# JOURNAL AND PROCEEDINGS OF THE

# INSTITUTION OF AGRICULTURAL ENGINEERS

VOL. 20 No. 4 - NOVEMBER 1964

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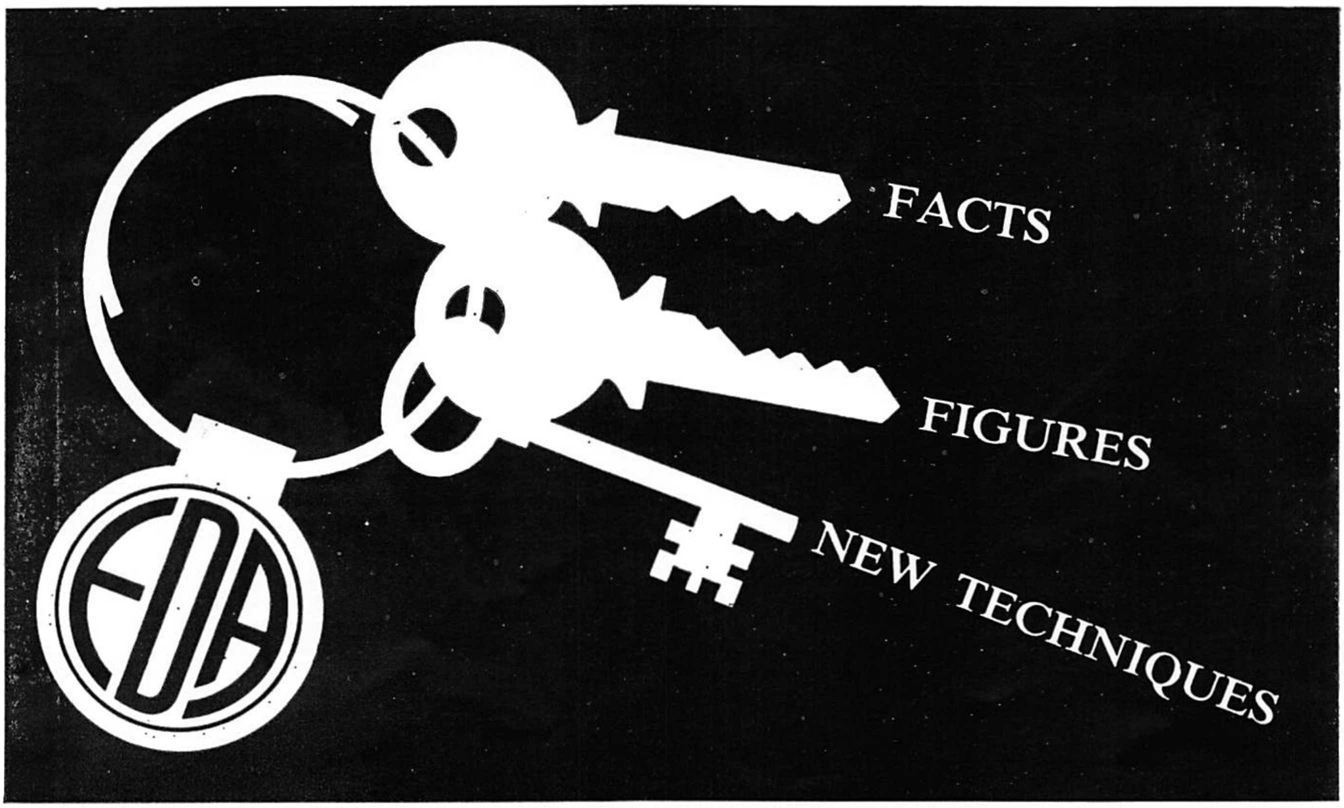


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# JOURNAL AND PROCEEDINGS OF THE INSTITUTION OF AGRICULTURAL ENGINEERS

**VOLUME 20 - NUMBER 4 - NOVEMBER, 1964**

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*IN THIS ISSUE*



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*The*

# INSTITUTION OF AGRICULTURAL ENGINEERS

OPEN MEETING THURSDAY, 28th JANUARY 1965

*to be held in the Main Hall of The Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1*

| | |
|---|---|
| 10.15 a.m. | COFFEE. |
| 10.45 a.m. | **'The Handling of Unit Loads in Agriculture and Horticulture'** by J. B. Holt, M.SC.(AGRIC.ENG.), A.M.I.AGR.E., Harvesting and Handling Dept., National Institute of Agricultural Engineering. |
| 11.45 a.m. | **'Work Study in the Mechanization of Farming'** by R. D. Hall, Horticulture (Work Study), Ministry of Agriculture, Fisheries & Food. |
| 12.45 p.m. | Luncheon Recess. |
| 2.15 p.m. | **'The Susceptibility of Fruit and Potatoes to Damage during Handling'** by H. C. Green, Harvesting & Handling Dept., National Institute of Agricultural Engineering. |
| 3.15 to 3.45 p.m. | TEA. |

Members will be pleased to note the increased facilities available within the precincts of The Institution of Mechanical Engineers; these include maximum visual aids in the presentation of Papers and buffet luncheon facilities on the premises.


## WATCH FOR

## *A Brighter Look*

in 1965

when the Institution Journal will include the following NEW features:

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together with the well-proved pattern of technical content that has built for the Journal an unsurpassed reputation of service to the agricultural engineering industry.

To set the mood for the brighter look, the Journal will appear in a re-styled cover design.

To harmonize more effectively with the Institution's calendar of activities, issues in 1965 and until further notice will appear in *March*, *June*, *September* and *December*, i.e. one month later than hitherto.

