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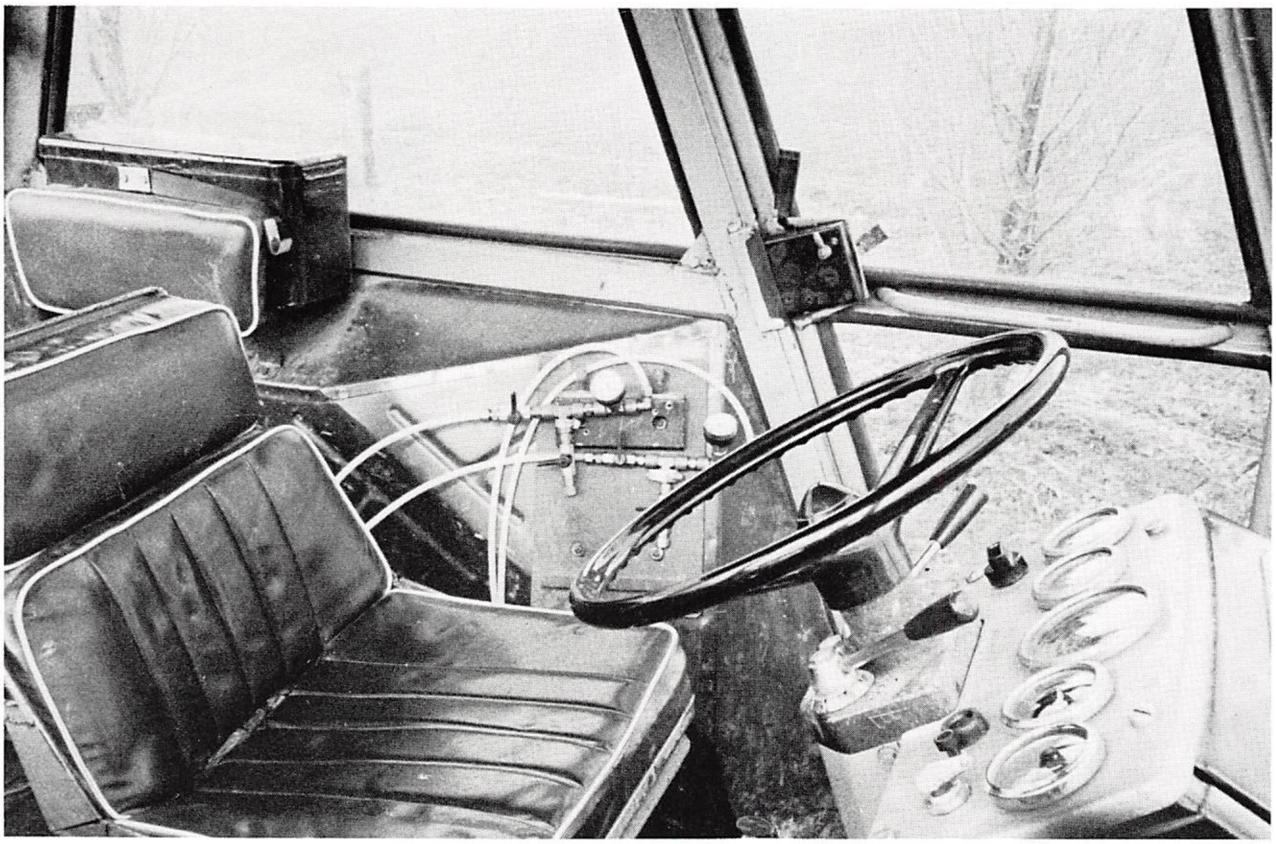

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Contents

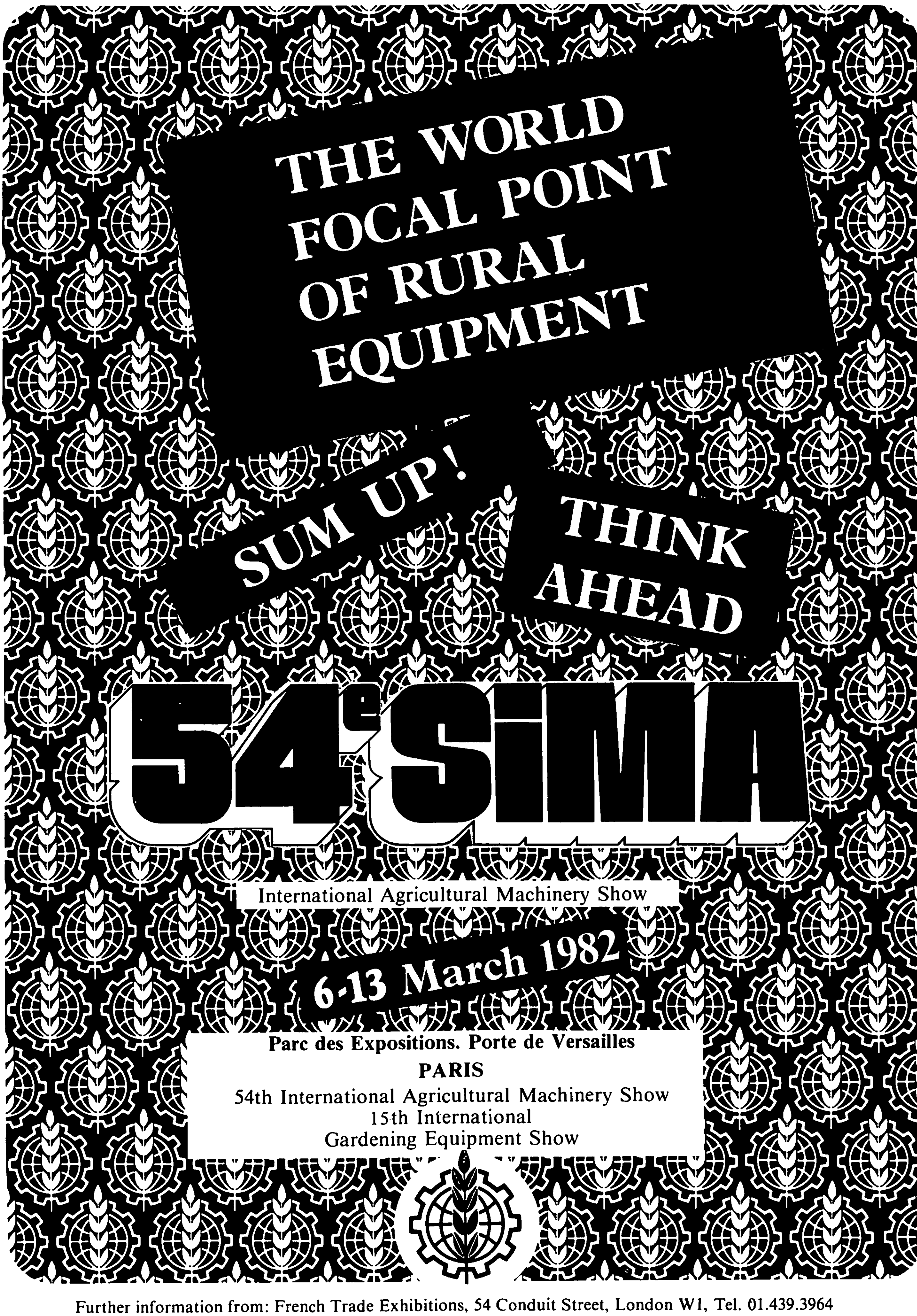
Three categories of paper appear in the Journal:–

a) Papers submitted to the Honorary Editor and subsequently refereed.

b) Conference papers not generally refereed but which may be if the authors so request and if the refereeing process can be completed before the Conference Report is due to be published.

c) Mechanisation and review articles not normally appropraite for refereeing.

Front cover: Above – Control panel inside tractor cab, showing valve gear and tyre inflation pressure gauges. Below – View of air feed, via the support structure to the rotary valve and hence to the tyre (see page 109)


THE WORLD
FOCAL POINT
OF RURAL
EQUIPMENT
SUM UP!
THINK
AHEAD
54e SiMA
International Agricultural Machinery Show
6-13 March 1982
Parc des Expositions. Porte de Versailles
PARIS
54th International Agricultural Machinery Show
15th International
Gardening Equipment Show

The Douglas Bomford Fourth Memorial Lecture

The task before us — meeting the engineering needs of tomorrow's agriculture

Sir Hugh Ford

Summary

FOR too long the research and development resources of the agricultural industry have been focussed on the biological aspects and the importance of the farmer's equipment needs have, until recently, received little of the available resources.

Although at one time Britain was major world producer and exporter of farming equipment, that position has been eroded over the years. The lecture examines the changes that have occurred and the ways in which new ideas could be more rapidly and effectively applied to the needs of the industry both inside and outside the farm gate.

The special features of agricultural engineering development are discussed arising from the seasonal nature of the use of so much equipment and the fragmentation of the industry.

The relationship between the small, specialised machinery manufacturer, the farmer, such organisations as the National Institute of Agricultural Engineering and Government funding are also examined and some ideas for improving the environment for the engineering innovator, to allow him to meet foreign competition, are put forward.

WHEN I was invited to give this, the Douglas Bomford Fourth Memorial Lecture, the first glow of pleasure at the honour changed to a hesitation on second thoughts as to "why me?". As a mechanical engineer — yes; as one who had served his five years on the Agricultural Research Council — probably; as one who has — and does — take a great interest in the work of the National Institute of Agricultural Engineering and its Scottish counterpart — getting warmer; as a member of the newly structured Consultative Board of the Joint Consultative Organisation for the Research and Development in Agriculture and Food — I might be expected to have something useful to say.

But I cannot claim to be an agricultural engineer, nor an agriculturalist, and it may be as well to make it clear to you all from the outset why I accepted with enthusiasm the invitation to give this lecture.

Most of the decisions — big and small — that we make in our lives have a personal tinge, rationalise them how we will.

Despite the importance of the task and the pressure of my professional work, I accepted it largely on sentimental grounds.

Professor Sir Hugh Ford is Director, Ford and Dain - Partners Ltd.

Now an audience having given up its time and made the effort to attend a lecture have a right to expect to benefit in some small way from attending it. But, as I hope to show, the nostalgia inherent in my sentiments has, I believe, a close link to the subject of my lecture and provides a pointer or two to what we need to do.

For the rest, my qualifications for giving the lecture must rest on your assessment at the end of it.

Let me then first clear away the sentimental and get down to the business of this lecture.

My paternal grandfather was a farm labourer all his life on what would now be considered a small farm. He raised a family of ten children in a small tied cottage under the Sussex Downs. It is a tribute to the fine relationship which existed between Master and Man at that time that his employer kept him on to the day he died in his 84th year.

My father's first job was to hold the horse's head when my grandfather was ploughing with the old Sussex plough and, at the tender age of ten, he suffered much from the horse's hooves. As I have said elsewhere, it led him to the conviction that there must be a better way of doing it (Ford 1977). This conviction never left him and it led, many years later, to his all-conquering devotion to the invention of automatic ploughing. At a time when the theory of control was hardly recognised as a science, he worked out many difficult control problems by a native genius that deserved a greater reward and recognition than it got. So this evening, I am trying to redress the score a little by showing you a short piece of film from a 1927 Pathe Gazette News. It shows the plough my father invented and built — and proved as a practical device — actually ploughing a straight furrow, reversing and returning. The headland anchors moved forward the appropriate distance (2 furrows width for a single furrow plough) and the plough pulled itself along on the stationary cable between the two movable anchors, being at the same time self steered by the taut cable. The main invention lay in the clever way in which the plough moved itself over to cut the next furrow.

The venture was, of course, totally unsuccessful: it was far ahead of its time, though the idea was to remove a big time consumer — ploughing and cultivating — to release the farmer (especially the small farmer) for other work: it was technically brilliant but needed skill and intelligence in setting it up in the field (abilities not often conspicuous on a farm at that time); it was not engineered for production, reliability, ease of handling or safety; and above all it needed a marketing exercise to sell something so revolutionary and provide after-sales service to ensure its acceptability.

So another Ford across the Atlantic who got all these factors right swept the market for a cheap, rugged general purpose tractor, despite the fact that it was less fit for the purpose of ploughing and cultivating — too heavy on the subsoil and dependent upon adhesion.

I have dealt with this at some length because I believe it illustrates what has gone wrong with so much of the British Agricultural Engineering effort of the last fifty years. George Stephenson, when he was approached to put his name to an ambitious new railway scheme, is reported to have said that "unless it serves a public need, is sound in engineering and provides a reasonable return to those who invest in it, I will have nothing to do with it". Those are the three ingredients for success in engineering and we overlook any one of them to our cost.

The object of this lecture is not to analyse and diagnose what is wrong with the agricultural machinery manufacture all over again. It has been done already far more thoroughly than I could hope to do; and it has been done too often. I would refer you to the study made by the Department of Industry "Report on the Agricultural Engineering Industry" (Department of Industry 1978) and the recent Review by the Engineering, Technology and Industries Committee of the Royal Society (Crossland 1982). All I shall do is to indicate that the trends shown — and feared — in the Department of Industry report have continued and worsened. I am indebted to Mr W. J. Course (National Institute of Agricultural Engineering) for this analysis.

Table 1 is the up-dating of Annex A of the Department's Reports based on the same assumptions and adjusted to 1970 prices. As you will see, the tables refer to all types of machinery except tractors. The trends are more easily seen in graph form (fig 1). The recent reduction in total sales has been dramatic. For all products, the exports have fallen roughly in proportion in total but "all other machinery" (which includes all machinery spare parts) has held up better than the rest.

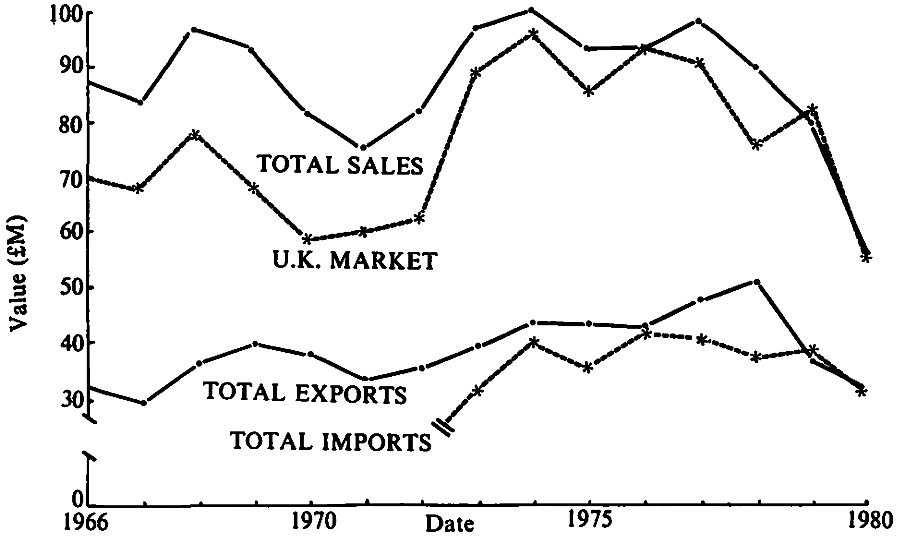


Fig 1 Agricultural machinery sales (1970 prices)

Table 2 shows the UK market and its

Table 1 Agricultural machinery sales by UK manufacturers (at 1970 prices) 1966-1980, £M

	All products		*Soil preparation and cultivation*		*Harvesting, feed processing*		*Milking machinery and parts*		*All other machinery*	
	Total sales	Exports	Total sales	Exports	Total sales	Exports	Total sales	Exports	Total sales	Exports
1966	87.8	31.9	18.3	5.0	36.2	11.9	4.3	0.7	28.9	14.2
1967	83.1	28.6	18.8	4.6	30.8	8.7	4.6	1.0	28.9	14.4
1968	96.5	35.5	19.3	6.1	37.3	11.2	5.3	1.3	34.8	17.1
1969	92.9	39.2	16.9	6.8	34.4	14.3	5.1	1.2	36.1	16.9
1970	80.9	37.3	14.7	4.9	28.5	13.0	4.3	1.0	33.5	18.4
1971	74.6	32.7	12.5	4.4	24.4	11.4	4.5	0.9	33.3	16.1
1972	81.4	34.7	15.3	4.2	28.2	11.8	5.8	1.5	32.9	17.6
1973	96.4	38.5	19.2	5.5	30.5	13.5	7.4	1.8	39.9	17.9
1974	99.6	42.9	21.2	6.6	33.7	13.2	7.2	2.2	37.9	21.2
1975	92.5	42.6		5.6	32.7	14.3	8.9	1.5	36.9	22.6
1976	92.9	42.0	18.1	6.4	32.7	14.6	8.8	1.7	34.8	20.2
1977	97.2	46.9	18.9	7.2	34.9	16.2	9.7	1.4	33.7	22.1
1978	89.2	50.6	17.1	6.4	27.9	13.4	10.3	2.6	33.9	28.2
1979	79.4	35.8	14.7	5.3	23.6	11.4	10.1	2.7	31.0	16.4
1980	54.2	30.4	10.2	4.0	15.1	7.8	4.1*	2.4	24.7†	16.2

**In this case the "total sales" excludes "parts" which have been included in the figure "24.7" marked †. The separate figure for milking machinery parts is not available but is estimated at £3.0M.*

Table 2 United Kingdom market and imports (at 1970 prices), £M

	All products		*Soil preparation and cultivation*		*Harvesting, feed processing*		*Milking machinery processing*		*All other machinery and parts*	
	UK market	Imports	UK market	Imports	UK market	Imports	UK market	Imports	UK market	Imports
1966	70.0	14.1	15.1	1.8	33.7	9.4	3.9	0.3	17.2	2.5
1967	67.6	13.1	16.3	2.1	30.8	7.9	3.9	0.3	17.3	2.8
1968	77.3	16.3	15.8	2.6	35.8	9.7	4.3	0.3	21.6	3.9
1969	67.6	13.9	12.0	1.9	27.5	7.4	4.1	0.2	23.4	4.2
1970	58.4	14.8	11.7	1.9	23.4	7.9	3.6	0.3	19.7	4.6
1971	59.5	17.6	12.5	4.4	21.1	8.1	4.1	0.5	21.8	4.6
1972	67.1	20.4	14.5	3.4	27.1	10.7	4.8	0.5	21.2	5.9
1973	88.5	30.6	18.9	5.2	32.7	15.7	6.2	0.6	31.1	9.1
1974	95.1	39.1	18.2	3.6	43.0	22.5	5.6	0.6	29.2	12.5
1975	84.9	35.0	15.5	4.6	37.5	19.1	8.1	0.7	25.4	11.1
1976	92.8	41.9	17.5	5.8	40.6	21.3	8.0	0.9	28.5	13.9
1977	90.4	40.1	17.1	5.4	39.8	21.1	8.4	0.1	25.1	13.5
1978	75.4	36.8	15.7	5.0	32.4	17.9	9.1	1.4	18.3	12.6
1979	81.6	38.0	14.3	4.9	32.0	19.8	9.1	1.7	26.2	11.6
1980	53.6	29.8	10.2	4.0	21.0	13.7	3.0*	1.3	19.3†	10.8

**This figure excludes "parts" which have been included in the figure "19.3" marked †.*

imports, corresponding to annex B of the Department of Industry study. Several aspects of these figures are worth noting. In "all other machinery" the export performance looks generally good but the down turn in exports in the last two years has been far steeper than the fall-off in imports; the home market has increased very little in real terms compared with 1966 yet imports have increased four times over the period while exports are back very nearly to 1966 levels. In this case, it could imply a loss of competitiveness of products.

