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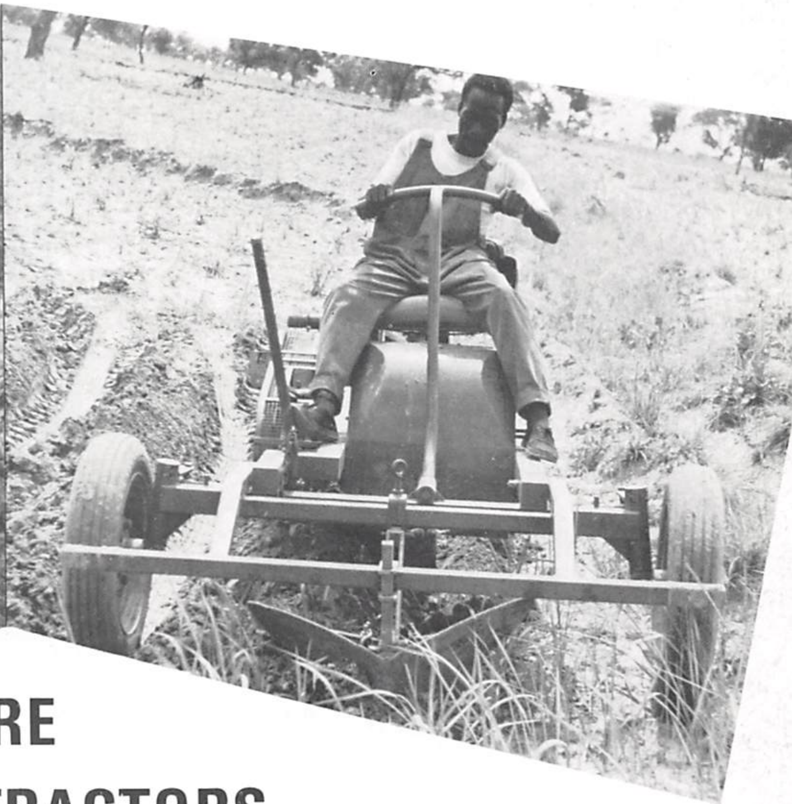
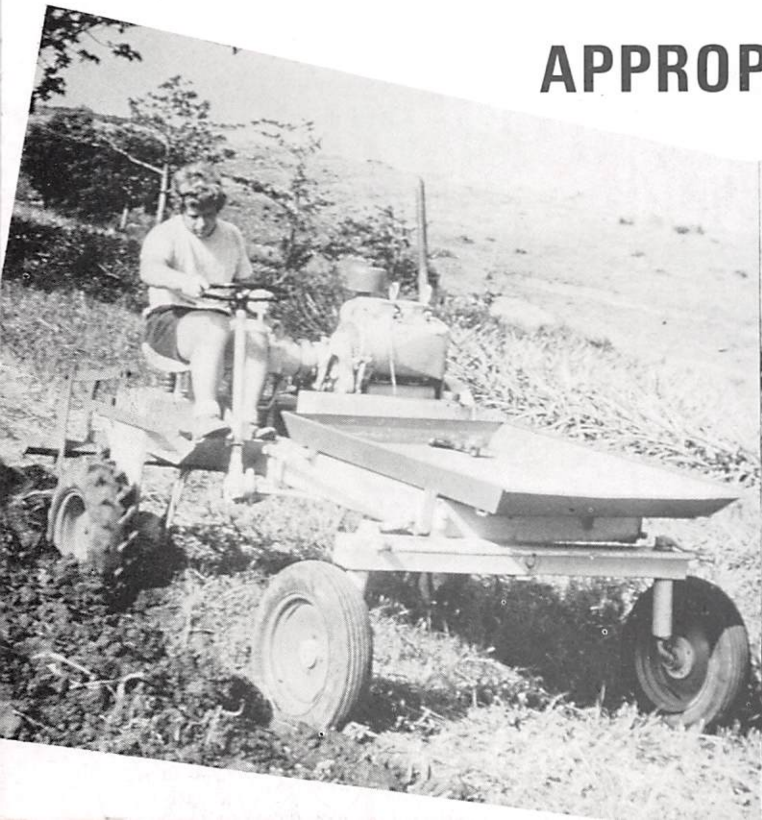
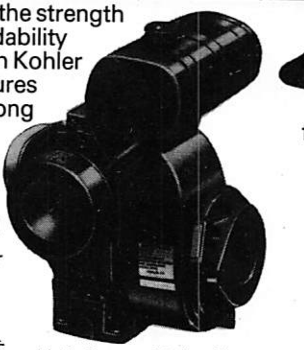
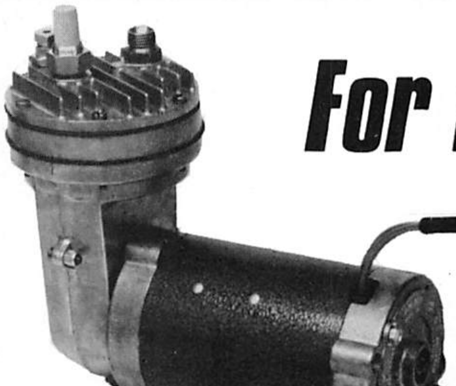


ARE SMALL TRACTORS APPROPRIATE ?







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Front cover: Top left - Amex; top right - Monowheel; bottom left - Tinkabi; bottom right - Kabanyolo small tractors.

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Institution of agricultural engineers

Fortieth anniversary

ON Wednesday 8 March 1978, to mark the fortieth anniversary of the Institution, Sir Peter Vanneck, Lord Mayor of London, delivered the second Douglas Bomford Memorial Lecture at the Mansion House. His title was –

British agricultural engineering – a service to the world

In welcoming the audience of 250 to the Mansion House, Sir Peter, who is a Member of the Institution, reminded them that the majority of the world's population spends most of its working hours meeting the simple needs for nourishment. In Western Europe, on the other hand, the emphasis was upon raising the output from our farms largely by the application of agricultural mechanisation. In certain areas of the world, where the total available area of land for cultivation was now exhausted, technology was being used to increase not only the yield per crop but also the number of crops per year.

What then was the role for Britain and its heritage of innovation in agricultural engineering?

Over the years Britain had built a manufacturing industry which was the largest supplier of agricultural tractors across the world. In 1977, agricultural engineering output totalled £1 220M and provided a net balance of payments surplus of £627M from tractors, engines and accessories, together with £35M from implements and machinery. The emphasis upon exports often gave rise to the problem of meeting the legal requirements of world markets – this was frequently an expensive task for manufacturers, there being little harmonisation of regulations concerning, for example, safety aspects such as guards, lighting, braking and noise. Many sections of industry had been assisted by the Technical Help to Exporters Scheme since its foundation in 1966. This unit of the British Standards Institution was now rapidly developing a service to assist manufacturers of agricultural equipment.

A major and beneficial legacy of the Englishmans' conquering zeal was the popularity of his language. One consequence was that students seeking further training abroad had been predisposed to choose Britain, whose language was perhaps a factor in the unification of disparate elements of their own countries. Since the inception in 1947 of the first agricultural engineering course of its kind in Europe, Kings College, Durham University, and its more recent incarnation, Newcastle University, had awarded 100 Master of Science degrees in agricultural engineering to students from 35 countries. More recently 15 overseas students had obtained the new degree in Agricultural Engineering and Mechanisation.

Since the early 60's, the National College of Agricultural Engineering had awarded 135 degrees and 273 diplomas to students from 72 overseas countries. It was to the great credit of the Institution of Agricultural Engineers and to the manufacturing and service industries, said Sir Peter, that they were instrumental in the creation of the College.

The valuable National Diploma courses ensured exposure to the operation and maintenance of real equipment and provided perhaps more suitable training than degree courses for students from many parts of the world.

In the field of manufacture, many private British companies developed machines specifically for overseas use. Topically, at least one company was developing a mechanisation system for cassava. There had also been a particularly noticeable increase in the number of enterprising companies undertaking consultancy contracts for overseas governments.

There was a major role for British agricultural engineers in advisory work through the Food and Agriculture Organisation of the United Nations; our own Overseas Development Ministry with its Land Resources Division was over 100 strong. Projects included the improvement of primary resources and food production for internal consumption as well as for sale abroad.

Most agricultural engineers now worked in multi-disciplinary teams, alongside soil scientists, plant and animal scientists, economists and marketing specialists. It happened that the pervasive influence of mechanisation, in physical, financial and sociological terms, suited engineers as leaders of projects. They were by nature and training concerned with making judgements, mostly involving innovative situations. An important activity of the Institution of Agricultural Engineers was, therefore, provision of multi-disciplinary exchange of information. About 25% of its members worked overseas.

An important aspect in UK agricultural engineering research at the present time was the provision of tools and facilities for the farmer to achieve timeliness in his operations. Timeliness was also vital in developing countries and the agricultural engineer had a major contribution to make in this direction.

Perhaps, however, the greatest challenge of the last quarter of the twentieth century would be that of finding a way beyond the availability of fossil fuel reserves. The solution would need to be one which could be adopted by the Third World – otherwise, peoples in these lands would discover that they had been led into a commitment to technology but that the hope of paradise was illusory.

We had always been a trading nation and we may always need to import food to live as we would wish. In return, our agricultural engineering industry had much to offer the world from its skill and expertise. Long may it prosper!

The Douglas Bomford second memorial lecture

THERE is insufficient space in this issue of the Journal to publish the full version of the Lord Mayor of London's presentation at the 40th Anniversary meeting of the Institution.

Copies can be obtained from the Institution Secretariat, on payment of cash with order:–

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Engineering for food production in developing countries — are small tractors appropriate?

J Kilgour

MORE than 200 delegates, some from the developing countries, attended the Spring National Conference of the Institution at the National College of Agricultural Engineering, Silsoe, on 21 March.

It has long been assumed by some enthusiasts that the small farmer in a developing country can escape from the vicious circle of low production and low income by simply purchasing a small tractor. In the past, many people spent a lot of time and effort in designing a "suitable" tractor, but after many years and many designs the small tractor has not been widely adopted in developing countries.

The purpose of the conference was to provide an opportunity for those experienced in the field to discuss the various aspects of small tractors, to try to pin-point the reasons for the lack of acceptance and to attempt to make recommendations for future work in this area.

In order to bring out the most relevant points, the papers were divided into three sessions. The first, chaired by Prof B A May, head of NCAE, was concerned with the economic and design theory of small tractors. The second, chaired by Mr Uzureau, acting director of CEEMAT in France, was a case study of a number of small tractors which are in various stages of development and which have been specifically designed for use in developing countries. The final session, chaired by Dr H von Hulst, chief of agricultural Engineering Services, FAO, was a discussion forum aimed at answering the question "Are small tractors appropriate?"

The series of papers in session 1 began by reviewing the philosophy of small tractor development. In many cases the design of these devices had taken place in isolation, whereas a multi-disciplinary approach was the ideal. Social, economic, political and cultural considerations must not be forgotten and each country or region, in which small tractor development is planned, must be examined in detail.

The various theoretical design features were pointed out and the necessary characteristics of both the tractor and its back-up services discussed. The Mexican approach to assessing the need for, and the design requirements of, a small tractor were taken as a case in point.

Operational aspects of tractor use were covered in a paper which described a method of calculating costs, based upon the application of appropriate factors to the well-established techniques used in developed countries.

In session 2 the case histories ranged from conventional tractors of European design, typified by the Deutz, to purpose made units built in the developing countries. A conventional tractor required an engine of power more than 30 kW to operate satisfactorily in hard tropical soils.

The Tinkabi system had been designed specifically for certain conditions and, with more than 400 tractors in the field, was showing the acceptance of this particular solution. The more conventional Bouyer tractor was a basic and strong standard vehicle, the smaller sizes being capable of using existing and accepted animal drawn equipment. Although small in size, the Japanese tractor was designed specifically for use in wet paddy rice production and was less suitable for dryland farming. The first prototype of the Amex tractor was also described and is due to be field tested later this year.

In the lively discussion session, the need was emphasised for careful study of a particular agricultural and national situation before any form of mechanisation, particularly small tractors, should be considered.

The conclusions reached by the conference were less than unanimous, but perhaps the general feeling could be expressed as follows. The small tractor can only satisfy the needs of a relatively small number of farms in developing countries. Its introduction may be politically desirable in some circumstances, but unless a total infrastructure is developed, the isolated introduction of the tractor is certain to fail. Each situation must be studied on its merits to discover if the particular circumstances may indicate that a small tractor could become part of the overall development. In many cases there may be a sufficiently large market to enable a manufacturer to obtain a reasonable return on his production investment. What is clear from the discussion is that much more information is required before any investment programme in small tractors is undertaken.

Footnote

This was the first of a series of conferences, pertaining to developing countries, which is planned by the Institution.

Economic aspects of the introduction of small tractors in developing countries - Towards a philosophy for small tractor development

S Pollard and J Morris

THE FAO definition of farm mechanisation encompasses all sources of power: man, animal and motorised, and considers all stages and processes of sophistication in the development and use of machinery and equipment. Mechanisation is seen in the context of a possible support to agricultural production and improvement.

What do we mean by the term appropriate?

It is now largely agreed that the new and improved soft and hard technologies to be adopted by the LDC's must be both appropriate and acceptable. That is not only in terms of operational and technical suitability but also with particular regard to the recipient socio-economic environment, and the resources and aspirations of its members. Defining the latter is of course hazardous. Machine design and development may itself approach a fairly rigid and well practiced science in terms of producing a machine to do the job. However defining the social, political, psychological, economic and cultural environment in which the machine needs to make a contribution, and thereby defining the job that needs doing and the possible ways of doing it, does not lend itself to fine calibration. This environment is ever changing, comprises many apparent anomalies and actual conflicts, and is subject to many and varied interpretations according to the spectacles of those who care to comment on it. To make a contribution, mechanisation, and in this case the small tractor, must meet the needs of those who use it. Mechanisation policy, and more specifically machine design, should be decided on after a careful assessment of resource endowment and the recipient's needs (at farm, regional and national levels). The approach required should be a simultaneous, multi-disciplinary one if mechanisation is to enhance agricultural and economic development.

What is a small tractor?

Small tractors have been viewed by their promoters as an appropriate though undeveloped stage in the dynamic process of farm mechanisation. Before considering the development of small tractors and the need for a guiding philosophy, an attempt must be made at defining what is often understood by the term "small tractor". Its promoters have looked for the following main attributes:—

(1) Simple construction using mass produced components, assembling or fabricating as much as possible locally;
(2) safe and easy operation and maintenance;
(3) reasonably rugged construction and reliable performance;
(4) improved performance (quantity and quality of work) compared to that of a pair of oxen;
(5) low initial cost, ie within the cash or credit reach of a "small farmer".

Both three and four wheel designs have been developed usually below 15 kW (20 hp). The small tractor for LDC's has, with a few exceptions, concentrated on a scaled down version of the developed worlds (DC) conventional tractor. For this paper "small tractor" does not include pedestrian controlled tractors sometimes referred to as power tiller tractors. Though many of the comments apply equally to the latter type.

In summary

It is the author's contention that to date small tractor development has largely not answered the LDC's need for greater farm power. Why has small tractor development failed? Though technical imperfections may well have played their part, this paper will not comment in detail on this aspect. However, it is proposed that the main reason for failure is the totally inappropriate approach to the problems of agricultural development.

Small tractors have so far largely been the concern only of the agricultural engineering profession. In part this has been due to the reluctance of other disciplines to involve themselves in the issues of farm machinery development. Although this has not been so in the area of work systems design. The language of machinery development, whilst necessary technical in nature, has often precluded communication between engineer and non-engineer. The resulting blinkered approach has been unable to resolve the enormity of unfamiliar and complex problems that confront many such well-meaning attempts at improving the lot of the developing world. Thus small tractors have been conceived, developed and even sold in blissful ignorance of the full implications of their ultimate use and effect.

What is the demand for a small tractor?

It is argued here that small tractor development should respond to the needs of the farmers for whom it is intended. What are the mechanisation needs of the LDC farmers and following from this what is the potential market for small tractors in the LDC's? The private LDC smallholder demand for a small tractor will mostly depend on:—

(1) Power requirements (holding size and farm production system, present and potential) and the extent to which existing power supply is a constraint to improvement;
(2) his net income and expected net income with a small tractor;
(3) the machine's price and associated ownership and use costs;
(4) the prices and net benefits of alternative power sources;
(5) and the net income associated with spending an equivalent amount on the best alternative investment, eg fertiliser, irrigation, (ie the opportunity cost of the small tractor investment).

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J Morris BA MSc, Lecturer in Economics and Management, National College of Agricultural Engineering, now on secondment to Bookers Agriculture International, Kano River Irrigation Project, Nigeria.

Opinions expressed are those of the authors only and can in no way be ascribed to the NCAE or NIAE.

Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

This is a simplified demand function outlining the main variables. Within these, other variables of importance are: the availability and cost of credit; the price relationships between the price of small tractors on the one hand and the price, availability and productivity of other farm inputs, and the price received for agricultural produce on the other hand; and the present level of farm mechanisation technology. Another factor is the attitude of LDC peoples to farming and within this their attitude to modern farm mechanisation.

Holding size

How do these factors influence farmers' effective demand? A major demand factor is that of farm size. Total farm power requirements and holding size by production system are interdependent. LDC farms are generally small, fragmented with small plot sizes and complex tenurial patterns. However, many small tractor promoters have aimed at the "emergent" 6 to 8 hectares farm. But where does this "emergent" tropical farmer exist?

An analysis of LDC holding sizes shows that this factor alone greatly limits the immediate market for small tractors. The inequality in the distribution of factors of production within the developing countries is well known but perhaps the extent of this inequality is not fully appreciated. Eighty to 90% of LDC holdings are of less than 5 hectares. The present market for individual ownership and use of tractor farm power is therefore limited. The reader will point to the relative abundance of land in a number of LDC's. Unfortunately, there are in-built pressures in the LDC economy that maintain the relationships of general inequalities. Taking Africa as an example, traditional patterns of ownership and use of land, ie usufruct (rights to use only) characterised by small, fragmented and widely dispersed holdings restrict the opportunity for expansion and consolidation of land. This combined with pressure on the farming sector to absorb an increasing rural population greatly limits the scope for sophisticated mechanisation. In fact policies which encourage mechanisation may endanger the viability and continued existence of small family farms. However, where collectivisation, consolidation and multi-cropping of land is feasible then there is a greater case for motorised mechanisation. But here the small tractor is only one alternative. As it stands at present it is probably an inferior one, both technically and financially.

Income

Of prime importance is the requirement that farmers be better off as a result of using small tractors. Low prices and low yields within a predominantly subsistence agriculture in the LDC's assist in sustaining a vicious circle of poverty and greatly restrict the farmers' ability to adopt new technology. The scope for such 'lumpy', medium term investments as the small tractor is thus limited. Average national income figures hide great inequalities of distribution. These figures have unfortunately been little researched. It is apparent however that individual LDC smallholders can seldom purchase motorised mechanisation.

For individual material improvement the LDC smallholder has to learn to take more and more calculated risks. The conservative nature of a farmer justifiably restricts him from taking too big a risk. The LDC farmer takes a risk when he mechanises. He can share the ownership or use of machinery and equipment either by using credit facilities or entering into various methods of multifarm use of machinery. In common with requirements for production the availability of credit is often restricted to the favoured minority. Traditional land tenureship and hence lack of acceptable collateral often prevents LDC smallholders from receiving any credit. Often what local credit is available is made at prohibitive interest rates. Again the vicious self-sustaining circle of subsistence and poverty is difficult to break. Careful assessment of creditworthiness on the basis of farm management ability rather than collateral might be an improvement. Even if credit is available the small tractor is not generally within the credit capacity of the smallholder. Alternatively if a farmer could profitably borrow £1500 to £2000 for a small tractor why not £3000 to £4000 for the cheapest imported DC tractor?

Small tractor costs

Turning to the costs of small tractors. Small tractors have not provided low cost mechanisation to the LDC farmer. Costs of manufacture are largely governed by basic design and the associated volume of production. Apart from a few noteable exceptions there appears to be little evidence that new designs are significantly different from those previous. Without fundamental design changes reduction in unit size inevitably leads to less than proportionate reduction in cost of manufacture. Without doubt, motorised farm mechanisation is expensive for the LDC's. Fixed costs can either be spread over a greater number of hectares or larger number of jobs. The latter has given rise to more complicated and more costly machines. In the light of previous comments, to spread machinery costs over a greater number of hectares, must lead to considerations of multifarm use or restrict small tractors to farmers facing very specific circumstances. Variable costs are largely difficult to reduce. These views need to be seen in the context of increasingly expensive fossil fuels which suggest higher operating and fixed tractor costs in the future. For mechanisation to be justifiable it needs to offer considerable economies of scale.

Alternatives

In examining the costs and benefits of small tractors to the farmer, attention must be paid to the cost and effectiveness of available alternatives. Hypothetically, compared to its most immediate alternative, the imported DC tractor, the initial cost and, consequent hourly cost of operation should favour the small tractor. However with full use initial cost per horse power, initial cost per effective horse power, work rate and hence hourly cost of operation per unit of output should still favour the imported DC tractor. Furthermore, a farmer does not just buy a tractor but also after-sales service, availability of spare parts and complementary inputs, and in the LDC farmer's case, a need for greater knowledge — for operation, maintenance and management. In short, an improved level of both soft and hard technology. To be appropriate, small tractors require the same kind of infrastructural support that should be, but is often not available for conventional tractors in spite of the commercial interests of large, established manufacturers and their agents. The knowledge, ability and infrastructural support required for the efficient and profitable (multifarm) use of a small tractor is little short of that required for the (multifarm) use of, for instance, a Massey Ferguson 135; especially when considered relative to the perdominant lack of expertise with any machinery in many LDC's.

In a free market situation the profitability of a private small tractor investment would have to be judged against that of alternative sources of farm power: human; animal; pedestrian controlled tractor; and the multifarm use of imported tractors. It is here that detailed farm production system studies have an important part to play. The smallest holdings are likely to feel there is no alternative to family labour. Slightly larger holdings may hire labour and those still larger may be able to profitably use the services of oxen, buffalo, camel, donkey or mule. For other holdings up to 10 hectares, in many LDC's there is little immediate alternative (multifarm machinery use excepted) to human and animal power. Some smallholdings in Asia and the Far East have adopted the pedestrian controlled tractor for paddy cultivation with a measure of success, but its international dry-land equivalent elsewhere is yet to mature. Some LDC's in Latin America, Asia and the Far East have developed the multifarm use of imported conventional tractors through private contracting. A number of successful forms of multifarm use of machinery do exist, with gradation of ownership and use from individual ownership of one machine and limited shared use (Sri Lanka, Yemen Arab Republic, N Nigeria, Ecuador) to the purchase by many farmers of the services of a number of mechanised crop operations, eg Gezira scheme in Sudan and Mwea in Kenya.

Where does the small tractor fit into this? The frequency distribution of holding sizes as described before greatly restricts the number of markets for which a small tractor can be considered and these markets already have their more competitive approaches to mechanisation. The small tractor case is left with the residue. Small tractors are more likely to prove attractive to the small private farmer where power supply is a recognised production constraint and where for a variety of reasons alternative power sources are limited, eg no history of, and no present interest in animal use; trypanosomiasis; and population pressure on land. Further, one's attentions are focused on those farmers experiencing labour/power shortages during peak work periods and who have the opportunity, via larger hectarage or multi-cropping to increase the production of high value cash crops (usually export or horticultural). It is important to remember that to be most effective mechanisation needs to be part of an appropriate package of inputs. Such requirements often narrow the field to those farmers enjoying the attention of most favourable agricultural development projects.

Farm power market imperfections

The farm power market in the LDC's is usually imperfect. Government intervention in the form of tractor hire schemes for those who have access to them, frequently undercuts most farm power alternatives, and thereby reduces any market for small tractors. Furthermore, duty free concessions to machinery importers, heavily subsidised credit to purchasers (particularly in inflationary times) and tax allowances on operating costs mean that for those few who are fortunate to obtain a tractor, it might as well be a big one, especially with private contracting as an additional lucrative enterprise.