# INSTITUTION NOTES

**Graduate Representation on Council**

In recognition of the growing strength of Graduate Membership of the Institution and the increasing significance of this section of the membership, Council has co-opted to its number a representative of Graduate Members, Mr J. Kilgour, M.SC., Assistant Lecturer in Engineering Design at the National College of Agricultural Engineering. The Council decision is reflected throughout the Institution's network of Branches on many of whose Committees a Graduate member serves.

**Appointments by Council**

Council is pleased to announce that Mr C. A. Cameron Brown (Past-President) has accepted its invitation to represent the Institution on the Agricultural Safety committee of RoSPA. Mr Cameron Brown has also accepted an invitation made by the Commission Internationale du Génie Rural to head a new Fourth Section devoted to rural electrification and to become U.K. Vice-President of the organization. A report on the VIth conference of C.I.G.R. appears on page 149 of this issue.

**A Branch in the south**

Council is investigating the degree of support expected from members for a proposal that the Institution should form its ninth Branch, comprising London, and other counties in southern England. Membership has developed considerably in these counties in recent years, and the response of members to a recent Council circular is such as to indicate that Branch activities would command a healthy following.

**Branch News**

*East Anglia*

The attention of members is drawn to the creation of two sub-Branches within the East Anglian area at Cambridge and Ipswich, where meetings have been arranged (see August 1964 *Journal*) in addition to those planned for Norwich. It is hoped that this diversification of meeting-places will enable members previously unable to partake in Branch activities to enjoy the benefits of a Branch. Enquiries should be addressed to the Hon. Secretary of the East Anglian Branch, C. V. H. Foulkes, County Education Offices, Stracey Road, Norwich, Norfolk.

*Yorkshire*

At its recent Annual General Meeting, the Yorkshire Branch elected its committee for 1964-65 as follows:

*Chairman:* J. H. Nicholls, A.M.I.AGR.E.

*Vice-Chairman:* J. R. Whitaker, N.D.AGR.E., A.M.I.AGR.E.

*Committee:* H. E. Ashfield, M.I.MECH.E., M.I.AGR.E.,
G. G. Baldwin, M.A., A.M.I.MECH.E., M.I.AGR.E.,
J. R. Fishwick, A.I.AGR.E.,
G. A. S. Frank, A.M.I.AGR.E.,
E. D. Frost, A.I.AGR.E.,
J. M. Reyner, A.M.I.AGR.E.,
J. T. Simpson, B.SC., A.M.I.AGR.E.,
D. A. Smith, A.M.I.AGR.E.

*Secretary and Treasurer:* T. H. E. Harrison, M.SC., GRADUATE I.AGR.E., 16 Wood Lane, Ashenhurst, Huddersfield

**Corrigenda**

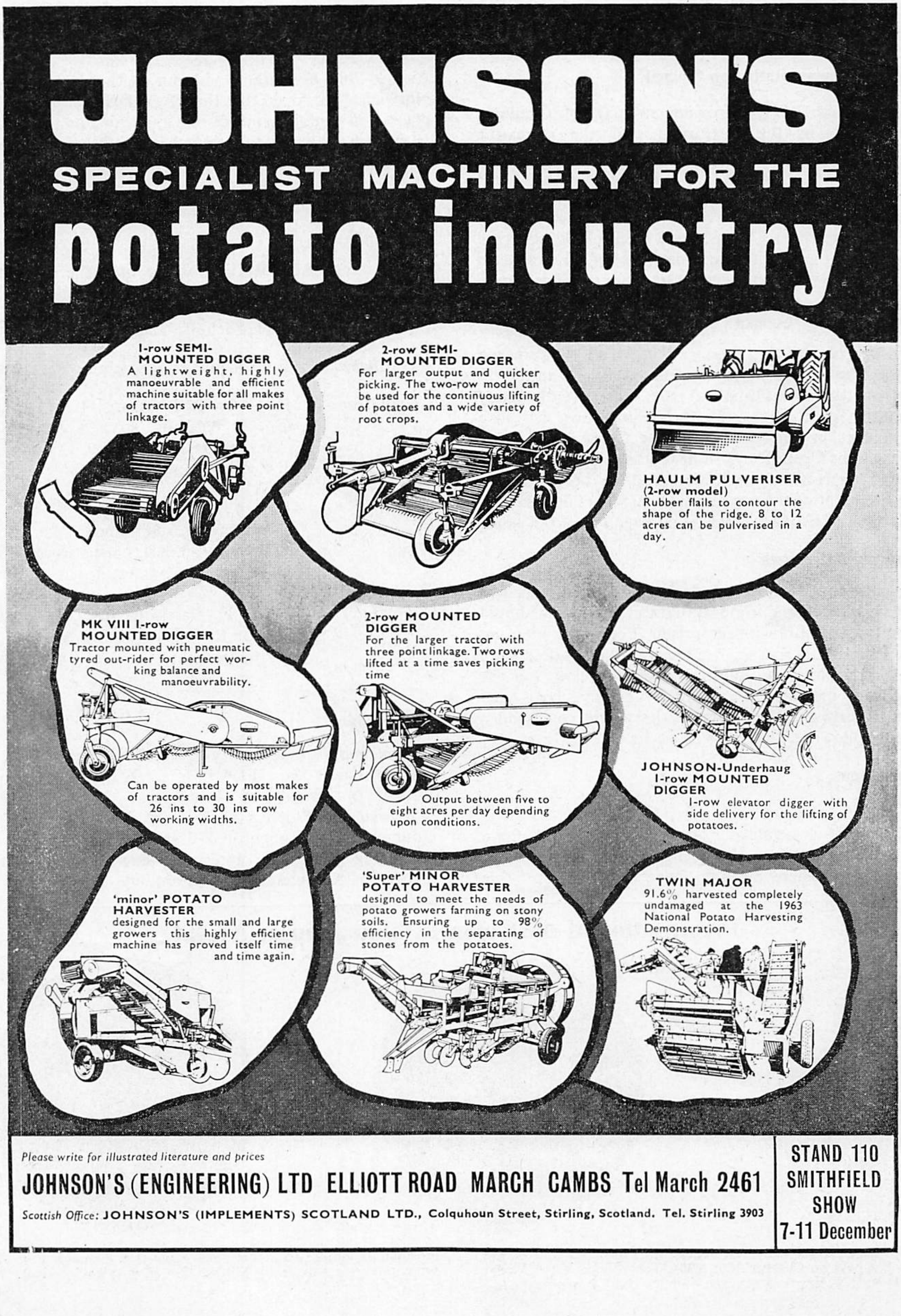
*Journal and Proceedings*, Vol. 20, No. 3, p. 131; 2nd column line 8 for N.I.A.E. read N.I.A.B. (National Institute of Agricultural Botany).