My next table (table 3) shows the main import penetration by product sector from 1977 to 1980. Except for manure spreaders — why, we may ask? — the performance is dismal. Even in drills and planters where previously we had some market leaders, we have lost out in the last four years and in cultivators and hoes we have dropped out badly and provided only one third of the home market for ourselves.

In his interesting Thomas Hawksley Lecture to the Institution of Mechanical Engineers, Dr R L Bell puts forward the view that, in backing the Engineer in UK agriculture, we are "backing a winner". I believe there is no argument about the great contribution that engineering and the engineer have made to the well-being of Britain's agriculture. Dr Bell points to the laudable increase in the productivity of the industry and speaking in Dr Frank Jones' terms of "value added per worker" (Jones 1979), the farm employee compares well with the very best companies in UK industry (indeed also on world terms). Dr Jones presented valuable information on the performance of the world's leading companies and emphasised — and dramatically demonstrated — the factors separating the sheep from the goats. There are four principal factors.

1 The added value per employee in real terms.

Table 3 Main import penetration by product sector

Product sector	*Imports, £ M current prices*				*UK market, £ M current prices*				*Import penetration, %*			
	1977	1978	1979	1980	1977	1978	1979	1980	1977	1978	1979	1980
Grain harvesters	25.9	29.3	42.0	30.8	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Balers	6.9	5.8	5.0	5.6	15.6	13.8	8.3	8.3	44	42	60	67
Forage harvesters	5.2	6.5	9.9	5.7	(a)	6.4	(a)	9.7	(a)	98	(a)	59
Root harvesters	8.0	4.7	3.8	4.1	13.0	(a)	(a)	7.6	62	(a)	(a)	54
Haymaking equipment	5.3	4.6	6.1	4.1	6.2	(a)	(a)	(a)	85	(a)	(a)	(a)
Cultivators and hoes	3.3	4.7	4.2	4.8	5 .9	9.2	8.3	7.3	56	51	51	66
Mowers	4.7	0.6	1.7	3.3	7.3	10.2	7.1	5.5	64	6	24	60
Mouldboard ploughs	3.3	3.0	3.6	2.5	6.4	6.0	6.5	6.5	52	50	55	38
Fertiliser distributors	2.8	3.1	3.3	2.5	4.8	5.5	5.6	4.3	58	56	59	58
Drill and planters	2.6	2.5	2.5	3.2	8.1	7.0	6.8	7.4	32	36	37	43
Manure spreaders	1.4	1.5	1.0	1.0	7.9	9.3	8.9	6.0	18	16	11	17
Total	69.4	66.3	83.1	68.0	116.9	118.1	127.8	106.0				

Note (a) Figures of sales of harvesting equipment not separated.

2 The cost of inflation in judging a firm's real performance. Activity and performance have to be judged in real terms, and need to be increasing or at least stable for success.

3. The value of bought-in items can mask the effective performance of the company.

4. Where wages, salaries, social service and pension costs rise above about 67% of the total added value, the company does not have enough cash for reinvestment (unless it is very large) and for sustained growth.

It could also be deduced that the high cost of borrowing in the UK cut heavily into profits.

It would be a very valuable exercise to look into the developments in these items from 1974 to 1980 to find out whether:

a) our foreign competitors made significant technical advances;
b) they improved production methods and offered the same goods at lower prices;
c) they established new UK agencies and extended aftersales service;
d) our UK manufacturers stood still;
e) there have been changes in the market leaders.

The above tables exclude the very large market for farm tractors and I do not need to tell an audience of this kind that, except for a few producers of special types, there are only five big companies involved, all of North American origin. The conclusions to be drawn are therefore somewhat different, although the opportunity for aggressive, innovative attack on special parts of the market are no less likely to be available to us in this market than any other. What I am going to say can apply equally to the tractor (table 4).

Table 4 Total UK tractor sales and exports at 1970 prices

Year	*Total UK sales, £ M*	*Total UK exports, £ M*
1977	326	—
1978	241	217.5
1979	257	187
1980	205	174

What can we do about it?

I have already said that we have had too much analysis — it is the British disease — and what is needed is a synthesis of the things we have learnt from the many analyses. The rest of my lecture is addressed to my conclusions and how I see the synthesis of that feature for which I have some authority to speak. I refer to the innovative aspect of all engineering activity. Let me first set out the major ingredients of my credo for recovery.

1 The shape of the industry
It is no longer practical or realistic to consider the engineering within the farm gate in isolation. It is necessary to think and innovate in terms of providing food in suitable forms for the market. There will be far-reaching interactions between the machinery and techniques developed for the farmer and those needed in food processing and packing.

2 An industry worth national support
Despite the small size of so many of the 500 (approx) companies in the agricultural engineering industry, total annual sales of about £1,300 million with an export of about £860 million (1978 figures) (Bell 1981) is an activity worthy of strong support for growth in the future.

3 Resources in research and development potentially available
Research and development capability and potential are available to back up the manufacturer if he goes out to seek it and the climate for investment in development is attractive.

4 Irrespective of size, innovation can be successful
Where UK companies have a good ear for the market and an urge to innovate, they have demonstrated that they can compete with the best even where they are relatively small.

5 Better use of available research and development resources needed
Insufficient companies are prepared to make use of the research and development facilities already available in the Country.

6 Greater proportion of public funds
Far too little of the public funds available through the Ministry of Agriculture, Fisheries and Food, the Department of Agriculture and Fisheries for Scotland, the Agricultural Research Council and the Department of Industry for agriculture in general have been directed to agricultural engineering. Although

there has been an increased awareness of this lately, the balance is still not right. For example, the National Institute of Agricultural Engineering receives only about 5% of the total funds from the Department of Education and Science and the Ministry of Agriculture, Fisheries and Food that are channelled through the Agricultural Research Council and, as table 5 shows, the larger part of this is for work commissioned by the Ministry of Agriculture, Fisheries and Food. The "other income" element includes contract earnings from the private sector.

7 Development of backing programme for the small firm
The backing programme of work at such centres as the National Institute of Agricultural Engineering has to take into account the great number of small companies (400 with less than 25 employees who contribute 20% to the total output). Properly supported, these companies have greater potential for expansion than the large companies.

8 Innovation needs resources far beyond those of research and development
The conventional idea of research and development is only part of a very much larger activity that adds up to innovation in the sense of "carrying a new idea through to commercial success". The major parts of time and cost are involved after "Research and Development" have shown the promise and timeliness of a new idea. Inability to recognise this has been the *prime factor in failure and the unwillingness of Boards to invest in new ideas even when they are needed for survival.*

9 Good project management is vital
Good project management, with one project leader with full accountability for all resources is a necessity for success. It is a full time job.

10 The seasonal nature of the market
Innovation in the Agricultural and Food Industries must take account of the seasonable nature of its demand on machinery. A one month overrun on a prototype or pre-production run can mean a year's additions to development costs and the risk of losing out to competition.

11 The importance of the systems approach
The systems approach to innovation is needed. It is also vital to recognise the difference between "cash generating" and "cash hungry" innovative work.

12 Innovation has to anticipate need
Above all, innovation should anticipate both in terms of the Company and the Market need. It is useless to wait until falling sales drive management to think — too late — about new products.

Proposals for implementation

There is nothing new in the above twelve articles of belief. They have been stated before in various ways and varying times. The differences lie in the means of implementing them. A few further figures need to be given. It is necessary to allocate cash below the line to design and development and, if this is not available, it has to be generated somehow. A vigorous company, like Bomford and Evershed, is spending between 3½ and 5%, where the industry's average is probably around 2% — and in many firms it is less than this.

Table 5 Sources of funds for the National Institute of Agricultural Engineering

Year	*Science vote, %*	*MAFF, %*	*Capital vote, %*	*Other income, %*
1979-80	24	55	9	12
1980-81	22	55	12	11
1981-82	25	50	11	14

It is useless to assume that, by scraping along, it is possible to make a worthwhile development. Much can be done to answer the basic question "What is really worth doing?" on a relatively small amount of investment and there are valuable techniques becoming available to assist the small firm to assess and to optimise the next step forward in some item of machinery (Audsley 1981, Audsley *et al* 1978). The National Institute of Agricultural Engineering has made considerable progress in looking at a potential innovation in machinery in relation to the total system in which it is to be applied. *This "systems" approach to innovation will become increasingly important in the next few years* as the farmer has to get the best value for money in terms of total profitability.

It is necessary therefore if more cash and profit is to be generated in the agricultural engineering industry for *an integration of all the resources available to be focussed on the urgent need for:*

a) new products to meet the market need, at home and abroad
b) rapid innovative work to provide the new products.

Let us consider the main ingredients.

Finance and other resources

As Mr Manby in his Presidential Address to the Institution of Agricultural Engineers pointed out (Manby 1978), the ratio of costs as between "Design and Development" to successful commercial realisation of a product, and the "Research and Development" part, is in the ratio of 7 to 1. Many would put it higher — even 10 to 1, depending on the product and the market. In Britain, we have been good in financing the research and development element but, in general, poor in providing the application and realisation in commercial terms. This has been particularly so in Mechanical Engineering.

To correct this situation rapidly — and rapidly is the word if we are to survive — *financial backing for innovation, on a more advantageous and longer term basis, is required.* Although the Department of Industry Requirements Boards backing has increased to 33% lately (and this helps), small companies cannot be expected to pull themselves up by their bootstraps: *cash and resources have to be injected against sound proposals for product and process developments.*

While Government aid, both direct and indirect, is clearly needed, there are several ways in which more resources could be made available. Despite the obvious, critical importance of good engineering to match the advances being made in the improvements in farm produce and food products, the financing bodies for research and development (Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries for Scotland and the Agricultural Research Council predominantly) still allocate to the National and Scottish Institutes of Agricultural Engineering less than 5.3% of the total spent. Moreover, it is restricted to the research and development end *where "engineering research and development," if it is to be "worth its oats", must go much further down the line to the final product.* While such Institutes working with their industries could be expected to generate cash to cover their own future needs to an increasing extent, again there is a need for more generous treatment for a period of five years.

The initiative

I am not proposing a "dirigiste" approach to our problem: the *initiative and determination to develop new saleable devices must come from the Industry itself.* It is significant that many firms are still unaware of the financial aid that can be obtained — on favourable terms — from Government sources, financing bodies like the British Technology Group (now incorporating the National Research and Development Corporation), Finance for Industry and the like, as well as private sources. Much can be done for both small and large companies alike if a good case has been worked out.

It is to be regretted that Agriculture — and therefore Agricultural Engineering — is considered to be "different" with the result that all too often neither the Department of Industry nor the Ministry of Agriculture, Fisheries and Food sees the development of its engineering equipment as part of a vigorous and successful engineering export trade in general.

The size of the market

Clearly this is an important factor in determining a business plan. Many of the innovations that arise do not require long and sophisticated development programmes — they need good engineering coupled with a background of experience. It is for this reason that relatively small firms can be successful without very large facilities. On the other hand where the research and development has been done in a high technology institute or research organisation, a relatively small firm can carry an innovation to the market with backing finance. A good example of this has been the blackcurrant harvester, where a very successful business has been built up on the sale of a few large, expensive machines on the background of research and development at the National Institute of Agricultural Engineering, with a good carry-over into the commercial realisation stage. Here it is encouraging to know that the main risk financing came from the National Research and Development Corporation.

The harvester has developed a very healthy export market and about 70% of all UK harvesting is now done by this machine. Here is a case of a market that is profitable on sales of around ten to twenty machines per year with high added value. Recent development covers crop spraying as well.

The pooling of resources

This success story gives us one clue to the way ahead. Only companies as big as John Deere (with a central research and development staff of about 80 graduates and with another 850 professional staff on product-oriented work, see Manby 1976) can be expected to mount an internal programme of innovation. Yet in the National and Scottish Institutes of Agricultural Engineering, we have a professional effort that can go a long way to match this, if they were given the freedom and support to use a considerable part of their resources in co-operative development on an exclusive basis with individual firms, to take product development as far as may be necessary to the market launch.

Such a co-operation need not reduce the value of these Institutes to the farmer: on the contrary, by involving him closely in the market need and assessment, it would greatly enhance their service to the farmer and provide him with better equipment fit for its purpose.

There are several good examples of this kind of co-operation already in both Institutes but *it needs to be recognised as the normal pattern.* In my view, there is no other way to build up a competitive industry in a short time. The number of trained graduate and technician staff is too small to be spread around so many companies, nor could the companies justify the employment of the various skills and backgrounds needed to look after all aspects of the development. The available staff in the individual firms have to be used for marketing and sales and really effective after-sales service — functions that can only be provided in the long run by each firm for itself.

The market opportunities

One of the urgent requirements is for a good, continuously updated market review on a world basis. In addition, all aspects of the industry need to work out strategies of the market opportunities. I believe there is enough expertise and awareness to identify the fields worth developing which must avoid the "me too" approach. It is not the purpose of this lecture to suggest what these fields are competent to do it nor am I. But a few pointers may be in order.

1 Software development
The United Kingdom is a world leader in software development. There are many opportunities for this in association with high added value microprocessor and control systems (glasshouses, cattle feeders, machinery choice, energy economy, etc). We should exploit it in agriculture/food industries.

2 Matching implements
Although wheeled tractor manufacture is in the hands of large multinationals, most of them source their tractors up to 100 kW from the United Kingdom. It is necessary for the implements to match the tractors. With the high production tractor base, surely there must be great opportunity for worldwide sales of matching implements.

3 Farm buildings
There remains a continuing need for better buildings. Much work is in hand: it needs exploiting.

4 Glass house technology
The same is true here. This is an intensive means of producing up-market foods with good added value but sophisticated reliable control and monitoring systems are a requirement.

5 Simple, reliable devices of high added value
Not all developments need to be large and ambitious. The National Institute of Agricultural Engineering chicken weigher is a good example of sound engineering applied in an essentially simple way.

6 Translating new discoveries into hardware
Many of the Agricultural Research Council's Institutes are making discoveries and exciting new advances in support of the farmer. Many of these require good engineering for realisation. While good work of translation of some of these projects into practical terms is in hand and, it is believed, increasing, there must be many cases where the market potential is not being sufficiently rapidly or effectively translated and is being siezed on abroad for sale back to ourselves.

Greater awareness of the commercial potential of new ideas and discoveries is needed throughout the Agricultural Research Council.

7 Forage harvesting and conservation
The British performance in this field has been good in the past and, with recent developments, could be a major contributor to the Home market and for Export (Klinner 1982).

8 Low-input farming
With rising costs throughout the world and diminishing returns in the use of fertilizers and insecticides etc, means of optimising the total return on a given amount of input inside and outside the farm gate will become increasingly important (Joint Consultative Organisation 1982). Engineering has necessarily to provide the means for its realisation.

The food industry

I cannot end this lecture without referring, however briefly, to the changing needs of the world for the form and nature of its food. "British farmers are today receiving an ever decreasing proportion of the total national expenditure on food, probably less than 30% of the whole" (Joint Consultative Organisation 1982). This means that the food manufacturers and retailers will have increasingly specific requirements from the farmer and research and development — and product development — must be steered appropriately. With a few fine exceptions, the food industry has to go abroad for its more sophisticated machinery and unless this changing pattern is recognised, the opportunity for engineering innovation will be lost.

Agriculture can no longer be thought of as a self-contained industry. There is an opportunity here for the Research Institutes to develop their capabilities in this direction and provide the same co-operative activity for food processing, treating and packaging as proposed above for agriculture.

Conclusion

I cannot sum up my lecture better than to quote from the recent paper from the Joint Consultative Organisation (1982).

"The whole subject of "value added" is a wide one and offers scope for much new thought. It ranges from higher quality primary products to streamlined marketing and processing, the better utilisation of every kind of by-product and a vigorous, well equipped and enterprising manufacturing sector. The potential rewards for getting "value-added" right are immense".

Nowhere is this statement more applicable than to the machinery manufacturer throughout the agricultural and food industries. We do not lack either the abilities or facilities to succeed: what is needed is the attitude of mind that determines success.

Acknowledgements

I wish to thank Dr Ronald L Bell, Director of the National Institute of Agricultural Engineering, for much help and advice. I am also very grateful to Mr T C D Manby OBE for his assistance in supplying information on several matters and to Mr W J Course for bringing tables 1, 2 and 3 up to date.

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Books

Methane — planning a digester

THE fact that this is a second edition indicates that this is a book which has sold well. Mr Meynell is described as "the country's leading authority on methane" and also on the back cover are approving words from the Journal of the Institute of Mechanical Engineers and the Water Pollution Control Journal. It is therefore with some trepidation that I put forward my opinion that judged by its title, this book is inadequate. It is a good introduction to digestion and it ranges far and wide over the subject. The list of organisations involved in digestion is the major update of the new edition and should be very useful. To cover the details of everything related to digestion in under 200 pages is obviously impossible so the odd gap here or there must be excused.