Opportunity cost

If a farmer spends his limited funds on a small tractor, he cannot spend them on other things. Mechanisation is often competing for limited funds with other forms of improved technology, particularly those which directly increase yields per hectare, such as improved seeds, fertilisers and sprays. Experience has shown that the returns to investment in the latter are generally much greater than to mechanisation. Increased use of fertilisers and improved seed varieties can usually be relied upon to increase yields but mechanisation is only likely to increase yields if it leads to improved timeliness and is complementary to other inputs. In fact, improved basic farm husbandry methods are usually a prerequisite for successful mechanisation. Thus, where farmers are not yet ready for small tractors, encouraging farmers to adopt them can involve real ('opportunity') costs in excess of the more obvious out of pocket expenses.

The need for further studies

As mentioned previously it is a prime requirement that farmers would be better off as a result of using small tractors. But predicting and measuring the net benefits of mechanisation is difficult. Many costs and benefits associated with mechanisation are indirect, hidden and therefore not immediately obvious. Some knowledge is required concerning the financial (and social) implications of alternative input-output strategies before it can be said that investing in more power is a most cost effective way of employing limited resources. Overcoming power constraints by tractorisation may simply transfer the bottleneck to other resources, eg management, which may well frustrate the potential gains to be had from improved power supply. It is here, particularly at farm level, that much more research needs to be done. It is generally considered that the small farmer is intuitively a rational decision maker, making the best of a difficult situation. It remains the responsibility, however, of policy makers, design engineers, manufacturers and distributors to provide him with alternatives which have a reasonable chance of meeting his needs.

The social demand for a small tractor

So far we have only considered the private sector's demand for the small tractor. Even in situations where the investment in small tractor production and use is seen to be financially more profitable (for manufacturers and users) than existing alternatives, such an investment may not be socially profitable and appropriate to the true resource endowment of the economy. Private profit rarely equates to social profit. Market prices do not often provide a meaningful basis for sound national or regional decision making where the objective is to maximise social welfare by making the best use of limited, community resources. For example, LDC currencies are generally overvalued and the true worth of scarce foreign exchange to the developing economy is not reflected in official exchange rates. Because of the predominance of both unemployed and underemployed labour in many LDC's, labour (even where it attracts only a bare subsistence wage) is often overpriced in real, economic (social opportunity cost) terms. Whilst, market prices may encourage the adoption of imported, capital intensive mechanisation projects which essentially substitute scarce and expensive capital for a plentiful, and otherwise unemployed labour resource, there is a realisation on the part of many governments that a rational agricultural development (and mechanisation) policy should favour endogenous labour-using projects, and discriminate against exogenous capital intensive projects. This applies to small and large tractors alike.

Supply of small tractors

This paper has looked at the market for small tractors in order to illustrate a preferred philosophy for assessing and planning agricultural development. Before we turn to this philosophy it would be remiss not to consider briefly the supply aspects of small tractors, especially with regard to the problems facing local manufacture in LDC's. The political prestigious ability to supply its own tractors may encourage an LDC to short cut recommended precedures. A small tractor, locally manufactured, sold at greatly subsidised prices on credit and at the exclusion of alternative farm power sources may be financially attractive to the farmer, but it would probably prove expensive to the economy. In many cases, with current designs, most parts have to be imported at considerable real cost, and unless governments are confident that the investment produces reciprocal real benefits (export revenues, import substitutions, greater social welfare) then local manufacture can only represent a hidden long term drain on the scarce capital resources of the economy.

Farm mechanisation and economic development

The approach implied by current aid policies, in common with the history of mechanisation in the developed world, tends to create conditions where motorised mechanisation falls late in the process of agricultural development. Furthermore, the failure of industrialisation to create work opportunities in LDC's and the realisation that (at least until the turn of the century) the farming sector needs to absorb the growing rural population, has meant that tractorisation per se, and many of the preconditions for it (larger holdings, commercialised land tenure arrangements etc) are rarely compatible with the important social, political and economic objectives of increasing rural incomes, maintaining rural employment (often through access to land use), and improving agricultural output.

An appropriate philosophy

To repeat, it is the authors' contention that the inappropriate approach to the problem of agricultural development has caused small tractor development to fail thus far. (Tractor engineers should not feel alone in this respect, the same can be said of many irrigation engineers and their products).

It may well be that where specific conditions allow there is a case for the small tractor:— favourable holding size and net income — present and projected; favourable design and price; and the lack of alternatives. But these provisos have not been adequately researched.

The philosophy is not a new one. It is a further request for a simultaneous multi-disciplinary approach to agricultural development. Though this must be undertaken with an understanding that economic development takes time. Too much too soon can be just as much a problem as no help at all. Many projects have failed through over-concentration on one aspect to the detriment or exclusion of others. Farm mechanisation can not be isolated. It can only be a successful process once other conditions have been met or set in motion. Many of the problems that have so far confronted small tractor development could have been anticipated by those knowledgeable in the fields of: rural sociology and the LDC peoples and politics; agricultural credit; farm management; tropical crops and livestock; soils; machinery manufacture; etc — as well as farm power. And the production formula will be unique for each country and region.

With regard to the implementation of the philosophy, which question has to be answered first: (1) Are small tractors technically feasible? or (2) Are small tractors needed and wanted? They are of equal importance and neither must be overlooked as they enjoy a symbiotic relationship. An examination of technical feasibility can assist a more accurate assessment of needs and the best ways of fulfilling them in view of the resource environment. An assessment of needs and resources can set physical and financial parameters for the engineer to work within. Overlapping engineering and "non-engineering" exercises should see a project from conception through to completion. But conceptually all development projects commence with the problems and potential of the individual LDC farmer and farm. And this is where small tractor development should begin.

The meeting award for 1977

THE meeting award for 1977 has been made to D A Crolla and A A W Chestney, both of the National Institute of Agricultural Engineering for their paper "Power take-off drive line dynamics and overload protection devices for agricultural machinery". The paper had been presented at a South East Midlands Branch meeting on 7 March 1977 and was published in THE AGRICULTURAL ENGINEER, Volume 33, No 1, in Spring 1978.

Publication in the Journal is a condition for papers to be considered, for this award.

Economic, political, and social aspects governing the success of small tractors

C G Cattermole

Historical perspective

IN all cultivation systems except paddy rice, the heaviest operational requirement is ploughing. In dry land terms, this translates into pulling a 25 cm share 20 cm deep at 4 km/h, against a maximum resistance of 1.0 kg/cm^2 at 50% overall tractive efficiency, producing minimum requirements of:—

Draught: 500 kg	Power: 11 kW

The mechanisation of agriculture in Europe during and after the war was largely carried out by 'small' tractors, typified by the Ferguson TE 20, introduced in 1948. These models were superseded, over the period 1955-1959, by the MF 35 and similar, and such 26 kW machines became the new standard. Whereas the TE 20, at around 15 kW and 1200 kg gross weight, had corresponded fairly closely to the requirements, in tropical countries, of a one-furrow machine, the "35" was, even in difficult conditions, a two-furrow one.

The gap, between the minimum requirements of developing countries and the smallest machines available from the majors had opened. It has been growing wider ever since.

Of the numerous under-18 kW machines then available from major manufacturers, only the Leyland 154 survives. Major manufacturers are now, under threat from Japanese machines, taking up marketing agreements with Japanese manufacturers to extend their own ranges downwards.

Japanese machines have, since 1970, achieved considerable success in the paddy areas of South Asia, and to a lesser extent in Brazil. In dry land areas however, their sophisticated specification has been a drawback, and so far prevented widespread adoption.

Within Europe, some 15 manufacturers in Italy, Spain and West Germany market single-axle machines convertible to articulated pivot-steer, four-wheel drive tractors, in the 11 to 26 kW range. In this case, the machines are conceived for vineyard and market garden use, and they are again considered too sophisticated for general purpose use in developing countries.

Finally, in the third world, small tractors are produced by the following concerns:—

Comparing the demand estimates of the 1973 UNIDO Report on small low-cost tractors for developing countries, viz:

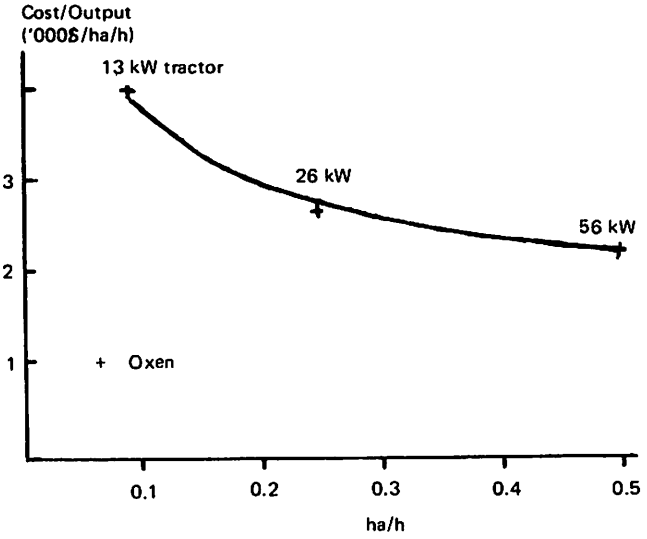
	1974	1980
Total LDC demand	51 970	180 940

with current production quantities, the scope of the shortfall becomes obvious.

Economic factors

Small tractors are relatively cost inefficient; the cost/output table below demonstrates why so many countries have mechanised directly from hand or animal cultivation to 26 kW machines or bigger.

	Cost US $ (1977)	Output ha/h
2 oxen+plough	800	0.025
Small tractor (13 kW)	3600	0.10
Tractor 26 kW	6800	0.25
Tractor 56 kW	10500	0.50



Farmers will therefore *only* choose small tractors where other constraints render them more operationally attractive, versus either animals, or conventional machines.

Such factors would include:

Against animal cultivation:

Tsetse infestation;
lack of labour at peak season for animal ploughing;
timeliness constraints — particularly where a long dry is followed by a short rainy season, and animals are out of condition when required for ploughing.
Also where tractor cultivation enables double-cropping.
lack of animal feed.
requirement for deep cultivation, beyond the strength of animals.
requirement for rotary powered operations — rice cultivation or grain threshing.
middle distance transport, where animals may be too slow.

Against conventional sized tractors:

Small farm size — ie below 20 ha cereal equivalent.
Small field size — where end-row turning time becomes preponderant.
Terraced land — where terrace width and strength precludes larger units.
Crop space characteristics: in vines, olives, citrus and some vegetable crops, where inter-row space is restricted.

Whilst farmers buy tractors for reasons other than purely economic, they are unlikely to mechanise with small tractors unless some economic return is foreseen. This implies, given the high cost/output of the machines a high incremental return to the

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Country	Manufacturer	Model	Production (1977 est)
India	Hindustan Tractors Ltd		
	Eicher Tractors India	T 27	
	Punjab Tractors Ltd	Swaraj	4000
Brazil	Agrale S/A/ Kubota Tekko		
Mexico	Siderurgica Macionale	T 25 (Belarus)	
Swaziland	National Development Corporation	Tinkabi	100
China PR		FS 20	
Turkey	TZDK	Basak 12	

farmer from the resultant increase in production. This would involve:

- High value crops — vegetables, fruit, rice, sugar, etc.
- Average or high farm gate crop prices.
- Intensive cropping, or double-cropping.
- Quick transport to market of perishable produce — fruit, meat, eggs, milk, vegetables.

Equally, comparatively few small farmers have the resources to purchase such equipment outright, so to obtain credits:—

- Farmers must be credit-worthy: this often implies freeholder farmers only, who can put up land or buildings as collateral.
- Farmers must have ready access, without excessive formalities, to medium-term (2-5 years) credit. Since in few developing countries are commercial banks willing to lend on such a small, fragmented scale, a government agricultural credit bank is normally required.

Finally, farmers must be able to rely on reasonable availability from their tractors. To avoid excessive downtime, this implies that marketing be carried out professionally, and that spare parts and service are available at reasonable notice throughout the area of tractor use. For conventional tractors, inter-manufacturer and inter-dealer competition provides the spur to improved parts and service provision; performance drops noticeably in monopoly situations. Since in most cases only one make/model of a small tractor may be marketed in a given country, some other mechanism must be devised to ensure adequate aftersales service from the distributor, whether private or nationalised.

Social and cultural factors

Even where the economic conditions are met, social and cultural conditions may affect the adoption and success of small tractors; these include:

- Availability of hired or family labour for field operations at peak times.
- Farmer traditions and skill in animal cultivation; where these traditions are advanced, farmers may be able to cultivate over 20 ha of cereal equivalent using animal traction, and then mechanise directly with a 26 kW or larger unit.
- Prestige attached to tractor ownership: in many areas, tractor ownership is synonymous with economic and social success. This may encourage farmers to buy small tractors, even where economic conditions are unfavourable.
- Attitudes to agricultural contracting, or inter-farm sharing: where these traditions exist, small farmers may well prefer to 'overbuy', and hire/lend the machine out for the portion of time not utilised on the owner's farm.
- Mechanical skills and traditions: countries and peoples vary enormously in the ability to keep machinery running. Where this ability is lacking, the economics of any mechanised cultivation scheme will be seriously affected. This includes skills not only in service and repair, but also in driving and operation.

Political factors

Government attitudes and action (or lack of action) affect many of the factors considered above. Thus:

Land Tenure/land reform: policy may encourage one or other of: Small tenant farmers; small freeholders farmers; 'groupments' of small freeholder farmers; co-operatives; state farms; private or mixed estates.

Of these, only the first and second are likely to consider small tractor mechanisation, and only for the second will collateral for credit be generally available.

Credit: State agricultural credit schemes are widespread in developing countries. In few cases are they geared, however, to financing small tractor purchases. Often, land area thresholds for credit are pitched with conventional machines in mind.

Tractor hire schemes: Where these exist, they provide an obvious dis-incentive to small farmers considering purchasing their own machines. Where hire scheme prices are below free-market rates, this may inhibit both formal agricultural contracting, and even informal inter-farm lending, since the Hire Scheme rate may be assumed to be the only legal one, and be uneconomically low.

Rural employment: Small tractor mechanisation may be officially discouraged, as causing a fall in rural employment, and therefore promoting urban drift. This ignores the very considerable prestige effect of tractor ownership, on raising farming from its traditional position as a low-status occupation.

Agricultural policy and back-up: Farmers' marginal income will depend on government crop prices, where produce purchasing is nationalised, as well as on the availability of high-yielding seed varieties, fertiliser and pesticide.

Cultural identity: Government policy may discourage small tractor mechanisation, as a European invention, and therefore an affront to traditional cultivations systems, closely tied to national pride and self-reliance.

Foreign exchange: Where this is scarce, governments may prefer to concentrate on large tractor imports for estates or state farms, leaving small-scale farming to traditional methods, and refusing import licences or foreign exchange allocations for small tractors.

Second-hand tractor imports: Where these are allowed, they compete with (new) small tractors for farmers on a limited budget.

Marketing: Policy may be pre-disposed towards one or other of:

- Private enterprise distributorships.
- Nationalised distributorships.
- Mixed administration distributorships.

This may have an adverse effect on the quality of after-sales back-up received by farmers.

Training: since most small tractor purchasers will be operating their first ever vehicle, governments may opt to supplement the efforts of distributorships in the training of tractor drivers, operators and mechanics. This has an obvious effect on tractor availability, and hence on their economic viability.

A country profile and checklist

From what has been said above, a profile can be drawn up of conditions likely to favour the adoption of small tractors in any particular country, so:

→*page 34*

Economic conditions are: many small farms in range 4 to 20 ha; small field size, or terraces; high marginal value of crop; high labour costs; tsetse, or other cattle disease infestation; short rains after long dry season; possibility of double cropping; freehold farmers, with collateral for credit; long transport distances to market; no on-farm collection; perishable crops; close-pitched bush crops — vines, olives, sugar, citrus, vegetables.

Socio-cultural conditions are: high prestige of tractor ownership; lack of labour at peak times; weak tradition of animal cultivation; resistance to inter-farm sharing of machinery.

Political conditions are: availability of small, medium-term agricultural credit; unbiased crop prices; availability of high-yielding varieties, fertilizer, pesticide; free import of machinery and spares: import licences, foreign exchange, customs duties and formalities; Operator and mechanical training provided by government.

The non-technical gateway

Comparing the observed characteristics of developing countries with the checklist, it becomes obvious that in many, non-technical considerations render the small tractor an entirely inappropriate answer. to the country's mechanisation needs. Even if an 'Ideal' small tractor were available, it would not be generally adopted. What therefore is required is an entirely new approach to the question of small tractor adoption; in place of the engineer's almost reflex query — "What is **wrong** with this particular machine? — when confronted with a lack of success in the adoption of one or other small tractor, a much more ecletic country-by-country approach is indicated, to discover where a suitable small tractor would stand a reasonable chance of general adoption. Many machines may have failed for the perfectly adequate reason that they were not good designs; others may have simply been promoted in countries where they stood no chance.

Theoretical design of small tractors

C P Crossley

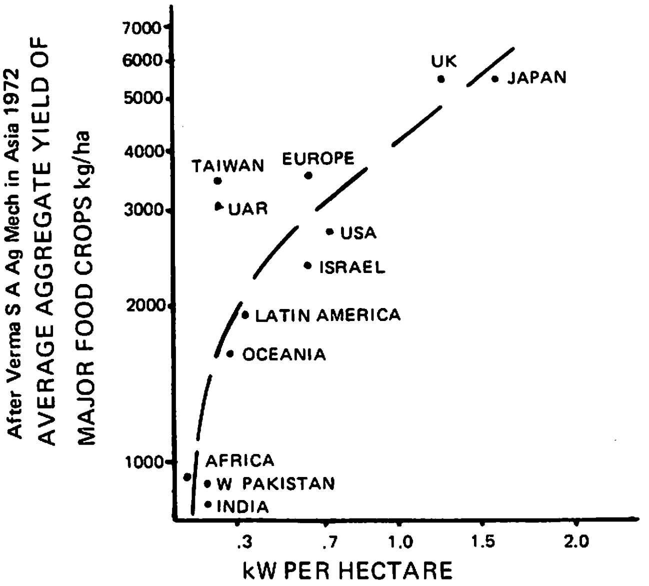
Power requirement for agricultural operations

CONSIDERABLE differences, typically of the order of 5:1, can be observed between the crop yields per unit area obtained on research establishments in developing countries and that obtained in similar conditions by traditional farming methods on small farms. Many factors influence yield and very considerable improvements can follow the balanced introduction of new cultivars, fertilizers and pesticides. A further important factor, however, particularly in areas where the wet growing season is preceded by a sustained dry period, is timeliness of cultivation since delay in soil preparation leads to late sowing and a consequent reduction in crop yields. Cultivation during the dry season would eliminate the timeliness constraint, but this cannot normally be achieved by traditional animal drawn systems because the force required to disturb hard, dry soil to a depth of 150 mm with a single narrow tine is of the order of 4.5 kN (1000 lbf). This draught force cannot be provided by a pair of oxen, particularly when in poor condition due to lack of feed during the dry season. Manual labour is subject to similar constraints which, together with the limited output available per person (approximately 0.075 kW) restricts the area under cultivation.

It is observed that the power available per unit area over much of Africa, for example, is about 0.04 kW/ha, while that in most developed countries, with yields per unit area of between 3 and 5 times greater, is in excess of 0.6 kW/ha (fig 1). It is suggested (UNIDO 1972) that in order to achieve reasonable productivity in developing areas such as Africa, a tenfold increase in power, to 0.4 kW/ha is necessary.

To increase the available power by the introduction of more people or animals is unlikely to be feasible since in either case a rise in productivity could be countered by an increased food demand. Fossil fuelled agricultural machinery offers a technically feasible way of providing additional power. The size of the average family holding in many developing countries is of the order of 2 to 5 hectares, with 3 hectares as an approximate average figure. Such a holding would therefore require a power input of 1.2 kW to provide the level suggested.

Many problems are associated with the indiscriminate introduction into developing countries of the technology evolved in Europe and North America, since the technical, economic and social conditions are entirely different. For the same reasons, the assumption that an intermediate level of technology is required, leading eventually to the application of the same higher technology, could be regarded as less than ideal. It is felt that a more promosing approach is the development of an "appropriate" technology, in which the most suitable aspects of all available expertise is logically applied to produce a satisfactory solution to the problems unique to developing countries.



RELATIONSHIP BETWEEN YIELD AND POWER INPUT.

Fig 1

The small tractor

Engine

The most commonly used power source is the internal combustion engine, either petrol or diesel. The initial cost of a small petrol engine is usually significatnly lower than that of a diesel of similar power, but the petrol engine is unlikely to have a useful life of more than 500-1000 hours when run near full power, compared with a figure normally in excess of 2000 hours for a diesel.

The fuel consumption is also higher than that of a diesel, in which the specific fuel consumption is substantially independent of engine size. Power outputs of all normally aspirated engines will be reduced by approximately 15% when operated at 1220 m (4000 ft) and 37°C (100°F) and for the design life to be achieved it is vital that adequate maintenance be carried out.

The fitting of internal combustion engines to small tractors for use in developing countries gives rise to problems in operation.

Transmission

A small tractor fitted with an engine rotating at 3000 r/min and running on 7.50-16 tyres in low gear at 1 m/s (2.2 miles/h) requires a total reduction in speed, between engine and rear axle, of 125:1.

Types of transmission

(a) Belts: Vee belts can be used for low power, high speed drives

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such as the initial reduction from an engine; a reduction in one step of up to 5:1 is feasible. Belts are reasonably tolerant of misalignment and environmental effects but maintaining correct tension can be difficult. Sprung tensioners can be arranged to act as transmission clutches, but will reduce belt life due to the extra bending. Variable speed or torque sensitive drives are available and, if properly matched to the engine and load, can be a useful and cheap primary transmission system. Typical losses in belt drives will be 5-10%.

(b) Chains: These high precision components are available in a wide range of pitches and sprocket sizes, and are generally suitable for higher torque and low speed. Reductions of up to 6:1 are possible.

Because of their conservative ratings (usually based on a factor of safety of ten on ultimate tensile stress, and a life of 16000 hours) it can be regarded as acceptable to overload chains by as much as twice their rated power for a design life of up to 5000 hours, but it is important to maintain correct tension, alignment and lubrication and to exclude environmental effects such as dust which can cause serious damage. Losses per chain will be between 2½ and 5%.

(c) Gears: Stepped gear boxes may be designed or specified. A minimum of two forward and one reverse gear is normally required so that such a gearbox is unlikely to be cheap. The efficiency of a transmission of this type will be around 85%.

(d) Hydrostatic: This type of transmission requires a variable displacement pump and a motor for each driven wheel, together with an oil tank and associated pipework and valves. It tends to be expensive and heavy, and is less efficient than mechanical transmissions (typically 65%) but possesses considerable advantages for small tractor design in simplicity of operation, infinitely variable gearing in both directions, built in braking and a wide choice of possible tractor configurations.

Tractive performance

The maximum shear stress at soil failure is given by $\tau = C + \sigma \tan \phi$ and the maximum soil thrust $H = Ac + Q \tan \phi$ corresponding to 100% slip. At lower values of slip the soil shear stress can be described by $\tau = (c + \sigma \tan \phi)(1 - e^{-\frac{j}{k}})$ and for a particular slip value, where at the end of the contact patch of length l j has a maximum value of sl, the soil thrust

$$Hs = (Ac + Q \tan \phi)\left(1 + \frac{k}{sl} e^{\frac{sl}{k}} - \frac{k}{sl}\right) \qquad (1)$$

The same thrust value with a shorter contact length (smaller diameter tyres) can only be achieved at a higher slip, resulting in less efficient operation. The maximum draw bar power for an average conventional tractor occurs at a slip value of 15 – 20%.

Lower slip values reduce the pull developed, while higher values lead to reduced field efficiency.

The useful work is further reduced by rolling resistance of the tyres, typically given by $R = 0.15 \frac{b}{l} Q$ (2)

Small diameter, wide tyres increase the ratio $\frac{b}{l}$ and hence reduce the useful diameter pull given by $F = H - R$.

For a particular tractor, knowing the total weight (including addition and transfer) on the driving wheels, together with the contact patch dimensions, the drawbar pull for a given slip can be calculated from equations (1) and (2). An example is given in Appendix 1, from which it can be seen that by fitting a light tractor with larger tyres the slip for a given (5 kN) drawbar pull can be reduced from 35% to 25%. The cost of the larger tyres, however, will be twice that of the smaller ones, and it can be argued that increasing the mass of the tractor by 40% so as to load the small tyres fully and obtain the same pull at 15% slip is a more effective solution. It should be borne in mind, however, that smaller tyres have reduced flotation and consequently more tendency to dig in and spin.