*Journal and Proceedings*, Vol. 20, No. 3, p. 125, 1st column line 33, Troughton T. J. should have been shown as having gained his Intermediate N.D.AGR.E. at the College of Aeronautical & Automobile Engineering.

## Presentation of the Colonel Philip Johnson Medal



The Johnson Medal was presented at the Open Meeting of the Institution held on October 12th, 1964. The winner of the Medal was Mr R. H. F. Brook, N.D.AGR.E. Simplex Dairy Equipment Ltd., outstanding candidate in the 1964 N.D.AGR.E. Examination. The presentation was made by Mr W. G. Cover, Vice-President.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# VIth International Agricultural Engineering Congress,

## Lausanne, 21st-27th September, 1964

*by C. Culpin, O.B.E., M.A., M.I.Agr.E., Chief Farm Machinery Adviser, N.A.A.S., who has been connected with C.I.G.R. activities since 1951, is a Vice-President of Section III, and has often represented U.K. on the Management Committee.*

C.I.G.R., the International Commission of Agricultural Engineering, was established in 1930 by a few far-sighted Continental university teachers and research workers in agricultural engineering. It was at first mainly a means of exchanging information between those whose job it was to establish and build up new departments of agricultural engineering. The first President was a Belgian.

After the 1939-45 War, it took some time to re-establish C.I.G.R. in the very changed conditions, but the IVth Congress was held in Rome in 1951 and the Vth in Brussels in 1958, both under the Presidency of M. Armand Blanc of France. Britain started to take an interest in C.I.G.R. about the time of the Rome Congress. During the early post-war period the Ministry of Agriculture arranged for U.K. participation, and as in most other European countries, C.I.G.R. was regarded at that time as an activity requiring governmental sponsorship.

Subsequently, inter-governmental discussions on agricultural engineering questions were more effectively dealt with by organizations such as F.A.O., O.E.E.C. and the U.N. Economic Commission for Europe; and it became increasingly clear that the future of C.I.G.R. was as an international association of national professional agricultural engineering institutions. C.I.G.R. was therefore re-shaped with this object in view, and in Britain, the Institution of Agricultural Engineers accepted the Ministry of Agriculture's invitation to take on the responsibility of running the national branch of C.I.G.R.

In the United States, at about the same time, the American Society of Agricultural Engineers decided to participate in C.I.G.R. activities.

C.I.G.R. is the only international society of agricultural engineers, and the Lausanne Congress showed that it is now beginning to achieve its objective of providing for exchange of technical information on a world-wide basis. At Lausanne there were about 650 delegates from 45 countries, including Argentine, Australia, Austria, Belgium, Brazil, Cameroon, Canada, Colombia, Czechoslovakia, Denmark, Finland, Formosa, France, Germany, Ghana, Greece, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Jugoslavia, Luxembourg, Morocco, Netherlands, Norway, Poland, Portugal, Russia, South Africa, Spain, Sweden, Switzerland, Tunisia, Turkey, United Arab Republic, United Kingdom, U.S.A., Vietnam.

C.I.G.R. has up to the present been divided into 4 Sections, dealing respectively with:

1. Soil and water problems. (Soil and water sciences in their application to the works of agricultural engineering. Techniques of defence of soils, agricultural management of waters, land management. President: P. Regamey, Switzerland).
2. Farm Buildings. (Rural constructions and connected equipment. President: K. Petit, Belgium)
3. Power and Machinery. (Agricultural machinery and rural electrification. President: E. Aranda Heredia, Spain).
4. Labour use and mechanization management. (Scientific organization of work in agriculture. President: G. Preuschen, Germany).

Not all 45 countries are yet fully affiliated to C.I.G.R.; but now that the American Society of Agricultural Engineers and the most important agricultural engineering institutions of Western Europe are taking an active part, there is little doubt that C.I.G.R. will steadily increase in stature and prestige. At Lausanne, the A.S.A.E. was strongly represented, papers being submitted by many well-known agricultural engineers, several of whom were present. Britain's technical contribution was relatively small, consisting of two papers by N.A.A.S. Mechanization Advisers, a General Report by the present writer, and contributions to the discussions by some of the 18 British participants.

The technical meetings at Lausanne were of two kinds, viz. paper-reading sessions during which the 12 General Reports were presented and discussion sessions in which both the general reports and the individual papers were discussed. Both the individual papers and the general reports were printed and were available at the Congress, in English, French or German, with a summary in all three languages. Altogether there were over 120 papers, which were grouped and reported on under the following broad subject headings:

1. Supplementary irrigation in humid regions (calculation of water requirements; economic effects). General Reporter: H. Grubinger, Switzerland.
2. Recent technical developments in the construction of underground drainage systems. Influence of terrain on choice of materials (tile drainage, other equipment, mole drainage). General Reporter: L. Sine, Belgium.