To plan a digester you need to estimate its size, cost and the amount of net gas which can be used over an average year. From this you can calculate a cost benefit analysis by whatever method. It is not necessary to do a detailed mechanical design at this stage but a careful analysis of the volume, dry matter content and temperature of the feed material is vital to allow a calculation of the size of the digester, and the gas production net of digester heating. The importance of having sufficient dry matter content is not emphasised, nor the fact that most UK farm digesters have suffered from receiving lower dry matter material than designed for. The great difficulties of measuring average slurry composition accurately are not stressed. A figure of 8% dry matter for pig slurry on p 102 is not impossible, but rather unusual in practice. If the true figure were 4%, then the digester volume would be half what was needed, leading to an underestimate of capital cost and the net gas production would be overestimated by a factor of 3 — and that assumes a digester sized for 4%!

Finding effective uses for all the gas produced is equally important, but is not properly covered. Biogas is so expensive to store that the storage of only twelve hours worth of production is about the most that could be considered economically. In order to use a large proportion of the gas produced, the load has to be rather continuous with a low ratio of peak to average demand. It is therefore ludicrous to suggest, p 82 that the use of biogas to dry grain could be significant in the economic case for a digester. The production of electricity from biogas is mentioned, but very little of the practical detail is given. Nothing about demand profile, phase imbalance, or part load efficiency. The only figure given is a gas consumption of 16 ft^3/hr per kW. This must be for a large engine (more than 50 kW) at three quarters full load or more, though the figure is given without qualification. Engine life and maintenance are not touched on at all.

It is difficult to see how you can plan a digester without some discussion of filthy lucre, payback and so on, but no numbers pollute these pages. Economies of scale are mentioned, but not the fact that a digester twice the size costs only 40% more.

In summary, this book would be fine as "an introduction to digestion" but I cannot recomend it as a basis for planning a digester.

Methane: planning a digester, by Peter-John Meynell. Prism Press, Stable Court, Chalmington, Dorchester, Dorset. £4.95. Paperback. *NEHF*

Great tractors

THE title explains the author's theme. This is not intended to be a comprehensive history of the tractor, but a description of some interesting and outstanding machines. Many landmarks in tractor development are included, others are machines which, for one reason or another, have taken the author's fancy. He has selected about seventy tractors to illustrate development from the Case experimental machine of 1892 to the Reading University driverless tractor controlled through buried guide wires. Purists might claim that some of the machines described scarcely deserve the title 'Great', and indeed, in places the choice does seem somewhat idiosyncratic. However, the author introduces us to some less-well known machines such as the luxuriously appointed Mineapolis-Moline UDLX with cab, cigar lighter, etc (only about 150 were sold, he tells us), the Bryan light steam tractor with its "flash" steam-generator, and the Vickers-Aussie using an early form of flotation wheel, and deserves our thanks for this. The reader may wonder why some notable tractors were omitted, for example the Ivel, which can be studied both at the National Tractor Collection and the Science Museum. The author tells us that some of the omissions may be included in a further volume, and this we await with interest. 'Great Tractors', then, is a book to complement, rather than to compete with, other books on the development of the farm tractor.

The descriptions of the tractors do not include extensive technical detail; for this the reader will have to look elsewhere. Horsepowers and weights are generally given, but usually little other constructional information. The philosophy behind the decision to produce a particular model is generally included and background information of this type, often not easily obtained elsewhere, makes enjoyable reading.

Interesting points appear on examination of some of the photographs, for example, the raised sprocket in the high-clearance Cletrac, and the spaced track plates on one of the Caterpillars. Both machines date from the 1920's, but these features reflect present-day design and thinking.

The author has, rightly, included some experimental tractors which could not have been expected to enter production in their original form. Mention has been made above of the Reading University driverless tractor, and the NIAE hydrostatic tractor also finds its rightful place among these pages as a pioneer tractor. A well illustrated description of the half-track Ferguson TE 20s used in the expedition to the South Pole undertaken by Sir Edmund Hillary in 1957-58, is also given, with pictures of the tractor in the Massey-Ferguson museum at the Stoneleigh training school. Developments such as these tend to be omitted from many popular works because they were never in series production. The recording of them in this volume is welcome.

Some fifteen manufacturers (including three examples of Henry Ford's experimental models), have been selected to cover the period up to the end of 1918, twenty-six makes cover roughly the period 1918-45, and another twenty-three take the reader up to the 1960s. In all, over eighty different models are mentioned, some manufacturers, of course, being represented by several models of tractor. Continental tractors are not overlooked, examples from Renault, Fiat, Landini, Hurlimann and Lamborghini are included.

The twenty-seven colour photographs are sharp and attractive. There are over a hundred black and white photographs, a few of which, in the review copy, had lost a little detail in the printing. This is a minor cavil, however. *Great Tractors* deserves a place on the bookshelves of everyone who is interested in the development of the agricultural tractor.

Great tractors by Michael Williams. Blandford Press, Poole. £8.95.

→ *foot page 126*

A system to control tractor tyre inflation pressure on-the-move

P F Hemingway, J S Price, and J D Scott

Summary

EXISTING theory and research work relating to the influence of inflation pressure on tractive tyre performance is reviewed. The need for a system of on-the-move tyre pressure variation is established and a prototype system described. Desirable features of a commercial system are outlined.

1 Introduction

IN recent years the demands placed upon agricultural traction tyres have increased greatly as tractor power, weight and work rates have risen. The farmer is now seeking not only increased traction but also a reduction in soil compaction, which, in the past, has resulted from high levels of contact pressure and wheelslip.

All tyres are designed to run at a set level of deflection (fig 1). The magnitude of the deflection is clearly a function of wheel loading, tyre inflation pressure and tyre stiffness. Despite the fact that tyre deflection is the most important criterion in obtaining optimum performance from a tyre, no real attempt has been made to date to match tyre inflation pressure to varying levels of loading and ground conditions. This results in less than optimum performance being achieved for much of the operating time.

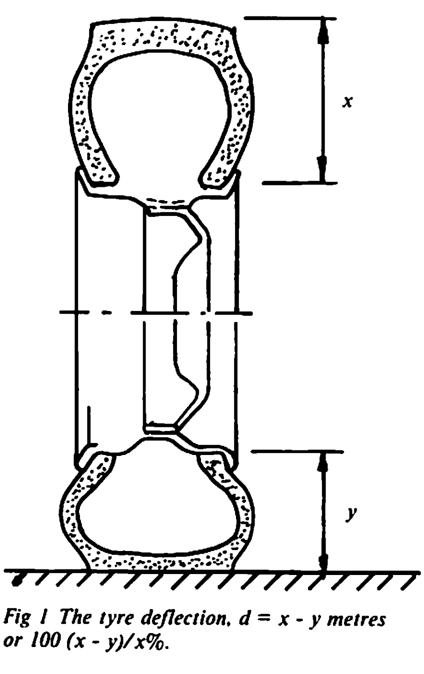


Fig 1 The tyre deflection, $d = x - y$ metres or $100(x - y)/x\%$.

Now that the pneumatic tyre provides the almost universal means of obtaining traction in agriculture, it is timely to incorporate a system of in-work tyre pressure control which will enable tyre deflection levels to be kept constant throughout the working cycle. The quest for increased traction with reduced levels of soil compaction makes the adoption of such a system increasingly desirable.

2. The influence of tyre inflation pressure on traction

Reece (1967) showed that drawbar power may be expressed as:

$$P = \frac{s}{1000}(1-i)\,[(blc + W\tan\phi)\,X - R] \quad (1)$$

This implies that drawbar power is a function of thrust attained and speed of travel, with subtracted allowances for rolling resistance and wheelslip. It is thus clear that the thrust term ($blc + W\tan\phi$) has a crucial effect on tractive performance. The soil characteristics, c and ϕ, are not easy to influence, except by selecting days of appropriate soil water content on which to operate. The operator is thus left with b and l, tyre characteristics and W, the weight on the driven wheels.

It may be assumed that tyre contact area ($b \times l$) is a function of wheel loading, tyre inflation pressure and tyre stiffness. In order to optimise the contact area, it is necessary that the side walls of the tyre deflect, thus enabling the tread to take up a flat form on the ground. Tyre deflection also provides cushioning for the machine and operator. Over the working inflation pressure range, it is reasonable to assume deflection to be inversely proportional to inflation pressure and directly proportional to soil contact area.

Although little work directly related to the effects of varying inflation pressures, has been done, results have been obtained in other experiments which prove interesting. Gee-Clough *et al*, in a comparison of radial and cross-ply tyres, found that a reduction in inflation pressure at constant axle load almost universally resulted in an increased coefficient of traction and a decreased coefficient of rolling resistance. Figure 2 (Gee-Clough 1980) illustrates the influence of deflection on the coefficient of traction graphically. It can be seen that the increase in coefficient of traction which can be gained by increasing deflection from say 10 to 25% is not too significant when tractive conditions are above average. In poor to average

Notation

b	width of tyre contact area	m
c	soil cohesion	N/m^2
i	wheelslip	dimensionless
K	constant for tyre carcase stiffness	dimensionless
l	length of tyre contact area	m
P	drawbar power	kW
R	rolling resistance	N
s	tractor speed without slip	m/s
W	weight on driving wheels	N
X	slip function	dimensionless
P_1	tyre inflation pressure	N/m^2
P_0	pressure transmitted by tyre carcase at $P_2 = 0$	N/m^2
P_c	average contact pressure	N/m^2
ϕ	angle of soil internal friction	degrees

Department of Agricultural Engineering, Harper Adams Agricultural College. The paper is based on a project undertaken by J S Price and J D Scott as part of the Higher National Diploma in Agricultural Engineering, under the supervision of Paul Hemingway. (Refereed paper).

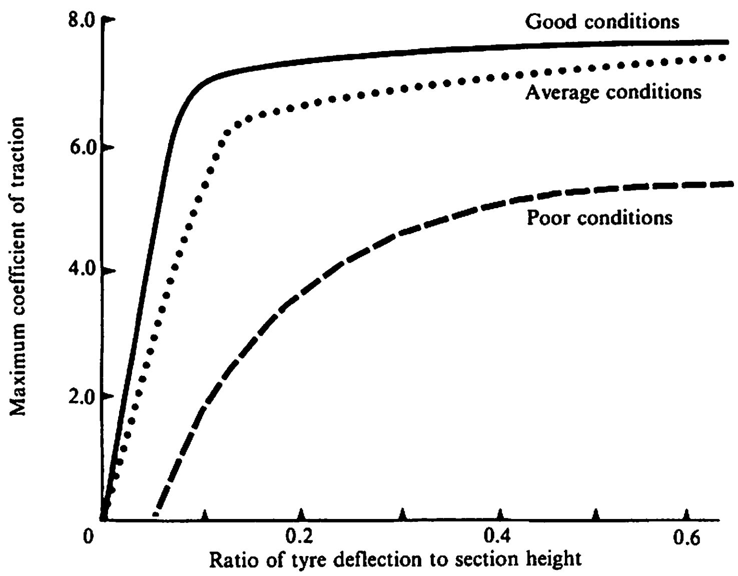


Fig 2 Variation of the maximum coefficient of traction with the ratio of tyre deflection to rection height for a tyre contact area of length 1.6 m and width 0.5 m at a loading of 25 kN on the driving wheels. (After Gee-Clough, 1980)

conditions, however, significant increases occur.

Although a static deflection on concrete may be 25%, it must be borne in mind that, in soft ground, this is quite likely to reduce to 10-15% due to deformation of the soil beneath the tyre and the consequent increase in contact area. This was proved by Domsch (1959) when he demonstrated that tyre deflection in soft soil at 0.51 bar inflation pressure could be less than tyre deflection on a hard surface at 1.08 bar (fig 3).

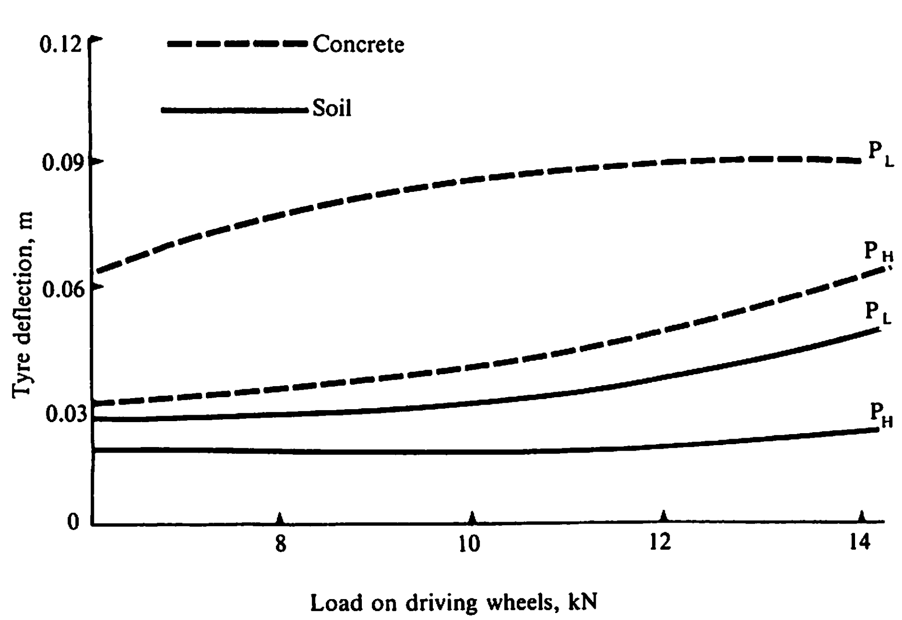
3 The influence of tyre inflation pressure on soil compaction

The exact mechanism of soil compaction is still under investigation. Experiments have assessed the relative importance of tyre inflation pressure, loading, deflection and stiffness (all contributing to contact pressure) and of wheelslip, forward speed and mechanical vibration. It has been shown (Domsch 1959) that contact pressure may be expressed in terms of tyre inflation pressure and tyre characteristics as follows:

$$P_c = K.P_i + P_0 \qquad (2)$$

Thus, it is evident that significant reductions in contact pressure may be made by reducing inflation pressure. Figure 3 illustrates that tyre deflection on concrete is in no way indicative of off-road deflection. It thus follows that deflections off-road may be considerably increased without fear of over-deflection of tyres. Little quantative analysis has been carried out on the effects of wheelslip on compaction. Davies *et al* (1973) concluded that wheelslip is more effective at causing compaction than additions of load. They also indicated that wheelslip generally may be reduced at a given loading and pull by reducing inflation pressures.

Fig 3 The influence of two ground conditions and two inflation pressures, P_H= 1.08 bar and P_L = 0.51 bar, on the relation between tyre deflection and wheel loading. (After Domsch, 1959).



4 Safety aspects and manufacturers recommendations

In the interests of safety it is essential that there is an upper and lower limit set on tyre operating pressure.

Upper pressure limit
This is set so that the tyre cannot:

i) physically rupture under localised stress
ii) fail to absorb shock loading so as to give the operator and machine some form of cushioning and stability.

Lower pressure limit
This is necessary to ensure that the tyre is held firmly against the wheelrim and cannot leave the same under the effect of side loading or high levels of torque transmission from wheel to tyre.

Accepting these two limits set by the manufacturers in the interests of safety, it is tyre deflection within these limits which is of interest.

The manufacturers in general provide load/inflation tables to ensure that tyre deflection is maintained within the correct range. Most of the data in these tables, however, are calculated to allow for road running at maximum speed. The manufacturers are obviously aware of the generaly apathy that surrounds the use of their products on many farms and consequent misuse that occurs. For this reason, the use of anything other than a very narrow range of inflation pressures is discouraged.

A deflection level of 18-20% is chosen as a fair compromise between reasonable field performance and freedom from damage on the road. The reticence of the manufacturers generally to encourage greater levels of deflection is understandable. The only way that the full traction and flotation benefits of high deflections can be attained is if constant adjustment of inflation pressure is possible.

5 The case for on-the-move tyre pressure control

In the light of all the experimental evidence considered, the desirability of being able to control the inflation pressure of agricultural traction tyres on-the-move is indisputable. In addition to the two major areas of traction and compaction already identified, there are several other benefits to be derived from on-the-move tyre pressure control.

i) *Increased tyre life* — By always running at the correct level of deflection, both tread wear and carcase life should be maximised.

ii) *Better transport performance* — With amalgamation of farms and increasing use of agricultural contractors, there is a growing trend in field/road/field movements which necessitate considerable changes in inflation pressures. This is accentuated by loaded/empty/loaded haulage cycles.

iii) *Mobility maintained with small punctures* — With possibility of continuously inflating a tyre on-the-move, much time could be saved by the avoidance of in-field repair and working down-time.

Prototype construction
Having considered the foregoing review, a prototype tyre pressure control system was constructed in order to gain a better understanding of the physical problems involved. The test tractor was equipped with 16.9 x 34 rear tyres and a single cylinder air compressor of 120 l/min output, the compressor being standard equipment on the tractor as part of an auxiliary air braking system. An adjustable pressure regulator was fitted directly on to the air reservoir which contained air at a pressure of 7 bar. The regulator was set to an upper pressure limit of 2.5 bar for safety reasons. The compressed air available at the regulator was supplied to two control valves which were capable of either charging, discharging or locking air in either back tyre independently (fig 4).

The air supply from the control valves was fed through 6 mm bore plastic pipe to rotary valves attached to the wheel centres and subsequently to the tyre valves. A structure was fabricated to provide support to the airline where it passed outside the tractor wheel. Some metal pipework was utilised to resist any torque which may have been transmitted by the rotary valves (fig 5). The total cost of components involved amounted to approximately £130.

System operation
With the compressor running and reservoir charged, on-the-move tyre pressure control was easily achieved. Individual control of each rear tyre was incorporated so that a tyre pressure differential could be maintained to facilitate uneven loading on each wheel. The classic application of this is in in-furrow reversible ploughing.

Pressure adjustment
The basic control system did not enable a new pressure to be set simply. Inflation involved opening the control valves, causing the pressure gauges to show full deflection, estimating inflation time and then reclosing the valves to obtain gauge readings. Deflation involved a similar process.

It was originally envisaged that small pressure regulators incorporating downstream venting could have been used. These would have enabled the required pressure to be dialled, with the regulator cutting off the air supply when the desired pressure was attained. In practise, the extremely slow venting characteristics of this type of regulator rendered it unsuitable for this application.