Implement attachment and control

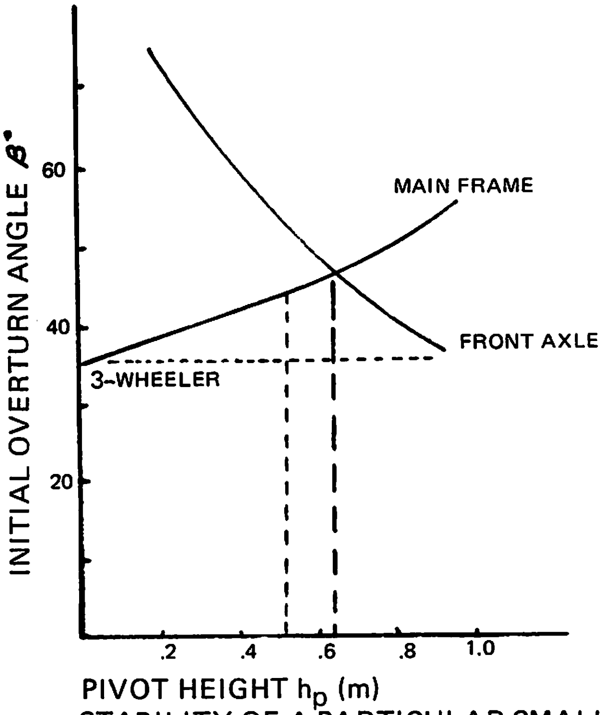
The hitch system should control the position of the resultant drawbar load K thus making effective use of added transferred weight to maximise traction. Control can be by depth wheel, by conventional hydraulic servo system, by adjustable free 3 point linkage or by a single pivot free in two planes but not in roll. Hydraulic systems are expensive and consume power, while mechanical lift systems require high operator effort.

A small tractor is unlikely to possess the traction capability for more than a single tine or mouldboard, which will generate a drawbar force F offset C from the centre line and will require a side force $Y = \frac{FC}{W}$ at the front wheels to maintain the direction of travel.

When the tractor is operating at maximum weight transfer the vertical load on the front wheels may be insufficient to allow generation of the side force, and tractor crabbing will result.

Stability

A 4-wheeled tractor having a pivoted front axle will start lateral overturn if the resultant external force falls outside the line linking a rear wheel contact patch to the front axle pivot point and, on a tractor having front axle stops, will continue if it falls outside a line joining the downslope tyres. Inherent stability will be greater with low centre of mass towards the rear and wide track and can be maximised by designing the height of the front axle pivot to equal that of the centre of mass of the tractor (fig 2).



STABILITY OF A PARTICULAR SMALL FOUR WHEELED TRACTOR

Fig 2

The stability triangle for a three wheeled tractor is that linking the tyre contact points. Rearward overturn of all tractors can be prevented by careful design of the implement attachment.

Operator comfort

The natural frequency of rear tractor tyres is in the range 2.2 – 4.3 Hz and for front tyres is 3.3 – 4.5 Hz. Damping ratios are normally between 0.06 and 0.08 and this will tend to amplify ground irregularities in the range 4 – 8 Hz, to which the operator is most susceptible (fig 3). As present tyre construction prevents a suitable damping ratio of 0.7 from being achieved, sprung and damped seats are usually provided on larger tractors, but these may introduce control problems due to the large deflections involved.

Noise levels in excess of 85 dBA are regarded as unacceptable, but many small units, particularly when the efficiency of engine and silencer has been reduced by wear and misuse, are capable of producing sound pressure levels at the operator's ear of up to 100 dBA.

Fundamental design of a small tractor

Basic design

Using the information presented in earlier sections of this paper and assuming certain agricultural and economic parameters it is possible to establish the basic design of a small tractor from "first principles" and to predict its performance and operating costs.

It can be shown (Appendix II) that, assuming an acceptable work rate on primary cultivation of 0.5 ha/day (1.2 acre/day) the basic design should be of a tractor with a mass of 1 tonne, fitted

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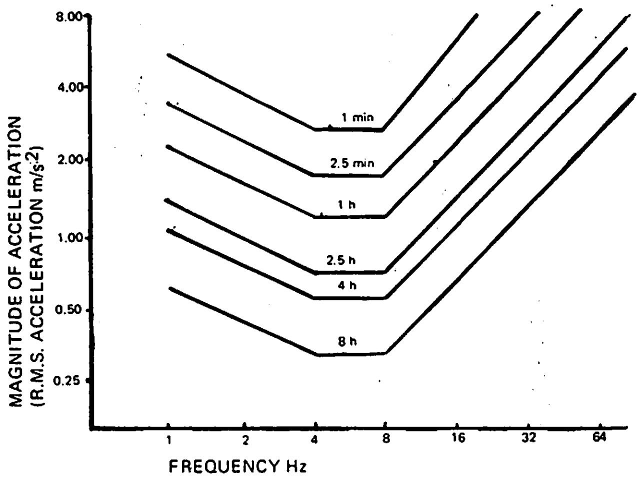


FATIGUE DECREASED PROFICIENCY BOUNDARY FOR VERTICAL VIBRATION OF FREQUENCY AND EXPOSURE TIME

Fig 3

with 7.50-16 drive tyres (two) and with an engine power of 9 kW (12 bhp). Such a tractor would be capable of carrying out 1 primary cultivation operation followed by three secondary operations on a holding of 31 ha, (76 acres), and its operational cost would be £32-60 per hectare (£13-20 per acre).

Configuration

A number of possible layouts exist and can conveniently be categorised as follows:

A 3-wheeled

(i) Two rear drive wheels, single front wheel, wheel or tiller steering. This arrangement is relatively cheap and simple and, if fitted with differential and steering brakes (or individually declutchable rear wheels) can turn in its own diagonal length. Spacing of row crops can however give rise to difficulties, and stability in the transport mode with a front load is likely to be a problem.

(ii) One (or two close-set) rear drive wheels, two front wheels, No differential is required, but a single drive wheel needs to be large. Mid-mounted implements are possible, but high offset rear drawbar loads under heavy traction work can affect stability and control. Turning at the headland will be more difficult than with a more conventional layout.

B 4 wheeled

(i) Two rear drive wheels, two front steered wheels, conventional rear axle. A major limitation here is the limited ground clearance available under the differential of a conventional (eg dumper truck) axle fitted with fairly small tyres. Provision for a differential lock may also not be available. With conventional steering a reverse gear is necessary.

(ii) Two rear drive wheels, two front steered wheels, high mounted rear axle with final reductions close to rear wheels (or hydrostatic transmission). Such an arrangement provides good ground clearance and, with a wide track, acceptable stability. The offset drawbar load problem, however, is likely to be aggravated by the wide track.

Economic Aspects

Assuming that a tractor has been designed, of a suitable configuration and with the ability to carry out the necessary operations throughout its design life in the physical conditions to be found in the developing world, it is necessary also to examine the socio-economic conditions which prevail, in order to establish the countries or areas where such a machine could be successful. It is felt that economic justification for a small tractor could be argued in two distinct cases:—

(a) Where tractor cultivation and weeding operations could eliminate the timeliness constraint on yield so that, used in conjunction with other necessary inputs such as improved cultivars, fertiliser and pesticides, the increased yields could produce an extra income in excess of the tractor operatings costs per unit area, or

(b) where the existence, (and social acceptability of the use), of previously uncultivated land can directly justify the tractor costs in terms of the yield produced from the extra area under cultivation.

Conclusions

A small tractor designed for use on direct traction in developing countries needs to be robust and heavy, with large tyres, good ground clearance and an engine power of at least 9 kW. The initial and operating costs of such a unit are likely to be high and prior to an application would require careful investigation to establish whether the economic and social environments were suitable. As with all engine powered mechanization devices, the successful introduction of a small tractor would be dependent upon the existence of, or early potential for, repair and maintenance facilities, extension, credit arrangements and marketing system.

Appendix I

Traction example

A small tractor fitted with two 7.50-16 traction tyres has a mass of 680 kg which loads each tyre to approximately 70% of its rated value. In order to pull 5 kN the tractor must work at 35% slip whereas if fitted with 9-24 tyres it would pull 5 kN at 25% slip (fig 4).

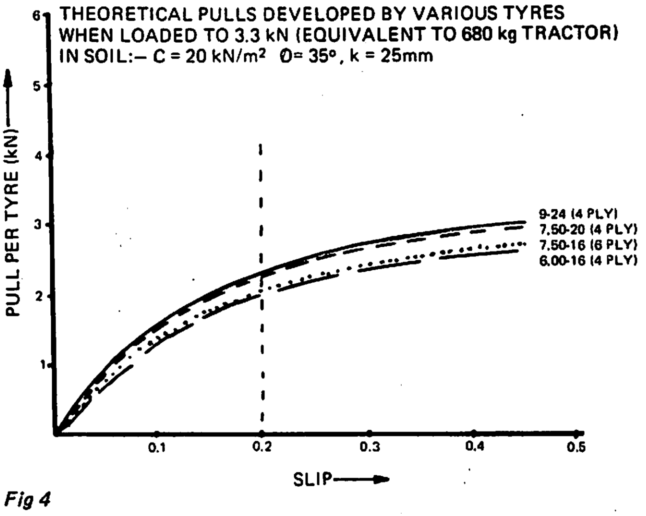


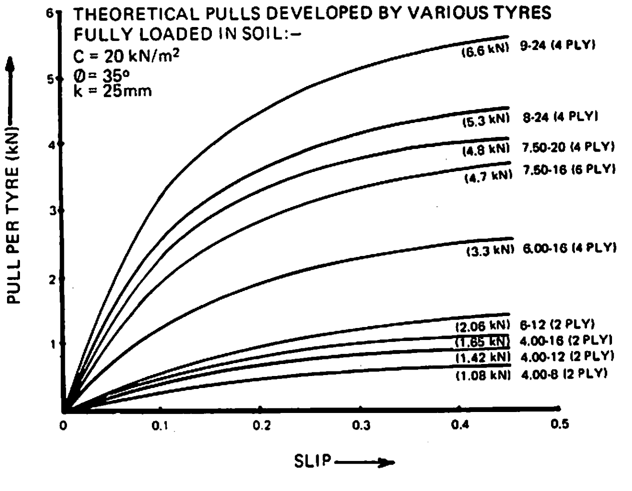
Fig 4

Neither set of tyres would, however, be loaded to their respective maxima. If the tractor mass was increased to 960 kg so as to load the 7.50-16 tyres fully (fig 5) it would pull 5 kN at 15% slip (and 6.4 kN at 25%). To load the 9-24 tyres fully would require a tractor mass of 1345 kg and it would then pull 5 kN at 7% slip (and 9.9 kN at 25%).

Appendix II

Derivation of basic design and operating costs — an example
(Assumptions are indicated thus *)

Fig 5



1 Specification

*	Acceptable work rate on primary cultivation	0.5 ha/day
	ie (in 8 hours) cultivation area rate is	0.173 m^2/s
*	Single-tine, disc or mouldboard width	0.25 m
	Thus mean forward speed required is	0.69 m/s
*	Field efficiency	65%
	Thus actual forward speed is	1 m/s
*	Pull required by implement	5 kN
	Thus power required by implement at 1 m/s is	5 kW
*	Slip at tyres	15%
*	Transmission loss	20%
*	Temperature and altitude derating	15%
	Thus engine power required is	8.8 kW
	For pull of 5 kN at 15% slip, tyre size required is	7.50-16
	Tyre loading (each)	4.7 kN
	Thus rear axle load is	959 kgf
	Thus minimum tractor weight is	1000 kgf

2 Predicted operating costs

	Time for one primary cultivation operation	16 hours/ha
*	Time for secondary operation	5.3 hours/ha
	Total time (1 primary + 1 secondary + 2 weeding)	32 hours/ha
	Diesel engine specific fuel consumption	0.36 l/kWh
	Thus fuel consumption at full power (65% of the time) is	3.25 l/h
*	Consumption during turning etc. (35% of the time)	0.81 l/h
	Thus fuel consumption per hectare (16 hours) primary cultivation is	38.3 litres
*	Average fuel consumption during subsequent operations	1.1 l/h
	Then fuel consumption per hectare (5.3 hours) secondary cultivation is	5.83 litres
	Thus total fuel consumption per unit area (four operations) is	55.8 l/ha
	Fuel cost (at £0.18/l)	£10.00/ha
*	Tractor life	5000 hours
	Annual usage (five years life)	1000 hours
	Then area cultivable at 32 h/ha is	31 ha
*	Initial tractor cost	£2000
*	Spares/repairs over five years	£1500
	Thus fixed cost per unit area is	£22-60/ha
	Thus total cost (fixed and variable) per unit area is	£32-60/ha

Large versus small tractors from an economic standpoint in Mexico

Francisco Murillo-Soto and Manuel Aguirre-Gandara

Introduction

SELECTION of the adequate size of farm machinery for a given farm or operation usually constitutes a rather complex problem in nearly every country or region in the world. Factors such as the cost of labour, requirements of the crop for particular machine operations, the effects on crop yields of the omission of some of those operations, losses for lack of timeliness of operations, reliability of machinery, calculated and actual depreciations, machine useful life etc, all contribute to the difficulty in selecting quantities and sizes of needed machinery.

In developing countries, where resources are often very limited, the selection of adequate machinery becomes a crucial problem, since economic efficiency is vital. In many such countries machinery is imported at usually very high prices or costs, credit is difficult to obtain and interest rates are high. Political and legal situations compound the problem in some instances by, for example, imposing limitations to the size of farm that can be legally owned by one person, by controlling the price of farm products, etc. To complicate matters even further, the population of many of these less developed countries grows very rapidly, making the production of food a very urgent issue.

The Mexican situation

At present, Mexico has 27.5 million hectares of farmland. Of these, 21.2 million are dedicated to cultivated crops, 1.9 million to plantations and agaves and the rest to grasslands. Approximately 4.0 million hectares of the cultivated farmland are irrigated and 17.2 million are non-irrigated. The last farm machinery survey in Mexico reported that every 53.6 hectares of irrigated lands had one tractor, while every 373.2 hectares of non-irrigated lands had one tractor, too.

Because of the agrarian land reform, the maximum farmland that can be legally owned by one person is approximately 100 hectares. Land expropriations and redistributions have resulted in a large number of very small farms, many of them of 10 hectares or less. In addition, most tractors now being produced in Mexico have pto powers of 34 kW or more. This is because most tractors and farm machinery are produced in Mexico by subsidiaries of USA companies using designs conceived in that country. In the USA, farm machinery is showing a tendency to increase in size, because the USA has practically no restrictions on farm sizes and also because labour costs are high. Due to all these situations, only the Mexican farmer that owns a reasonable size farm and has sufficient resources, and those farmers who have formed cooperative farms and/or have sufficient support from Government agencies, are more or less mechanised. Recently, the Mexican Government has expressed a desire to do a more thorough job to collectivise small farms, to make them eligible for government and/or private banking support and thus achieve a higher degree of mechanisation more rapidly and extensively. Clearly, the larger a farm is, the more economically feasible its mechanisation is, too.

If this collectivisation of farms is to be successful, careful planning should be made to determine the adequate characteristics and quantities of machinery for each particular cooperative farm, since, very likely, each farm will be different to most others in size, crops, weather conditions, soils, etc.

Labour costs are relatively low in Mexico, and the present rate of industrial growth is such that large numbers of people are unemployed. Because of these factors, extensive and rapid mechanisation of farms may not be desirable given that the unemployment problem might be compounded. From a social standpoint, it may be highly profitable to perform many farm operations by hand, because of the employment generated. Even from the farmer standpoint, some operations may be more economically performed by hand (crop picking, for example), if the high investment and operation costs of some machinery are considered.

Large tractors have a number of advantages over small tractors. They can reduce labour costs, perform subsoiling operations, etc. However, in some instances, they may have disadvantages with the

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Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

Table 1 commercially available tractors and recommended implements, in Mexico *

Company Model	Pto kW	Price New	Plough (No. discs)	Price New	Harrow (No. discs)	Price New	Planter (2 rows)	Price, New
Massey Ferguson								
MF 250	34	200 000	50 cm (2)	30 000	120 cm (14)	22 000	65-90 cm	25 000
MF 265	45	225 000	75 cm (3)	37 000	140 cm (16)	28 000		
MF 285	54	240 000	100 cm (4)	42 000	180 cm (18)	32 000		
MF 1105	75	419 000	125 cm (5)	46 000	220 cm (24)			
Ford								
F6600	48	250 000	75 cm (3)	35 000	200 cm (16)	35 000	65-90 cm	25 000
International Harvester								
744	55	254 000	75 cm (3)	38 000	220 cm (20)	51 000	65-90 cm	30 000
866	64	410 000	100 cm (4)	45 000	280 cm (26)	75 000		
1486	110	600 000	150 cm (6)	67 000	350 cm (32)	119 000		
John Deere								
2535	51	245 000	75 cm (3)	32 000	220 cm (20)	40 000	65-90 cm	25 000
2735	60	268 000	100 cm (4)	39 000	220 cm (20)	40 000		
4235	97	423 000	100 cm (4)	53 000	280 cm (26)	75 000		
4435	120	453 000	125 cm (5)	60 000	350 cm (32)	95 000		
Sidena								
T–25	18.5	67 000	50 cm (2)	25 000	100 cm (12)	20 000	65-90 cm	25 000

* *Many optional machines are not listed. Prices (in Mexican pesos) were, in many instances estimates of the dealers visited. Implements are the ones recommended by the dealers. A corn planter was assumed. Most farmers use only a two-row planter.*

small tractor: they may cause undesirable compaction when seeding, for example. Also, when a farm operation is to be performed by one tractor alone, and this tractor has a breakdown, substantial losses may occur because of lack of timeliness for seeding, for application of pesticides, etc.; while if two or more small tractors are to perform the job of the large tractor, if one of them breaks down, the losses may be reduced. In general, smaller tractors cost less per hour than larger tractors. Unless a large tractor has a high annual usage or it is planned to own it for long periods of time (ten years or more), overhead or fixed costs could make ownership of that tractor very unattractive, from an economic standpoint.

Doubling the (pto or engine) power of a tractor does not, in most cases, mean that the tractor will be able to pull an implement doubled in effective width, thus doubling field capacity (Traction theories show that increases in weight and/or power do not always produce linear increases in drawbar pull or drawbar power). The question then arises as to wheather two 18.5 kW tractors could have higher field capacity than one 37 kW tractor, with the implements recommended for each type of tractor, or as to whether four 18.5 kW tractors could have higher field capacity than one 75 kW tractor. Inspection of the available tractors and recommended implements, in Mexico, appears to give a positive answer to the above questions.

Table 1 shows the available tractors and their recommended implements, in Mexico. Prices shown are as of 31 December 1977. (An increase in price was expected to take place during January 1978).

Objectives

1 To provide some guidelines for economic selection of farm machinery in Mexico.

2 To point at information that is needed and not available in Mexico to aid in economic selection of farm machinery.

3 To seriously consider the role of the small tractor in any farm whether large or small.

Necessary information

1 Farm size, or the effective area that the machinery is to service.

2 Crops selected for the time period over which economic evaluation is to be made.

3 Required operations per crop.

4 Effects on crop yields caused by lack of timeliness and/or by neglecting operations. Some minimum or no-tillage practices might be considered here, as economic alternatives.

5 Commercially available machines, and their cost.

6 Field capacity and field efficiency of machinery.

7 Reliability of machinery, and variations in reliability with age of the machines.

8 Useful life of machinery.

9 Fixed and variable costs associated with machinery.

10 Statistics of prices, to make estimates an expected value of crops.

11 An inflation forecast, to adjust fixed and variable costs, to obtain a better estimate of salvage values, to obtain better estimates of costs of replacement of equipment, etc.

A brief description of the method

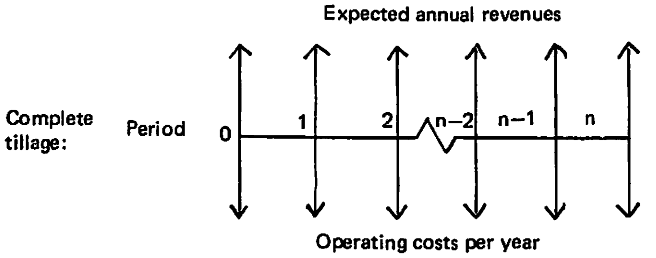
The method proposed here does not present revolutionary innovations. However, it is intended to serve as a guide for a very thorough study in economic selection of machinery.

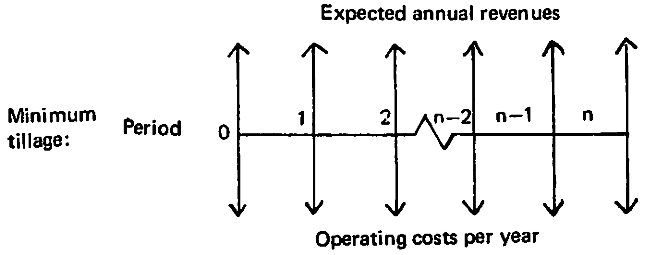
The intent exists, in the near future, to gather all or most of the necessary information and implement this proposed method.

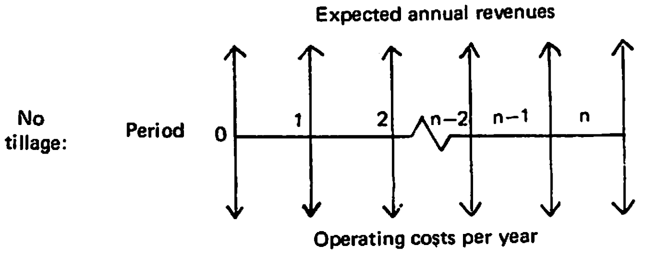
The method is as follows:

1 Once the effective area, and its shape, that the machinery is to service, has been determined, careful planning of the fields should be made, with rows as long as possible, to minimise times lost in turning, thus increasing field efficiency.

2 Determine operations to be performed on each crop. If possible, make an economic evaluation of alternative minimum or no-tillage practices. Determine cash flows resulting from each alternative (complete tillage, minimum tillage, no tillage), and calculate the internal rate of return of each. For example, if complete tillage for corn consists of ploughing, harrowing and one cultivation, some minimum tillage practice consists of only harrowing and one cultivation, and a no-tillage practice consists of seeding only, the cash flows might be as follows:







3 Make estimates for losses resulting from lack of timeliness of operations. These losses will vary from crop to crop and from one region to another. Therefore, regional data should exist for these timeliness factors.

4 Determine field capacities and field efficiencies of available equipment. Field efficiencies will be largely affected by irregularly shaped fields that result in short rows, by using the machinery to only fractions of its capacity, by breakdowns and by required service.

5 Determine annual usage of the choices of machinery under consideration. This will be determined by the size of the effective area to be serviced by the machinery, by the requirements of the crops selected, by field capacities and field efficiencies of the machinery.

6 Make estimates of machinery expected down time, taking into consideration, as far as possible, the decreased reliability, with age, of machinery. Use available statistics to determine probabilities for breakdowns, mean failure rate, expected time spent in repairs.

7 Determine fixed and variable costs associated with the available choices of machinery. Fixed costs are those that are unaltered by the extent of use of the machinery, eg depreciation, taxes, insurance, necessary or recommended shelter for the machinery, interest. Variable costs are altered by the extent of use of the machinery, eg fuel, lubricants, repairs, labour, tyres.

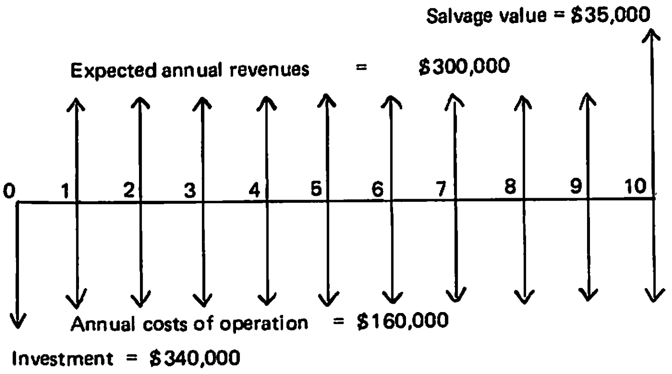
8 Determine the time period over which economic evaluation is to be made. Usually, the useful life of the machinery is adopted as that time period, but if it is desired to trade in or to renew machinery more often, this period may have to be changed.

9 From the information, determine cash flows for each year. Present worth, benefit/cost analysis or internal rate of return criteria may be used in selecting the best alternative. An example of a cash flow diagram is given below.