*(continued on page 162)*

*Advertisement*

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# SOME ASPECTS OF THE ECONOMIC UTILIZATION OF FARM MACHINERY

by B. M. CAMM, M.A., M.SC.*

*Presented at an Open Meeting of the Institution in London on 12 October 1964.*


## SUMMARY

1. A brief survey is made of the principles underlying the economic use of farm machinery. Attention is focussed on the use of marginal costs and marginal returns for the determination of optimum machine use. The substitution of machinery for labour with cost reduction in mind is discussed.
2. Reference is made to the special problems of dealing with discrete and durable assets. Most farm machines exhibit both these qualities and as a result tend to become fixed assets. The time value of money is introduced as a means for the comparison of costs and returns.
3. The opportunity costs of labour and capital are illustrated as they affect the purchase of a machine and the minimum economic acreage.
4. A model for estimating the present value of future costs of tractors of various ages is built up from hypothetical data. Schedules, when the opportunity cost of capital is 5 and 20 per cent, are calculated.
5. The problems of machinery scheduling in the face of uncertainty are introduced and an attempt is then made to show how the optimum size of machine can be determined with this factor in mind.


The sufficient conditions for economic efficiency on the farm are that resources are used in such a manner to maximize the particular objective of the farmer. Where the purchase and use of farm machinery is concerned objectives have often been discussed. Doubt has been thrown on the usually accepted belief that farmers own machinery solely for productive purposes, for the more expensive items have been regarded by more cynical observers merely as status symbols. Much of what they say has been true, but fashion is changing. Every farmer now owns machinery and many are able to afford the luxuries provided by engineers. The shiny new combine is no longer the distinguishing feature that it was. The most probable reasons are that machinery loses its lustre, is often noisy and is usually operated by the farmer's employees rather than himself. It is, therefore, rapidly losing its attraction as an asset in its own right and its place is being taken by a greater interest in real estate and the amenities of living in the country. The return to farming as a way of life recalls the work of Carslaw and Culpin, who, in a discussion on labour, power and equipment in arable farming, stated 'however much controversy may have raged round questions of ethics, there can be little doubt that one common objective has been to produce the maximum of material comforts with the minimum of human effort.' To this end machinery has an increasingly important role to play in British agriculture. But first of all, a backward glance will put the subject in perspective and indicates the rate at which changes are occurring among some of the main machinery users.

The way in which farmers in the Eastern Region have adjusted their expenditure on labour and machinery over the past thirty years is shown in Table I, derived from the University of Cambridge Farm Management Survey.

| *Labour and Machinery Costs as per cent of Total Costs* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1931 | 1935 | 1940 | 1945 | 1950 | 1955 | 1960 | 1965? |
| Labour | 37 | 32 | 28 | 36 | 33 | 27 | 24 | 20 |
| Machinery | 10 | 10 | 13 | 19 | 24 | 20 | 18 | 15 |

**TABLE 1**

Attempts to reduce labour costs were being made during the Great Depression and even by 1940 machinery was beginning to play an important part in reducing the drudgery of farm work. However, during the war the policy of production at any cost brought an influx of labour to agriculture and mechanization proceeded under the influence of War Agricultural Executive Committees. In spite of this considerable increase in the use of basic resources, total agricultural production failed to respond dramatically, although the composition of the output changed and farmers were forced to do without imported feeding-stuffs. By 1945 the proportion of costs taken by wages was similar to that in 1931 and that of machinery almost double. The war had definitely disrupted the

* Managing Director, Farm Planning & Computer Services Ltd, Cambridge.

natural process of substitution, forcing a more drastic rate of change in the immediate post-war period. This was the machinery boom.

In the late 1950s and in recent years farming has become more competitive and valiant attempts have been made to pare costs. Labour charges reached their peak in 1959 and, unless rapid wage increases occur, will probably slowly decline as more powerful machinery displaces men.

*Labour and Machinery Costs (£/acre)*

| | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 |
|---|---|---|---|---|---|---|
| Labour | 11.9 | 12.8 | 12.8 | 12.6 | 12.6 | 12.5 |
| Machinery | 8.3 | 8.7 | 9.2 | 8.7 | 9.1 | 9.2 |

**TABLE II**

(Cambridge University Farm Management Survey)

**Farm Problems**

Considering the farm solely as a business, the relevant quantity to be maximized is profit. The problems in farming are those of making decisions about the use of resources and patterns of production that will achieve this end. To help in making the correct decisions there are several commonly known choice indicators. In their more simple form they are ratios of the price of one factor or product compared to another. Where they are not allied to the profit motive, the problem of choice is difficult to define and decisions fall back upon the individual concerned. An illustration of a simple choice indicator is where a number of suppliers are offering a given product required by farmers in their production process. The prices at which the merchants are prepared to sell their wares may be used to determine the least expensive means of purchase with the view to reducing costs and raising profit.

Given the problem of choosing the level at which variable factors necessary for production, such as machinery or labour, should be applied to fixed factors for profit maximization, due account must be taken of the diminishing rate of return produced by successive applications of the variable factors. Diminishing returns form an almost universal feature in agriculture and is usually exemplified by the use of fertilizers. The theme is that a greater increase in the rate of application of fertilizers at high levels of application is required to increase the crop yield by a given amount than at lower levels of fertilizer use. The same phenomenon is experienced when capital in the form of machinery is applied in increasing quantities to other more limited factors such as land. Therefore, for economic utilization of machinery the same criteria may be used as apply to any other factors of production.