Inflation/deflation rate
An on-the-move tyre pressure control system does not demand a particularly fast response rate because the adjustments are being carried out as work proceeds. However, reasonable speed of operation is desirable. With the overall system pressure regulated to 2.5 bar for safety reasons, inflation was rather slow at 0.2 bar/min. Flow rate seemed to be the limiting factor because, in normal working, the reservoir 7 bar relief valve was observed venting during tyre inflation.

Deflation rates were similar at 0.15 bar/min between tyre pressures of 1.4 and 0.7 bar. The utilisation of larger bore pipework and fittings undoubtedly would have speeded response time.

Table 1 Mean wheelslip, %, developed whilst exerting varying levels of drawbar pull at varying levels of tyre deflection on two surfaces.

Surface: concrete

Drawbar pull, kN	Tyre deflection, % 22	14
13.4	24.7	35.7
17.9	40.2	47.6
22.3	64.1	86.9

Surface: sandy loam — 16% mc

Drawbar pull, kN	Tyre deflection, % 18	15	12.4	9.5
13.4	15.8	30.2	42.7	51.55
17.9	39.4	75.0	100.0	100.0

System testing
A series of drawbar pull tests were performed on both concrete and a sandy loam soil. The drawbar pull was gauged simply by a hydraulic drawbar dynamometer, the resistance to motion being provided by a second tractor with brakes applied. In order to emphasise the potential of this system, the extremes of the likely range of deflections were taken as being 9.5 and 22.0% of tyre section height. Whilst it can be argued that perhaps the range of deflections tested is rather too wide for agricultural usage, it nevertheless becomes quite clear from table 1 that by increasing deflection levels, one may either:

i) reduce wheelslip at the same level of drawbar pull or
ii) increase drawbar pull at the same level of wheelslip.

The test run on soil at a deflection of 9.5% was deliberately included to demonstrate the penalty which can be incurred by gross over inflation. As can be seen, by increasing deflection from 9.5% to 18% at 13.4kN drawbar pull, slip levels can be reduced from an unacceptable 51.6% to 15.8%. A major point emerging from the test is that as deflection increases, so does the self-cleaning ability of the tyre. It is likely that, on the relatively low cohesion soil of the test area, high levels of traction at high deflection were as much due to improved cleaning of the tread as increased contact area.

Fig 4 Control panel inside tractor cab, showing valve gear and tyre inflation pressure gauges.

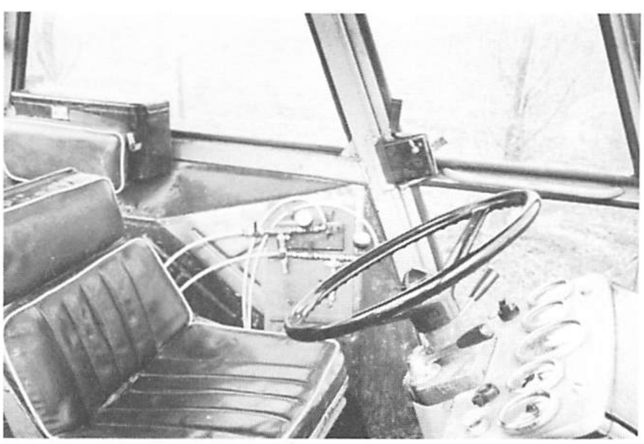


Fig 5 View of the air feed, via the support structure to the rotary valve and hence to the tyre.

6 Desirable features in a commercial system

Air feed to wheel

The routing of an airline around the outside of a tractor wheel is clearly laying the system open to mechanical damage. Thus, it would be highly desirable to utilise an annular rotary valve mounted inside the wheel around the axle trumpet housing.

Pipework

The prototype utilised 6 mm BSP fittings and matching pipework. A larger bore system, as already indicated, would be desirable in order to improve response times.

System control

In order to simplify operation of the system, use of pressure regulators enabling the required pressure to be dialled and the system left to control the final pressure would be highly desirable.

System extension

Any commercial system designed for two wheel drive tractors would need to be extendable to cope with the addition of dual wheels. On-the-move tyre pressure control would then have to apply to all four rear wheels. In the event of a low ground pressure application, the inflation pressure of the front tyres may also need to be controlled, even though those tyres are not necessarily driven. A system of on-the-move tyre pressure control has obvious application to four-wheel-drive machines and would entail relatively little additional mechanical or pneumatic complexity.

Deflection indication

The whole purpose of a system of on-the-move tyre pressure control is to enable the deflection of the tyre to be adjusted to its optimum setting throughout greatly varying loading regimes. Thus, it would be highly desirable to monitor deflection on-the-move and link this to the on-the-move tyre pressure control system. For example, if a plough was lifted out of the ground at the end of a days work, the load on the tyres would increase, deflection would increase and the system would inflate the tyres sufficiently to compensate. A maximum and minimum deflection warning system would need to be included.

Due to the conditions encountered off-road, the deflection of a tyre is a rather difficult phenomenon to measure. It would seem that the only realistic solution would entail a device actually mounted inside the tyre. The practical difficulties of this are obvious, but may doubtless be overcome.

7 Conclusions

Evidence exists of the importance of appropriate deflections of agricultural traction tyres in relation to traction, soil compaction and tyre life. This is especially evident when the widely varying levels of loading, operating speed and working surface are taken into account.

Tyre deflection at any given loading can be directly controlled by the tyre inflation pressure and it is thus proposed that a system of on-the-move tyre pressure variation is necessary.,

Such a system may be constructed at low cost, although it may lack sophistication and be prone to mechanical damage.

More work is required to extend the concept of this work into a viable commercial system.

8 Acknowledgements

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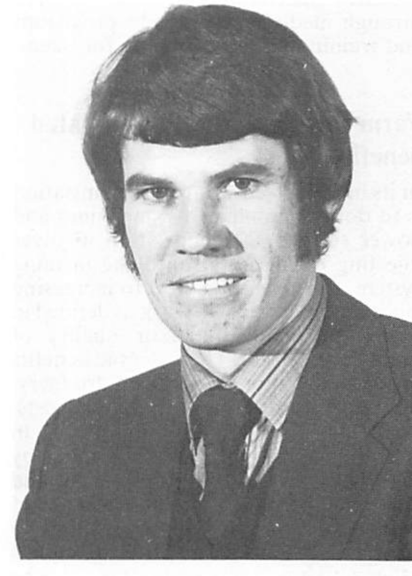
Technology choice in smallholder mechanisation

J Morris

Summary

FARM mechanisation is often proposed as a means of improving productivity in the smallholder sector of developing countries. In this context, this paper reviews the basic features of mechanisation technology and the smallholder system as they determine the scope for mechanisation and its potential contribution. The smallholder sector, for the most part, can be generalised in terms of small-scale, labour intensive, semi-subsistence, low income farming systems with limited access to a supporting infrastructure. Mechanisation technology, for its part, can be categorised into man, animal and engine powered systems on the basis of power source, sophistication and cost. Having identified the need and justification for more farm power, selecting the most appropriate form of mechanisation should incorporate the criteria of power performance, work rates and capacity, cost, infrastructure requirements, and social impact. Man, animal and engine powered forms of farm mechanisation are examined using these criteria. The best choice is largely determined by the objectives of agricultural development and the prevailing resource/constraint environment. More recently, attempts have been made to devise smallholder mechanisation strategies in the context of overall development programmes and this has involved a careful assessment of mechanisation needs, an appraisal of available technology and the formulation of policy measures to encourage the development and selection of mechanisation conducive to predefined development objectives.



Introduction

ALMOST without exception, Third World Governments emphasise the role of agriculture within their overall development strategy, with particular reference to increasing food production. With the smallholder/peasant sector often accounting for over 70% of total agricultural production, 'Green Revolution' programmes are necessarily small farmer oriented, especially where attempts in other directions, notably large scale public sector farming, have met with imited success for a variety of reasons. The overall purpose of such programmes is to improve small farm productivity and further mechanisation is one possible way of achieving this. However, a number of features of mechanisation technology and of the smallholder production system may reduce the scope for mechanisation and its potential contribution. This paper, in very general terms, considers the basic features of smallholder systems relevant to mechanisation, the nature of mechanisation, and a comparative analysis of alternative smallholder mechanisation systems in terms of selected criteria.

Joe Morris is Lecturer in Agricultural Economics and Management at the National College of Agricultural Engineering, and permission from "Outlook on Agriculture" to publish this paper is fully acknowledged.

Features of the smallholder production system relevant to mechanisation

IT is now largely agreed that the new and improved technologies to be adopted by developing countries must be both appropriate and acceptable, not only in terms of technical suitability, but also with particular regard to the resources and aspirations of their recipients. In this context, the mechanisation planner needs to consider a number of features of the 'smallholder target group' which influence the need and scope for mechanisation. These can be briefly generalised as follows.

Farm size

Some 80 — 90% of holdings in developing countries are below five hectares and often 50 — 60% are two hectares or less. Complex land tenure arrangements and excessive farm fragmentation may further limit the scope for sophisticated farm power systems more suited to large contiguous holdings. The natural characteristics of smallholder land itself can limit mechanisation feasibility, namely, topography, drainage, natural vegetation and accessibility.

Labour

Smallholder systems are by definition labour intensive and family oriented. In many cases, the smallholder sector engages over 60% of the economically active population. Family sizes average six to eight persons, usually with two to three adult male equivalent workers. Larger than average farms are import-and sources of paid employment. With rapidly increasing populations, many countries look to the smallholer sector to absorb rural population growth.

Semi-subsistence farming

The average two to three hectare holding generally devotes 60 — 70% of its area to household food crops, mainly cereals (at yields of 1 t/ha, a family of six would need about 1.6 hectares of cereal equivalent to sustain itself). Crop and livestock production are typified by low and unreliable yields, unimproved species, low use of fertiliser or animal fodder, and limited pest and disease measures. The more intensive smallholder production systems involve dryland inter-cropping or irrigated relay cropping.

Low and variable incomes

All the foregoing features combine with low produce prices to generate low and uncertain disposable incomes for smallholders. The arithmetic is simple: at world market commodity prices, a two hectare holding producing say 1.5 tonnes of cereals at £80 and 0.5 tonnes of groundnuts at £250 is equivalent to a gross income of about £250 for six people. Most farmers receive much less than world market prices. Even with improved practices, the situation is not much different: a two hectare holding in northern Nigeria (1978), Egypt (1979) and Malawi (1980) was estimated by the author to give net incomes of about £500, £350 and £200 respectively in 1981 prices. This level of income leaves little room for any form of new technology, much of which remains expensive and inherently risky.

Institutional support

Input supply, marketing, credit, extension and training are limited and a major constraint to improved productivity. In the past, such services have been aimed at the larger more progressive farmers. Most recently, a number of countries, for example Malawi and Nigeria, have devised more modest and appropriate 'basic service' packages which provide input supply, marketing, credit and extension. Selective mechanisation has featured through medium term credit provisions and training schemes, mainly for oxen.

Farm mechanisation and related benefits

In its broadest sense, farm mechanisation is to do with implements, machines and power sources. Mechanisation involves injecting extra capital into the farming system, mainly with a view to increasing labour's capacity to do work as defined in terms of quantity and/or quality of output per worker. The potential benefits of mechanisation are reduced drudgery, increased returns and reduced costs. Reducing drudgery is important in retaining a commitment to farming by the young and in releasing women and children particularly, from the sweat and tedium of many farming operations to spend their time more productively on other activities. Increased returns may be evident from increased yields, an expansion of the cultivated area, new crop/livestock systems, and higher commodity prices facilitated by mechanisation. Where mechanisation is substituted for hired labour, cost savings may be apparent to the farmer employer.

In the main, mechanisation is a 'labour augmenting' technology, increasing output per worker rather than output per unit of land. The benefits of mechanisation have been greatest where labour is scarce (and therefore expensive) and/or land is plentiful. This characteristic of mechanisation has important implications for the role and impact of mechanisation in the smallholder production system where, for the most part, land, capital and management are limiting and labour is generally abundant.

Alternative mechanisation systems

Mechanisation systems are often categorised into man, animal and engine powered technology on the basis of sophistication, capacity to do work, costs, and in some cases precision and effectiveness.

The predominant form of smallholder technology is that based on manual labour, with the hand hoe as a basic ingredient. The main attributes of this system are that it represents a low cost, low energy, labour-using, family oriented technology, which is closely attuned to traditional farming methods such as minimum tillage and intercropping and is largely self sufficient, drawing on locally made implements. Furthermore, hired employment with payments in cash or kind is an important source of off-farm income. The main disadvantages of human powered technology are that it often requires long, hard and tedious work and the low level of labour productivity acts as a constraint on output and incomes. However, because of the primitive nature of many traditional implements, there exists much scope for increasing labour productivity by improved hand tools and man-powered machines. Examples are the replacement of knives with scythes and the introduction of hand operated maize shellers.

In some areas, work animals such as donkeys, oxen, cows, buffaloes, mules, horses, and camels are a common feature for farm transport if not for field work. They are especially common where there is a long history of animal husbandry, where tsetse fly is not a problem and where farms are relatively large (above three hectares), population pressure is low and land is available for grazing or fodder production. The advantages of work animals are that they can offer a relatively low cost, low energy, self-supporting, reproducable (with the possible exception of mules) and potentially comprehensive system of appropriate mechanisation. Animals can improve labour productivity and help overcome major power constraints for small farmers without displacing labour. Animals can also provide a basis for informal contract hire. The main disadvantages of animal powered technology are that it requires animal husbandry skills which are not always in evidence, and animals and equipment remain expensive for the average smallholder. Furthermore, animals have a limited power capability, particularly if underfed, and feeding costs can be high, especially where fodder and grazing land are limiting. Work animals also require their share of institutional support, particularly regarding the supply of suitable animals and equipment, credit, training and veterinary services. Animal draught power is often seen as the most 'appropriate' mechanisation package for smallholders. The critical factors determining uptake are usually the availability (and cost) of oxen, feed, and the acquisition of animal management skills. Oxenisation packages include oxen, a range of equipment, credit provisions and operator and animal training.

Farm size and income largely preclude the average smallholder from acquiring engine powered technology for use on his own farm only. In the main, it is not possible to scale engine powered technology down to the level where it is technically or financially suited to the individual smallholder. Stationary power units driving processing machines have a particularly important role, as do tractors for land preparation and transport but their potential is in terms of multi-farm use through co-operatives, private contractors or government hire schemes. In this context, the advantages of engine power are that it undoubtedly makes the greatest contribution to reducing drudgery. High power, high capacity, tractor-based systems theoretically offer the greatest achievement of the previously enumerated mechanisation benefits particularly those resulting from improved timeliness, new cropping patterns and an extension of the cropped area.

Engine powered systems can encourage general farming modernisation and concommitant benefits such as the acquisition of new mechnical and management skills. The disadvantages of engine powered systems are well documented. They are relatively expensive to acquire, operate and maintain (in spite of often heavy subsidies), require a high (largely non-renewable) energy input, and often represent a non-indigenous, high foreign exchange technology. Multi-farm systems are often difficult to organise and manage, and usually need considerable institutional support (Lonnemark 1967). Engine powered systems have been particularly criticised for their undesirable social and environmental impact, especially the displacement of labour in conditions of general underemployment. Small tractors (below 15 kW), however, have been designed with the smallholder farms in mind. Except for wet-land power — tillers, they have met with little success, mainly because they are expensive to buy and operate, demonstrate high costs per unit of work and are generally not powerful and heavy enough to perform primary tillage satisfactorily. In addition they require an order of institutional support similar to the conventional tractor (Pollard and Morris 1978).

The mechanisation needs of the small farm

The mechanisation needs of the small farmer will vary according to the power requirements of his farm (as determined by farm size and production system) and the extent to which existing power supply is a constraint on improving output. From the farmers viewpoint, the justification for acquiring more mechanisation will depend on such factors as:

— the financial worthwhileness of the mechanisation investment; how the benefits compare with the costs,

— the ability to finance the proposed investment,

— the opportunity cost of the mechanisation investment; would it be better spent on other things?

Where the choice exists, farmers will weigh up the relative attributes of alternative approaches to mechanisation. Although not expressed in these terms, power performance, work capacity, cost effectiveness and financing capability are likely to be important selection criteria. At the same time, national governments will be interested in the social, economic and political ramifications of alternative approaches to mechanisation, and they will be concerned with encouraging individual farmers, by a variety of policy measures, to adopt mechanisation systems which are in the overall national interest. Some of these criteria are examined in turn.

Criteria for selecting farm mechanisation

Power

Power per cultivated hectare can be used as an indicator of existing mechanisation and a basis for mechanisation planning. Studies of the relationship between effective kilowatts per hectare and average aggregate yields for major crops show that traditional smallholder systems have about 0.1 kW/ha. This reflects the observation that one man provides around 0.07 kW and that there are often one to two workers per hectare.

Considerable improvements in smallholder performance can be achieved mainly by the use of improved inputs (other than mechanisation) which increase yields per hectare, such as improved seed, fertiliser, pest controls, irrigation, and these can be facilitated by modest increases in power inputs. For instance, traditional cereal yields of say 0.8 t/ha can be increased to about 2.5 t/ha for an increase in power input of 0.3 kW/ha (Giles 1975).

In terms of power sources (table 1), a supplement of 0.3 kW/ha would require another four men per hectare using traditional hand methods. Alternatively, a pair of well fed 500 kg oxen can pull 10 — 20% of their weight and exert a draught force of about 100 kg, enough to plough one furrow to a reasonable depth. In the time available, a pair of oxen could work about three to four hectares. Tractors can pull approximately half their weight. A 3000 kg tractor with a pull of 1500 kg force can manage a three furrow plough. This means that a 50 kW tractor with about 25 kW at the drawbar could handle about 80 hectares per season. This aspect of Newtonian physics largely explains why small lightweight tractors, confounded by wheelslip, are often technically incapable of performing rudimentary cultivation work to an adequate standard.