Example

Alternative 1: Acquisition of a Massey Ferguson MF 285 tractor and recommended implements, to service a 60 hectare farm.

* Annual revenues are the product of sale of the crop.



* Annual costs of operation are composed of:

1 Fixed costs of ownership of the machinery.

2 Variable costs associated with operation of the machinery.

3 Labour.

4 Other costs, such as chemicals, fertilisers, transport etc, may or may not be included in the analysis. They are assumed to remain constant, regardless of the machinery selected.

* Machine useful life: 10 years (Annual usage: 1000 hours).

* On the final year, a salvage value of the machinery is added to the revenues for that year.

* The cash flow diagram shown does not reflect the fact that operation costs of the machinery increase with age, ie fixed and variable costs are averaged over the 10 year period. This is inaccurate, unless the time value of money is considered when averaging.

* Annual revenues may be reduced to a uniform series of payment as an expected annual revenue, ie probabilities of good and bad years and of varying prices are considered. Again, the time value of money must be considered.

* Present worth of this alternative can be computed as follows:

$$\text{Present worth} = -\text{ Initial investment} + \text{Annual revenues}^{*}\,(P/A,i,n) - \text{Annual costs}^{*}\,(P/A,i,n) + \text{Salvage value}^{*}\,(P/F,i,n)$$

where:

n = 10 years

i = rate of return

$$(P/A,i,n) = \frac{(1+i)^n - 1}{i\,(1+i)^n}$$

$$(P/F,i,n) = \frac{1}{(1+i)^n}$$

The rate of return used for calculation of the present worth should reflect a cost of opportunity for alternative uses of capital, e.g., the interest rate of a savings bond or of a savings account.

* The internal rate of return may be computed as the rate of return which makes present worth of the project equal to zero.

Comments

The decisions resulting from the proposed method will only be as good as the information put into it.

At present, a good deal of the necessary information mentioned above is either defective or non-existent, in Mexico. This is due, in part, to the fact that most farmers do not keep accurate records of their operating costs, repairs, total down time per year, number of working days per year, field efficiencies of their machinery, annual usage, in hours, of their machinery, etc. Also, from the government standpoint, obtaining information, organising and updating it, and making it readily available to the public, is usually expensive.

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Much data can be obtained from the USA. However, it is data which should be used very carefully. For example: data of losses due to lack of timeliness of operations for several crops is available in the USA, but may not be very valuable for use in Mexico, due to differences in weather, soils, crop varieties, cultivation practices, available water, fertilsing, etc.

Ideally, data concerning expected crop yields, losses for lack of timeliness, required operations per crop, field efficiencies, should be obtained and kept regionally.

To date, there is only one small tractor 18.5 kW in the market in Mexico. Its low price suggests it as an attractive alternative to larger tractors. Two of these small tractors cost less than one 37 kW tractor. Further, four of these small tractors cost less than one 75 tractor. Obviously, labour costs and some variable costs may increase by operating four tractors instead of one, but losses resulting from lack of timeliness may be reduced, and some fixed costs might be reduced, too. The value of the small tractor could be even greater in collective farms, where the cost of labour is very low.

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Changes in the demand and design of small tractors during the period 1960 to present date

Peter Stewart Barton

I SHALL define small tractors as those with engines of under 15 kW. They can be two wheel (powertillers), four wheel riding tractor types or any other variation.

The design of four wheel tractors up to 15 kW available in 1960 mainly consisted of conventional integral designed units. The power units could be of any number of cylinders between one or four and these tractors were usually two rear wheel drive.

Since that date there have been some attempts to design and promote various frame type tractors in which the engine, transmission and final drive unit have been mounted on to a fabricated frame. This has the advantages of allowing high technology volume-produced parts to be assembled to frames which could be manufactured in more simple workshops in either the developed or developing countries.

Many different designs have been tried using various numbers of wheels, types of engines, and types of transmission. Some of the designs were:

(a) *NIAE tractor* 3 wheels, one wheel drive, belt and gear transmission. Jockey pulley clutch.
(b) *Barford Maskel tractor* 4 wheels, 2 wheel drive, gear transmission, plate clutch.
(c) *NIDCS Tinkabi tractor* 4 wheels, 2 wheel drive, hydrostatic transmission.
(d) *Thailand Iron Buffalo tractor* 4 wheels, 2 wheel drive, gear belt and transmission. Jockey pulley clutching. The main advantage of this design of tractor is that many of the components are obtained from used vehicles. The rear wheels are 20 inch truck wheels in which the discs are welded up and re-drilled to suit the rear axles. The tyres are re-moulded to R-1 or similar lugged pattern, the front wheels are from used cars with the tyres re-moulded to rib pattern. The transmission consists of gears from an old truck incorporated into a frame and coupled to a differential, the final drive is by roller chain and sprockets. The steering box is also from an old truck.
(e) *NCAE Snail tractor* This is a winch type unit which pulls the implement along by a cable.
(f) *French Bouyer* 4 wheels, 2 wheel drive.
(g) *The Uganda Boshoff tractor* (Kabanyolo).

During this period the Japanese have been establishing the manufacture of conventional integral designed tractors of under 15 kW. The design of these has advanced to incorporate most of the features found in tractors of larger horsepower, such as sophisticated hydraulics for implement control, pto shafts, electric starting, and smooth running multi-cylinder engines. Many have 4-wheel drive. These tractors, due to the sophistication of the design, are too expensive for the farmers in the developing countries.

The 2-wheel tractors (powertillers) in 1960 were mostly of the two axle type using an axle on which were mounted powered wheels to produce forward motion while on the rear powered axle were mounted rotary hoe blades. Around this time interest was aroused in the possible market for a simple single axle 2-wheel tractor (powertiller) to provide basic power for farmers of small areas in the developing countries. In one country co-operation was tried with one of the sewing machine companies; unfortunately this project had limited success. In the mid 1960's there was a number of attempts to establish the manufacture of power tillers in the developing countries as well as a number of joint venture projects in co-operation with established developed country companies. The local manufacture of simple designs specially suitable for manu-

Availability of government credit programmes for machinery manufacture and purchase

Country	Manufacture	Interest rate	Farm purchase	Interest rate
Bangladesh	Yes	11	Yes	7.5
Brazil	Yes $^{a/}$	40	Yes	15.0
Burma	No		No	
Colombia	Yes	20	Yes	15.0
Egypt	Yes $^{a/}$	7	Yes	7.0
India	Yes	16	Yes	10.0
Indonesia	Yes	12	Yes	24.0
Japan	No		Yes	6.5
Korea	No		Yes	10.0
Malaysia	Yes	12	Yes	8.0
Nepal	Yes	14	Yes	14.0
Pakistan	Yes $^{a/}$	10–13	Yes	8.5
Philippines	Yes	16	Yes	13.0
Sri Lanka	No		Yes	10.0
Taiwan	Nil		Yes	8.5
Thailand	Yes	11	Yes	13.5

$^{a/}$ *Private sources.*

Source: *International Agricultural Machinery Workshop Supporting Tables and Charts*
Agricultural Mechanisation: A Summary Review by Bart Duff.

Peter Stewart Barton NDAgrE, TEng(CEI), MIAgrE, AMASAE, The International Rice Research Institute, Thailand.

Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

facture in the developing countries was also established. Two of the most successful have been the IRRI 5–7 hp single axle tractor and the Thailand Iron Buffalo single axle tractor.

Since 1960 there have been considerable changes in the size and nature of demands. At the start of the period the major market was in Asia but since this time the market has expanded into Europe, the Middle East and Africa.

There has been much progress during the period. The demand for small tractors has increased considerably. However, unless the owner can show a profit on his investment he will not be able to continue to run the machine. There is also a limit to how low the cost of manufacture can be, and the final cost per kilogram cannot be ignored.

Estimated demand for locally manufactured machines – 1977–1982

Year	Power tillers	4 wheel tractors
1977	16,237	2,918
1978	18,267	3,282
1979	20,550	3,692
1980	23,118	4,153
1981	26,007	4,682
1982	29,257	5,268

Source: Suwit Disayamaren, Industrial Service Division, Department of Industrial Promotion: 1977.

Aspects of size and concept of tractors for tropical agriculture

Dr-Ing Arno Gego

FOR use in small-size farms, the tractor must feature good manoeuvring and be equipped with power lift for three-point linkage to enable operation of attached implements. Moreover, a pto shaft will be required for driving specific implements (eg a spinning fertiliser distributor).

The minimum size of the tractor is governed by specific operations that have to be carried out by the machine:

- the rotary tiller for wet rice cultiivating requires a minimum engine rating of the tractor of 15/20 kW
- soil cultivating in Egypt with the aid of the grubber requires a minimum tractor size of about 29/40 kW
- the use of the two-furrow disc plough in dry areas requires tractors of more than 37/50 kW.

The technical design of the tractor has to be matched to the particular local conditions. Transmission of 6–8 forward speeds and a standardised pto shaft of 540 min^{-1}, as well as a single clutch will be adequate for the early phase of mechanisation.

Efficient air cleaning, that provides for top intake and requires little attention should be installed in dusty atmospheres.

Seen as a whole, the volume of functions should be tailored to the specific requirements of tropical farming and preferably be limited to these (such as a smaller lighting system).

The concept of the standard tractor has to be considered suitable for most of the tropical farming methods.

Solidity and reliability of the tractor must be ensured for practical application. Adequate training of the drivers is just as important for a substantially trouble-free tractor operation.

An economic comparison reveals that, subject to an identical operating time per year, the medium-size tractor is superior to the small one as regards cost, eg for ploughing. This fact results in the necessity of interfarm machine pooling in different farms due to the small-scale agricultural structure.

Basic situation

Developing countries of most varying stages of development are situated within tropic and sub-tropic regions. Some of them have reached the threshold of agricultural mechanisation. Traditional farming of these countries is mainly characterised by minimum size units and small plots. Since the tractor as driving unit has to be considered the core equipment of motorised agricultural production in view of its versatile applicability, the question of suitable sizes and layouts of tractors for tropical farming has to be investigated.

Tractor and plot size

As the plots are small in most traditional farms, it is of specific importance for combined tractor and implement that they are capable of manoeuvring and turning within a restricted area.

Therefore, the implement has to be joined to the tractor over a power lift that enables the driver to lift the implement at the end of the field, thus permitting turning on the spot. Operation with pulled implements is of no advantage because it strongly impairs manoeuvrability.

Since even for small tractors there are implements that are too heavy to be lifted manually, it will be of advantage to use the internationally standardised hydraulic three-point linkage power lift.

Hence, from the point of view of small farms and small lots, suitable tractors should feature the following characteristics:

- small turning radius of the tractor
- double pedal brake (for promoting the turning operation)
- hydraulic power lift for three-point linkage.

Moreover, using the power lift implies the advantage of carrying implements to the field and back to the farm without requiring additional means.

Driving of implements that require rotary power

Apart from attached passive implements, such as plough, grubber, and the like, there are important agricultural tools that require rotary power for operation.

Experience has shown that the pto shaft is an efficient and low-priced means for driving implements and it should, therefore, likewise be provided for tractors used in small farms.

Aspects of tractor size with respect to practical application

The possible use of the tractor for different operations and the varying conditions of the duty are decisive for determining the minimum tractor size. Actually, the method of soil cutivation governs the tractor size. The statements given below analyse three different applications:

- soil cultivation with the aid of the tiller for wet rice growing in Asia;
- soil cultivation with the aid of the grubber for irrigated field work in Egypt;
- soil cultivation with the aid of the disc plough in arid zones in Africa.

Soil cultivation for wet rice growing in Asia

Provided soil cultivating for wet rice growing is motorised, the rotary tiller is used mostly. The power requirement and the necessary tractor size primarily depend on:

- soil resistance
- working depth
- working width
- working speed, and
- intensity of cultivation.

Practical experience gained for wet rice growing in Asian countries (eg Malaysia, Indonesia), have resulted in empirical values for tractor sizes as a function of working width and speed, which have been enumerated in table 1.

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Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

Table 1: Guidelines for tractor sizes required for wet rice growing; the sizes are a function of working width and speed of the tiller

working width rotary tiller m	working speed km/h	tractor size required hp	kW
1.2	3.5	20	15
1.5	4.0	30	22
1.8	4.5	41	30
2.0	5.0	50	37

Moreover, it has turned out that using tractors of less than 15 kW will entail reduced reliability and service span (eg small tractors operated in practice in Sulawesi, Indonesia).

At any rate, the tractors have to have adequate soil clearance to be able to cross the dams easily that border the rice fields.

Soil cultivation for irrigated field work in Egypt

By tradition, soil cultivating is done in Egypt either with animals and hook plough or with a tractor and tiller fitted to the tractor over a three-point linkage on dried fields. A plough is not popular. To avoid non-worked tyre traces and to ensure symmetric attachment of implements, the working width of the tiller must at least be identical to that of the tractor or even be slightly larger.

Duly considering practical parameters results in an engine rating of about 44 kW (60 hp) for the tractor at an operating speed of 5 km/h. Smaller tractors of about 26 to 33 kW (35 to 45 hp) can be applied for identical operations on the condition that the working depth and/or the working speed are suitably reduced.

It will be of little use to have tractors of less than 26 kW (35 hp) applied in Egypt for soil cultivating with the aid of a grubber.

Soil cultivation in arid zones in Africa

Soils in arid zones of Africa or other regions are characterised by a particularly high specific resistance which may equal up to 20 N/cm^2. This results in relatively high pulling forces for soil cultivating. Although these may be lowered by pre-irrigation, that remedy is mostly unrealisable for farmers in these areas.

The rough model calculation (see table 2) reveals that a tractor of more than 30 kW (53 hp) is required for managing soil of a specific resistance of 10 N/cm^2, and to pull a double-furrow plough at moderate working depth.

When using tined implements (for dry-land farming) which are especially suitable for arid zones because of their water-retaining effect, even larger tractors will be necessary provided the working width shall correspond to the tractor width.

Comments on the question of tractor concept

During the last 50 years, the concept of a standard tractor of ratings that by far exceed 74 kW (100 h_p) has been successful against a multitude of alternative layouts, due to its practical and economical operation for standard agricultural work.

Its outstanding features are:

- block-type design (engine and transmission being one block)
- large, driven rear wheels
- small, steered front wheels that can be driven, if required
- driver's cab in the rear section of the tractor
- axle load distribution:
  approx. 1/3 at the front, and 2/3 at the rear (the point of gravity is shifted somewhat more to the front in case of four-wheel drive).

By now, standard tractors are successfully applied in many countries with tropical farming. In some of these, they have even resulted in most advanced mechanisation (eg in Algeria, Brazil, Punjab/India, Turkey).

So far, no alternative tractor concepts have become known which would be superior to the standard type within the power range specified, as regards:

- practicability
- simple handling and implement operation
- sturdiness
- versatile applicability.

It can be taken as granted that the standard tractor will take a dominating position also in those countries where farming is to be gradually mechanised in the years to come.

Aspects of cost saving

Apart from aspects of practical application which will give information on the required tractor size for specific duties, the question of an efficient use of tractors is of outstanding importance. To get an idea of the economy of eg ploughing work, table 3 quotes the cost of ploughing work for different tractor sizes. The figures are based on annual operating periods of 300, 600 and 900 service hours.

Moreover, that comparison indicates the machine cost/tractor size and the influence of wages, equalling US-$1 and 2/h respectively, on the overall expenditure for ploughing work.

The comparison shows that the standard tractor is more economical than the single-axle tractor for all cases. Furthermore, it turns out that the medium-sized standard tractor (44/60 kW/hp) results in less cost of ploughing work than smaller standard machines, even at an annual operating period of no more than 300 service hours.

In addition, it has to be pointed out that although annual

Table 2: Rough model calculation for farming in dry areas with a double-furrow plough

pull

$$\boxed{F = i \cdot k \cdot b \cdot t \quad [N]}$$

tractor mass

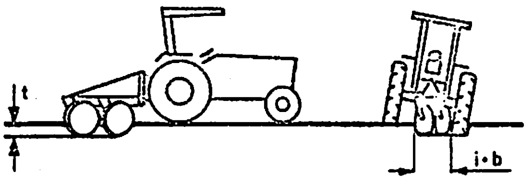
$$\boxed{m = \geq \frac{F}{g \;.\; (0{,}8 \cdot \varkappa \;\cdot 0{,}2 \cdot \zeta\;)} \qquad [kg]}$$

engine rating

$$\boxed{P = \frac{(F + m \cdot g \cdot \zeta\,) \cdot v_f'}{1000 \cdot \eta_{tr} \cdot (1 - \sigma)\;\lambda} \qquad [kW]}$$

result of model calculation

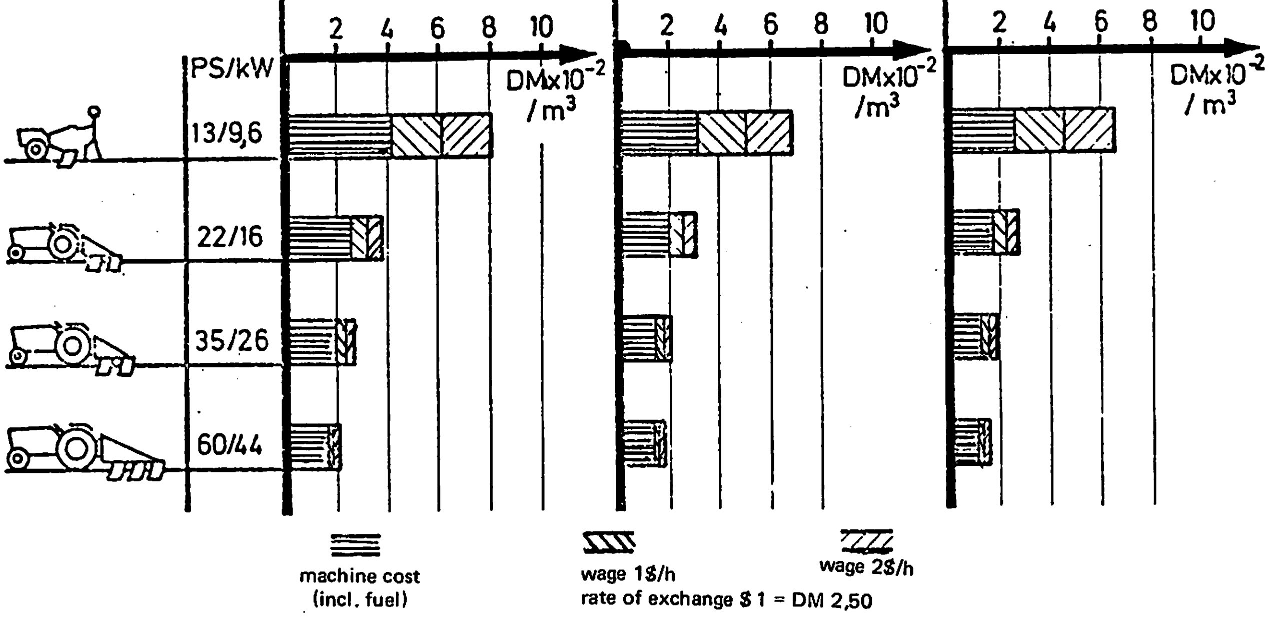
pull	F = 10.000 N
tract. mass	m = 1.820 kg
eng. rating	P = 39 kW = 53 hp



where:
i = 2 furrows
k = 10 N/cm^2
b = 25cm/
t = 20cm
$\varkappa$ = 0,7
ζ = 0,15
v_f = 1,5 m/s = 5,4 km/h
η_{tr} = 0,8
σ = 0,15
λ = 0,7

Table 3: Cost of ploughing work determined for varying tractor sizes and varying operating periods of the tractors/year.

tractor service	300 h/a	600 h/a	900 h/a
tractor depreciation	10 years	9 years	8 years
repair + maintenance	30% of depreciation	35% of depreciation	40% of depreciation
plough work	150 h/a	150 h/a	150 h/a



operating periods of 600 and 900 hours have been included in the comparison for the single-axle tractor, these values will be achieved in practice only with the standard tractor.

However, the crucial problem existing in practice is that most farms in tropical countries can avail themselves of agricultural areas of no more than 1–10 ha. Such small farmland will by no means use the standard tractor, ie not even the small size of 16/22 kW/hp, to capacity. In general, they remain far below 300 operating hours/year.

These facts necessitate interfarm machine pooling (see table 4) to improve tractor utilisation. The guidelines specified in table 4 have to be considered reference values only; they show but a rough trend. There may, of course, be variations in practice.

Table 4: Guidelines for efficient types of farm mechanisation

Farm size	area (ha) cultivation		Type of mechanisation		
	intensive	extensive	intra-farm	partly interfarm pooling	interfarm pooling
small	< 10	< 30	–	+	+
medium	< 50	< 100	+	+	–
large	> 100	> 200	+	–	–

The Tinkabi system

Alan Catterick

AGRICULTURAL development in Africa is essential not only to provide food and food reserves but to increase the standard of living for more than 90% of the continent's population.

It has been shown that agricultural operations relying entirely upon hand labour are sub-economic and barely provide substance for the family. Where animal power is utilised a greater area can be ploughed, but generally subsequent operation rely upon fickle hand labour which is extremely limited in its output and attitude to this kind of work. Mechanical operations are expensive not only in initial capital outlay but also in running cost; here the farmer has to have knowledge, large areas of arable land and access to finance.

In Africa the vast majority of farmers cultivate an area of less than two hectares, thus making the conventional range of prime movers uneconomical. Co-operative ownership, sharing, contracting and hiring have to date generally proved to be unworkable under African conditions. Also the small power units, single axle or low horse power 4-wheel units currently available, although lower in cost than conventional units are not physically capable of dealing with the hard, harsh conditions found in Africa.

The Tinkabi Project was born in Swaziland to draw up a list of the basic requirements of a unit suitable for African conditions. This was done with the aid, advice and co-operation of countless people engaged in agriculture throughout the continent and resulted in the following requirements, not necessarily in order of priority as all of them are of prime importance.

1. Cost — this must be within the potential credit limit of the progressive small scale farmer.
2. Transport — the unit should be capable of carrying a payload of at least 500 kg and have an effective range of at least 40 kilometres.
3. Ground clearance — effective ground clearance should be such that inter-row cultivation or crop spraying can be carried out to a late stage of growth or canopy in crops such as maize, sorghum, cotton.
4. Wheel track — such as to give good stability in relation to 3 above and to fit into row crop widths recommended by research results.
5. Weight — should be distributed so that most of the dead weight is situated over the driving wheels, additional removeable ballast being used for stability of the unit.
6. Wheels — four wheels are essential.
7. Power — should be adequate for ploughing during the dry winter season and should be at least 8 kW.
8. Controls — should be simple with ease of operation.
9. Electrical equipment — should be omitted.
10. Range of equipment — the machine should be designed so that a wide range of work can be undertaken and that, as and when necessary, the unit can be upgraded/converted.
11. Maintenance — should be reduced to a minimum.
12. Service — essential for any programme, without it any programme is doomed to failure, this includes mechanical services, training, spares, etc.

The choice of transmission and power units was given the most consideration. From the data collected it was shown that a slow speed diesel engine could offset the extra cost of initial purchase within a period of 800 hours running, and in addition the engine required less maintenance and had a life beyond that of 3500 hours operation under normal circumstances. The transmission system was required to transmit adequate power to the drive wheels. Conventional gearbox/differentials were looked at but discarded because of low ground clearance; chains and belts were discarded because of cost, noise and maintenance; electrical transmissions were not readily available and so the choice went to fluid drive. This gave a very flexible system, enabled ground clearance and wheel track to be set with minimum additional expense and gave the simplest control system. This system consisted of a bi-directional variable displacement pump driven direct by the engine coupled by a closed loop circuit to fixed displacement radial piston motors to which the drive wheels were attached. A single lever controlled direction of travel, speed and braking and maintenance was reduced to one filter change every 250 hours.

The engine and transmission system were then built into a fabricated chassis. The design of the chassis enabled 80% of the weight of the tractor to be positioned over the drive wheels. The chassis also had built into it as part of the structure the fuel reservoir and the transmission fluid reservoir.

A centrally pivoting single beam front axle is provided with extended king pins to give ground clearance and the space between the power unit and the front axle adapted to carry a load of 1000 kg.

Steering of the unit is through a recirculating ball type steering box which actuates rods attached to the king pins. This steering limits the load carrying capacity by virtue of the force required to operate the steering when under load.