Employing choice indicators in increasing the use of a factor, the cost of applying the last or marginal unit of the resource should not exceed the value of the increased production that ensues from its application. Yet, in order to ensure that no profit is foregone, more of the resource should be used until the added cost is just equal to the increased return. Profit is at a maximum when output is positive and $\frac{dy}{dx} = \frac{px}{py}$ where d denotes a small increase in y (product) and x (factor) and p their prices.

A consequence of equating the marginal cost with the marginal return is that whenever there is a cost involved in the increased use of resources, the maximum physical yield possible does not bring the highest profit, and it is only where the marginal cost is very low, as it is for many machine operations once the equipment is purchased, that yields approaching the maximum are economic. Increasing the use of machinery services can only be justified if the extra cultivations or improved timeliness increase crop yields or quality to influence the gross returns sufficiently to offset the higher costs. A concern with the marginal effects in this manner is essential in order to maximize profit.

While adjustments in the total quantity of factors to the economic level of production are of prime importance in farming, a simultaneous need is the consideration of the substitution of one factor for another to minimize cost, particularly in the face of changing factor prices. In the past few years wage rates have risen more than machinery prices, requiring farmers intent on profit maximization continually to review their labour and machinery policy. The problem in resource substitution is one of combining factors in a manner to minimize the cost of producing a given combination and level of outputs. Choice indicators in the form of price and substitution ratios may be used to come to correct decisions. Where one factor costs less than another to produce a given output, it can be profitably substituted for it. Normally, factor prices change slowly in relation to each other, resulting in a gradual decline in the use of one factor as the input of the other is increased. Over the years, working horses have largely disappeared from farms as the cost of keeping them rose in relation to the cost of the tractor power that would displace them. Yet horses did not disappear immediately tractors were introduced, because until comparatively recently it was still cheaper to use them for some tasks. It is rare to find a simple means of cost reduction by the straightforward substitution of the whole of one factor for another. More frequently, the rate at which factors substitute for one another changes as substitution proceeds. A straightforward comparison of prices is then inadequate to decide the least cost combination of the factors involved. Because of diminishing returns, the successive substitution of one factor for another requires increasing quantities of the former to displace unit quantities of the latter and maintain constant production. Costs can be reduced as long as the quantity of the factor displaced × its price is less than the quantity × the price of the substituting factor. Substitution is worthwhile until a small change in the quantities of either factor has no effect on costs. At this stage the ratio of the rates of substitution of the quantities of the factors equals that of their prices.

Minimum cost is achieved when $\frac{dR_1}{dR_2} = \frac{pR_2}{pR_1}$ where

$R_1$ and $R_2$ are the resources, d denoting small changes in their quantities and p their prices.

As unit costs are reduced to a minimum by adjusting the proportions of factors involved in production, the input of all factors may now be changed until the level of output is reached where the marginal returns just balance the marginal costs. In changing the output, changes in the proportion of the inputs may be required to maintain the minimum cost, explaining why different combinations of labour and machinery may well be found on farms of different sizes producing similar products and assuming that farmers make continuous efforts to equate marginal costs with marginal returns.

## Special Problems of Machinery

Indivisibility: in a bold statement of principles, farmers are assumed to be able to adjust their factors of production in suitably small amounts both to achieve an initial optimum use of resources and to take advantage of price changes to maintain a favoured position. In practice this is not possible when dealing with indivisible factors such as machinery. However, indivisibility of factors does not invalidate the use of the marginal effects as decision aids. In many circumstances indivisibility tends to simplify decision making. The lumpiness of the resources involved makes it unnecessary to consider changing their combination in the short term unless large relative movements in prices occur or the marginal rates of substitution indicate a sensitive balance between resources.

The integer restraints imposed by discrete elements mean that relatively few combinations of factors need be considered. Tractors without men and, in many circumstances, men without tractors do not pose great difficulties in decision making. Nevertheless problems do exist and one illustrating the integer combinations of tractors and men is shown in Figure 1. Points where the same output

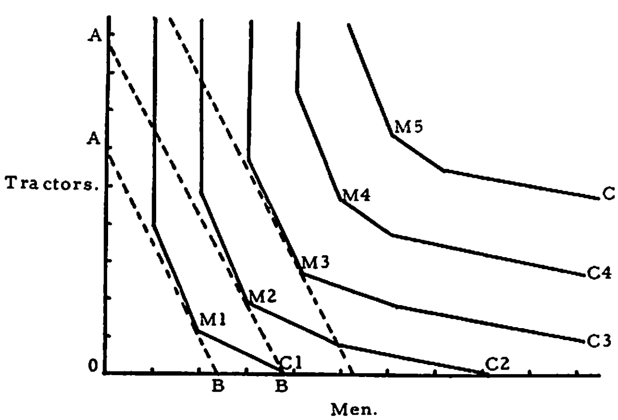


Fig 1.

occurs are joined by lines although it is only feasible to operate at integer quantities of both factors. The price ratio of tractors to men is shown by line A-B where it is assumed that a man costs nearly 2.5 times as much as a tractor each year. The minimum cost combination is achieved where the line is nearest the origin O and just touches the iso-product 'curve' C. For any given output $C_1 \ldots C_5$ a minimum cost, $M_1 \ldots M_5$, can be achieved by substituting one factor for another until substitution ratios are nearest the price ratios of the factors.

The most profitable level of output occurs where the marginal cost of tractors and men combined in their least cost proportions is just covered by the marginal return—a jump onto a higher iso-product curve. If diminishing returns operate, the curves will be further apart as higher levels of output are achieved, making precise adjustments more difficult as the optimum is approached.