In situations where energy is particularly limiting, traditional smallholder systems are seen to be relatively efficient. The small farmer consumes about 0.1 kW/ha of mainly renewable energy; the UK farmer about 1.7 kW/ha of mainly non-renewable energy. The energy conscious will point to an energy-out to energy-in ratio of 10.5 for cereals on the Nigerian smallholding and 2.4 for the UK farmer (Leach 1976). Food production, however, varies in the opposite direction, at 0.8 and 6 t/ha, respectively.

Work rate and capacity

Peak power requirements are more important than averages. The size and nature of the task and the time available will together determine peak power requirements. Where time is limiting, the rate of work of alternative systems of mechanisation as determined by their power characteristics, will be an important factor in selecting mechanisation.

Seed bed preparation is often a critical period. Depending on local conditions manual labour can do the job in 15 — 25 days per hectare (table 1). An ox team will take four to five days and a tractor about two hours of field time. Assuming a ten to fifteen day planting season these capacities accord with those based on power requirements. Where timeliness penalties are high, as for instance during the cross-over period between irrigation seasons, the provision of high powered, high output, albeit expensive forms of mechanisation could be justified. However, experience shows that the actual performance of tractor hire services, for instance, is much below theoretical capacity, due to management shortcomings and an environment that is often hostile to tractor use.

Reducing the peak on one task may serve no more than to transfer it to another. Weeding, particularly, is an operation that is often overlooked, in part, because it is more difficult to mechanise or schedule.

Table 1 Work potential of alternative farm power sources

		Man (1 man)	*Animal (1 pair of oxen)*	*Tractor (50kW 67hp)*
Weight	kg	55	750-1000	2500-3000
Pull	kgf	-	100	1500-2000
Speed	m/s (km/h)	-	1 (3.6)	1.7(6.1)
Power	kW(hp)	0.07 (0.09)	1 (1.3)	25-34 (35-46)
Power requirements for mouldboard ploughing	kg/cm²		0.7	0.7
Work capacity:				
implement size	cm, depth × width		10 × 14	20 × 100
work rate*	ha/h		0.04	0.45
work rate	h/ha	75-125	25	2.2
work day length	h	5	5-6	8-16
daily output	ha/day	0.07-0.04	0.20-0.24	3.6-7.2

* *assuming 70% field efficiency*

There are qualitative aspects to the power criteria. Maximum power ratings can only be achieved for about two hours and five hours for men and animals, respectively, whereas with proper maintenance engines will keep turning. Engine power is potentially also more adaptable and manageable.

As previously mentioned, there are opportunities for improving the productivity of existing power sources rather than switching to higher order ones. Introduction or modification of hand tools, such as rice planters and scythes, or the use of more advanced devices such as seeders, knapsack and ultra low volume sprayers are cases in point. The development of ox tool bars and attachments are other examples (ITDG).

Costs

Making a cost comparison of alternative mechanisation systems is difficult because, first, there may be qualitative differences in the task performed and, secondly, the definition of costs will vary according to the purpose of the analysis. On the latter issue, a basic distinction needs to be made between financial and economic costs. The mechanising farmer will be concerned with financial prices as these are what he pays for equipment or services in the market place. The government, however, will be more interested in economic prices which reflect the scarcity value, before taxes and subsidies, of the mechanisation inputs to the economy. A rational mechanisation policy would seek to bring the two price bases together.

An analysis of land preparation costs for smallholders in northern Nigeria, using government tractor hire services, hired or owned oxen and manual labour is contained in table 2. In financial terms, labour appears least expensive where there is family labour with nothing else to do. But hired labour can be expensive and scarce during busy periods. Here, as in many other places, government tractor services are heavily (80%) subsidized. Private contractors charge twice the price but still do not recover full costs. Generally, tractor services are limited in availability and mainly directed at the larger farmers. The costs of owned oxen vary, mainly with level of use and the cost of feeding. Actual oxen hire rates depend on whether farmers reciprocate other favours. Full ox hire rates are often high, reflecting a small work bull population and the high cost of maintenance. Full hire costs and the full cost of properly fed and equipped owned-oxen are usually very similar.

Table 2 Comparative land preparation costs, Northern Nigeria [N/ha (1978 prices)]

	Financial cost to the farmer	*Economic cost*[1]
Tractor	10[2] (45)[3]	58
Oxen	20-39[4]	20-29
Hand	0-30[5]	15-30

[1] *Adjusted to allow for taxes, subsidies, shadow prices of foreign exchange, fodder and labour.*
[2] *Subsidised hire rate.*
[3] *Full financial cost including administration.*
[4] *Hire or ownership costs, depending on feed costs.*
[5] *Depending whether unpaid family labour or hired labour.*

NI = S£0.8

Viewed in economic terms, adjusting for subsidies, taxes, shadow values of labour, fodder crops and foreign exchange, tractors appear most expensive and labour cheapest. During busy periods when labour is scarce, particularly on larger farms, the use of oxen power may become relatively attractive.

This order of ranking is common to most smallholder situations, although animal power tends to be less expensive where local conditions (particularly fodder availability) favour livestock. In Egypt for instance, with a heritage of working animals, land preparation costs in 1980 were LE 8.8/ha (about one-third of full cost) by the co-operative tractor, LE 12.5/ha by the private contractor, about LE 25/ha by oxen, and about LE 20/ha for hired labour (S£1 = LE 1.50). Private contractors were not fully recovering costs and the condition of their tractors reflected this. Understandable, the demand for tractor services exceeds availability.

This simplistic analysis can be misleading. For instance, costs per unit of work vary according to how intensively the animals or tractor are used throughout the year. Government tractors (noted for broken hour-clocks) often achieve only 500 hour per year. Private sector tractors often work more than 1,000 hours per year. Furthermore, there may be differential benefits between systems arising from more timely or more effective operations. With respect to the latter, however, in the context of mechanised cultivation, there is little evidence to show that tractor cultivation in itself provides long term yield improvements.

Where power is the constraint and cost per usable kilowatt is the criteria, there is little to beat the conventional tractor. Attempts to develop cost-effective small tractors bear witness to this (Morris and Pollard 1981).

Even where more mechanisation is deemed cost-effective and worthwhile for the private farmer, it may not be within his financing, cash flow capability. Mechanisation packages, on cash or credit, would need to be designed with this in mind.

Institutional support

Mechanisation, like any other input, requires institutional support in the form of input supply, credit, extension and training and adaptive research. Generally, the more capital intensive and the less indigenous the technology, the greater are the demands for support services. Improved hand powered systems are most easily supported. Establishing oxen programmes requires the provision of oxen, implements, medium term credit and veterinary, extension and training services (Mettrick 1977). Tractors, whether public or private sector, require the highest order of support services, particularly with respect to spare parts supply (Dalton 1976).

Given the complete absence or low level of institutional support in many smallholder situations, the most appropriate mechanisation system is that which is most reliable and self-sufficient.

The social and economic impact of mechanisation

The effect of mechanisation on labour employment and related issues such as rural income levels and distribution, is a hotly debated topic, supported by a weighty literature. Improving hand or expanding animal systems are generally considered to have a gentle and mainly beneficial effect on employment and other socio-economic parameters (Eicher *et al* 1970, Yudelman *et al* 1971, Mettrick *et al* 1976, Bartsch 1977).

The available evidence suggests that, where mechanisation facilitates an expansion in the cultivated area, an increase in cropping intensities, new crop mixtures and the use of other improved inputs, overall employment can be increased. In many smallholder situations operating at low power input levels, this is often the case (Roy and Blase 1978, Bala and Hussain 1978, El Hag 1975, Giles 1975, Clayton 1973, Yudelman *et al* 1971). After a certain point, however, further mechanisation begins to substitute for labour, particularly permanent hired labour. The big debate is primarily concerned with defining this point. Extensive tractorisation is usually associated with labour (and animal) displacement. Estimates for Latin America suggest that one tractor has replaced about five horses and 20 men (Abercrombie 1973). In parts of Pakistan, a tractor has been associated with the net loss of eight permanent jobs (McInerney and Donaldson 1975). The effect on labour employment has varied between type of worker; family and permanent hired labour inputs have tended to decrease whilst, in some cases, this has been partially offset by increases in casual labour requirements (Kahlon 1975, Singh and Gaswami 1977). Tractorisation may also have implications for agrarian structure, particularly farm size and tenure systems. A number of observers have pointed to increasing farm size and the dispossession of tenants to allow machine owners to achieve economies of scale (Yudelman *et al* 1971, McInerney and Donaldson 1975).

Where tractorisation projects have been subject to cost-benefit analysis, it is suggested that mechanisation is economically profitable to the nation as a whole and generally much more financially profitable to participant mechanising farmers (Era 1979, Dalton 1976, McInerney and Donaldson 1975, Gotsch 1975). Many studies, however, vacillate whether labour savings should be measured as an economic cost or benefit.

The long term social and economic implications depend on whether displaced farm labour can find gainful employment elsewhere. In many Third World economies this may not be possible.

The best system: mechanisation policy

The best course of farm mechanisation to follow depends on the objectives of agricultural development and the prevailing resource/constraint environment. Agricultural development strategies generally show a commitment to increasing production, rural incomes and employment opportunities. Given the nature of most developing economies and their smallholder sectors, the most appropriate system of mechanisation would be that based on a readily available, renewable and self-sufficient and therefore low cost power source. Unfortunately, price structures in many developing economies are often imperfect and do not necessarily lead to the best use of available resources. Farm power is no exception. For example, overvalued currencies, government subsidies to tractor manufacturers and users, duty free concessions to importers, cheap credit (particularly during times of inflation) and tax allowances on operating costs may encourage the adoption of imported capital intensive mechanisation projects which essentially substitute scarce and expensive capital for a plentiful and otherwise unemployed labour force. Labour, even where it attracts a barely subsistence wage rate is often overpriced in real economic terms which may further encourage wanton mechanisation.

Given the role of mechanisation in the process of getting agriculture moving and its important social ramifications, mechanisation policy becomes an important aspect of agricultural planning. In an attempt to remove smallholder power constraints but to avoid the wasteful and undesirable effects of overmechanisation, particularly labour displacement, many Governments have embarked on a programme of 'selective mechanisation'. This involves, by means of detailed farm management and agricultural engineering study, the identification of power peaks and the most appropriate, cost effective way of dealing with them. Whilst some cynics regard selective mechanisation as a conspiracy by engineers to do no more than placate welfare economists, proponents see that it provides a basis for a mechanisation strategy involving a technical, financial and economic assessment of the feasibility and the justification for mechanising particular operations in given farming systems (Stout and Downing 1975, Voss 1975).

For a given farming system, selective mechanisation would attempt to exploit the potential benefits of mechanisation as previously enumerated; opportunities for increasing the area cultivated, the timeliness of operations, cropping intensity (multi-cropping), the quality of work, and labour employment. Consequently, a selective mechanisation approach may incorporate all three technology types — for example, oxen for land preparation, manual harvesting, engine power for water-lifting or threshing.

In an attempt to achieve a rational approach to mechanisation, a number of developing countries have devised smallholder mechanisation strategies within the context of an overall development programme. For example, an ongoing US $40 million mechanisation project in Egypt (USAID, 1979) has the following components:

- research and development into farm power needs; inventory of existing machinery, adaption, improvement, development and testing,
- mechanisation planning and extension management,
- the provision of selected mechanisation services (manufacture, maintenance and repair, operations) through public sector or govenment assisted private sector operators,
- formulation of selected smallholder mechanisation 'packages',
- institutional support measures; pricing policies (taxes and subsidies), supply, credit, assistance to machine sharers, training and extension, demonstration, workshops.

Such a comprehensive and problem-oriented approach to mechanisation technology choice and policy making remains the exception rather than the rule. There are signs, however, of an improved rapport between engineers and economists, and a realisation on behalf of policy makers of the effect of mechanisation on the nature and rate of agricultural and rural development, such that mechanisation components will become a more important feature of future development projects.

Conclusions

At present levels of productivity, it is debatable whether the average smallholder should give priority to either yield increasing inputs, such as improved seeds and fertilisers, or to mechanisation. In practice, the two are often inseparable. The use of improved inputs provides the potential and justification for more farm power. Simultaneously, more farm power may be necessary before the potential of new yield improving inputs can be realised. It is difficult to give a general answer to the question 'Man, Animal or Engine?' In some situations, all three power sources may be appropriate. From a policy point of view, this requires a careful assessment of mechanisation needs, an appraisal of available technology and the formulation of policy measures which would encourage the development and selection of mechanisation appropriate to the predefined development objectives.

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Crop establishment: biological requirements and engineering solutions

Summary of a three-day conference

R W Radley

Introduction

A MEETING organised by the Association of Applied Biologists, Plant Physiology Group and the National College of Agricultural Engineering was held at the National College of Agricultural Engineering during the period 7-9 September to review the science, engineering and practice of crop establishment. Organisational support Institution of Agricultural Engineers and the Soil and Water Management Association. The programme was co-ordinated by Dr Mike Carr of the National College of Agricultural Engineering.

The meeting comprised twenty-one papers (see table 1), a poster session and an afternoon visit to the National Institute Agricultural Engineering to see aspects of their row crop, tillage engineering and transplanting work. About 130 people participated and the wide range of disciplines represented (plant physiology, soil science, agronomy, engineering), including participation by leading farmers, undoubtedly contributed to the usefulness of the meeting. Unfortunately, UK farm machinery manufacturers and distributors were thin on the ground — a stronger representation by companies with tillage, seed processing, seed sowing and related interests would most certainly have been welcomed by those who did attend.

The programme

DURING the course of the three days, almost all aspects of crop establishment received attention. The Association of Applied Biologists Presidential Address given by Professor J K A Bleasdale set the scene by discussing plant population and spatial distribution effects on growth, development and yield of crops. This subject featured in many of the subsequent papers.

The principal features, management and relative merits of three forms of planting material — dry seed, pre-germinated seeds (fluid drilling) and transplants — were explored for glasshouse and field crops along with a review of equipment for placing each of them into soil.

The time dimension of crop establishment was referred to in several of the contributions, especially in the context of manipulation of planting material to achieve earlier full ground cover by crop leaf canopies.

The soil physical and chemical factors impinging upon crop establishment were discussed at length. Also, the means by which acceptable soil environments might be obtained through appropriate tillage, use of agrochemicals, application of soil conditioners and irrigation.

The two final papers, in quite different ways, sought to bring together the biological, engineering and economic components of crop establishment with special reference to cereal crops.

Plant population considerations

The 'Parable of the Sower', St Luke, Chapter 8, was invoked to emphasise that it has long since been appreciated that good crop establishment is an essential pre-requisite of satisfactory yields. Whilst, in general terms, the relationship between plant population and yield is known for most crops, there were many

Table 1 A list of speakers and paper titles

	Speaker	Title of paper
	The seed and the soil	
1	J K A Bleasdale	The importance of crop establishment
2	T W Hegarty	The influence of environment on seed germination
3	J A Currie	The physical environment in the seedbed
4	G Spoor	Seedbed preparation
	Seedling establishment	
5	D A Perry	Factors influencing the establishment of cereal crops
6	R K Scott, M J Durrant and K W Jaggard	Meeting the challenge for sugar beet: magnitude and origin of the problem and possible solutions
7	D Patterson	The mechanisation of seed sowing — 1 cereals
8	L P Bufton	The mechanisation of seed sowing — 2 rowcrops
	Plant establishment	
9	P S Salter and R K Scott	Plant establishment: the role of transplanting
10	D Gray	The role of fluid drilling in plant establishment
11	W Boa	The development of transplanting systems
12	A J Prestt and M K V Carr	Development in soil management and planting techniques for potatoes
	Seedling protection	
13	A E Johnston	Nutrition of seedlings
14	J C Taylor	Disease, pest and weed control in the seedbed
15	R J Godwin	Mechanical methods of chemical application
16	M K V Carr	Irrigation, shelter and other ancillary aids to crop establishment
17	E R Page	overcoming capping problems
	Crop establishment in the farming system	
18	J M Lynch and L F Elliott	Crop residues
19	B D Soane, D S Campbell and J W Dickson	Avoiding compaction
20	B D Witney	Selection of tractor power and machinery systems for the production of spring cereals
21	R G Dawson	A systems approach: a case study

Bill Radley is Professor of Agricultural Production Technology at the National College of Agricultural Engineering. Permission from the Association of Applied Biologists to reproduce the summary of the conference is fully acknowledged and the complete proceedings of the conference will be published by Pitmans.

calls for better information on spatial distribution effects. In particular, what are the consequences for individual plants and whole crop communities of irregular distribution patterns and to what extent does the spread in time of seedling emergence exacerbate irregularity problems? This was acknowledged to be especially important for those crops where quality is a more crucial consideration than quantity. Thus, not only do engineers need advice from biologists concerning target populations for crops but much more quantitatively-based information about tolerances with respect to both population and spatial distribution. Precision can be achieved but only at a cost and it is the trade-off between these two which is of concern to those seeking to optimise establishment practices.

With a notable exception (sugar beet), very little appeared to be known about what farmers are actually achieving in terms of plant population. Year-in, year-out, what seedling populations are UK cereal, oilseed rape, field bean and pea growers attaining, what stem populations in potatoes and so forth? Further, if we are to learn lessons from recent sugar beet research, we should seek to determine the extent and causes of post-emergence plant death.

Time of establishment

Of the two key components of crop establishment, *viz,* plant population and time of sowing, the meeting tended to focus on the former — on the reasons why some seeds fail to germinate or germinate but fail to emerge, etc. However, reference to any planting date/crop yield response curve will reveal just how critical it is for farmers to avoid planting delays. Perhaps more time could have profitably been spent discussing alternative biological and engineering solutions to obtaining timely sowing for a greater proportion of the national crop. Given that there are a range of machinery and labour-machinery management options available to growers, each with their own cost and performance characteristics, it is an essential prerequisite that agronomists together with engineers develop the necessary data upon which decision-making can be based.

Whilst in the past we have quite rightly been preoccupied with the late sowing problem, it was apparent from a number of the papers that the means are steadily being developed whereby growers can get earlier sowing and emergence than hitherto, even in marginal weather circumstances. For spring-sown crops, these include better exploitation of natural weathering processes of autumn cultivated soil, methods of reducing the maximum ground pressure of vehicles by attention to tyres, direct drilling, fluid drilling and even a major change involving a switch from use of dry seed to transplants. For very early established crops, post-emergence growth checks were reported by some authors. The explanation for and consequences of these growth checks need further investigation including the interaction between time of establishment and plant population.