A four point manual lifting drawbar was designed and fitted to the rear of the unit. The width of the tractor 1500 mm prevents the more conventional three point system being incorporated. Depth is controlled by a depth wheel attached to the drawbar and implements can be fitted by means of bolted brackets at any position on the drawbar.

Tyre equipment was given very careful consideration. The objective was to find a traction tyre that would be capable of absorbing the power available and give adequate traction under reasonable conditions. A 14 in tyre gave adequate traction and also was low in replacement cost. For soft, wet soil conditions either double wheels, cage wheels or 20 in wheels can be fitted.

Up until 1971/2 this development work had been undertaken on a part time basis with very little finance available. The results had been encouraging and it was decided that the design should undergo more vigorous field testing outside of the control of the designers.

For this purpose 20 units were built to the then specification and used as field test units on the recommendations of the National Institute of Agricultural Engineering, UK, in Tanzania, Zambia, UK and Swaziland.

Summary of the Swaziland tests (March 1973—March 1974)

Tractors started work on 5 March 1973 undertaking two types of work, ploughing and transport.

Tractor No.	Hours ploughing	Hours transport	Hours total	Days	Av/day
12	2134	1393	3527	302	11.68
89	2277	1006	3283	305.5	10.75
Circular track			4500		

Ploughing

The ploughing consisted of each tractor pulling a single furrow 30 cm by 20 cm deep.

Transport

All transport utilised the loading capacity of the tractor, no trailer was used.

Circular track test

The tractor was run continuously under load by the weight of extra fuel and periodically by a load cell, which simulated more strenuous work. The tractors were serviced at 250 hour intervals.

Results

On the basis of the test programme the tractors proved themselves under extremely arduous conditions to be mechanically sound. They met the work requirements indicated by the designers and the requirements of the small scale farmer. This testing here and elsewhere brought to light several problem areas in the unit, noise, comfort, safety and final quality. All these areas have been examined and changes have been made to overcome the problems.

Alan Catterick, Project Manager, Swaziland.

Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

The field testing with the commercial farmers proved the unit to be a sound financial investment by the owner; of the ten units sold four were fully paid for from the first cropping season, five were fully paid in the second season and the last unit is keeping abreast of loan repayments. In regard to this latter unit the farmer is limited to an absolute arable area of less than 2.2 hectares.

Design of a tractor unit must take into consideration the end user. In the Tinkabi case, the end user was going to be a person who had no mechanical knowledge who had little or no education and was living most probably many kilometres from transport routes.

The actual driving and control of the unit was ultra simple with a single lever which, when put forward caused forward motion, progressively faster as the lever was pushed further forward. Pulling the lever back to the centre position braked and stopped the tractor and pulling further back brought the tractor into reverse. The system had no adjustments and required only the changing of a spin on/off oil filter every 250 hours and oil change every 2500 hours.

The engine was built with an oil sump capacity of 10 litres as against the normal three litres. This meant that unless there was a serious oil leak the oil did not need to be checked in between service intervals of 250 hours. The fuel system caused probably the most problems because of contamination of fuel by water and dirt. To overcome this the fuel system was fitted with three filter units. Although this sytem had overcome most of the fuel problems the amount of contamination was so great at times that filters were choked within a week of operation.

The engine cooling was by means of an axial flow fan driven from the crank shaft by means of vee belts. Although a single belt would be adequate to drive the fan, two belts were fitted as standard, belt tension was by a spring loaded jockey pulley which ran on pre-greased ball bearings. The fan also ran on pre-lubricated bearings making it maintenance free.

The air cleaner, consisted of a single paper element type mounted horizontally on to the air intake. This filter was replaceable at 250 hour intervals and experimental work had shown that the filter under normal conditions did not need to be removed between these times. However, normal conditions were hard to define and as the tractor was used by the public it is now found necessary to fit a more comprehensive filter unit with a pre-cleaner and a larger paper element.

The remainder of the tractor unit was maintenance free. All pivot points on the front axle and king pins ran on self-lubricated bushes which showed a life expectancy equal to or beyond that of conventional bushes. Front hubs utilised two pre-lubricated ball bearing units, which also required no adjustment.

Even with such a design one cannot expect the end user to be able to effectively service the unit. It has been found that the small scale farmer uses his unit approximately 500 hours/year, this means servicing twice a year. As the agricultural year consists of only two seasons, servicing is recommended to be carried out at the beginning and end of each season.

In Swaziland, a service contract is entered into with Tinkabi purchasers, this means that twice/year the Tinkabi Company will service the unit in the field.

The provision of in-field repairs is always a major problem, the lack of sufficient qualified staff, poor working conditions and long travelling distances have proved time and time again to be uneconomic from both the repairer's point of view and also the farmer.

The Tinkabi is designed so that this problem is eliminated to a large extent. The transmission system is of modular design where each component is a self-contained unit, bolted on to the chassis or engine and easily accessible. This enables the field mechanic to easily and quickly check the transmission. If a unit is found to be faulty, it is removed and an exchange unit replaces it. The faulty unit is then returned to base where there are qualified engineers and the proper facilities for repairing the unit are available. The fixed cost of such an exchange unit is currently, pump £128.00 and hydraulic motor £100.00 each.

Although a similar situation exists with the engine it is very rarely used. Because of water contamination of fuel it is generally fuel pumps and injectors which are exchanged in the field by the service mechanic. The provision of other back up facilities including easily read parts books and instruction books are essential for any success in such schemes.

The Tinkabi system has now completed five years of in-field work with 400 tractors in the field. The system differs greatly from other systems, but is based upon actual field results, not boardroom decisions. The system is designed in such a way that the basic unit can incorporate a 20 kW power unit, hydraulic lift and more sophisticated equipment as the end user requires it. It does not fill every gap, but it provides a development tool for the emerging farmer, and may be a foundation on which countries may establish their own agricultural engineering manufacturing. It is an area that has long been neglected and an area to which more attention should be paid.

The light low-powered tractor for agricultural work in hot countries

J Bouyer

IT is important to give a short historical account in order to understand better the reasons which directed us toward the tractor for intermediate motorisation.

Agricultural mechanisation of tropical countries is vital to raise their economical level.

Therefore, it is indispensable to undertake at the same time:

the use of specially designed machines,

the creation of a specialised organisation for the introduction, maintenance and repair of the equipment.

The equipment for wet and dry cultures have to be studied according to a certain number of conditions, principally:

a) a simple machine which can be used and repaired by unskilled workers.
b) robust machines suited for hot climates and hard conditions of operation.
c) standard controls on the different models in order to be able to change operators.
d) a general design which enables local assembly requiring conventional machine-tools and normal workmen.
e) maximum standardised components and parts to enable quick repairs in changing sub-assemblies.

In West-Africa, namely in Ivory Coast and Senegal, trials have been carried out for more than four years and the results have led to the specification of a perfectly suitable two-wheel tractor.

On wet land cultivation: the equipment with a power of 7.5 to 12 kW meets all required conditions for paddy work ie providing good performance and allowing a normal profit compared with manual work.

On dry land cultivation: Possibilities are very great. The versatility of the two-wheel tractor enables an easy adaptation to the different cultivations found in various areas.

On vegetable cultivation: Row cultivation is very important and the different implements, *hoeing*, *weeding* and *scarifying* tools give excellent results under all conditions.

Ploughing can be carried out by a single or a reversible plough.

So we can tell that a special two-wheel tractor for tropical cultures can now play an important part in countries laying plans for agricultural development on *small areas*. Nevertheless, as another result of the numerous trials organised between 1973 and 1975 it appeared that, if the two-wheel tractor was well suited to the requirements of small scale farming, it was also necessary to complete the range by a four-wheel tractor with seated operator whose design and specifications were to be determined.

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J Bouyer, Tomblaine, France.

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This equipment is not able to replace either the two-wheel tractor for wet land cultivation or the high-powered tractors available on the market. It has to take its place between these machines, to perform on dry land cultivation, in middle scale farming, in the areas where an economical medium tractor with a high ground clearance could be introduced.

Numerous tests have been made with existing small tractors but results have not been satisfactory. The main reason for this failure is the design of the proposed equipment which were too sophisticated for simple work to be carried out under hard conditions and by inexperienced operators.

This important project had to be undertaken in close cooperation by an Organisation for the Development of Tropical Cultures, by a technical centre knowing perfectly the handling conditions of the machinery and also by a manufacturer believing in good prospects for the new equipment.

The CFDT (French company for the development of textile), the CEEMAT (Centre for the Study and Experiment of Tropical Farm Machinery) and the Bouyer Company, agreed to make out this programme of design, trial and advisory work.

The economical tractor of middle power had to be studied considering the particular conditions of the cultures and of the farmers and retaining the principles of simplicity, robustness and ease of operation and maintenance.

The reliability of the tractor had to be obtained by the use of standard components and further the design had to preserve the possibility of manufacturing *locally* certain sub-assemblies with conventional production-lines and normal workers. According to these requirements Bouyer Company has designed a machine which offers principally the following possibilities :

1 — Traction of all existing trailed tools (even those derived from animal drawn equipment)
2 — Adaptation of rotary tools similar to those of two-wheel tractors (rotary-tiller, shrub clearing cutter, stalk shredder . . . .)
3 — Adaptation of all semi-mounted ploughing tools for ploughing and row cultivation
4 — Adaptation of an irrigation pump
5 — Adaptation of a rear sickle mower mechanism fitted with a special cutting bar which avoids any grass clogging
6 — A front transport tray to be loaded up to 700 kg
7 — Quick adaptation of a treating set.

Also any optional implements which could be desired..

Literature with specifications is available for persons interested.

As it is stated on the literature, this tractor is composed of three types of sub-assemblies:

I *Mechanical assembly*, including:
Clutch — gear-box/differential and wheel-reducers.
Set of gears — differential lock.
Independent brakes on rear wheels.
This new designed set manufactured in the Bouyer factory benefits from the quality and price of standard parts.

II *Steering standard front axle assembly*
Also manufactured for classical agricultural tractors.

III *Frame and body*
Composed of simple rigid welded parts which can be manufactured easily on the spot.
Two optional equipments are available:
a) *Power take off*: either direct coupling with engine or standard speed rear power take off (1000 r/min).
b) *Drawbar or hydraulic lift*: The drawbar's height is adjustable to obtain the best draw-point.
The single acting hydraulic lift can draw universal semi-mounted implements of simple design.

The unit is propelled by any engine, single or two cylinder of between 12.5 and 21 kW.

The first prototype, tried in Ivory Coast, was equipped with a manual lift and with a set of different implements in order to assess the robustness, handiness and efficiency and the results made up by the CEEMAT in a detailed report show the reliability and the profitability of the machine. Certain rotary tools are now well tested and can be considered as effective.

Two other tractors equipped with pull-type implements were despatched to Centres of Experimentation in Mali and Senegal for a trial period during a normal growing season. They have been subsequently described by important persons "as equipment perfectly suited for tropical cultures". It should be stated that the pulled implements used were tropical cultivators called Tropicultors fitted with the standard line of tools for dry cultures: single and two-furrow ploughs, ridgers, scarifiers, etc. . . . .

Thus, a part of the objective, ie the simplicity and the possible progressive introduction at a low price was met, including the possibility to use as ploughing tools implements derived from animal drawn equipment already utilised by local growers and often already manufactured in certain countries.

By this method which involves a limited investment, growers who wish to come to motorisation, can re-utilise without important modifications the animal drawn equipment they possess, with which they are well-acquainted for use and adjustment.

It was then necessary according to the comments noted during the trials to study in a second stage *the adaptation of tractor mounted tools*.

There is no need to mention the great advantages of this process in terms of size, handiness and profitability.

The proposed method is directed towards an ease of adjustment and use due to a single acting hydraulic lift hitching semi-mounted tool with working depth adjustment by a depth wheel.

Effectively, as we consider as a principle that the tractor must be simple, that the implements have to be composed of well known and tested tools, often manufactured on the spot, it is a matter of course that the unit must remain simple in this connection and therefore not be fitted with a standard hydraulic lift as used on traditional tractors.

These standard hydraulic lifts, whose quality and performance are evident, are once again too sophisticated to have the tropical reliability considered as essential not only for use but for operating and maintenance in very difficult conditions.

Therefore, we have designed a very simple hydraulic lift requiring a one piece hydraulic kit, interchangeable at once which *can not cause trouble*. However this excludes an automatic depth regulation, all possibilities of self compensating for unevenness of soil and also of weight transfer effects.

The adaptation of semi-mounted implements give excellent results and owners are not finding problems of complicated adjustment and difficult operating, requiring constant attention. This adaptation enables the use of tools normally mounted on animal drawn equipment.

From the technical point of view, we think that we have designed an equipment appropriate for tropical cultures and placed at the top of agricultural machinery for intermediate mechanisation.

This technical experience had to be confirmed on a larger scale and therefore an advisory action was undertaken with the support of the CFDT (French company for the development of textiles) thanks to its local cotton companies.

For the growing season 1977, 70 tractors were distributed in seven countries: Senegal, Tchad, Cameroun, Mali, Upper-Volta, Ivory Coast, Central African Empire, and operated in areas permanently supervised by agents of the CFDT and the CEEMAT.

After one season of operating, which means about 1000 working hours for some tractors, a meeting of the concerned persons of each country was organised in October 1977 in Bouake (Ivory Coast) in order to draw up the results and conclusions.

It was stated unanimously that the principle of an economical tractor with the technical specifications of the equipment produced by Bouyer met the defined objective viz the motorisation of small and middle farms according to rational conditions of work and profitability. During this meeting, all information which was necessary to start a serial assembly was also given to the manufacturer.

Now it remains to be defined accurately the labour and machinery costs and the exact return. Therefore a further development of the advisory operation is necessary. This will be made during the next season 1978 by the introduction of approximately 200 new tractors. It is to be noted that the various questions asked confirm that users accede to this idea of intermediate mechanisation.

All this proves that it is really possible in devoting oneself to resolve the problems raised by tropical cultures and to create satisfactory equipment but the main question now is to convince the local authorities and the potential users who are showing some reluctance as a natural consequence of the previous tests made with equipment, certainly of excellent quality, but which were not designed to work in the local conditions.

We have not yet spoken of commercial problems and I believe that it is indispensable to mention briefly the different conditions required for a definitive introduction which will give total satisfaction to users. Let me mention the necessity of operator's training, an organisation for after sales, maintenance and service for the equipment set in work.

I am convinced that even equipment perfectly suited to cultivation in hot climates but which was not matched with a training scheme for the operation and maintenance would not give the hoped for results.

The training of operators has to be undertaken with special attention. It is to be noted that even in Europe certain equipment of excellent quality and of a very modern design has failed to meet the requirements simply because it was mis-operated by untrained people. In tropical countries where workmen are not used to mechanical equipment, it is much more important to do this training, which is an essential condition for the development of mechanisation.

As for spare parts and repairs service, it can be considered a vital principle of all development plans, having taken into consideration the disappointment noted in the results of farm-mechanisation which was due to lack of spare-parts and technical staff. An insufficiency of organisation in this matter might destroy any effort undertaken from the technical point of view. So it would be a pity to be trapped once again and special attention has to be directed to this matter of training and service, and availability of spare parts in the territory, which is a complement to the previous research.

This organisation must be carried out by the concerned local authorities, by the importer and by the manufacturer together. In the particular case of the Bouyer Company, we are executing training schemes either in our factory or on the spot and the programmes implemented up to the present time have given excellent results.

This was a team effort and I would like to take this opportunity to thank the different French authorities which have participated to this programme and particularly the CEEMAT and the CFDT which were very efficient in promoting the general idea of designing a range of equipment not existing but surely required.

The Japanese small tractor

Noburu Kawamura

Introduction

TWO wheel tractors have played a leading role in farm mechanisation in Japan and about 3 million units are now in use. Recently, owing to a high degree of economic growth and a shortage of rural labour, four wheel tractors have been extensively introduced and 832 000 units are in use. Four wheel tractors are in use on only 17% of the total number of farms but riding tractors are now taking the place of the walking type. Production of four wheel tractors in 1976 amounted to 235 900, whereas in 1967 it was 23 900, an increase of about ten times in ten years. On the other hand the production of two wheel tractors has decreased to 295 600 units from 477 700 units at the peak production time of 1967. Most of the tractors used in Japan are small ones. The number of tractors under 11 kW accounts for 47.8%; 11–15 kW, 24.2%; 15–22 kW, 20%; over 22 kW 8%. The bigger tractors are almost entirely imported and domestic production is limited to those under 60 kW. This is mainly due to Japanese agricultural conditions of small farming, part-time farming and rice cultivation. The total number of farm households is 4 953 000 and 87.8% of these are part-time farms whose owners depend on employment in industry and/or commerce for supplementary earnings, whilst the rest are full-time farms. The typical farm has an area of approximately 0.5–1 hectare. The total arable land area is 5 615 000 hectares, of which 3 209 000 hectares are paddy field and the rest upland field. The size of paddy field is normally about 0.1 hectare for convenience of irrigation and drainage. Paddy fields are now being consolidated to 0.2 to 0.3 hectare or more for improving the field efficiency of riding type farm machinery.

Tractor types and characteristics

The tractors produced in Japan are of the conventional type and most of them are in the range from 7–22 kW. The Japanese tractor may be classified as a small tractor, but it is a farm tractor, rather than a garden tractor which has a gasoline engine and lighter construction. The main characteristics of Japanese tractors may be indicated as follows:

(1) Rotary tiller tractor
(2) Multiple speed with creeping speed
(3) Multiple pto shaft speed
(4) Multiple cylinder diesel engine of high speed
(5) Four wheel drive.

These characteristics are very suitable for Japanese farming, ie small and intensive farming, small fields, soft and wet paddy fields, higher precision work and ergonomic demands which year by year become important.

Rotary tilling is more dominant than ploughing in Japanese paddy fields and Japanese tractors are designed to operate with rotary tillers rather than as traction type tractors. Ploughing leaves furrows and ridges and a secondary tillage such as harrowing and puddling for levelling the field is required. On the contrary, rotary tilling results in good soil pulverisation and there is no need for harrowing, since the puddling operation with a rotary tiller makes a level paddy field.

A rotary tiller has advantages when running on the paddy field. Rotary tilling is a positive tillage and the soil reaction R as shown in fig 1 resulting from the up-lift force V and the horizontal thrust H, being just the reverse of those of a plough, assist the running of the tractor on the field. On the paddy field conventional traction efficiency is lower, with higher rolling resistance and slippage of wheels. In rotary cultivation, however, engine power is directly transmitted to the rotary blades for tilling the soil, so that the active tillage with a rotary tiller is more effective than the passive tillage as with a plough.

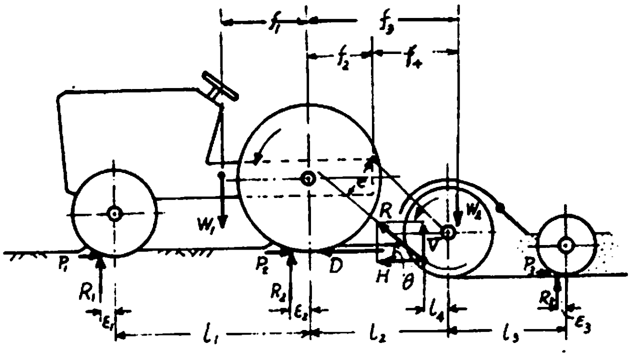

Fig. 1 Forces acting between the tractor and rotary tiller (four wheel tractor).

Tractors need more durable engines and construction for farm use. Diesel engines of multiple cylinders are dominant. Even a 10 kW small tractor has three cylinders, and a 7 kW has two cylinders. It is mainly due to the severe ergonomic demands in domestic use, especially noise and vibration reductions, which are important in the tractor design.

Multiple running speeds and pto shaft speeds are suitable for rotary tilling and other operations on the paddy field and the up-land field.

Another characteristic feature is 4-wheel drive, and hydraulic position controls are also common for the small tractors. They are also very suitable for rotary tilling. Draft control is usually available only on the bigger tractors of over 22 kW. Recently electronic position control or power control of the rotary tiller and hydro-static drive or power shift transmission has come on the market.

Design and technical features

In 1977 about 157 models of domestic produced tractors with engines ranging from 7 kW to 60 kW were available on the market. Their design and technical features are adapted to Japanese conditions.

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Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

Tractor weight

The tractor weight and its distribution on the front and rear axles are important factors for the trafficability of the tractor. The weight per kilowatt of the small Japanese tractors has lower values than those of European tractors as shown in fig 2. The domestic tractors have about 40–75 kgf per kilowatt, and have a general tendency to decrease these values with increase of engine power. The main reason why the tractors have lower weight per kilowatt is to suit the extensive usage of the rotary tiller, ie the design principles of the rotary tiller tractor. It needs more power applied to the pto shaft and less tractive force and power. The lower value of the weight per kilowatt is achieved by using high speed diesel engines and lighter construction, and this improves the trafficability on soft and wet fields. Almost all tractors have two models, 2-wheel drive and 4-wheel drive. The weights of the 4-wheel drive tractors are higher than the 2-wheel drive ones by 40 to 100 kgf because of the increased engine power.

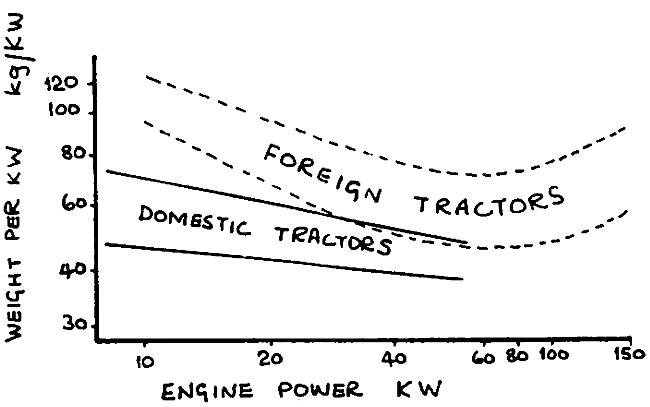

Fig. 2 Power weight ratio of tractors.

The weight distributions on the front and rear axles for the rear wheel drive tractor are about 45% at front and 55% at rear. For the bigger tractors the front weight percentages decrease to 40–42%. If the front axle lead is light, there is a danger of the front wheel rising. If it is heavy, on the contrary, the steering on soft and wet fields is worse. These front axle values may appear a little higher than is common with tractors, but with the mounting of the rotary tiller on the tractor the values become about 23–28%. The weight distributions of the four wheel drive tractors are almost 50% to 50% on the front and rear axles.

Engine

Almost all of the tractors, even those of low power, are fitted with multi-cylinder diesel engines rather than gasoline engines. A few years ago there were some tractors which had single cylinder horizontal engines but almost all of these have disappeared from the market. The tractors in the range 7–19 kW are normally fitted with two cylinder diesel engines, 19–26 kW, three cylinders and over 26 kW four cylinders. Recent trends are for even 10 kW class tractors to have three cylinder diesel engines. In spite of small horsepower multiple cylinder engines resulting in smaller cylinder diameter and a loss of the advantage of the flexible torque characteristics of the diesel engine and a higher cost, the design is aiming to adapt to the demands of lower noise and vibration.

The typical characteristics performance curves of diesel engines are shown in fig 3. Torque curve of smaller engines is comparatively flat for a wide range of engine speed, and this is suitable for the heavy rotary tilling work. This means that the smaller engine has less power in reserve and must be able to work on heavy load without being sensitive to speed changes. The bigger tractors which are used for tractive works or for export have characteristics that the torque curve increases by 20–25% with a drop of speed from the maximum horse power.

The speeds of engines are higher than those of European ones, resulting in the trend to lighter weight of engine and higher power output per displacement (fig 4). The rated speed of a typical engine is about 2200–2800 r/min.

The minimum specific fuel consumption is about 270 g/kWh at the speed ranges of the maximum torque.

A small turbo super charger of 15 000 r/min maximum has been applied recently to a tractor of 22 kW with 1487 cm^3 displacement, in order to obtain 28 kW output from the same engine. The super charger increased the output horse power per displacement to 19 kW l as shown in fig 4 and also improved its thermal efficiency. Another aspect of the application of the turbo super charger is that the driver who has an easily obtainable small car licence can drive a tractor of which the engine displacement is under 1500 cm^3, under current traffic regulations.