The sensitivity of the farm to price changes in these factors depends upon the shape of the iso-product curve and the price ratios. In Figure 1, the price of labour would need to rise to three times that of tractors before tractors should be substituted for men. The vertical sections of the iso-product curves indicate that at these resource combinations true complementarity exists; output cannot be increased by an increase in tractors unless some minimum additional quantity of labour is also added. In practice, the choices of combination of machinery and labour are not so rigidly defined because by varying the quality of the factors purchased a greater choice is introduced. Smaller tractors can be purchased or less able men paid a lower wage to blurr the sharp distinctions imposed by integer combinations. However, with minimum wages and only a narrow range of prices for machines, the choice is more restricted than in many other branches of agriculture.

## Fixed Resources

Resource fixity occurs with assets having a wide margin between acquisition cost and disposal value, particularly those acquired in discrete quantities and supplying a service over time. Unlike fuel or feeding-stuffs which are purchased and used regularly, and if not used, costs can be curtailed, the cost incurred by fixed assets continues whether advantage is taken of the services available or not. Such resources have a discontinuous marginal revenue corresponding to the indivisible units that can be purchased. Whenever the marginal return of the last unit owned is less than the purchase price or sale value of it, the asset is fixed in that further purchases or sales would reduce profit. An extreme example is provided by farm buildings that are tied to the land. No one attempts to add a building such as a tithe barn to the assets of a farm because its marginal cost would exceed its return. At the same time farmers with tithe barns make little attempt to dispose of them because their scrap value is very low, but continue to use them for a variety of purposes.

Most farm machines exhibit similar tendencies but to a lesser degree. They may be said to have two costs; a cost of acquisition and an opportunity cost in sale value, the difference being the dealer's margin and cost of marketing. Machines continue to be of value to the farm as long as the marginal return exceeds the salvage value, but in order to increase the number of machines profitably the marginal return must rise above the cost of acquisition. If, as a result of age and obsolescence, the marginal return falls below the trade-in or scrap value then the opportunity of sale should be taken to free the farm of future costs.

**Measuring Returns**

The problem most frequently met in adjusting the inputs of machinery in respect to output or to other factors is that of estimating the marginal cost and return of investments. Machinery like buildings or land is not completely consumed in one production process; time is needed to gain the full return. Time clouds management decisions, because estimates of future costs and returns are to some extent unreliable. A very simple technique that may be used to sift the more likely investments from those of doubtful value is the write-off method. This determines the number of years necessary for the annual savings or increased returns to pay back the original capital. For example, an original investment of £2,000 may be just sufficient to reduce annual labour costs by £600 for an increase in machinery running costs of £100. The additional earnings of the investment are then £500 which may be divided into £2,000 to give four years for the investment to pay for itself. Straight comparison with alternative investments will show those which are likely to show a profit in a reasonable period of time.

The write-off method relies upon the immediate cash aspect of the investment and may be used to advantage in considering investments where the risk is too great to make fair estimates of the earnings beyond the write-off period. It has serious limitations in determining the economic worth of an investment because it does not recognize that earnings may not accrue in a steady stream. Neither is consideration given to the scrap or trade-in value of the investment and the rate of interest is ignored.

More accurately the value of an investment may be determined by calculating the average net earnings on the average capital employed. Not only is the investment expected to pay for itself, but to provide a reasonable and competitive return on capital. The investment is amortized over its life and the return, above the running and depreciation costs, expressed as a percentage of the average capital employed.

In the example above, the increased running costs of machinery may be deducted from the labour saving to give the gross return on the investment. An allowance for depreciation is deducted, e.g., asset cost divided by its life, to give the net return. This may then be expressed as the return on the average capital employed to give the percentage return. With a life of ten years the investment produces a net return of 30 per cent.

$$\text{Per cent Net Return} = \frac{600 - 100 - \frac{2{,}000}{10}}{\frac{1}{2}\,(2{,}000)} \times 100 = 30$$

Various modifications may be made to take account of investment allowances and income tax rates.

There are still flaws in this approach for the unwary, although it does approximate the rates of return for investments having a relatively short economic life and a uniform stream of annual earnings. A more critical appraisal reveals that it can produce severe distortions with investments bearing fruit later in their life when compared with those giving immediate returns and also where the investments compared have widely differing depreciation schedules.

The cash flow of an investment is always important where alternative investments are available to take up the cash released and earnings of the primary investment. The investment that brings high earnings early in its life is at an advantage with one giving a similar average return later because the cash released can be reinvested to produce a secondary flow of income. Failure to recognize this time value of money tends to overstate the rate of return on long term investments by considerable proportions. Most machinery produces returns in savings of other costs or increased output above its current cost as a flow in similar although not necessarily equal amounts each year. The funds invested in the machine always have an alternative use even if it is only in securities outside the farm. Therefore, it is necessary to discount the returns from the machine by the appropriate earning power at compound rates of interest. The current value of the machine may then be ascertained to decide the propriety of the investment. The present value $V_o$ is the sum of the respective net returns (R) divided by the appropriate compound interest figure (r), i.e.,

$$V_o = \frac{R_1}{1+r} + \frac{R_2}{(1+r)^2} + \cdots\cdots \frac{R_n}{(1+r)^n}$$

The more relevant situation is where, to reduce costs to a minimum, a comparison is attempted between alternative techniques with different labour and machinery usage over differing periods of time. The present value of the costs $C_o$ incurred can be calculated for each technique where I is the initial investment, S is the scrap or trade-in value and C the annual running costs of the system made in each year i; r is the rate of interest on the borrowed funds if the whole of the transaction is financed from outside, or the rate obtainable on securities with the farmer's own monev.

$$C_o = I + \sum_{i=1}^{i=n} \frac{C_i}{(1+r)^i} - \frac{S_n}{(1+r)^n}$$

Where the rate of return can be achieved in less than a twelve-month period, $(1+r)^n$ becomes $(1+\frac{r}{x})^{xn}$, where x is the number of times a year that interest is added.