For many years the British Sugar Corporation has recognised the value of collecting comprehensive farm performance information with respect to all aspects of sugar beet production technology. They are thus in a position to combine these data with the results of field experiments to estimate such things as the annual loss of sugar yield attributable to poor plant stands and late drilling. This approach could most usefully be applied to the other major field crops in the UK.

Planting material

Planting material takes many forms but the meeting concentrated on dry seed, pre-germinated seed and transplants. At the next meeting of this kind, no doubt tissue culture will begin to take its place alongside the more conventional forms of planting material.

The information presented on the subject of seed vigour was especially useful. The last ten years has witnessed a rapid advance in our understanding of this phenomenon. We are learning more about how to recognise it, how to avoid poor seed vigour and how seed vigour and soil environment interact with one another. Seed vigour serves to emphasise that the crop establishment period starts with the harvesting of the previous seed crop in that seed vigour is largely dependent upon the weather circumstances at harvest, harvest method and the seed store environment.

The sowing of osmotically primed seed or pre-germinated seed (fluid drilling) has been a positive development from a number of standpoints — both in its own right as a technique but also because it has provided the stimulus for crop establishment research more generally. The problems which the technique still faces were referred to in the paper which dealt with this subject. We look forward to solutions emerging in the next few years.

The role of transplanting, the various approaches to the production of transplants, methods for successfully establishing them in soil and transplant biology excited considerable interest during the meeting. A whole range of problems were dealt with and whilst it is clear that we have answers to some, we still have big gaps in our knowledge. Engineering has a key part to play in reducing the costs of raising transplants and getting them into the field; better automated techniques are much needed. This will have a crucial bearing on whether the use of the transplanting technique will ever seriously challenge the use of seed in the sugar beet crop.

The soil environment

Given the different demands of crop species, of varieties within species, soil-to-soil variation and climatic variations, speakers generally counselled that it was not particularly helpful to seek to define the "ideal" soil environment for germinating seeds and transplants. Most preferred to address themselves to the problem from the other direction, *viz,* to establish what constitutes a hostile environment and how the most serious hostile elements might be overcome.

All of the major components of the soil environment were examined, including interactions between factors and the effects of fluctuating levels over time. Soil temperature, soil moisture, pore space and gaseous exchange between the seed, soil and air, mechanical impedance and capping, salt concentration in the liquid phase of soil, toxins from decaying crop residues, and soil-borne pests were all allocated time.

Tillage engineering

Many papers referred directly or indirectly to the ways in which the soil environment might be manipulated through engineering. A comprehensive review of tillage equipment was presented and the circumstances in which each category should be used to achieve defined end soil states were outlined. The origins, effects and avoidance of compaction rightly found a place in the programme.

As was the case for seed vigour (referred to earlier), the tillage question served to illustrate that, in thinking about crop establishment, we should look at problems in the context of an annual cycle of events, processes and operations, not just those few weeks surrounding seed sowing. As an example, what steps can be taken during the grain harvest with combines and grain trailers to reduce wheelings which can be expensive to remove and deleterious to establishment and growth in the following crop? In the same vein, the method of crop establishment in terms of row width, within-row spacing, degree of irregularity, the various flat/ridge/bed configurations all have a bearing upon the harvesting operation at the end of the season.

Establishment systems design

Most researchers and certainly most of those who participated in the meeting enjoy the luxury of being able to pursue in-depth studies into just one component of a much larger and more complex production system. But, it should never escape our attention that farmers have to establish crops to a specified population in fields and usually more than one crop species is involved. Establishment must be accomplished in a relatively short time period, when weather is variable and only predictable for a few days ahead. Given that the decisions the farmers take both before and during establishment will affect his profitability considerably, it is important that his planning is soundly based. So, to meet his needs what tractor-equipment combinations should he invest in? How many men and tractor units are needed? What day-to-day choices does he make in deployment of his resources and what compromise can he safely take?

One of the final papers sought to unravel this complex problem for one crop enterprise. Much more work is needed in this area with a view to coming forward with models which can be usefully applied to whole farm business planning. This is not something which can be left to agricultural economists, it needs the combined involvement of biologists, agricultural engineers, farm advisers and active participation by farmers themselves.

Arable work scheduling and projection: an adviser's method

F M Barrett

Summary

THIS paper describes an analogue modelling method called Field Work Planning (FWP) which has proved useful for studying the work capacity of worker/machinery teams on arable farms in the SE of the UK.

For this purpose, time is divided into 4-hour periods, each represented by a coloured magnetic symbol. Each month is represented by a calendar chart, pasted on a steel board.

The model is built up by placing the symbols on the charts so that each job is done in the correct time and order, and by a worker with suitable skill.

Interpretation of the model enables an adviser or a manager to make recommendations regard machinery capacity and farm policy.

The method was first devised as a precursor to developing a computer program, and this intention is being progressed.

1 Introduction

IT is normal for machinery advisers and consultants to advise on the suitability and work capacity of individual machines, but there are few established methods for studying the work capacity of a whole team of men and machines, performing a series of operations, over an extended period of time.

This paper describes just such a method, a manual one, for scheduling and predicting the progress of field work on arable farms in the UK, during the peak period July-October. It was devised, first, as a precursor to a computer program, but, while it still has that purpose, it has turned out to be a useful method in itself, and has demonstrated that a considerable demand exists for this style of advice.

This method, called Field Work Planning (FWP), does not include any financial considerations — merely the physical and time aspects of fulfilling a programme of work. Of course, financial matters must be considered, or at least borne in mind, but this has to be a separate exercise.

It is a simple, perhaps primitive, method using magnetic symbols to build an analogue model on a steel-backed chart. Each symbol represents a 4-hour period of work, in the field — called a "stint", for the purpose of this method. Since they are magnetic, the symbols can be moved about until a satisfactory schedule is achieved.

So far, about 30 cases have been done, mainly for large arable farms of 400-800 ha. Without exception, farmers and managers have found the exercise illuminating — indeed the response seems likely to overwhelm us.

The main use has been to predict the likely result of changes in farm policy and organisation, for example, changes in cropping, tillage practice, machinery and labour force. It has also been useful where farms are being amalgamated and has served to reassure, or forewarn, new managers who need to know whether they have enough capacity of machines and men, to fulfil their work programme.

With this magnetic symbol method, one has a useful visual aid which farmers can relate to and understand. But once a model has been built for a given set of information, it is very tedious to make alterations in the work capacity of machines, for example, to answer the question — what if we exchange our 75 kW tractor for a 100 kW? Variations will be much easier to make when our computer program is running but the output, in the form of a screen display or a print-out, may be less acceptable than the tangible coloured chart that we have at present.

2 The method

The model is built on a time chart set out as a calendar for each month, July-October. There are 12 lines, one for each worker, so each square on the chart represents a man-day — which is an opportunity to do work. The size and shape of the chart are governed by the steel boards which were readily available. These are shelves from office cupboards and they can be carried conveniently in a car, when going out to farms.

The coloured magnetic symbols, manufactured by the firm Sasco Ltd, are available in six colours and the 11 mm square shapes are the most convenient and economical. The following colour code is used to signify types of activity: orange — harvesting; blue — transport; green — tillage; yellow — drilling; red — spraying; pink — miscellaneous.

This colour code has been partly superseded by a system of alphabetic and numeric coding which will be more serviceable when the output is in the form of a one-colour screen display or print-out.

Wet weather is represented in a conventionalised way by marking every third week with black triangular symbols. Similarly, every fifth day is marked as being windy. This stylised pattern corresponds to average weather in SE England during those later summer months. One could of course, set the black triangles to represent the weather in a particular season — say 1981 when most farmers had difficulties.

A particular task, say, ploughing an area of land, and given the code number A24, is evaluated as follows: area, 100 ha; rate of work, 4.0 ha/stint; result, 25 stints are needed. So 25 green magnetic squares would be counted out and marked A24. The letter A refers to a particular area or block of land, and the number 24 is used to denote ploughing.

Every task that can be foreseen is evaluated in this way so that a total of several hundred symbols, or stints, is counted out and marked, representing the workload during the whole period.

Then comes the process of matching

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this workload with the opportunities, or man-days, on the time chart.

The coloured symbols, each representing a 4-hour stint, in the field, are generally placed on the chart at 2 per day. This 8 hours per day in the field would probably mean, on average, a 10-hour working day, what with servicing, hitching, travelling etc. Six such 2-stint days per week, a 60-hour working week, would be considered as moderate.

To allow for more over-time, a third symbol could be put on alternate days to indicate a working week of about 75 hours — heavy pressure if done for prolonged periods. A third symbol on all six days would mean severe pressure — 90 hours per week — which could not be kept up for many weeks without risk.

If, in matching the workload with the work opportunities, the total number of symbols can be placed on the board only by cramming them on at 3 per day over long periods, then the programme may be judged to be highly stressed and somewhat risky. Any small mishap, an injury, illness or mechanical break-down, could cause the programme to founder. Sometimes it is one particular person, the driver of the main tillage tractor, who is over-loaded with work — so the system is heavily reliant on him.

In order to allow a margin for contingencies, Sundays are left free of work on the chart although, in practice, if the weather is suitable and work is pressing, farmers would work and their staff would be keen on the overtime.

Of course, in reality, work is not done in neat 4-hour stints, particularly in difficult weather but building a model of any sort necessitates some distortion. To use 1-hour periods would have the same disadvantage, plus that of using a very large number of symbols.

3 Executing a case

It is possible to complete a case within a day — a fairly long working day of 10-12 hours, spent in the farm office. The work proceeds in stages, the first three being the collection of information from the farmer, using specially designed forms. Next follows the organisation of information and of the symbols, then, building the model.

Stage 1 in doing a case is to define the cropping because the workload during late summer and autumn consists of the transition from one year's crops to the next. Most farmers in UK do not follow a rigid rotation. Cropping is very flexible so there is a risk of omitting areas of work. This danger is avoided by setting out the crops for Year 1 and Year 2 in the form of a table (table 1).

It can be seen that the lines and columns (hectares) add up in both directions — and this is the check that nothing has been left out — though small errors can be tolerated.

Several of the numbers have an alphabetic character beside them — these are to label the particular blocks of land, or transitions. Block A, in this case, is 100 ha of rape which is to be harvested and then sown to winter wheat. The allocation of these letters will be different in each case, and indicates as far as possible, the order in which the work is to be started. Blocks may be one field or several fields. The 50 ha block of grass which is to remain in grass, has not been given a label — because no work will be done on it.

Table 1 Farm cropping plan with areas in hectares and labels to identify particular blocks of land.

Year 2 \ Year 1	GRASS	WHEAT	BARLEY	RAPE	ETC	TOTAL YEAR 2
GRASS	50		50 B			100
WHEAT	50 E	150 D		100 A		300
BARLEY		100 C				100
RAPE						—
etc						—
TOTAL Year 1	100	250	50	100	—	500

Block C is going to need more attention when the model is being built because it represents 100 ha of wheat which has to be harvested, possibly as late as early September, and which has to be drilled to winter barley, possibly as early as mid-September. So a whole sequence of operations may have to be done within 2 weeks.

Block A would be much easier, being harvested in late-July and drilled by mid-October. There will be much more opportunity for such jobs as sub-soiling and ploughing during this transition.

Each block, therefore, is a critical path and a Field Work Planning case is a complex Critical Path exercise in which several paths have to be integrated.

Stage 2 is to enter these blocks on a form which is a "menu" of operations from which one can choose the jobs to be done, to achieve the transition. This menu has been satisfactory for our purposes but, of course, different versions could be drawn up for other circumstances (Appendix 1).

Stage 3 is to ask about men and machines; men, so that work can be allocated to capable people; and machines, so that work rates can be discussed and agreed. Special forms are used for collecting this information, to ensure that no aspect is neglected.

Stage 4 is to take each block in turn, considering each operation, and putting values in terms of work rates. The result is that every job is evaluated in terms of the number of 4-hour stints needed to fulfil it. The total number of stints for all the operations on all the blocks is a measure of the total workload: On the work sheets used at this stage coloured adhesive symbols, similar to the magnetic ones, are used — so that the farmer has a key for reference purposes (Appendix 2).

In a typical case, which was for a 519 ha farm, the total number of stints was 574. This is quite a small number for such a large farm — but they have a simple tillage policy and most of the straw is burned.

Stage 5 is to count out the coloured magnetic symbols and mark them with the code number (eg A24) for each operation. Normally this would take about 1½ hours, and the farmer need not be present since the work is basically clerical.

Stage 6 is the creative stage when the model is built by placing the magnetic symbols on the board. It would normally occupy the greater part of the afternoon and the farmer would need to be present to advise on starting dates and to discuss variations.

To start with, symbols would be placed at 2 per day but as the board filled up, it may become necessary to close them up to 3 per day, in order to find enough places.

Eventually, if the workload is capable of being achieved, it will be possible to place all the symbols in such a way that all the dead-lines are met, all the work is done by the appropriate person and nobody is unreasonably stressed.

If it is not possible to build up a balanced work pattern, then that would be the basis of the mechanisation management advice, and one would have grounds to suggest modifications of machinery, work force and policy.

A false aspect of this model building method is that one can scan backwards and forwards across the time chart, foreseeing periods of wet weather and correcting previous errors, in a completely unrealistic way. But the result is that one can then advise changes which should prevent problems, if put into practice.

A computer program would proceed, one day at a time, making decisions and allocating work, just as a farmer would in real life. The effect of variations will be examined by repeatedly running the program, making one change at a time. For example it may indicate little benefit from buying a bigger tractor and that a bigger combine would be a better investment because it releases land faster for subsequent tillage operations.

Stage 7 is to make a copy of the finalised magnetic model, using adhesive symbols on a paper chart. Since each month is on a separate chart, several people can work independently, making these one-for-one copies sometimes the farmer's family will volunteer to help.

In most cases, it is possible to complete these 7 stages during one, long, working day but a few things still remain to be done. A consultant or adviser would normally want to write a letter stating the conclusions of the exercise. Also, the forms and work sheets should be photocopied so that both he and the farmer have copies for reference. Finally, the magnetic model would be dismantled and the symbols washed, dried and sorted ready for re-use.

4 Conclusions

Experience has shown this to be a workable method and readily accepted by farmers, so it is the intention to build on this encouraging response.

It has become clear that to do this kind of work, two things are needed: a method and data.* The magnetic board and symbols, described in this paper, provide an acceptable interim method but data on work rates is generally lacking. Within the agricultural professions generally, whether academic, practitioners, consultants or manufacturers, there is a surprising dearth of sound information on the capacity of machines. A programme for recording comparative data, on a long-term basis should be set up.

Though this 4-hour symbol method is workable for prediction purposes, it has difficulties if used for recording the progress of the season's work. If a farmer tries to build up the chart day by day, or even on a weekly basis, there will be problems because the work is done in odd times — not neat 4-hour stints.

Eventually, computer programs may be developed, for use by farmers, which would overcome this difficulty and, also, help him to decide which is the most advantageous work to do each day.

Appendix 1 Summary of cropping and operations

		CROP (HARVESTED)							
		Rape	Barley	Wheat	Wheat	Grass			
	ha	100	50	100	150	50			
		A	B	C	D	E	F	G	H
1 HARVESTING	SPRAY 10 desiccant etc			C10					
	MOW, SWATH windrow etc 11	A11							
	HARVEST, 12 forage, roots	A12	B12	C12	D12				
	CART, 13 produce of 12	A13	B13	C13	D13				
	HARVEST, 14 secondary, bale, save tops.		B14						
	CART, 15 produce of 14		B15						
	CHOP, 16 SPREAD, gather debris	A16							
	BURN 17	A17		C17	D17				
2 TILLAGE	SPRAY 20					E20			
	SLURRY/ 21 FYM								
	BREAK 22 STUBBLES								
	SUB-SOIL 23	A23				E23			
	PLOUGH 24	A24				E24			
	SECONDARY TILLAGE 25	A25		C25	D25	E25			
	FERTILIZER 26		B26		D26				
	SECONDARY TILLAGE 27	A27		C27	D27	E27			
	SECONDARY TILLAGE 28 or nominate								
	WORK 29 DOWN	A29		C29	D29	E29			
3 DRILLING	DRILL or 30 plant	A30		C30	D30	E30			
	ROLL 31			C31		E31			
	HARROW 32								
	SPRAY 33	A33			D33				
	34								
	CROP (SOWN)	Wheat	Grass	Barley	Wheat	Wheat			

Appendix 2 Calculation of total workload in the field in 4 hour stints

Coding	*Operation*	*Purpose or crop*	*Area*		*Work*		*Number of stints*	*Symbol and colour*
			hectares	*acres*	*ha/stint*	*ac/hr*		
C10	Spray	Pre-harvest desiccant	100		20		5	C10 red
C12	Combine	W wheat	100		5		20	C12 orange
C13	Corn cart						20	C13 blue
C17	Burn	Straw	100		10		10	C17 pink
C25	Disc x 2		200		12.5		16	C25 green
C27	Spring tine		100		10		10	C27 green
C29	Harrow		100		12.5		8	C29 green
C30	Drill	W barley	100		15		7	C30 yellow
C31	Roll		100		25		4	C31 green

Recirculation ventilation design for small rooms in pig production

J F Buckingham

Summary

THE use of small rooms to house farrowing and early weaned pigs requires accurate control of very low ventilation rates if suitable temperatures are to be maintained without excessive use of supplementary heating. Rooms housing pig liveweights of 9000kg or greater can be adequately ventilated by fans controlled in sequential steps. The control of ventilation rate by recirculation is an attractive solution for smaller rooms, although a single fan can only be used for rooms housing less than 6000kg.

Commercial recirculation units are relatively expensive and inflexible devices and fan speed control is the unsatisfactory alternative often adopted in practice.

A series of simple recirculation unit designs have been developed which can be built by local labour and which utilise readily available control components. The completed units can halve the cost of ventilation for a small room when compared to a commercial recirculation unit and yet have more sophisticated controls and can be specifically adapted for any application. One such unit, installed in a farrowing room, maintained temperatures within its control zone (17.8 — 21.0°C) during the winter of 1981/1982 using only a small amount of supplementary heating.