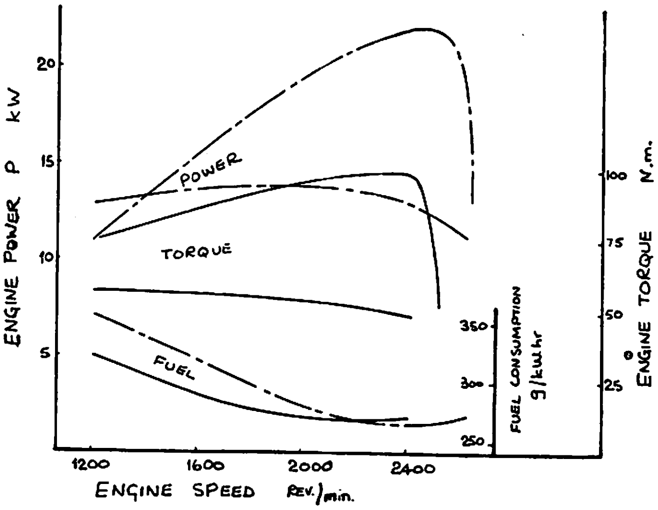

Fig. 3 Characteristic performance curves of tractor engines.

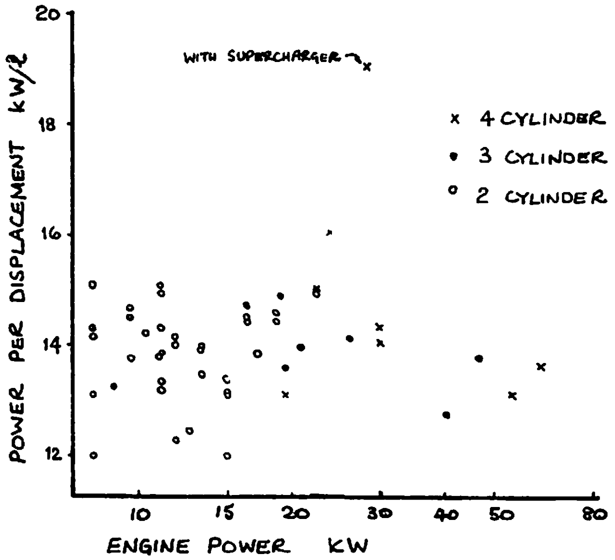

Fig. 4 Power per displacement

Transport devices

The majority of the tractors used in Japan have six forward speeds from 0.85 to 14.6 km/h, and two reverse speeds. The maximum speeds of the smaller tractors is a little lower, around 10 to 12 km/h. New tractors have more speeds, often 16–24 speeds with creeping speeds. The minimum creeping speeds are about 0.1–0.2 km/h. Normal tilling speed is 1–2.5 km/h, so that six speeds are enough for ordinary tilling works. But lower travelling speeds or creeping speeds are used for fine tilling, deeper tilling and transplanting etc. These multiple speeds of small tractors enable them to adapt the rotary tilling operation for various soil conditions. Many gear ratios are necessary for the pto driven equipment which must run at fixed speed and hence does not allow the travelling speed to be changed by altering the engine speed.

The highest speeds of small tractors of which the engine displacement is less than 1500 cm^3 is limited to 15 km/h by the legal restrictions of the road traffic regulations.

Some tractors have stepless hydrostatic transmission. They have an advantage that the travelling speed can be changed under loaded conditions without stopping. They are also very useful for front loader operation with repeated forward and reverse travelling. The efficiency of the hydrostatic transmission is lower than that of a gear type. Some tractors have power shift transmission in which gears are shifted by hydraulic power. It has a better efficiency than that of hydrostatic transmission, but is not a stepless change.

Continued effort is being devoted to the development of automatic control of the forward speed with sensing of the rotary tilling load or engine output.

For travelling on soft soil a differential lock is essential, and also there are many subsidiary devices such as girdles, strakes, cage wheel, half track and special pneumatic tyres, so-called high lug tyres. Nowadays country roads are paved using revenue from petroleum tax, so that high lug tyres are more common.

Four wheel drive with smaller front wheels is another useful layout for travel on soft soil. It has about 30–40% more tractive force than the rear wheel drive under the same condition. It is also convenient for travelling over the ditches of paddy fields and for hillside work. The wheel bases of the smallest tractors of 7 kW class are about 1100 mm; tyre sizes of the front wheel are 4.00-10 2 ply; 4.00-12 2 ply for four wheel drive; 7-14 2 ply for rear wheels.

Power take-off shaft

Most European tractors have only one or two pto shaft speeds of 540 and 1000 r/min, but domestic Japanese tractors have usually three or four speeds. The tractors over 11 kW class have a standard speed of 540 r/min, but smaller tractors have their own speed ranges suitable to own rotary tillers. Some examples of pto shaft speeds are shown in table 1.

Table 1 Pto shaft speeds

	Engine power kW ⟶	8	8	16	22
Pto shaft speed	1st	462	540	547	542
	2nd	765	847	709	686
	3rd	1280	1320	929	1005
	4th			1230	1268

Rotary tilling operations require more rotary speeds according to the soil condition and the degree of soil pulverisation required. If the change gears are on the tractor, not on the rotary tiller, the gear shift is easily operated from the driver's seat and allows a lighter weight of rotary tiller. Small tractors can be used with the combinaation of many pto shaft speeds and many travelling speeds for various farm conditions.

Hitching and hydraulic system

The tractors over 11 kW class usually have a three-point linkage hitch. The smaller tractors ranging 7 to 11 kW have a special two-point linkage hitch or direct fitting devices such as the rotary tiller. The bigger tractors have the three-point linkage hitch of category 1. The smaller tractors have that of category 0. The category 0 in JIS (Japanese Industrial Standard) is almost the same as that of category 1N in ISO plan, except that it has a wider hitch point spread of 565 ± 1.5 mm (400 ± 1.5 mm in ISO), a longer mast height 410 mm (360 mm) and a smaller lift range of 300 mm (420 mm). These differences are mainly due to the fact that the Japanese hitch is for the rotary tiller but the European one is for the plough.

The capacities of hydraulic pumps used in the 7 kW class are about 7 l/min, and gradually increase with higher power to 30 l/min in 22 kW class. The relief pressures usually used are about 13.7 – 15.2 MPa).

Small tractors have no position control system, and tilling depth is controlled by the gauge wheels attached behind the rotary tiller. The tractors over 11 kW class usually have position control. It gives a more level cultivation and more tilling force by combining the weight of the tractor and the rotary tiller, when the control valve is in neutral. The bigger tractors over 22 kW have also a draft control system.

Recently the electronic hydraulic position control system or the combination of position and power control system of the rotary tiller has come in the market. One position control system has a sensing device attached to the rotary tiller cover which touches on the ground. Another position control system has a sensing device consisting of a potentiometer attached to the lift arm shaft, and rotary tilling power is sensed by the drop of engine speed using the alternator's electric pulse and converted to an electric voltage by means of an electronic circuit (fig 5). The electric signal actuates the magnetic valve and lifts the rotary tiller in steps. With this system there is no need to use the gauge wheel and it can be easily adapted to various soil conditions and cultivation requirements.

Farm implements

Although the rotary tiller is the main implement for the small tractors as mentioned above, there are many choices of other implements such as plough, harrow, vibrating mole drainer, seeder, broadcaster, pest control machine, hay making machines and front-loader.

The rotary tillers for small tractors have relatively shallow tillage depth between 10 and 15 cm. The tilling widths are usually wider than the outer width of the tyres to achieve higher capacity and better finishing of tillage. The minimum width of the rotary tiller for tractors in the 7 kW class is about 900 mm.

The desirable design features of the rotary tiller for the small tractor are to reduce its power consumption in spite of its width, so that the number of tilling blades is reduced, tilling speed is lowered

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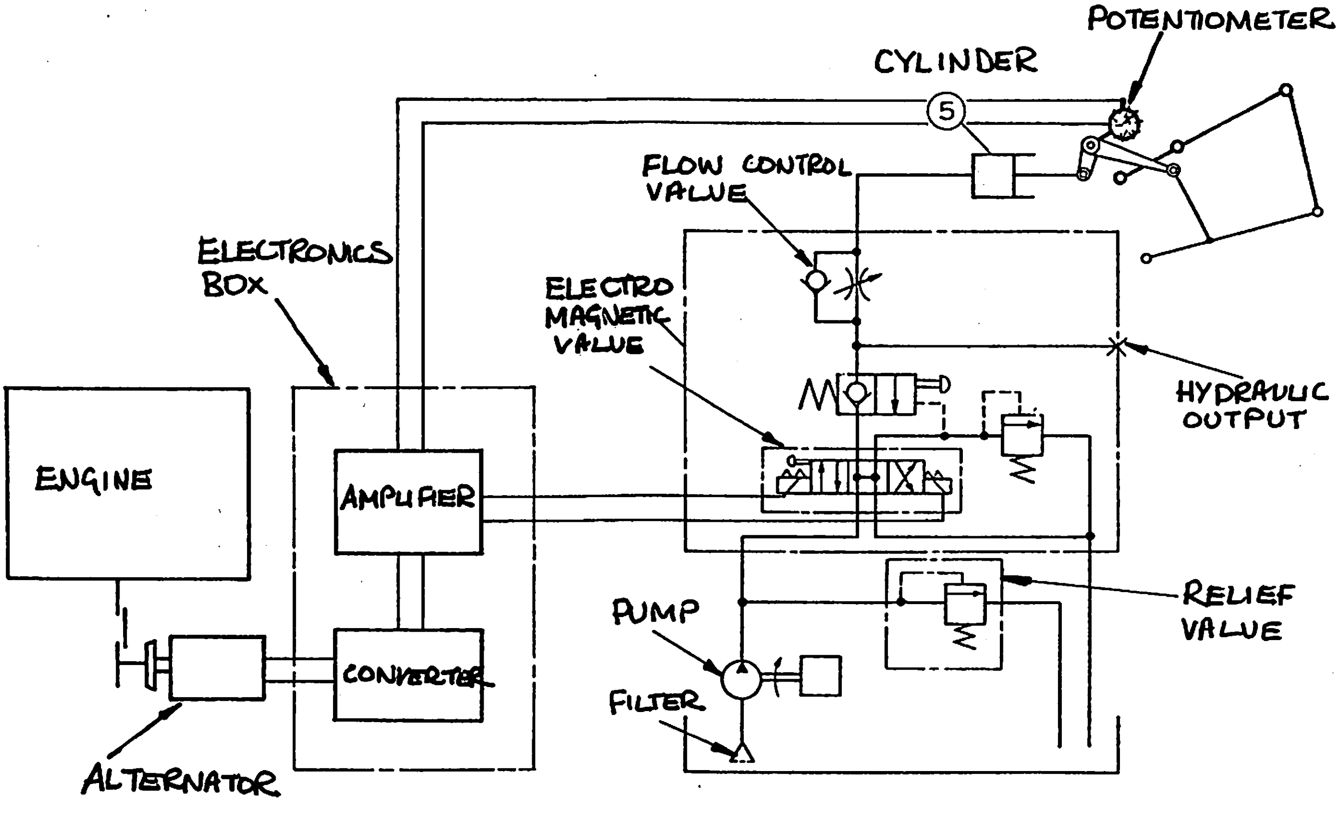
Fig. 5. Electronic hydraulic control system



and lower strength blades can be used. Ordinary tilling speeds are, for example, 170, 220, 320 and 410 r/min. The high fluctuating torque of the rotary tiller are the limiting factors of the rotor design.

The deep tilling depth rotary tiller is designed so that its shaft sinks down under the ground level, using very slow travelling speed and a special blade arrangement.

The front loader is also attached to the small tractors. It is very useful for hay handling for small farms and for snow moving. The rotary tiller is not removed for these operations as it provides rear weight. There is a quick attaching device for the front loader (docking loader).

Other technical problems

The tractors are often used for puddling on paddy fields, and then the water-proofing of the brake system, front axle, rear axle, pto shaft and rotary tiller shaft is an important design factor for rice cultivation. The brakes of domestic tractors are sealed and sited on the shafts in front of the rear axle. Rubber seals and O-rings are fitted at many places on the shaft systems.

Safety and comfort of the driver are a big problem for the designer of a small tractor. The safety frame for small lightweight tractors gives new problems due to the higher centre of gravity and consequent danger of overturn. Although there is not yet a legal requirement to attach a safety frame or cab, this is a future problem to be solved.

Other ergonomic demands of noise and vibration reduction, as well as lower emission of CO and NOx are current problems of new tractor design and technology.

The Amex tractor

V J Dare-Bryan

Introduction

IN 1975 AMEX, the Shaftsbury-based overseas consultancy firm, and myself became associated in a research and development programme into small-scale mechanisation possibilities for smallholder farmers, especially those in the tropics. Specificaly, we aimed to design a small tractor which would be appropriate for such situations and would fill the gap between a team of good oxen and a 26 kW (35 hp) conventional tractor. Thus, right from the start we considered that such a machine would be successful only if, amongst other things, it produced sufficient tractive force to be able to plough and cultivate the land in dry soil tropical conditions, where delay in planting after the onset of the rains can have a dramatic effect upon food crop yields.

The failure of past attempts elsewhere to produce a successful small tractor for the tropics was considered by us to be most often a result of one or other of the following errors in design concept:—

(1) Attempting to employ a design so far removed from a conventional tractor with four wheels that in practice it turned out to be either insufficiently powerful or stable or else very difficult to control; or

(2) conversely, simply scaling down a conventional tractor design while attempting to retain all or most of its design features (electrics, full hydrualics, 4-wheel drive, etc) which, although convenient, are a positive disadvantage in the less developed market due to greater risk of breakdown and also make the machine prohibitively expensive both to buy and to maintain.

Both of these errors are, in fact, the result of an inaccurate appreciation of the actual requirements of the majority of smallholder farms in developing countries where power, reliability and economy relative to their particular cultivation needs are all essential.

We therefore determined the following design:—

(i) The tractor should be powerful enough to plough a furrow through the hardest tropical soils likely to be cultivated — dry, compacted or panned ferruginous soils requiring up to 4.45 kN (1000 lbf) drawbar pull per single furrow.

(ii) The tractor must be durable, keeping breakdowns to the minimum under adverse conditions demands the utmost simplicity of design and construction, large safety factors in designed stress-loadings, while engine, bearings, etc must receive maximum protection from dust, shock and overheating. Simplicity of design will also mean that assembly or chassis fabrication can be carried out locally, where this will save costs.

(iii) The tractor must be cheap to buy; we judge that it should be able to be sold in export markets at a price of not more than US $3,000 equivalent, in terms of today's prices, bearing in mind that the farmer will also have to purchase implements, trailer, etc.

(iv) The tractor must be economical to run) low fuel consumption per acre, infrequent servicing and renewals, ability to run on the cheapest fuel locally available.

(v) The tractor should be safe to operate; in particular, risks of overturning as an indirect consequence of operator inexperience to be minimised through exceptionally high design stability, within the constraints of sufficient ground clearance and maximum track width.

Traction was the number one factor taken into account in the design of the Amex tractor. Number two was initial cost, and three, durability and operating economy.

Required drawbar pull could be roughly established in excess of 4.45 kN (1000 lbf). Tractive efficiency of the average tractor is approximately 70%. Therefore, the approximate minimum weight of the tractor works out at 590 kg (13 000 lb). This weight rules out a 2-wheel or single axle design. Cost ruled out a 4-wheel drive design.

Concerning weight distribution, as it is a 4-wheel, 2-wheel drive tractor, a greater percentage of weight was required on the rear wheels. This indicated a rear engine configuration. It was also necessary to keep the centre of gravity as low as possible due to narrow track.

Finally, every effort was made to keep the tractor compact, thus ensuring good manoeuvrability when working in small awkward shaped fields or narrow tracks.

The tractor is relatively simple and cheap to manufacture and therefore lends itself to production or assembly in developing countries. Ease of maintenance and durability were major considerations in the design of the tractor which will plough, cultivate, and can be used as a power source to drive other types of machinery as well as to fulfil essential transportation needs.

General layout

The tractor consists of a full length chassis which carries the front axle, and the engine-transmission-rear axle package, and the hydraulic three-point linkage at the rear. The engine is transversely mounted on top of the transmission directly over the rear axle. The driver sits in front of the engine, and under the seat is the fuel tank.

Engine, transmission and rear axle

The tractor uses either a petrol or diesel engine. The petrol engine is a single cylinder, 4-stroke, developing 12 kW (16 hp) at 3500 r/min. It is cast iron and air-cooled, with a recoil pull for starting. The diesel engine is a single cylinder, 4-stroke, developing 13.5 kW (18 hp) at 3000 r/min. This engine uses a counter shaft driven by spur gears from the crankshaft, which cancels out the out-of-balance forces associated with single cylinders and hence avoids much of the excessive vibration associated with this type of engine. This engine is aluminium alloy and air-cooled, and uses electric starting.

Either engine is mounted directly on top of the cast iron transmission casing. On the engine crankshaft is a multi-pulley for

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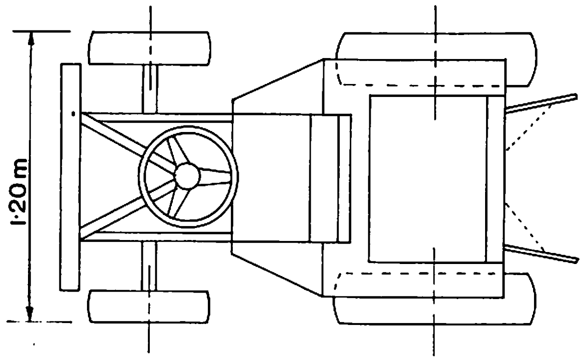
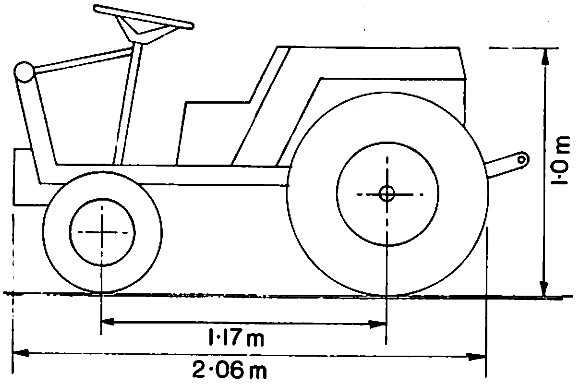
Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.





the belt drive to the gearbox, which acts as the clutch by the use of a sprung jockey pulley. Also driven off the crankshaft pulley is the hydraulic pump and a spare pulley for driving stationary machinery.

The gearbox has four forward speeds and one reverse. Maximum road speed in top gear is 20 km/h. The gearbox output shaft speed is reduced by spur gears to the differential. The half shafts are open and extend on either side. The disc brakes are mounted inboard and the mechanical calipers are bolted directly on to the sides of the transmission casing. Outboard are the main wheel bearings which are mounted on the chassis.

The chassis

The chassis is a simple twin-rail type with raised cross members front and rear. The front axle is centre pivoting and the steering box mounted directly behind. Over the front axle is a concrete ballast weight incorporating the battery. Brake and clutch pedals are on either side of the steering column. The throttle control is below the steering wheel. Hand brake and hydraulic lift control are on either side of the seat. Rear mud guards and the seat are a single moulding, pivoting at the rear for easy access to fuel tank, transmission, hydraulic pump and clutch mechanism. The rear cross member behind the engine carries the inboard mountings of the three-point linkage and the single acting hydraulic ram which lifts the lower arms. Levelling of the implement is done by hole selection in the drop links. Also incorporated in the cross member is the drawbar.

Testing

During the tests we increased the front wheels from 4.00 x 8 to 5.20 x 10. This reduced pitching over rough ground and improved steering.

The rear tyre size was also increased from 6.00 x 16 to 7.50 x 16 and water ballasted. Wheel weights were fitted at the rear, 68 kg per wheel.

The all up weight of the tractor plus single furrow mouldboard plough was now 800 kg. Depth of furrow was 180 mm, width 250 mm.

Fuel consumption was 1.1 l/hr (diesel) ploughing medium-heavy clay loam; slip was approximately 10%.

Further tests have shown that the tractor achieves a very high ratio of tractive efficiency, even under adverse ground conditions, with measured drawbar pull figures well in excess of those required for penetration of hard panned tropical soils.

Operational aspects of tractor use in developing countries – A case for the small tractor

F M Inns

Summary

THE costs of tractor operations in developing countries are estimated by extension from well founded data in developed areas using comparative cost factors. Apart from intensively managed projects, operating costs are likely to be at least twice the cost of use in developed countries. The difference is due to the costs of repairs and poor serviceability.

It is argued that these costs can be very substantially reduced by local manufacture of a "low powered agricultural machinery system". Beneficial effects will also accrue to the strategic infrastructure of the country through the development of manufacturing and management skills.

Introduction

Methods and data for identifying optimum mechanised farming systems, which of necessity include the costing of farm machinery operations, are well established (*vide* Culpin 1975, Hunt 1973). These methods have reached a high and effective level of sophistication when applied to a wide range of enterprises in industralised countries where high value agricultural produce has an established and stable market.

The background against which mechanised farming systems must operate in developing countries shows marked differences from that in the developed countries (table 1). Many of these differences will have a considerable effect on the costs of and returns from mechanised agricultural production. Data required to evaluate these effects are not easily available and often unreliable. Nevertheless significant contributions, such as by Chancellor (1968), have been made towards developing viable techniques of direct analysis.

Agricultural production infrastructure

Encouragement to persist in applying conventional costing methods in developing countries arises from the success of such methods when applied to many estates and intensively run farming schemes. Such schemes are usually not characteristic of the general country background, relying heavily on a concentration of scarce local skills, imported management and modification of the local infrastructure, such as communications, supplies and services.

Strategically, development should encourage more widespread progress. Such progress might not at first appear as impressive as a number — perhaps a considerable number — of concentrated schemes, but the argument can be sustained that steady progress on a wide front is complementary to intensive schemes, and possibly the more desirable form of development. Therefore the general strategic infrastructure should be developed together with limited areas where a tactical infrastructure may be imposed in advance of more general progress.

The application of conventional costing systems

Conventional costing systems have been less successful in assessing tractor costs for operations conducted in the general infrastructure rather than a locally modified one. Necessary data to feed the assessment method are lacking and would in any case show considerable variation depending on locality. An alternative approach can be made starting from existing data for developed countries and applying factors to take account of relevant variations of infrastructure between developed and developing countries.

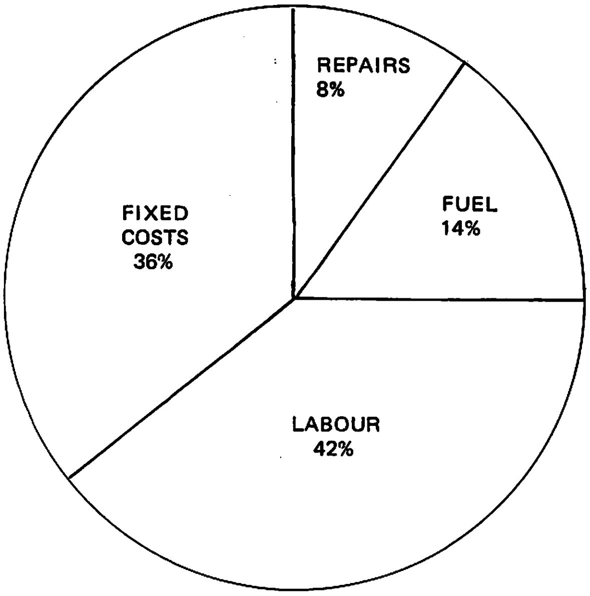
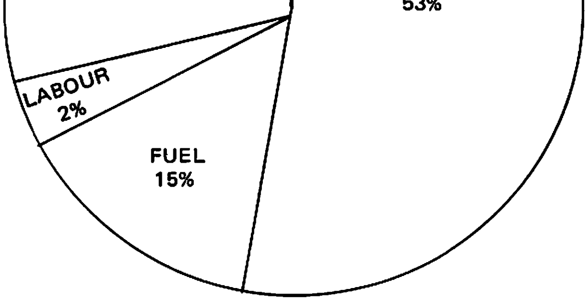


Fig 1 Relative importance of cost items for diesel tractor operation (USA figures)
Source: Hunt 1973

Fig 2 Relative importance of cost items for diesel tractor operation in a developing country
Calculated figures, see Table 2
Repair frequency factor = 2



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Paper presented at the Spring National Conference of the Institution of Agricultural Engineers, held at the National College of Agricultural Engineering, Silsoe, Bedford, on 21 March 1978.

Table 1 Factors affecting planning, operation and profitability of mechanised farming systems. A comparison between developed and developing countries.