**Opportunity Costs**

The rate of interest is frequently the deciding factor in the choice of investment and in the choice between investing and not investing. Currently, with a possibility of lending money at 6.5 per cent, equivalent to 5 per cent return earned income, a lower limit can be set on the rate of return that must be attained within the farm. Where funds are limited and alternative investments compete, the principle of opportunity cost may be invoked to force a decision on the choice of investments. To ensure that no better opportunity is missed, the rate of return expected in the best alternative enterprise should be used as the rate of interest in estimating the current value of future returns or the costs of different techniques under review.

The average return on tenant's capital is about 20 per cent on the farms surveyed by Cambridge University. Of these, over 16 per cent made a return in excess of 30 per cent. There is also every indication that the returns on large farms are greater than on small. However, average returns are irrelevant, for it is marginal returns which govern the allocation of new investment. Marginal returns may be higher or lower than average returns depending on individual circumstances, but the use of such high discounting rates has the effect of stifling most long term machinery investments unless they have considerable cost advantages. Two examples in the past have been combine and sugar-beet harvesters. In the future the effect of rising wage rates will influence costs on many more farms in favour of mechanical singling of root crops, wider ploughing and cultivation implements, and more powerful tractors. However, on farms where labour is not so expensive and high value investment opportunities exist there is an alternative to poor cultivations imposed by out-of-date equipment. Contract services may be engaged to relieve the farmer of heavy long term investment and at the same time free labour at critical periods of the year, so that more remunerative opportunities need not be foregone.

The value of alternative investments and use of labour is the opportunity cost of these factors if purchase of machinery is insisted upon. Adding these costs to the normal operating costs distinctly alters the acreages of crops at which special machinery for them may be justified. In many situations addition of the opportunity cost raises the minimum economics acreages (Figure 2). In other circumstances where contract services are not available, machinery investment frees labour for other tasks where returns of over £1/h are possible, giving high impetus to machine purchase.

The effect of using a machine over a larger acreage of crop is to reduce the average cost per acre. The average cost of a sugar-beet harvester drawn by a tractor declines from £9/acre for 4 acres to 35s 6d/acre for 30 acres, as seen in curve A of Figure 2. However, if capital can be used elsewhere to give a return of 13 per cent, then 13 per cent must be charged to the sugar-beet harvester before deciding whether a contractor would be cheaper, as indicated by curve B in Figure 2. The effect is to raise the minimum economic acreage for owning a harvester to over 10 and, if the opportunity cost of labour to drive the machine is also considered, it is possible that curve C is the real cost of operating one's own machine. Here, less than 29 acres is insufficient to compete with the contractor provided the funds are invested in the alternative enterprise and the labour used to earn 35s per hour in other work.

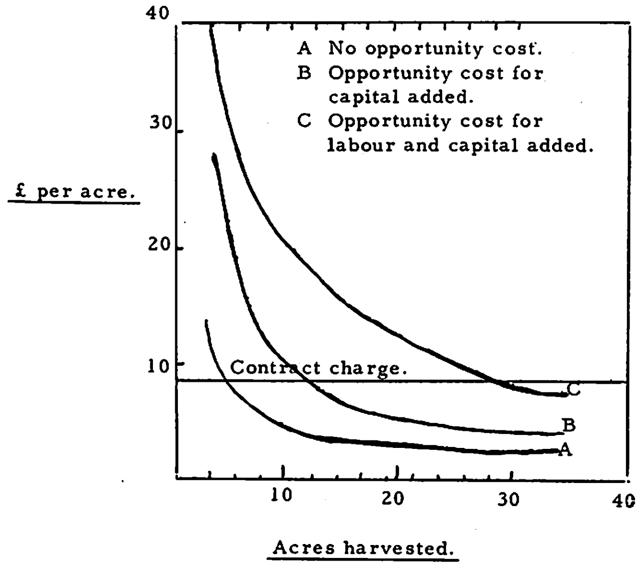

Fig 2.

### Risk and Economic Life of Equipment

In all methods of evaluating an investment (except the write-off method) some attempt must be made to estimate the life of the investment and the uncertain stream of earnings forthcoming. In the majority of machinery situations there is insufficient evidence on physical life and repair schedules to enable precise valuation to be made. We are then left with a range of probabilities of scrapping or repair charges between the minimum and maximum periods expected. Barring accidents, the life of most machines can be prolonged almost indefinitely by repairs. The exact age when repairs will be incurred is not known and therefore the sudden rise in cost which would probably result in the scrapping of the investment cannot be attributed to any one time period. However, the cost may be spread over a range of periods on the basis of the probability of it occurring by the end of a certain time span and the flow of earnings in these periods discounted by this factor.

The risk of obsolescence can be treated in the same way with the probabilities of obsolescence used to discount earnings. For the adroitness of this procedure, maximum and minimum periods for the life of the machine must be specified. The probabilities of obsolescence within these boundaries can then be computed from empirical data.

## II

## TOWARDS A MODEL FOR THE PURCHASE AND REPLACEMENT OF TRACTORS

The following example is included to show how the theoretical considerations may be incorporated in a calculation to determine the present value of the costs that may be incurred in buying tractors of various ages and keeping them for various lengths of time.