Introduction

THE importance of achieving suitable climatic environmental conditions for pig production is well understood and documented (Boon 1981, Bruce 1981, Holmes and Close 1977) but there is a lack of guidance concerning the selection of ventilation designs for specific applications. The variety of designs that exist in practice suggest that either there is little difference between the performance of different systems or that pig farmers are content to bear the burden of the resulting financial penalties.

The choice of design for the relatively large scale accommodation used for pregnant sows and growing and fattening pigs rests between the relative merits of automatically controlled natural ventilation and high speed jet forced ventilation. The trend towards small rooms for farrowing and weaning accommodation poses design problems which are too often solved by the excessive use of supplementary heating.

This article reviews the work carried out at the Edinburgh School of Agriculture on the design of recirculation ventilation systems for small rooms.

'Ventilation design' criteria

The essential criteria for ventilation design are the provision of enough fresh air to maintain a healthy atmosphere, sufficient ventilation rate control to maintain room temperature within the thermoneutral zone and the development of predictable airflow patterns. The success of any ventilation design must be judged upon its ability to satisfy these criteria over the range of prevalent weather conditions and the cost effectiveness of such control.

An examination of the basic design criteria for ventilation systems is necessary if they are to be successfully translated into practice. The definition of a minimum ventilation rate necessary to maintain a healthy atmosphere is clearly important. Randall (1977) quotes a figure of $0.53 \times 10^{-4} m^3 s^{-1}$ kg (liveweight) $^{-1}$ for all categories of pig production, however Bruce (1981) suggests that minimum ventilation rates should be based upon a design limit of 0.3% CO_2 and calculated using a bioclimatic analysis. In small rooms, it has proved difficult to achieve the low minimum ventilation rates suggested by either Bruce or Randall due to the combinations of unsuitable design, the influence of wind and adventitious air infiltration. In practice, design emphasis should be directed towards achieving very low ventilation rates. Although it is relatively simple to increase an insufficient minimum ventilation rate, it is very difficult to reduce an excessive minimum ventilation rate without major design changes.

Ventilation rate control is the medium through which temperature control can be achieved. The high sensitivity of house temperature to small changes in low ventilation rates has been demonstrated by Carpenter (1972). The success with which a ventilation system can control temperature cost-effectively is therefore highly dependent upon the capacity for accurate control of low ventilation rates. In small rooms, the importance of accurate ventilation rate control is intensified by the extremely low rates demanded and, in the case of weaning accommodation, by the wide range required.

The distribution of ventilating air determines the type and range of temperature profiles occurring within a room. The mode of air distribution determines not only the air temperature and air speed to which the pig is subjected but also acts as the link between the thermal performance of the room and the temperature sensor which effects control of the ventilation system. If stable airflow patterns can be achieved at any ventilation rate, the temperature sensor can be sited in the room as a matter of convenience rather than necessity. Predictable air distribution has other potential benefits such as the reduction of vertical temperature gradients and as a vehicle for supplementary heat distribution.

Definition of a small room

Two categories of a small room can be defined for the purpose of forced ventilation design, those which can be ventilated adequately by a single fan and those which require more than a single fan but less than the number necessary for sequential step control.

In practice, approximate limitations can reasonably be assumed to be imposed by the ventilation rates provided by a single 620 mm diameter fan (960 rev/min) and that provided by six 380 mm diameter fans (1400 rev/min). These limitations correspond to housed liveweights of about 6000 kg and 9000 kg, respectively, based upon Randall's (1977) recommendations of a maximum ventilation rate of ten times the minimum.

The control of ventilation rate by recirculation offers considerable advantages over other methods of forced ventilation rate control for a single fan and can therefore be recommended for housed liveweights of up to approximately 6000 kg. This includes most farrowing and early weaning accommodation and some dry sow accommodation. The selection of a forced ventilation system for a weight range between 6000 kg and 9000 kg is less straightforward and can be achieved by

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either multiple recirculation units or a combination of recirculation with step control of additional fans or step control of a combination of different diameter fans (Buckingham 1982).

Recirculation ventilation design

Recirculation is a well established ventilation design (Carpenter 1972, Owen 1978, Pringle 1981) which controls ventilation rate by regulating the proportion of fresh and stale room air passing through a fan (fig 1). The proportioning is usually achieved by a flap on the suction side of the fan which may be automatically controlled. Air distribution is achieved either through a perforated duct or from centralised air jets. An important feature of this type of recirculation design is that the air distributed throughout the room is a mixture of warm recirculated air and fresh air. The problems of avoiding cold draughts when introducing cold air directly into a room are therefore considerably alleviated.

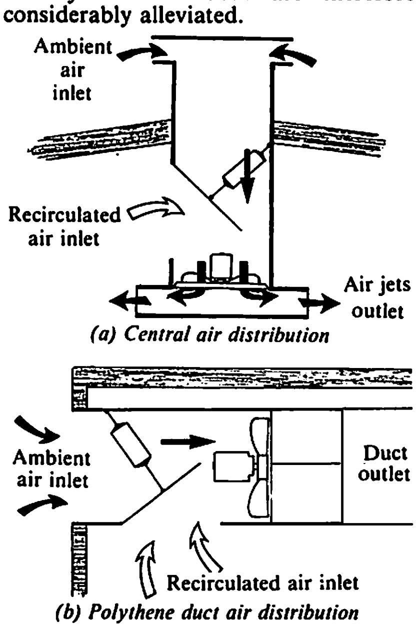


Fig 1 Recirculation designs

An additional advantage of recirculation is the use of a proportional mode of ventilation rate control which does not incur the disadvantages elaborated by Randall (1981) when applied to fan speed control. The flap position, as opposed to fan speed, can be regulated in proportion to a set room temperature. This mode of control even provides some inherent wind proofing as the area of the fresh air inlet is decreased as the ventilation rate is reduced.

Other benefits are that the velocity of the distributed air is approximately constant ensuring a consistent air flow pattern and the whole design can be incorporated into relatively compact units which have the potential of reduced installation costs. In practice, the relatively high cost of commercial recirculation units has deterred their widespread use, especially for the ventilation of a series of small rooms.

An effort has been made, therefore, to produce designs which are relatively cheap, which can be built by local labour and which utilise readily available control components, whilst retaining enough versatility to be adapted to the individual requirements of specific applications.

The design of a simple recirculation unit

Control modes

The use of a proportionally controlled actuating ram for the recirculation flap position is well established (Owen 1975). Using controllers from the air conditioning industry, a wide variety of control modes can be developed to suit the differing requirements of particular installations. The basic recirculation design uses a two stage control mechanism incorporating proportional control of the recirculation flap with the fan running at either full speed or a predetermined lower speed (fig 2). The fan speed is automatically switched at either end of the ram control zone, using a switched control mode set so that it overlaps either end of the proportional control band width. For example (with reference to fig 2), if the fan is running at low speed, the fan will be switched to full speed when the temperature increases to AB. The ventilation rate will then be controlled by the recirculation flap between C and D until the temperature falls to EF when the fan is switched to low speed. If the lower fan speed is selected so that the ventilation rate at AH is just greater than that at ED, the overlap will prevent any tendency to hunt between the two fan speeds.

The use of two fan speeds enables ventilation patterns to be established which are suitable for cold and hot weather conditions but which maintain ventilation rate control over the same temperature band width. The use of a lower fan speed should be treated with some caution as the risk of wind interference is greatly increased. With a fan running at low speed, a recirculation design is susceptible to wind interference (fig 3) due to pressure differences created between the fresh air inlet and recirculation inlet. The balanced flue and double acting flap design mentioned later may alleviate this problem.

Additional modes of control (fig 4) can be incorporated in the form of supplementary heating and extra fan capacity. Both are interlocked so that they are only brought into operation at the extreme ends of the proportional control zone with suitable temperature differentials. Both supplementary heating and extra fans can be sequentially stepped if required.

Recirculation flap design

The recirculation flap is of simple design, the flap itself being the full inside dimensions of the inlet duct. The flap pivot is connected to the actuating ram via a crank arm with an adjustable effective radius and a connecting rod of adjustable length (fig 5). This enables the minimum ventilation rate flap position to be completely adjustable for a constant ram extension. The establishment of a

Fig 3 Measured from air ventilation rate (static pressure is positive in the same sense as the fan pressure difference)

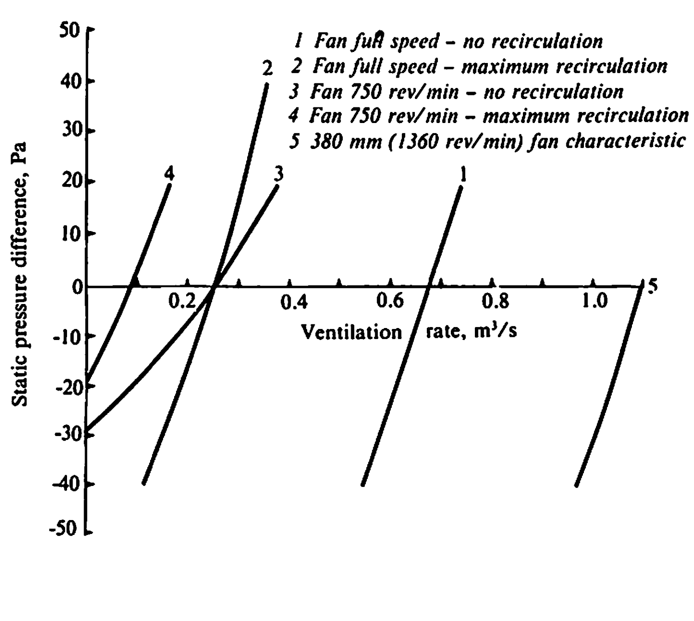
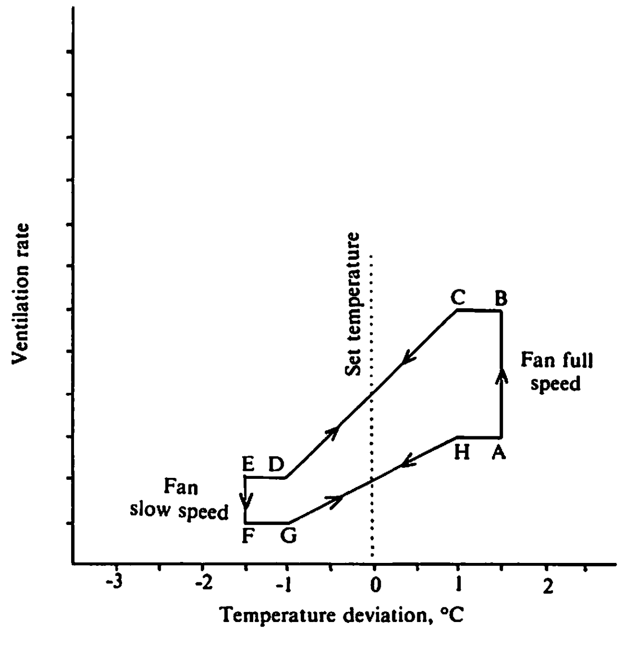


Fig 2 Two stage recirculation control



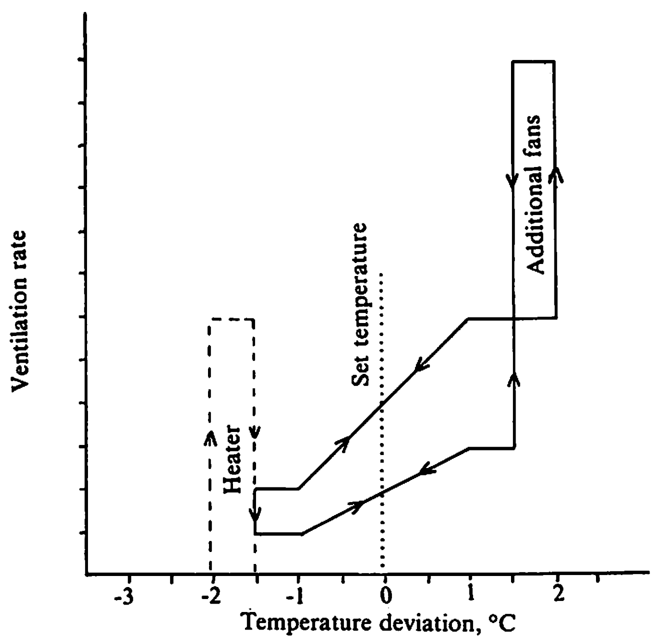


Fig 4 Recirculation control with heater interlock and additional fan

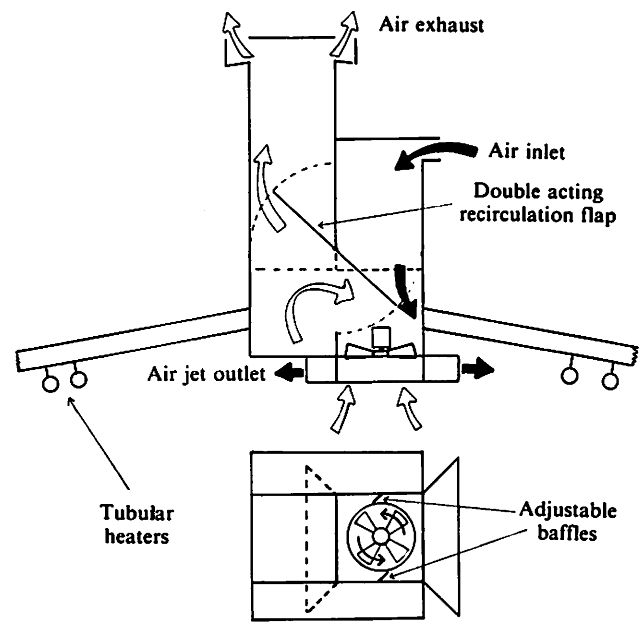


Fig 6 A simple design for a combined inlet/outlet recirculation unit

suitable minimum ventilation rate for any application is, necessarily, an empirical process and a simple method of adjustment is essential. Fig 3 provides some idea of the ratios between maximum and minimum ventilation rates that were achieved using one design with the flap set to sweep through a 45° arc.

The balanced flue concept (fig 6), reviewed by Pringle (1981), provides the opportunity for a double acting recirculation flap which should considerably reduce the effects of wind interference.

Air distribution

In general, air distribution from a central unit is preferable to that from a perforated duct as the constructional cost and effort is reduced and the overall design has less impact on other aspects of pig husbandry. Perforated ducts are required, however, if effective air distribution is to be achieved in long, narrow rooms. The design features of perforated polythene ducts have been comprehensively designed by Carpenter (1972, 1979).

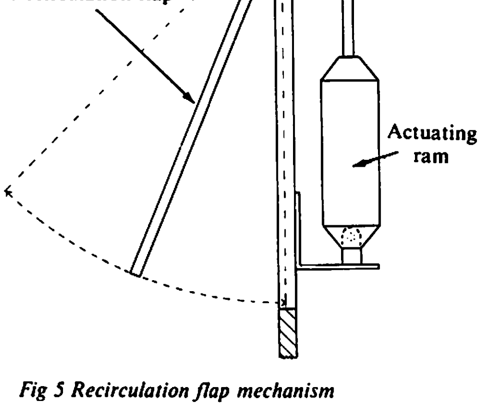


Fig 5 Recirculation flap mechanism

The important design features of a simple central distribution unit are the position of the fan, the area over which the air jet is distributed and the uniformity of air velocity within the jet. The internal static pressure differences created across the unit are relatively high, causing the air to be discharged radially from the fan blades. This effect can be effectively utilised by placing the fan at the bottom of the inlet duct (fig 6). A previous design using a higher fan position reduced airflow rates by approximately 30% of that obtained with the fan at the bottom of the duct.

The rotation of the air as it is discharged from the fan inevitably creates uneven air velocities across the width of the air jets. These can be effectively reduced by two small, adjustable baffles placed either side of the fan (fig 6) which counteract the effect of air rotation. Relatively even air distribution has been achieved using distribution units discharging air at 45° to the direction of the jet. The distribution units should be attached to the recirculation housing by toggle clips to allow easy access to the fan.

Controller and temperature sensor position

The controller may be mounted either on the recirculation unit or remotely, preferably outside the room to reduce cleaning problems. The temperature sensor can either be mounted in the recirculation duct or in the outlet of balanced flue designs. The airflow patterns produced by the recirculation designs give temperature profiles that can be related directly to the temperature sensor in either of these positions. If the sensor is mounted in the recirculation duct, a small amount of induced leakage will ensure that it is always ventilated.

Heating

Supplementary heating is often incorporated into recirculation designs but tend to add to the bulk and complexity of the units. An alternative approach (fig 6) is the use of independently mounted tubular heaters attached to the ceiling or wall in the path of the air jets. Both approaches ensure that heat is adequately distributed and prevent the occurrence of vertical temperature stratification.

Evaluation of a recirculation design performance

The performance of a central distribution recirculation unit with interlocked heater and a separate outlet installed in an eight sow farrowing room, was monitored during the winter of 1981/82, (Buckingham and Webster, 1982). Over a 30 day period, the room temperature was maintained within the control zone of 17.8°C-21.0°C. During this time the mean outside shade air temperature was 2°C with extremes of 14.0°C and - 3.7°C. The mean wind speed was 3.2 m/s with gusts of up to 16.9 m/s. An average of 160W supplementary heat usage was recorded in addition to the heat provided by the eight 275 W creep lamps. The total capacity of the supplementary heating was 3 kW and the electrical consumption for the 30 day period corresponded to a cost of £4.75.

It is difficult to make relative evaluations as there are few valid comparisons. Comparison with a theoretical prediction of supplementary heat usage, based on a steady state analysis, suggested that the average minimum ventilation rate achieved was approximately twice the design figure of $84.0 \times 10^{-3} m^3/s$. The 45° arc swept by the recirculation flap was not adjusted as spot measurements of ventilation rate carried out with the sealed unit suggested that adventitious air infiltration, under windy conditions, accounted for ventilation rates higher than the required minimum.

Temperatures recorded at pig level remained consistently within 1.0°C of the temperature recorded at the sensor which was situated in the recirculation duct. Measurements of humidity and gas concentration did not exceed the limits suggested by Bruce (1981).

