200 pigs. These pigs are taken through from 10 weeks of age (approximately 30 kg) to heavy bacon weight in this outdoor finishing system, achieving 95 kg at around 22 weeks of age.

The performance of the pigs growing outdoors has been comparable to that of the indoor pigs, except during the winter period, when growth rates are about a week slower. We are currently conducting a joint project with the Tasmanian Department of Primary Industry and Fisheries to monitor the performance of batches of pigs grown outdoors.

The weaners which go through the flat deck sheds go on into the Trobridge type buildings on the computerised liquid-feeding system.

Our property "Juniper Lea" has 340 hectares, on which we also run 800 crossbred ewes. These are mainly kept to graze a hill which cannot be cropped. We also buy and fatten yearling cattle, turning off about 400 head each year. We have an 800 tonne potato contract, which we have filled for the past 3 years, and approximately 60 hectares of green peas are grown for the Edgells cannery, and of course we have 900 sows which we use on the land before we crop it.

We have a rainfall of 18 cm (45 inches) per year, with the bulk of it falling from June through to September. A very hot summer day here would be 30 - 35°C, with an average summer day temperature of between 22 - 26°C. However, even in mid summer we can get an odd frost and we do get plenty of cool evenings. We are at 150 m above sea level and have mountains which rise behind us to 1,000 m. Most summer afternoons we get a sea breeze, which is ideal for the outside pigs. Without this breeze, the heat distresses farrowing sows and additional water is required for cooling, usually by letting water troughs overflow.

Our soil type is heavy black loam, with a few free draining sandy banks. All the heavy black loam soil we have pigs on is drained with clay pipes or plastic perforated pipes and back filled with gravel. The lateral runs of pipe are put in at 20 metre intervals. The ideal country would be free draining sandy soil with a temperate climate.

Shade can be provided by natural shelter such as trees. However, if pigs have direct access to trees, they will soon ring bark them, so they need to be fenced off.

I am sure there would be many places on mainland Australia where the soil type is right, the rainfall about 20 - 25 inches per year, but the heat would be a worry to me to run sows outside. We in Tasmania probably have the highest feed costs in

Australia but our natural advantage is our climate, which lends itself to outside pig production.

Each year the sow units are moved to a fresh site to stop a build up of parasites and other pathogens. After all the arcs and electric fences are moved there is generally no grass left, there are wallow holes at the drinking troughs and to be quite blunt, the paddock looks a real mess. We then put the plough through and grow a crop of potatoes over the next summer. Over the last three years we have averaged 55 tonnes per hectare.

For the following two years we grow canning peas and then sow down to pasture. After two years of pasture, we then move the pigs back in. It is therefore about a five-year rotation. We have been rotating the pigs around the farm for about 18 years. We also use the raw effluent from the indoor piggery on our pasture and cropping paddocks. We consider the effluent from both the free-range pigs and the piggery as a valuable asset.

The main factors in making this system work, and I guess it is no different from any other business, are good staff selection and job allocation, together with appropriate training. The success of outdoor systems depends on highly motivated staff, who can work well even under adverse conditions. The wants and needs of the sows, boars and growers are really no different in principle from that of a fully intensive system. However, outside the sows are in groups of 14 rather than individually housed or in small groups and we work the boars in pairs. Only three years ago all our paddocks were in squares with connecting laneways and to move sows from A to B took two men, a tractor and trailer and several hours, just to move 30 - 40 sows. Now that we use a radial system it takes only one stockperson to look after the 300 sows from conception to three weeks of age.

We feed the sows on the ground with mash. We have used pellets, but our soil type tends to pack down after a couple of feeds in the same place, and we find very little wastage on the ground with mash. Our growers are fed in bulk using self feeders, filling them with a bulk pack with a hole in the bottom, which is opened and closed with a draw string. This is suspended from the forks of a front-end loader. It is essential in our climate to provide arcs for both the growers, sows and boars. The arcs are kept strawed up with barley straw in the winter and in the summer time we put some of the arcs up on metal stands, to provide shade for the pigs in the heat. All arcs have a wire through the top of them so they can be easily transported or moved. Each time piglets are weaned, the farrowing arcs are moved to a fresh site within the paddock and strawed up to start again.

It is essential to provide plenty of water. We use 25 mm polypipe around the outside of the circular layout with 12 mm going off the main line to each water trough. We find a 12 mm main is not big enough to provide enough water in summer if we have to overflow troughs.

Our old bedding from the weaner kennels is picked up by a flower grower who uses it for compost. It would take some time for it to compost completely but because we need to use the paddock for potatoes we must remove it. We tried last year to spread some out but because it was still so 'concentrated', it had a burning effect on the potatoes, so this year we will remove all of it. It would be excellent fertiliser after composting, if you had the right kind of spreader and could put it evenly over the paddock.

In summing up this paper, I believe this outdoor system to be a viable alternative to the intensive indoor system. The welfare and financial aspects of this system are very positive and as I learnt in Europe two years ago, the world is going 'greener' and the consumer is demanding a better product at a cheaper price. Farmers need to take a hard look at traditional farming methods, especially in times of recession - we must move through the 90's with farming techniques that are cost effective and that produce a product meeting the demand of the consumer.

SYMPOSIUM CONCLUSION

M.R. Cowan

Mr Riley has identified the social and political pressures that have increased the number of sows being kept outside in the UK. It is evident that community awareness and questioning of animal production systems is increasing pressure on conventional methods of production. Both Mr Riley and Mr Terry conclude that climate is a major limiting factor to the success of outdoor systems, with high temperatures being the major problem. There is sufficient evidence to suggest that research in the area of reproduction would provide results that would be beneficial to both the outdoor and indoor sectors of the industry.

Mr Riley has identified the major limitations on production and described both strategies to overcome them and areas for further investigation. One of the major problems is the lack of sound data for analysis.

With continuing low returns for agricultural commodities, producers are constantly searching for ways to lower costs. Housing pigs outside offers considerable savings in capital and the opportunity to provide lower input costs to other farming enterprises. Mr Terry has described how his outdoor system is fully integrated with his other cropping and livestock enterprises to the benefit of all enterprises - a whole farm approach.

It is evident from my work that there has been little investigative work done on these systems of pig production. These papers have shown that much of the work of developing outdoor systems is being done on-farm by farmers, with little scientific research to assist them.

So far most of the practices have been adopted directly from intensive systems, with little or no modification to take account of outdoor conditions and demands. This is particularly true in the area of nutrition. For example, there is a need for investigation into the specific nutrient requirements of breeding stock, particularly in respect of energy, vitamins and minerals. Further investigation is needed into the environmental impact of outdoor units, recommended siting areas by soil classification and practices to reduce the effect of temperature on fertility.

Although Mr Riley has proposed some strategies to avoid the reproduction problems associated with high temperature, it is more likely that in Australia we will see large scale successful units located in the temperate areas of southern Australia.

Mr Terry has a particularly practical approach to his production system, relying heavily on his ability to motivate staff to maintain their enthusiasm through the worst of conditions. Under outdoor systems, much of the detailed approach to management, which is expected on intensive units, is not practical, for example supervision of individual matings and farrowings and yet good litter sizes and numbers weaned are achieved.

Perhaps there are lessons to be learnt regarding the selection of stock for good mating and farrowing performance, and the knowledge of stock behaviour that can be adopted to indoor housing.

The challenge is there for science to improve the performance for an area of pig production, which has been founded on practical experience.

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