Developed countries	Developing countries
Markets Stable high prices, often guaranteed, from a well organised protected home market, underwritten by a viable industrial economy.	Precarious export prices dictated by a relatively volatile world market. Domestic market often poorly organised with low prices to the producer.
Communications Intensive high grade network with well organised services.	Often sparse, based on low grade roads and consequently high costs and unreliable performance.
Supplies and services	
(i) **Engineering products.** Intensive and strongly integrated distribution and servicing networks. Short and rapid supply lines. No foreign exchange problems.	(i) Availability of spares frequently poor with long delays. Usually expensive. Servicing organisation frequently poor and sparsely located. Shortage of foreign exchange can influence availability adversely.
(ii) **Agricultural inputs.** High grade seeds, fertiliser etc. freely available.	(ii) Often unavailable, or at high cost, with supplies unreliable as a result of poor communcations.
Labour Skilled and educated labour available at high cost.	Moderately skilled and educated labour available at relatively low cost. Shortage of skilled and experienced techncal staff.
Management High grade and experienced managers widely available. Reliable planning data available.	Shortage of experienced managers. Planning data sparse and variable in its reliability.
Information dissemination Written and broadcast information widely available. Well organised advisory services.	Extension services often well organised by relying heavily on verbal communication.
Capital Readily available to credit worthy customers.	Credit worthiness of customers and their proposals often difficult to assess. High cost of private capital but low-cost government sponsored credit often available.
Land Highly priced but well developed.	Developing farming land is often highly priced. Less developed land usually requires considerable investment to make it suitable for mechanised operations.

Such factors, many of them based on direct price comparisons, may be readily determined or judged.

Hunt (1973) suggests, quoting Fairbanks, Larson and Chung (Kansas State University) a cost breakdown for operation of a diesel tractor as shown in figure 1.

The cost breakdown in a developing country will obviously differ from that shown by Hunt — it would for example be expected that labour costs would be much lower. Table 2 shows one way in which an adjustment can be made and the result is illustrated in figure 2. Assumptions which have been made are:—

a) Fixed costs: These (depreciation, interest, taxes, insurance and housing) are all taken as proportional to initial cost, which is itself taken as 50% higher in the developing country.

b) Labour cost: Taken as one tenth of the labour cost in the USA

c) Fuel: Cost taken as double

d) Repairs: Hunt quotes 8.4%, taken here as 8% and considered to be broken down into 75% spares cost and 25% labour cost. Cost of spares is taken as five times the cost in U.S.A., labour as one tenth.
Superimposed on these ratios is a factor for increased frequency of repairs in developing countries, taken as x 2 in column a, x 3 in column b and x 4 in column c. The replacement factor is suggested as a function of serviceability: 80% serviceability is assumed and the 20% may be looked on as a hire charge for a replacement tractor whilst the primary tractor is under repair.

The estimates can be improved by the use of more refined data for specific cases but a general conclusion is evident: the operating costs of a tractor in a developing country may well be more than double those in a developed country, and the increase is entirely due to lower serviceability and increased costs of repair. Without the increase in repair costs there is the possibility of a slight

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Table 2 Comparison of tractor operating costs in developed and developing Countries

Item	*% total cost (USA)*	*Developing country factor*			*New weighting*			*% total cost (developing country)*		
		a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Fixed costs	36	1.5	1.5	1.5	54	54	54	29.5	26.4	20.9
Labour cost	42	0.1	0.1	0.1	4.2	4.2	4.2	2.3	1.9	1.6
Fuel	14	2.0	2.0	2.0	28	28	28	15.3	12.7	10.8
Repairs: parts	6	10.0	15.0	20.0	60	90	120	32.7	40.7	46.4
labour	2	0.2	0.3	0.4	0.4	0.6	0.8	0.2	0.3	0.3
replacement	—							20.0	20.0	20.0
								100.0	100.0	100.0
Ratio of total costs — Developing country/USA								1.8	2.2	2.6
Increase due to increased repair costs								0.9	1.3	1.7

Note: a, b and c refer to factors of two, three and four for frequency of repair — see text.

decrease in operating costs because much lower labour costs would more than compensate for higher fuel costs and purchase price.

It is necessary to look in more detail at the assumptions made in estimating repair costs with a view to reducing the cost factors put forward.

Tractor repair costs in developing countries

The multiplication of cost of spare parts between producer and user country has been taken as five times. In the author's experience multiplication by seven is not uncommon and the factor chosen appears justified. The dealer's justification will lie in the cost of shipping, clearing, insurance and/or pilfering, transport and distribution, the need to maintain a high level of stocks due to extended delivery times and the cost of maintaining sufficiently high stock levels to service a scattered and relatively small group of customers. An additional justification for the factor chosen is that the price paid for a spare part and entered on stores records is often a quite inadequate reflection of the true cost after taking into consideration the time and money which is frequently involved in travel to locate or pick up essential spares.

Possible methods to reduce the high cost of spares include standardisation of equipment, local production of spares, or the establishment by manufacturers of regional depots so that spares not obtainable immediately can be called up within two or three days.

It was suggested (table 2) that repairs may be undertaken several times more frequently in developing countries. Factors of two, three and four used in the calculation can readily be observed in practice due to severe operating conditions, unskilled operators, poor maintenance, unnecessary repairs due to wrong diagnosis, lack of diagnostic equipment and tinkering, consequential damage arising from non-replacement of failing parts and other causes. This factor could be reduced by the use of simpler equipment, operator and mechanic training and perhaps most of all by the pride and responsibility promoted by ownership.

A serviceability factor of 80% is, from observation, not unrealistically low for tractors which are not operated on intensively managed projects, nor by owner operators. It is assumed in calculations that a similar tractor is hired or kept to undertake any shortfalls due to unserviceability. Otherwise loss of timeliness or even failure to complete essential operations could multiply the assumed cost of unreliability.

A strategy for developing countries

If one accepts that the tactical solution to the problems outlined, i.e. setting up intensively managed large scale projects, is not feasible due to limitations of capital and of skilled and experienced managers or else is undesirable because it concentrates development into too limited an area, then a strategic solution may be looked for.

Many of the spares problems outlined could be alleviated by local production, with beneficial saving of foreign exchange. But current mass-produced tractors are economically produced by using sophisticated materials and production techniques, which are not consistent with the infrastructure generally existing in developing countries. Nevertheless basic manufacturing skills are available and could be developed to produce components which are specifically designed for small-batch production from general purpose materials by processes which are relatively labour-intensive. Such specifically designed components would stem from a specifically designed tractor.

Such a tractor would in consequence be radically different, from a production engineering point of view, from existing mass-produced tractors. A number of advantages would arise if it were a small tractor. It would be cheaper than a large tractor produced by similar techniques, though how much cheaper would be a matter for investigation.

Ownership could thus be more widespread. A more significant fact might be that the management skills to plan the effective use of a small tractor would be much more widely available than for a large tractor and their further development would be encouraged.

The essential small tractor

The essence of the small tractor is that it must be produced in the user country. A small tractor exported from an industralised country will suffer from high cost of spares and delays in availability and delivery which lead to high operating costs as previously identified. Its design rationale rests equally on its integration with viable agricultural production systems, which might be novel but must be proved and acceptable, and the contribution it can make to developing the strategic infrastructure of the country.

The design of a small tractor

It is not necessary to this conference to expound views on the design of a small tractor since others have that brief. Let it merely be recorded, from a personal viewpoint:

1. The term "small tractor" is used as a synonym for "low powered agricultural machinery system"
2. The insight exists to design an effective "small tractor"
3. It will truly be the work of an agricultural engineer.

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1978 Autumn National Conference

10 October 1978, starting at 10 30 h, closure approximately 16 45 h.

At The Lorch Foundation, High Wycombe, Bucks.

Subject: "Specialised Prime Movers in Agriculture"

Conference Chairman: D N Scott BSc AMIO *Past Chairman National Association of Agricultural Contractors*

Programme:

Paper 1	Horticultural tractors including vineyard and orchard. John Bennett BA *Product Planning Specialist, Massey Ferguson Co*
Paper 2	High clearance tractors. Lamar Williams *John Deere, Spain*
Paper 3	Large four wheel drive tractors. David R F Tapp CEng MIMechE MIAgrE *Director, County Commercial Cars Ltd*
Paper 4	Forestry tractors. Airlie Bruce-Jones *Director, James Jones Ltd*
Paper 5	Crawler tractors. H F W Flatters, *Aveling Barford International Ltd*

Registration forms for members with registered addresses in the UK and Eire will be mailed about 18 July 1978.

Members abroad, and any other persons, requiring further details or registration forms should write to the Conference Secretary:

Mrs Edwina J Holden, Conference Secretary,
The Institution of Agricultural Engineers,
West End Road, Silsoe, Bedford MK45 4DU

Telephone: Silsoe (0525) 61096.

Engineering for food production in developing countries - are small tractors appropriate ?

Edited summary of discussion

The discussion was opened by Mr R D Bell (Overseas Department NIAE). He observed that Mr Pollard had referred to the small number of farms which are suited to small tractors whilst Messrs Cattermole and Catterick referred to problems of service, which are greater with small numbers of widely scattered units. Should not the servicing of small tractors therefore be tied in with an existing network of workshops, taking for example motor vehicle engineers? Secondly, small tractors must essentially have well designed implement systems and linkages. To-date, many good designs of tractor appear to have been marred by the lack of integrated implement systems.

In offering reasons for the rather limited up-take of small tractors at the present time Mr Bell suggested that, in the past, there has been a tendency to try to fit the small tractor into existing cropping systems. A better approach would be to use the tractor as a catalyst or an extension tool, changing farming systems to suit the mechanisation available. History has shown that, under present farming systems, many farmers do not want a simple tractor. Adequate operator training is difficult to provide in the case of small numbers of (small) tractors.

Finally, and probably most important, the manufacturer of a small tractor and the dealer must both be in a position to make satisfactory profits. If this incentive is lacking, the small tractor can never be satisfactorily developed on a production scale.

H J Von Hulst (Chairman) agreed that the primary focus must be the small (subsistence) farmer — this, in LDC's implies by far the greatest proportion of farmers. Small tractors can not be considered without full consideration of their economics. Social and technical problems can probably be overcome if economic considerations are met. Though the prices which farmers receive for their produce may be outside their own control, nevertheless these govern the economic situation and vary greatly from country to country.

Farm gate prices — rice

Country	Dollars/tonne	Tonnes = 1 tractor
Japan	900	3.3
Sudan, Korea	500	6.0
Nigeria, Pakistan	250	12.0
Malaysia	200	15.0
Philippines	170	18.0
India	90	33.0

M Cooper (Hunting Technical Services Limited) asked where the main components of the Tinkabi tractor are made. Perhaps the production of a successful small tractor should be an international effort? Mr Catterick explained that the sources of components were as follows: the diesel engine, India; hydraulics, Italy; hydraulic pump, USA; steering box, UK. Other components (tyres etc.,) also all imported into Swaziland.

Dr E S Clayton (Wye College) felt that the requirement of 10-20 acres for justification of the type of small tractor being discussed at the Conference was too large for most developing countries. A better propostion might be the modification of existing 2-wheel designs.

Dr P Cowell quoting recent experience in the Philippines and Laos, suggested that change in technology may lead to an increase in income, particularly if it enables the use of high yielding varieties of crop. Pursuit of this concept is being facilitated by the local manufacture of very cheap tillers (at a price equivalent to two or three buffaloes) in South East Asia. This was achieved largely by the use of second-hand or ex-war materials. If local manufacturing capacity is developed, the community benefits — this has historically often been the case where agricultural machinery has been concerned.

B C W Loades (Salisbury, Rhodesia) was surprised that no mention had been made of the SNAIL tractor developed at the NCAE, which is particularly suitable for use in dry climates. He showed slides of his own tractor, developed for Rhodesia which was based on NCAE designs. This was a simple welded 2-wheel construction with vee belt drive to the wheels.

B P Pothecary (Consultant, Woodbridge) questioned the need for so much emphasis on the matter of ploughing. He also pointed out the need for an unconventional method of marketing any small tractor; the emphasis must be on the simplicity of the equipment and ease of repair in order that indigenous expertise might be utilised.

Mr Catterick agreed that ploughing was now not favoured as a method of cultivation because of the reduced cost, time and tractive effort required by tine cultivation. However there existed the problem of convincing the farmer, so that a mouldboard plough will continue to be made available for the time being.

Marketing in developing countries is difficult. Distributors are often widespread and lacking in competence. The tractor manufacturer must make the enterprise profitable for the distributor — the increase in the number of farmer co-operatives will help in this direction.

Prof C Uzureau (CEMA) observed that the device must be considered as part of the farming system — not in isolation — and a maintenance service must be organised. There is much to be said for local manufacture which eases the spares situation, provides local employment and can use locally available components.

I M Johnson (Overseas Department, NIAE) questioned Professor Inns' statement concerning the ready availability of spares if the tractor is locally made in its country of use. On the subject of marketing, success often only continued whilst the manufacturer maintained an active interest in the purchasing country. An active sales force is a vital need as had been displayed in the success of the Landmaster in both East Africa and the Philippines. He went on to suggest that local taxation situations often had a large effect on tractor usage and quoted an example where at one time 90% of the tractors in Korea were used for road transport because they were cheaper to tax than vans or lorries.

W J Ascough (University of Rhodesia) had been responsible for the construction of an NCAE type of SNAIL in Rhodesia. This had suffered from all the disadvantages which had been discussed earlier. Rhodesian agricultural engineers had now turned their attention to improving ox cultivation using a ripper tine, mounted on a conventional ox plough frame, to rip a seed furrow first, Later, after the first rains, inter-row "wet ripping" effectively increased the working capacity of oxen without requiring sophisticated technology. Work was continuing on minimum tillage and extension.

T C D Manby (President) drew attention to the BMB Plough Mate tractor produced in 1945, which used a winch for forward propulsion and had a simple device to ensure that the cable ran regularly on to the drum. This was a precursor to the SNAIL tractor. He also asked for comment on service problems with the Tinkabi tractor, particularly regarding hydraulic components. Earlier workers had felt that hydraulic drive was too sensitive to dirt to allow it to be used in LDC situations. Mr Catterick

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replied that the hydrostatic transmission had been criticised but in his five years experience all units had proved satisfactory. Filtration was good and there were no flow dividers except within the swash plate pump. Because of the shortage of skilled workers, those who are available are retained in the central workshops whilst semi-skilled workers go out to the tractors in the field. Simple tests could be done in the field which gave positive results with little need for judgement by the tester.

Capt E M Griffith (Howard Machinery Limited) referred to the success of small tillage devices in India and Japan since the late 1940's. Also some 500 rotavators had been purchased by Uganda since 1952. He emphasised that unusual marketing methods were often necessary and must show an advantage both to buyer and vendor.

Prof W Boshoff (IITA, Nigeria) said that he was formerly known as a small tractor man and seven years ago had defended these devices in this very hall. His experience over 14 years with small tractors, however, had changed his views, there being two main questions to be answered. First, how big is the market? Second, what is the intensity of use? Even where a small tractor is made from as many standard mass produced parts as possible there are still economies of scale of production, as there still is an infra structure to be costed against each individual tractor built. As the numerical answers to these two questions become larger, it is difficult to avoid the big tractor approach.

Other important factors are the skill of the farmer and the price of his crop.

C J Redfern (Amex) felt that there was a potentially good market for small tractors in LDCs both among the medium (two to six hectare) sized holdings, and in the field of transportation and contract work. Also such tractors would encourage farmers to expand their acreage. In most parts of Africa, Latin America and some of Asia land is not the limiting constraint — rather it is shortage of energy and manpower.

A D Wilcher (Consultant) in a written contribution stated that "Small tractors are appropriate for improving agricultural productivity in developing countries. Alan Catterick deservedly, has proved that in the case of his Tinkabi and the Swazi smallholder. It is the 'system approach' of seeds, fertilisers, management, marketing, credit and mechanisation that is essential for development.

Any mechanisation plan is merely contributory, and appropriate only if considered with other inputs, available management and social requirements".

A J Casebow (Scot-wilson, Kirk-Patrick & Partners) observed that the purpose of mechanisation must not be to replace labour (since there is much unemployment in LDCs). In Africa there may be plenty of cultivable land still available; in India there was not. Mr Casebow thought that we were trying to solve different problems with the same solution. His experience of Landmaster tractors in India, where 33% of farms are less than 5 hectares, was that any device larger than a Landmaster involved too much maneouvring out of work.

C Voss (Leamington Spa) questioned the theme "Are small tractors appropriate". We **should** be asking the question "How can we best help subsistence farmers rise above subsistence level?". The answer was by providing a package of the correct inputs supported by the correct infra-structure. Mr Catterick in Swaziland and Monsier Bouyer in Francophone West Africa had shown that the small tractor could be an appropriate ingredient of the input mix for increasing agricultural output.

R Gifford (FAO, Rome) supported the point made by Mr Voss. Equipment in isolation cannot determine its appropriateness. The effects of its use have equal importance. Effect must be directed to ensure that a farmer is given the choice of equipment according to his own needs. The economics will follow and large or small tractors will be used as appropriate.

G Muchiri (University of Nairobi) observed that the small tractor seemed to have been developed for African conditions particularly. It was unfortunate that there were few present who were able to give an account of experience in other continents. He pointed out that only a small fraction of farmers can hope to utilize small tractors. Of 1.5 million small farmers in Kenya, if only 1% of them adopt the small tractor and if 1 000 such tractors are made per annum, 150 years would be required to satisfy the demand. In this time, what can the agricultural engineer offer to the remaining 99%? Perhaps the pre-occupation with the small tractor is giving the wrong emphasis and animal and human power should be the main consideration.

It should be recognised that there were two sectors in Africa, which could be termed the modern (about 20% of the population) and the traditional sectors respectively. The modern sector, with its income of ten times that of the traditional, offers life very similar to that in developed countries. Technology in the traditional sector will take a long time to develop. In the context of the small tractor we must beware of developing another modern sector — that is an "elite" who own tractors. As much as possible, small tractors, where they are used, should be manufactured in the developing country. The participation of the population is important — then it may be that the involvement and the possible use of manufacturing facilities to provide hand tools for the 99% of un-mechanised farmers, may provide an altogether more integrated social structure.

Ian Constantinesco (in a written contribution): I believe that small tractors are appropriate but what needs to be established is the circumstances and the extent of the market. The general indications are that the potential market is considerable.

About 30% of the world's cultivatable soils, and 40% of them in Africa, are under traditional subsistence forms of agriculture such as shifting cultivation. Increasing populations, food demand and pressure on land are eliminating family migrations and the long fallow from the shifting cycle, leading to more intensive methods of production. In spite of this, farm sizes remain very small. This is due not so much to lack of additional land for expansion (although this is a major constraint to some areas) but to the constraints imposed by available family labour.

The results of a recent survey which I did in semi-arid areas of Tanzania show that the average farm size is still 1.2 ha (3 acres.) Land is available for expansion but restricted to 2.5 ha (say 6 acres) by hand methods of production. Beyond 2.5 ha labour available for land preparation becomes critical and some form of mechanisation though oxen power or tractors is needed to achieve timely planting. Labour available to drive and tend a pair of oxen and time factors restrict farm size to 3.7 to 4 ha (say 10 acres). Beyond this point labour peaks become critical for weeding and harvesting as well. In areas of higher rainfall and fertility labour peaks become critical for land preparation above 1.2 ha and for weeding and harvesting as well above 1.7 ha.

In the above example the extent to which oxen power can be developed to meet the needs of 1.3 to 4 ha size holdings is limited among other factors, by the incidence of tsetse fly, availability of oxen, competition for food and last but not least, acceptance levels of farmers. For example the predominantly cattle owning tribes are against using their animals for draft work. It is a fair assumption therefore that a large proportion of farms of 1.3 ha and above are a potential market for small tractors. Why a small tractor and not a large one? Because the use of large tractors would be dependent on aggregation of small holdings, loss of individuality (unpopular with all farmers), much higher yields and farm gate prices. Undoubtedly some progress will be made in Tanzania and elsewhere with aggregation and the creation of conditions suitable for large scale mechanization. Previous attempts at this line of approach have not been noted for their success. New attempts are as yet experimental.

On the Indian sub-continent ox-cultivation is almost universal, but apart from other considerations, the competition for food between man and animal will eventually eliminate the ox as a source of power. In the Punjab alone there are 1.3 million holdings of which 75% are 4 ha or less in size. This area is cultivated with the aid of 700,000 pairs of oxen and (in 1975) 45 000 tractors. On irrigated lands the Government has imposed a ceiling of 7.2 ha (18 acres) under land reform laws.

The above two examples alone suggest that there appears to be a sizeable potential market for small tractors. In many of these countries, it may well be that future developments will tend towards the Japanese pattern, with high yields from small individual farms using small tractors.

Multi-purpose implements and particularly ox-drawn tool frames. These machines worked well in East Africa during the 50's and 60's, but failed due to lack of acceptance. Why? Apparently farmers preferred a separate implement for each job which could be easily hitched to oxen or a tractor without tools and with the minimum of adjustment. Three point-linkage for tractors was more readily accepted and understood, because most of the tractors seen had it.

The degree of acceptance in terms of actual sales to farmers will determine the suitability of designs such as the Tinkabi and Bouyer tractors in their respective areas. However, manufacturers will be looking for a basic standard design suitable for use on small farms in developing countries. I believe the design will have the

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Electronics in agriculture

S W R Cox

Introduction

THIS is a very personal report, It is 25 years since I joined NIAE as a physicist specialising in instrumentation and electronics engineering. Electronics developed enormously during World War II and industrial applications were growing rapidly in the immediate post-war period. The potential for electronic instrumentation and control systems in agriculture and horticulture was apparent then. Instrumentation provides quantitative data which can lead to improved utilisation of human and material resources, through better management of an enterprise and better operation of machines and equipment. Automatic control is a logical extension of electronic measurement in the many cases where it is more efficient than manual control or where it can release people from tedious or laborious tasks. Thus freed, people can undertake more rewarding work and have greater opportunities for leisure. The rapid post-war progress of mechanisation in agriculture and horticulture provided the necessary basis for the introduction of electronics and the opportunity to realise all of these advantages in the two industries. Despite this, applications of electronics to agriculture and horticulture have been on a minor scale up to now. Why is this so? I will give my reasons before explaining why I expect much faster progress in future.

The development of electronics

First, it is necessary to look at development in electronics over the past quarter of a century, pausing to explain briefly some of the jargon familiar to the electronics engineer but frequently off-putting to others.

In 1953 the thermionic valve ('vacuum tube' to some) ruled in industrial electronics, as in radio and TV. The electron current in this valve was generated by an electrically heated filament and it needed a high voltage supply. In consequence, valve circuits required power supplies which were usually bulky, whether the power was supplied by batteries or drawn from the mains. Furthermore, portable battery-powered equipment could — and often did — suffer from waning batteries at inconvenient moments.

At that time circuit design contained a strong element of cut and try, in my experience, in part due to the wide production tolerances on many electronic components. As a result it was necessary to have built a batch of equipment to a given circuit design before its performance could be specified with any precision. The literature of the period is strewn with 'one-off' designs which worked for their creators and no-one else!

A big step in the right direction took place when the germanium transistor appeared on the market in the early 1950's. This semiconductor material is prepared with carefully controlled impurities to create mobile electronics (negative or n type material) or positively charged regions (p type material). A transistor is an npn or a pnp sandwich (fig 1), the central 'base' region controlling the current (charge) flow between the other two electrodes. Its well-known characteristics are small size and the ability to operate from a low voltage, low power supply. The germanium transistor has a less desirable characteristic — its performance is very dependent on the temperature of the material — and means of counteracting this had to be devised before it could be put to wide use in industrial measuring equipment. However, this problem was largely circumvented with the arrival of silicon semiconductor devices in the early 1960's. Silicon technology holds the stage now.

In the 1960's, too, the digital circuit began to challenge analogue circuits in industrial electronics. Essentially, in an analogue instrument information is conveyed by the magnitude of an electrical signal (voltage or current) but with a digital instrument signals occur at one of two levels — termed logic levels 0 and 1 — and information is conveyed by sequences of these two binary digits. Eight-bit sequences (bit = binary digit), known as bytes, are a common basic grouping: each of these can represent numbers up to 255 in decimal terms.