Conclusions

The increasing use of relatively small rooms for farrowing and early weaning accommodation requires careful design of environmental control systems if suitable climatic conditions are to be provided economically. Recirculation control of ventilation rate satisfies the required design criteria but is relatively expensive. The costs of recirculation units can be considerably reduced by fabricating units based on simple design procedures which utilise readily available control components and which can be adapted to suit specific applications. The units are effective in providing close control of the climatic environment and the range of control options available is far wider than those provided by most commercial units. An additional advantage is the necessary involvement of the farmer in the specification and constructional organisation of each unit which generally leads to a very good understanding of the control procedures. Many good ventilation designs can fail simply due to a lack of understanding on the part of the farmer and stockman.

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Books

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Water engineering for agriculture

IT is pleasing to come across a text book which sets out details of the principles and practice of water engineering, for the benefit of the agricultural engineer. Agricultural engineers are likely to become more involved with good husbandry of water resources than they have previously.

Professor Waterhouse draws on some 20 years' experience as a civil engineer, working with consulting engineers, municipal authorities and overseas governments. In addition, the author has taught agricultural engineers at the National College of Agricultural Engineering and now he holds an appointment in Canada.

Individual chapters cover assessment of needs, engineering aspects of resource development, principles of hydraulics, open-channel and pipe-line calculations. Water quality and the planning of resource development are also fully discussed in separate chapters. The practical considerations regarding choice of water storage facilities and the development of ground water are particularly well described and annotated. It is only in the first chapter that I feel that there is rather less discussion than I might have expected, relating specifically to crop water requirements and water for livestock.

The description of hydraulic principles and examples of engineering computations are sufficiently comprehensive for agricultural engineering applications. There is an adequate number of worked examples to demonstrate application of equations and good use is made of illustrations throughout the text. The value of this book would have been enhanced if at least one further chapter had been devoted to pipelines and pumping plant. Details of pump sumps, pump mounting arrangements, pipe fittings and valves must be found from other text books. In the context of farm water supplies, the engineer needs an appreciation of the different approaches to controlling the automatic operation of pumps.

The final chapter includes an example of cost benefit analysis, through net present value calculations relating to the construction and operation of water supply works. The references for this material and most of the rest of the book are drawn from literature written predominantly for the civil engineering industry. Thus, much of it will be new to the agricultural engineer. Consequently, I would expect to find this book on the shelves of many of those with an involvement in field engineering.

Water Engineering for Agriculture by J Waterhouse. Batsford Academic and Educational Ltd, London. £17.95.

M E P

The 1982 George Bray Memorial Lecture

Application Technology and Agricultural Production

R F Norman

Summary

OVER the last two decades, the UK has significantly increased its production of temperate foodstuffs and, in particular, cereals to such an extent that it is now 70% self-sufficient. This has arisen from a number of factors, principally amongst them plant breeding and the application of pesticides.

Pesticidal application must be achieved during a very short period of time and in a manner which is effective in control of biological pests but at the same time does not impinge on the environment.

Traditional application methods of pesticides have been modified through the application of production engineering techniques to increase outputs under variable conditions. Developments of application techniques utilising spinning discs and electrostatics to increase output and effectiveness are proceeding.

Computer-based techniques enabling decision-making relating to choice of pesticide which ultimately will be linked to the application equipment are also discussed.

IN the UK, a relatively small proportion of the population (in the order of 2½%) is engaged in agriculture and the production of the temperate foodstuffs for the populus. By 1980, some 75% of the temperate food required was produced within this country, a dramatic increase from the 60% which was produced in 1960. The impact of this growth on the import bill has also been significant for imported foods which represented 30% of the import bill in 1960 had dropped to only 10% by 1980.

The available land on which to grow this food is a finite resource and the increase in food production represents a very significant development in productivity over two decades. This progress is frequently quoted as an example of what can be done within an industry where due attention is paid to all factors relating to production, especially in terms of output per man and per unit of capital. This progress has no doubt also been assisted by the relatively small size of the average production unit within the agricultural industry and the consequent excellent industrial relations which exist.

Basic production of food is, in many ways, a response to political decisions. Whilst all industry is influenced by such decisions, agriculture is subject to much greater influence since it is dependent upon politically decided price levels for its output. The political climate which has encouraged a rapid increase in agricultural production in the UK, is a reflection of the impact upon British agriculture of the UK's entry into the European Economic Community. The Community's agricultural policy (CAP), in its simplest form, encourages production through a system whereby the output of the majority of crops and their relevant products are guaranteed a minimum price level. The Intervention system which is, in effect, a safety net, provides a price level which is secured by budgetary mechanisms and can lead to the need to export excess production at prices below those paid to the original producer. This movement of the surplus production is, in many ways, at the centre of the CAP budget problem.

Within the UK, this development of agricultural production has been centred on the cereal crop. It has created a position where the area under cereals is now at one of the highest levels ever. A high proportion of this area is in winter crops, that is to say crops sown in the autumn and harvested in the succeeding summer. The development of such high levels of cereal growing has been at the expense of other crops. Consequently, traditional rotations have been abandoned and, in many areas, continuous cereal growing is now common. The consequence of cereal crop following cereal crop is to create, amongst other things, conditions under which weeds, diseases and pests can flourish unless timely application of appropriate control systems are applied. The increase in cereal area has also been accompanied by substantial increases in the yields of all cereals. For instance, in the case of winter wheat, average yields in 1960 were 3.5 t/ha and this has increased to 5.88 t/ha in 1980.

Such substantial yield increases have occurred at a time when cereal production has been extended on to land which is not ideally suited for the crop. The effective increase is, therefore, greater than the figures may at first suggest.

Many factors have contributed to these developments but the most significant are undoubtedly plant breeding and the provision of effective agrochemicals.

The search for new varieties capable of much higher yields than the traditional varieties, was given a substantial spur by the Plant Varieties and Seeds Act, 1964. This provided the plant breeder with what is, in effect, the same protection for his invention, ie a new variety, as the more traditional inventor had enjoyed through patent protection over the centuries. The end result has been the introduction of a very large number of extremely successful varieties of cereals.

Again taking the case of winter wheat, there are over 30 varieties available for sowing this autumn which compares with a mere handful in 1962.

Almost all of these varieties have been introduced in the last 10 years and it is very doubtful if any of those being sown this autumn will be of any significance in 10 years time. This rapid change of variety is clearly a challenge to the management of the cereal crop and also the agrochemical industry, for different varieties perform differently in relation to specific pesticides.

The development of agrochemicals to meet changing weed, disease and insect problems has also been a feature of the last two decades. The industry itself in its present form is relatively new, but the control of pests, whatever their form, has been a problem to man as long as he has existed. The higher the input of capital, manpower and cash into the production of a crop, the greater is the need to protect that input through the use of appropriate pesticides. It must be emphasised that this protection with pesticides does not increase the yield of a crop beyond that which is inherent in the

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Permission to reproduce The 1982 George Bray Memorial Lecture which was presented to the Institution of Production Engineers on 29 September is fully acknowledged. Reg Norman is managing director of Ciba Geigy Agrochemicals and is also Immediate Past President of IAgrE.

genetic make-up of the crop and the availability of nutrients, water and energy.

Agrochemicals take many forms but, in essence, are a means of protecting the crop from the deprivations of weed, pest and disease. For example, in the case of a weedkiller, the objective is to remove either a broadleaved weed such as poppy or a grass weed from within the cereal. It will be obvious that the removal of a grass weed from within a grass crop, ie cereals, is an extremely complex operation combining both the selective property of an appropriate chemical with an application technique that enables the pesticide to be applied to the offending weed.

The protection of the cereal crop against the ravages of pest, weed and disease has to take place throughout the whole period of the crop's life. Thus, the application of the material may have to be directed at bare soil for the control of weeds, at a very early stage in the crop's growth for protection against insects, or even at the fully mature stage when the ear is to be protected against insect or fungal attack.

Thus, the application of the pesticide is aimed at a target that is constantly changing. It is also a target which has to be reached over a very wide period of time. The earliest application may be required in September and the last in the following July.

It will be very apparent that during this period a wide range of weather and ground conditions can be experienced and these will have a significant effect on the ability to treat the crop with the appropriate material. In most cases, there is a relatively narrow band of time usually linked to the crop growth stage over which the chemical will be truly effective. Applied too early, there will be no effect; too late the damage has been done and although some cure may be effected, it is unlikely that the true return from the investment can be achieved. The available periods for treatment may be as short as a few days and rarely extend beyond a week.

This requirement for treatment in a short period has to be compared with the time when conditions are suitable to treat the crop, time which is dependent upon weather conditions and more specifically wind speed and rainfall. Analysis of weather records show that, with conventional agricultural equipment, the number of days on which spraying can be carried out average 4 in March; 5 — 7 in April; 5 — 10 in October. It will be apparent that this lack of time in which to carry out the operation which is critical to the satisfactory economic return of the crop, places a great pressure on the farmer to achieve rapid treatment of the crop when weather conditions permit.

The application of a pesticide to a crop requires that the active chemical substance be applied to the crop in a way that ensures uniform coverage of the target. The target may be the crop itself, for example when a fungicide is being applied for disease control, or it may be the weeds within a crop when selective removal of the weeds is the objective. Whatever the target, the amount of active chemical required to achieve the desired result is usually relatively small in terms of amount per hectare of crop or land treated. For example, the selective residual weedkiller chlortoluron (DICURANE) is applied at 3.5kg/ha (0.35g/m^2) whereas some highly active pyrethroids may be used as low as 10g/ha.

The distribution of this small quantity of active ingredient is normally achieved by diluting the formulated product with water and applying the resultant diluted substance to the target area. In order to achieve the desired cover, this material is usually applied as droplets of a size that will reach and stick on the target. As a general rule, such droplets are produced by forcing the liquid through hydraulic nozzles of either the flat fan or hollow cone type. Other mechanisms for droplet production such as spinning discs, cages or brushes can be used and are currently being more widely accepted but the majority of application equipment remains based on hydraulic nozzles.

When the correct conditions for treatment of the crop occur, the farmer requires to achieve a very high output in the limited period available and consequently is looking for means of achieving this goal. In particular, it has to be recognised that it is rare in the application of pesticides to be able to repeat the process and errors which may be made at the time of treating the crop remain until the end of that production cycle, usually the harvest of the crop.

In many ways, the problem facing the farmer is typical of that facing the production engineer: but there is the added problem that the working area is extremely variable in terms of working conditions. Nevertheless, the underlying problem remains the same viz how to maximise output, minimise down time and eliminate scrap. The major factors affecting output are:—

— speed over ground
— width treated in any one pass over field
— unit area treated per fill of equipment
— down time

As in any engineering operation, these factors are subject to physical limitations that have to be recognised and taken into account in developing the target outputs and, in particular, in analysing the means of maximising useful production.

Increased speed is the rather obvious means of achieving higher output; but in agricultural activities, there is a significant limitation to the rate at which vehicles can travel over land due to the nature of the surface. With normal agricultural tractors this is usually in the order of 6 — 10km/h. A second problem arises in the case of application of pesticides since the nozzles must be maintained at a uniform height from the ground. As the width of the spray boom increases, so the difficulty of maintaining uniformity in distance between crop and nozzle increases. Problems arise due to vibration and boom bounce which affects not only the accuracy of application, but can be a significant factor in down time due to boom breakage.

The problem of boom bounce is coupled not only to speed but also to width and hence the possibility of increasing the area treated in any one pass is significantly limited by this factor. In addition, it is limited by the ability of the operator to match up adjoining treated areas. Failure to achieve accurate matching will result in either untreated areas with subsequent reinfestation or overlapping which is costly in terms of chemical and, under certain circumstances, can create damage to the crop.

The problem of matching adjacent bouts applies not only to spraying activities but also to other operations. Generally, experiments with electronic systems have been less than satisfactory. Farmers have now turned to the so-called practice of tramlines which is a system whereby the crop is marked out at the time of sowing by leaving rows unsown along which the tractors are driven for all subsequent operations. Provided such marks are put in accurately at the time of sowing, correct treatment of the crop is assured.

Since these two factors of speed and width of pass are constrained even with specialist equipment such as low ground pressure vehicles, attention has been directed to the other major target for improvement in output viz increasing the output per vehicle load of the diluted chemical. Traditionally, chemicals have been applied in the order of 200 l/ha. This traditional volume has many advantages in that nozzle orifices are moderately large, filtration is therefore easily achieved and generally the likelihood of nozzle blockage through poor water supply is remote. Reducing volumes clearly increases the problems of filtration and requires the provision of high quality formulations of pesticides which will not cause problems in the small orifices which are essential for low volume rates.

Given that the application of a pesticide at a lower volume is acceptable, then the question arises as to what is the ideal volume. It can be argued that there is no ideal volume and that the objective must be to reduce the volume applied to as low a level as can be handled efficiently by equipment in the hands of the normal agricultural operator. Even relatively small reductions in volume eg from the traditional 200 to 100 l/ha will double the output and, more significantly, eliminate one of the stops for refilling.

The development of the most efficient level of application has been the subject of considerable study mainly through computer simulation at the National Institute of Agricultural Engineering. These have shown that, whilst very low volumes can increase the output significantly, there is little point in going below around 50 l/ha since at this level, the output per unit load fits well with the traditional period of working and gives a reasonable number of stops per day for the operator to take food etc.

Thus, one of the main objectives of eliminating down time can be achieved by reducing the volume of application. Down time can be further minimised by ensuring that the supply of chemicals to the application unit in the field minimises the time taken to refill between tank loads.

The gain in output as a result of these developments brings with it some risk. There is the obvious problem at lower volumes of dilution that there is a higher concentration of chemical. Under certain circumstances, this can lead to pipe blockage and inefficient application. This can be overcome by effective maintenance of the equipment but here again, the complications of maintenance in the field as against the shop floor, create additional problems.

Another risk relates to the potential problem arising from the higher concentration of the chemical in droplets which, if they drift outside the target crop area, may cause damage to other crops or provide a hazard to the environment and perhaps even man himself. For this reason, it is a requirement that any change in application technique is subject to formal clearance through the Government's independent scheme for the clearance of pesticides known as the Pesticides Safety Precaution Scheme. All materials sold in the UK have to be cleared through the Scheme but it is often not adequately recognised that change in application method requires further clearance even though the original chemical has been on the market for use through traditional systems.

The approach to the application process outlined is aimed, essentially, at improving the output per unit time using the accepted mechanisms that are common practice on the farm. But these techniques still rely on the ability of the operator to maintain a constant forward speed under varying ground conditions and assume that the variation in application of the chemical is acceptable in terms of its safety to the crop and efficiency in use.

In production engineering, it has been common practice to effectively "design out" the impact of the operator wherever this can be economically achieved and show an improvement in efficiency. Such an approach in application of pesticides would require the provision of a device that will measure the speed of the tractor and adjust the chemical application rate in accordance with that speed.

Speed measuring devices based on radar are now readily available. Attempts have been made to integrate these devices with a computer controlled hydraulic pump to adjust the chemical dosage. The use of such devices faces major problems in that they are subject to considerable vibration and have to operate under very adverse weather conditions. They also require to react to small differences in speed which, in turn, have to be reflected in changes in flow rate.

There can be little doubt that, in the long term, these devices will be developed but currently the efficiency required creates a much higher cost than the process can afford.

The application of such devices to the existing application system makes the assumption that the present method by which the farmer chooses the pesticide and applies it to the crop is appropriate. It may well be the best in today's circumstances but for the future, it would seem appropriate to explore a fundamental change in the approach to pesticide application including both the choice of the chemical and its usage in the field.

The first problem facing the farmer is the choice of the most appropriate chemical and associated application technique that will provide the most economic return for the investment he makes. There are already computer programmes which enable the economics of alternative chemical choices to be analysed, eg (Ciba-Geigy's Sprayplan). Currently these are usually on stand-alone computers but it seems reasonable to predict that the time is not far distant when farms will have access to such programmes on line through Prestel or similar. Once the choice of chemical has been made, then this can be matched to the application system which the farmer has available. The application system would consist of equipment that is computer controlled relating the chemical, the speed of application and the dilution rate to the requirements of the particular problem in hand. Then the operator would choose the chemical, possibly in a coded container, which would only be accepted by the computer provided the code matched the programme that was present in the machine. The operator, having placed the programme into the machine, would be faced simply with the necessity to drive accurately but all other factors would be dealt with by the computer.

Such a system, of necessity, would have to have an over-ride built into it for there will be times when a machine would reject application as being unacceptable but where the farmer might have to carry out the operation or miss the opportunity to treat the crop, even though such treatment may not be ideal in terms of timing or other factor.

The development of more sophisticated application equipment along the lines indicated would also provide a means of more effective utilising very low volume methods of application. In particular, it would permit the further development of the electrostatic charging of droplets which have much to commend them for application, especially for insect control.

No matter what application technique may be developed, the requirement is essentially the same as that facing any production engineer, viz efficient operation at minimum cost and maximum output. However, there is one further factor impinging on the pesticide application process that will be apparent viz that the use of pesticides has a potential impact on man's environment. This requires that, whatever the process, it shall ensure that the optimum quantity of material is applied to the target area and there is a minimum impact on any other related area. Whilst this is a particular aspect of pesticide application, it is no more than the same problem which is applicable to every tool available to man for the production of his foodstuffs.

The more traditional tools of fire and axe have an equal impact on the environment. Indeed, some might say more. As with the traditional tools, so with pesticides. They can be misused and it is an essential part of the development of any technology relating to pesticide application that the appropriate balance between risk and benefit to man is maintained. Pesticides are an essential part of food production and their application is but another factor in the general management of land by man for his own needs. The application of analytical, production engineering, type techniques has provided means of ensuring improvements in the rate and accuracy of pesticide application. There is reason to expect that this development will continue provided always that the technology as a whole is not subject to excessive political interference and unrealistic environmental pressure.

It is perhaps appropriate to close with a quotation from Swift

"He who can make two blades of grass where but one grew before, will make more contribution to man than all the politicians throughout the world".

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The integrated pest management issue
Plant protection in modern agriculture

Correction

In the reporting of the conference discussion on the *Engineering Developments for the Drying, Storage and Handling of Materials*, the answer to Mr Langley is incorrectly printed in respect of gas consumption. It should be 200 tonnes of grain dried per tonne of gas with a five per cent moisture content reduction *not* 1200 tonnes.