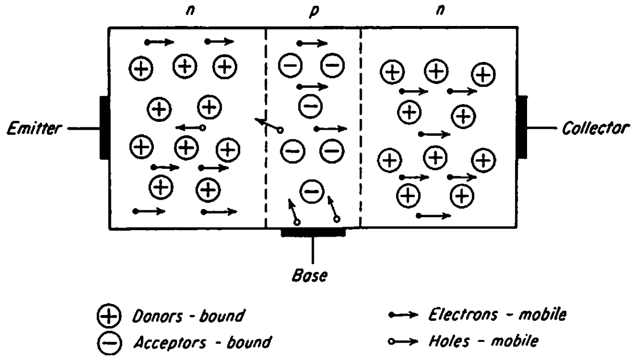

Fig 1 NPN transistor (schematic).

Electronic digital computers, born in the late 1940's, provided the starting point for this change. Computing in binary arithmetic developed because of the reliable way in which electronic and magnetic devices can be made to operate in a switching mode, corresponding to the two logic states.

Within the computer some circuits operate as binary counters, others as logic 'gates' which produce an output 1 if and when a given set of 0s and/or 1s appear at their inputs. For example, a commonly used gate is the NAND (= Not AND) which gives an output 1 when one or more of its inputs is at 0. With the establishment of transistors manufacturers began to market logic elements such as this, in encapsulated blocks, for application to industrial control systems. Large-scale production provided the industrial applications engineer with 'components' of well defined performance.

With these elements I designed a control unit for a selective rowcrop thinner in the mid 1960's. This unit measured the forward travel of the thinner by counting pulses from a ground wheel, noted the position of each seedling in a row (seedlings were detected by a probe which generated an electrical signal on contact) and made the decision to preserve or destroy the seedling by reference to the desired average spacing between surviving plants (stored as a preset binary number).

The first thinner — a single row unit — worked well enough to encourage plans for a five-row machine. However, by this time the logic blocks that I had been using were out of date: the silicon IC (integrated circuit) had arrived. In this device the whole circuit is formed on a tiny chip of silicon, packing a complex circuit into the volume once occupied by a single transistor (fig 2).

The five-row thinner controller used ICs costing about £20 per package. If we had waited a few years they would have been about 20p each: such are the advantages of mass-production. But the progression was not ended. With the 1970's came LSI (large-scale integration) which put large numbers of circuits on a silicon chip. The dramatic results of this development are well illustrated by what has happened to the size and cost of electronics calculators.

LSI has made possible a further development — the microprocessor — which is basically the heart of a small computer in a single, small block. Its low cost has profound implications for industrial measurement and control systems, although it is necessary to sound a cautionary note, since many applications require additional units of much greater cost. For example, if large amounts of information have to be stored the computer's local memory will have to be backed by bulk recording on magnetic tape or disc. Also, these systems employ measurement sensors or electrical transducers, many of which given an analogue output, requiring an analogue-to-digital convertor unit, which samples the analogue signal repeatedly and converts it into digital form each time. Yet again, if management is to take advantage of the improved information that computer systems can provide the systems must have conventional 'peripherals', such as a keyboard for entering instructions and display devices such as printers or VDUs (visual display units).

To summarise over 25 years electronics has changed radically and is still changing rapidly. It is now dominated by mass-

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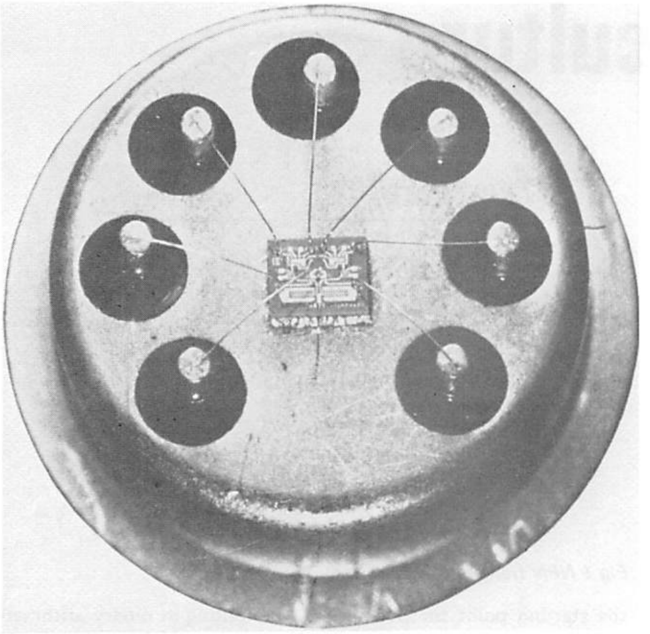

Fig 2 Silicon integrated circuit in transistor mount (diameter of mount 10 mm approx).

produced, low cost, digital circuits of small size, low power requirement and still not fully comprehended industrial potential, capable of working reliably in all except the most extreme industrial environments. This is not to suggest that the application of electronics to agriculture, or any other industry, is plain sailing from now on. Although much of the detailed circuit design is done by the manufacturer of the IC and LSI devices, the applications engineer still has design to do and problems to face. Also, the hardware for major microprocessor systems may cost £1000s at present and the associated programme development is also expansive, requiring many man hours by specialised programmers, using costly equipment.

Transducers and other measurement devices

However remarkable the electronics, automatic measurement and control systems can only be as good as the measurement sensors allow. To a degree, agriculture and horticulture rely on electrical transducers used widely in industry and so benefit from the availability of well-developed devices, produced in quantity. A well-known example is the thermistor for temperature measurement (the temperature sensitivity of semiconductor material is a desirable quality here). Again, electrical strain gauges are commonly used to measure mechanical force and are incorporated in load cells for weight measurement.

However, often it is necessary to develop measurement devices for agriculture and horticulture and this usually requires a long period of experiment and evaluation. The determination of moisture in crop materials – a crucial problem in many farming operations – illustrates this point. The common requirement is for portable apparatus (inexpensive, of course) which will provide quick and easy readings of the moisture content of crop samples, so enabling the farmer to determine the average moisture content of the crop, and – equally important – its variability.

The most widely used moisture meters are those for cereal grain, whose development began in the late 1940's. Several commercial meters appeared at that time but their basic principles were not fully explored until the 1950's. The NIAE was deeply involved in this subject throughout the 1950's and early 1960's, identifying and quantifying the factors which affect the accuracy of measurement that can be achieved by the two basic electrical measurements – resistance and capacitance. In the case of resistance, it was necessary to take measurements with whole grain and milled grain of different coarseness, under different degrees of compression. Capacitance measurments, using alternating current, introduced considerations of frequency, repeatability in filling the sample cell and the need to weigh the sample. In both cases the effects of the degree of surface wetness or dryness of whole grain, its temperature, the variety and its variability from year to year all had to be studied, and this work had to be repeated for wheat, barley and oats. A formidable research programme, extending over many years, was therefore necessary before the measurement was put on a sound footing, and even then the results only applied to grain at less than 30% mcwb (moisture content, wet basis).

With this background, it is not difficult to appreciate that however urgent the need for a similar instrument for forage moisture determination, the preliminary research programme presents even more formidable problems. The forage crop is far more varied than grain, we are concerned with it at all stages of maturity and its moisture content covers a far wider range. Electrical measurements can achieve moderate accuracy in some circumstances, given careful calibration, but much research remains to be done, in my view.

Electromagnetic radiation has found other uses in agriculture and horticulture, especially for sorting produce. For many years optical separators have been used on conveyor lines to reject discoloured peas and other seeds. Sorting at x-ray wavelengths has been developed by the SIAE, to remove clods and stones from harvested potatoes. This operation depends on the potato's lower absorption of x-rays and the SIAE's successful design (shown schematically in fig 3) was the outcome of much patient work on the measurement system and on the problem which is crucial to all sorting and grading systems – presentation of the produce to the measurement unit.

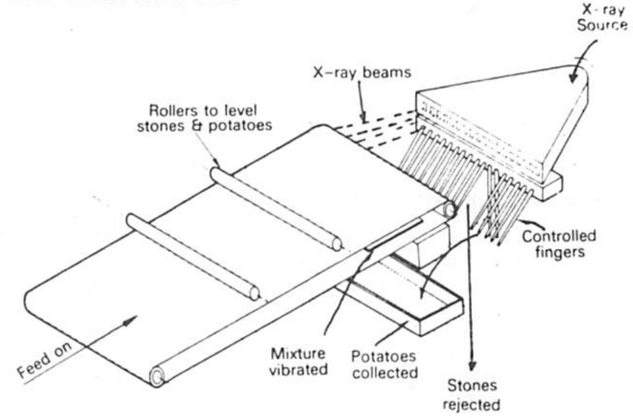

Fig 3 SIAE x-ray sorter (schematic).

Automatic measurement of many other physical properties of crops, animals, animal products and soils could be beneficial to farming but, as I have tried to show by these few examples, such developments are mostly long-term, requiring close collaboration between teams of scientists, engineers and agriculturalists. Realisation of much of the latent potential of microprocessor systems will depend on this collaborative effort.

Agricultural and horticultural attitudes

A third important influence on the uptake of electronics in agriculture and horticulture is the attitude of people in these industries. In my early days at NIAE it was often said that electronic equipment was too expensive, too complicated and likely to be too unreliable. To whom would the farmer turn when the equipment broke down? Some of this was and, unfortunately, sometimes still is fair comment. But it need not be so. Modern electronics can be made reliable enough to satisfy the most demanding customer. In fact, from my experience of automatic control systems, it is often the reliability of the mechanical equipment which causes most frequent concern. With the advent of pocket calculators and digital timepieces, the issue of complexity is rarely raised nowadays. Cost remains a crucial factor but, faced with the rising costs of machinery, feedstuffs, chemicals, labour and so on, many farmers and growers are now much keener to reduce waste and generally to improve the monitoring and control of their operations. Overall, there is now a far greater interest in electronic instruments and control systems than was evident only a few years ago.

However, electronics is still a relatively new technology to much of the farming industry and confidence in it will soon be undermined if the farmer or grower buys equipment which is not properly designed for and proven in his demanding environment. Also, no matter how cheap and reliable the electronic circuits, equipment will develop faults or will be damaged. To meet the resulting emergencies there must be efficient service arrangements based on readily available spares, and these cost money.

Electronics in agriculture and horticulture today

I have outlined briefly three factors which, in my view, have been the main constraints on the progress of electronics in agriculture and horticulture, arguing that a greater interest is now apparent, because farmers and growers need better information on, and control of, their operations and that electronics is now well-fitted to meet this need. A summary of the present situation seems appropriate at this point.

The list of existing agricultural and horticultural instrumentation and control systems is not overwhelming, as I noted at the start; neither is it insignificant. On mobile field machinery pride of place must surely go to the x-ray sorter but there are now many "bolt-on goodies" for tractors, combine harvesters and implements. The combine harvester is well served, with loss monitors, acreage meters and an instrument for measuring the amount of grain harvested. Some forage harvesters are now fitted with ingenious tramp metal detectors. Monitoring devices are fitted to drills and sprayers, to convey essential information to the driver, now enclosed in his quiet cab. Some American tractors are being fitted with digital instrumentation to indicate forward speed, fuel flow and engine power output during work.

The glasshouse sector has always been quick to adopt new technology and electronic controllers (analogue, rather than digital) have been in use for years, controlling heating and ventilating systems. Electronics has also been applied to control of mist propagation of cuttings, CO_2 enrichment of the atmosphere in the house and, recently, the pH and conductivity of nutrient film solutions.

Looking at the rest of the crops sector, environmental controls are commonplace in crop stores: the principles of grain moisture meters have been applied to control of grain drying; automatic weight classification is used in grading installations. This list could be lengthened.

Although uptake in the livestock sector was slow initially, apart from environmental controls in small livestock houses, it is now gathering pace. Feeding weighed quantities of mixed bulk rations to cattle is becoming more common and the NIAE has developed automatic conveyor feeding systems for dairy farms, in which silage emerging from a tower silo is continuously weighed by a belt weigher incorporating a strain-gauge load cell. The signal from this cell is used to control the addition of concentrates and minerals, producing a uniform mixture. The integrated signal is a measure of the total weight of silage discharged and the control system shuts down the feeding operation when a pre-set amount of silage has been weighed out. This system has worked well on farms over several years. Now the Institute is studying the performance of feeder wagons, developed in North America, which also employ load cells to weigh out the rations.

At NIAE we have also shown that load cells attached to weigh crates, coupled with pneumatically controlled inlet and outlet gates, make it possible to weigh pigs and cattle with 1% accuracy, at high throughput rates and with minimal labour. However, the most advanced forms of livestock electronics have evolved from individual rationing of cattle. Ten years ago the 'electronic key', giving an animal access to its own ration, was developed at the North of Scotland College of Agriculture. A tuned unit on the animal's collar drew power from a corresponding oscillator at its manger. This released a bolt on the manger door and allowed the animal to feed. Several variations of this 'transponder' theme have appeared since then, some of wider application than others. The NIAE version, intended for the dairy cow (fig 4), collects power from a transmitter, mounted in an archway or at a manger, and responds with a transmitted signal of its own, which carries the animal's code number to a radio receiver'. In parallel with these developments, programmed parlour feeders have found a growing market. These employ a keyboard which is used to store the weight of each cow's daily concentrate ration in a memory unit. The ration is automatically dispensed to the animal in the parlour when the cowman has identified its visible code (freeze band, collar number, etc.) and keyed in this number. Given automatic dispensers of good long-term accuracy, such as the gravimetric type, the dairy farmer can make efficient use of his concentrates in this way. For those who prefer to feed concentrates outside the parlour there is now a choice of equipments which allow the cow to obtain its ration: some provide preset quantities, others feed ad lib, but all use some form of electronic or magnetic key.

Fig 4 NIAE automatic identification unit for cows, mounted on a standard collar.

Overall, few areas of agriculture and horticulture have remained unaffected by electronics but major commercial applications are hard to find. The last part of this paper outlines some developments which may change this picture.

The future

Back in 1969, NIAE started collaboration with NIRD at Reading on a 'computerised' dairly parlour, in which it was intended to identify animals, to record their individual milk yield at each milking, together with their weight on leaving the parlour and – if someone could work out how to detect these conditions electronically, by monitoring the milk – onset of oestrus and clinical mastitis. We recognised that this would be a long-term development, possibly bearing fruit in the 1980's. In fact, commercial

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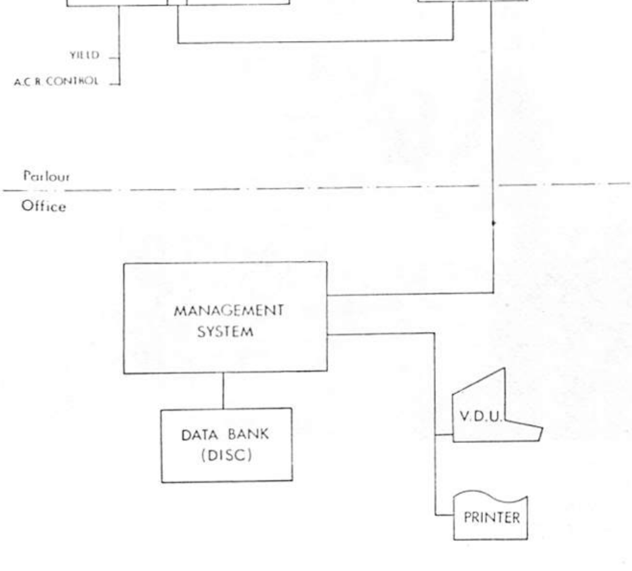
Fig 5 NIAE microprocessor based monitoring and control system for the dairy parlour (schematic).



**Note: Systems employing radiated signals must be approved by the Home Office Radio Regulatory Department* developments based on minicomputers and microprocessors are oestrus and mastitis detection, which are still some way off. The NIAE microprocessor system, about to be marketed, is shown in outline in fig 5. It has a magnetic storage unit with a capacity of ½M byte, for the large amounts of information on the herd which will be available to the herd manager in summarised forms, as required. Inevitably, a system of this complexity, costing about £100/cow, is for larger herds initially and to this end the automatic identification device carries a 2-byte code (one byte copes with 255 animals, two with over 65 000!).

Another candidate for this type of controller-cum-management system is the glasshouse, which represents a high capital investment (about £150 000/ha) and has a profitability which is highly dependent on precise environmental control. If temperatures are too high, expensive fuel is wasted; if they are low, yield is reduced. Surveys have shown that many growers unknowingly lose in both these ways. Control of greenhouse environment does not stop at temperature and humidity, of course. CO_2 enrichment and NFT (nutrient film technique) have been mentioned but there are many other plant growth factors which can – and most probably will – be integrated under the control of computers in their mini or micro forms before long.

Simple applications of microprocessor are bound to appear on field machines, to take over some engine and implementcontrol functions from the driver and to give him essential information during the operation. Longer term, there are prospects for fuller automation of field work and I do not find it too fanciful to think in terms of largely unattended field operations. In fact, a pioneer driverless tractor system was built at Reading University in the 1950's and brought to the commercial stage in the 1960's. Guidelines for this tractor are provided by parallel buried wires, traversing the field and energised by alternating electric current: turning at headlands is controlled by a boundary wire. So far this system has only been taken up on a small scale. A long-term study of the economic and technical aspects of driverless tractors is in progress at NIAE. Technically, it has been shown that a fairly simple optical system can guide a tractor along a ploughed furrow and this system has been used for ploughing, starting with the necessary first furrow tunred under manual control (fig 6). Encouraging progress has been made with control of turning at headlands, again using an optical system which ranges on reflecting posts at the field boundary. I need hardly add that the digestion of the optically acquired information and the calculation of the control action to be applied to the tractor controls involve a microprocessor. For other operations than ploughing, the system is being developed to follow a small marker furrow, although several types of plant sensing device have already been developed and could be used. Economics studies of the acceptable cost of such a system are incomplete and at present are neither encouraging nor discouraging. The crucial component of cost is likely to be the necessary monitoring and safety features on the tractor and implements.

Fig 6 NIAE optical furrow-follower for automatic ploughing.

To end, three points summarise my view on the future of electronics in agriculture and horticulture:

> Electronics technology has advanced to the stage at which it is ripe for much wider application to these industries, technically and economically. In the immediate future, progress will be more rapid in static installations than in the field.
>
> The application of microprocessors will proceed rapidly to the limit of existing measurement methods. Thereafter progress will depend on the development of new electronic measurements for such things as oestrus detection in cows, on-line feed analysis, field soil conditions and plant responses in greenhouses.
>
> There are unlimited opportunities for agricultural engineers wishing to specialise in the applications of electronics, which is now a recognised part of the agricultural engineering spectrum, helping to create in the UK and elsewhere an efficient and profitable agriculture and horticulture.

Structural steel hand book

CASHMORES, structural steel stockholders, of Risca, Gwent, have recently published a handbook showing dimensions, safe-load tables, specifications, chemical and mechanical properties and weights, etc of all general steel products.

Cashmores also specialise in hollow sections and in this book particular emphasis is given to both metric and imperial sizes of this product.

A free copy of this publication is available on request to Cashmores Limited, Commercial Road, Risca, Newport, Gwent.

Edited summary of discussion concluded from page 56

best chance of general acceptance if it is based on a small compact four wheel tractor with drawbar and simple linkage for separate implements, and a trailer. It must be capable of working in confined spaces on both rain-fed and irrigated lands and on the terraced lands of mountain areas.

The mouldboard plough for semi-arid areas, wrongly used, can be downright harmful and lead to serious soil erosion.

Soil inversion is not necessary or even desirable in semi-arid areas. Mouldboard ploughs (of western design) and sometimes disc ploughs (except very heavy and expensive ones) will not penetrate hard dry soils. Tined implements can generally be persuaded to penetrate hard soils and are also suitable for lighter soils. They leave the soil in the cloddy condition required to dessicate weeds and to minimise erosion by wind and water. If a plough is used at all, the semi-inversion Japanese and Chinese designs penetrate hard soils better and can also work better in very soft or sticky soils. They use less power per unit of soil moved than their western counterparts.

In the tropics all cultivation must be done in such a way as to minimise soil erosion. This means all cultivation must be done on the contour and never up and down the slope. This has a bearing on the design of the tractor. A very effective method of soil conservation and increasing yields in areas of low rainfall is ridging, and preferably tie-ridging. Many crops have to be grown on ridges anyway. Therefore, the small tractor must be capable of pulling at least one ridging body.

May I suggest that the Institution sponsor the establishment of a working group to arrive at a basic design for a small tractor for wide acceptance in developing countries. This will entail detailed sifting of evidence already available and detailed market research in areas of high potential. If the results are favourable no time should be lost in starting manufacture and developing markets. Undue delay can only mean that the potential market will be soaked up by the Japanese.

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Health and safety at work

The first report in a new series produced by the Health and Safety Executive on the work of the Agricultural Health and Safety Inspectorate entitled *Health and Safety – Agriculture 1976* has been published recently. It is available from HMSO price £1.00. The report includes a section on machinery hazards and analyses of tractor overturning accidents. A review of harmful substances in agriculture and other hazards is also presented.

The report draws attention to the fact that overturning tractors not fitted with approved safety cabs caused the deaths of more than 200 people on British farms in less than nine years. In accidents where approved cabs or roll bars have been fitted, only 12 operators have been killed, all while outside the protection of of their cabs.

Overturning tractors are still the largest single cause of farm fatalities, but the number has declined since the introduction of approved safety cabs in 1967. The report details 114 overturning tractor incidents in 1976, analyses the type of equipment involved, severity of overturning, operator escape routes and the extent of injuries suffered. It draws the general conclusion that, provided the operator can remain within the cab or frame during overturn, he is unlikely to be killed.

The power of the Inspectorate to issue prohibition and improvement notices under the Health and Safety at Work Act to supplement existing enforcement procedures has been 'most effective'. During 1976, inspectors issued 877 improvement notices and 212 prohibition notices.

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The Inspectorate has placed special emphasis on Section 6 of the Act which has a requirement, amongst others, that articles and substances for use at work, as far as is reasonable practical, should be safe and without risk to health when properly used. This has resulted in manufacturers of new agricultural machines and equipment incorporating higher safety standards than required by agricultural Regulations and providing more information on the safe and correct use of the machines concerned. The report draws particular attention to the high risk of "overturning" accidents during coupling-up operations between tractors and trailers or trailed machinery.

The Inspectorate records an increased awareness of the dangers and pitfalls associated with the use of agricultural chemicals. Publicity surrounding the fact that the self-employed come within the scope of the Health and Safety (Agriculture) (Poisonous Substances) Regulations 1976 appeared to stimulate interest in the Regulations and the safe use of pesticides generally throughout the industry.

With the increasing demand for 'quiet cabs' there has been a number of developments in the design of fresh air ventilation. In order to provide guidance to manufacturers on acceptable standards of ventilation systems, work is being carried out to make available a specification which will be acceptable to the industry as well as to the HSE.

1979 National Conferences

Spring 1979

At the Key Theatre, Peterborough, on Tuesday, 20 March 1979. One day.

Subject: **Mechanisation in the Production of Vegetables for Processing.**

Annual 1979

Venue to be announced later, on Tuesday, 8 May 1979. One day.

Subject: **Durability and Wear of Equipment.**

Autumn 1979

At the National Agricultural Centre, Stoneleigh, on Tuesday, 9 October 1979. One day.

Subject: **Tillage Equipment Design and Power Requirement in the Eighties.**

This Conference is being organised by the Royal Agricultural Society of England, in association with the West Midlands Branch of the Institution.

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Details will be published, and registration forms distributed, as and when information is made available.

All enquiries concerning conferences should be addressed to:

Mrs Edwina J Holden, Conference Secretary,
The Institution of Agricultural Engineers,
West End Road, Silsoe, Bedford MK45 4DU

Telephone: Silsoe (0525) 61096

Address correspondence correctly

All letters and enquiries for the Institution of Agricultural Engineers should be addressed to Silsoe.

Only advertising enquiries and copy should be sent to PO Box 10 Rickmansworth, Herts.

Education and careers advisory service

READERS are reminded that an Advisory Service is provided by a senior member of the Institution – in an honorary capacity – to both members and non-members who are seeking advice covering possibilities for initial or further education, and career development.

Introductory leaflets:

F.51	*So you want to be an agricultural engineer?*
F.52	*Full-time courses – other sources of information*
F.53	*What is agricultural engineering?* *Careers in agricultural engineering* *Aims and objects of the Institution* *Courses leading to membership of the Institution*

are available on application to:

The Secretary, The Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU
(tel Silsoe (0525) 61096).

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