The factors taken into account are:

### Investment Allowance

Under the present fiscal arrangements an Investment Allowance of 30 per cent may be claimed against tax liability for the purchase of new equipment. On a tractor costing £750, £225 may be set against tax which at the standard rate of taxation of 7/9d in the pound on seven-ninths of earned income is worth £67.8 in cash on agreement of the accounts by the Inland Revenue. Assuming that the farmer's taxable income will be reduced by this amount, he has to wait at least a year for the money. The present value of the allowance is worth only £64.6 discounting at 5 per cent or £56.5 if 20 per cent is the relevant rate. The investment allowance is similar in its effect to an outright grant, the amount depending on the marginal rate of taxation of the individual. The discounted sum may be deducted from the purchase price to arrive at the cost to the farmer.

Initial and Annual Allowances may also be claimed and, insofar as they exceed the actual rate of depreciation, they allow the farmer to claim more against taxation in the early years of the investment than later on in its life. However, eventual sale brings a balancing allowance or charge to equate the actual depreciation with that allowed for tax purposes. The only advantage to the farmer is that he may gain the equivalent of a small interest-free loan for a few years until a balancing charge is levied. On the other hand a balancing allowance means that he has given an interest-free loan to the tax authorities. No account has been taken of the latter tax effects in this example.

### Dealer's Margin

In the trade-in of a tractor for a new model the dealer's margin may appear to be absent due to averaging of the mark-up of the new tractor over two sales, but whenever a tractor is traded in for a second-hand model a margin of not less than 10 per cent occurs between the value offered to the farmer and the price asked from a subsequent buyer. The dealer's margin used in the example ranges from £30 to £50. At the lower levels of second-hand values a constant £30 is used rather than a percentage of the asking price as being more likely to approximate to the dealer's costs in handling the transaction.

### Opportunity Cost of Labour

As a tractor ages the probability of a breakdown increases. The value of the time lost may be considerable if critical operations are being carried out at the time. In a generalized example only hypothetical figures for the opportunities lost through breakdown can be formulated. More appropriate calculations can only be carried out if details of the farm organization are known. The expedient has been adopted of assuming that the cost of breakdowns in lost production or higher costs incurred to cover the eventuality is proportional to the repair schedule, on the basis that for every £1 spent on repairs a quarter-hour's working time will be lost. Furthermore, the assumption is made that breakdowns are equally divided between critical and slack periods so that the marginal cost of the tractor and driver at the time is about £1/h.

### Opportunity Cost of Capital

This incorporates the time value of money concept for discounting future costs. Two schedules are adopted, one at 5 per cent for farmers with adequate funds where off-farm investment is the most likely alternative investment; the other, where moderately remunerative investments at 20 per cent may be indulged in on the farm. Compound interest has been levied annually although it is recognized that in enterprises such as pigs it may be possible to turn over the capital invested more frequently. A 10 per cent return twice per year would then be worth 21 per cent on an annual basis.

The discounting feature is applied to the stream of annual costs for repairs, breakdowns and obsolescence. In a similar way the re-sale or scrap value is discounted back to the present time.

### Repairs and Obsolescence

Repair costs are lumpy in their nature. In some years several high unrelated charges may be incurred whereas in others very little may be spent. The incidence of repairs is related to the use of the tractor but in an unpredictable way. Experience gained from a few past observations is of little value in estimating future repair costs for a new acquisition. However, in the absence of reliable information an approximate repair schedule may be constructed by redistributing lumpy costs expected from past experience on the basis of probabilities of their occurrence in any use period, e.g., a tractor on certain work will sooner or later require a new set of tyres costing £70. If the chances of this occurring in the second year after its acquisition are 20 per cent, the costs may be allocated as £14, £42, and £14 for the second, third and fourth years respectively.

The cost schedule constructed is purely hypothetical although it could conceivably be appropriate for 50+ hp tractors working between 1,000-1,200 h/annum. Data to construct a more realistic schedule are not available because it is unusual to find a tractor accomplishing similar work throughout its life. The new tractors do the hard work and the older ones are slowly retired to more menial tasks. Surveys of tractor expenses then indicate that it costs less to run an old tractor than a new one. For the same reason it is not known to what levels repair charges would eventually rise on a tractor under pressure continuously, as it frequently is in its early life.

Obsolescence occurs quite suddenly but does not completely wipe out the value of the tractor. The effect is to introduce a break in the sequence of the trade-in values. When a new model is introduced that offers some distinct advantage over previous models, the value of all ages of tractors of the preceding model drops. The worst affected are those tractors purchased immediately before the introduction. This is because it is unlikely that they

| Age at Sale Years | Price | | | Expected Costs | | | |
|---|---|---|---|---|---|---|---|
| | to Buy | to Sell | Dealer's Margin | Repairs | Breakdowns | Obsolescence | Total |
| | £ | £ | £ | £ | £ | £ | £ |
| 0 | 685.4* | | | | | | |
| 1 | 580 | 530 | 50 | 8 | 2 | 15 | 25 |
| 2 | 480 | 430 | 50 | 27 | 7 | 35 | 69 |
| 3 | 400 | 360 | 40 | 65 | 16 | 25 | 106 |
| 4 | 340 | 300 | 40 | 120 | 30 | 10 | 160 |
| 5 | 290 | 260 | 30 | 100 | 25 | 5 | 130 |
| 6 | 250 | 220 | 30 | 120 | 30 | 3 | 153 |
| 7 | 220 | 190 | 30 | 120 | 30 | 2 | 152 |
| 8 | 190 | 160 | 30 | 130 | 32 | 2 | 164 |
| 9 | 160 | 130 | 30 | 140 | 35 | 2 | 177 |
| 10 | 130 | 100 | 30 | 150 | 37 | 1 | 188 |

* Investment Allowance.
£750 less $\frac{1}{3}$ at 7/9 in the £ equivalent to 6/- in the £ earned income discounted at 5%, or 20% rate of discount= £693.5

**TABLE III**

Assumed Schedule of Costs for £750 Tractor

| Age at Sale | Age at Purchase (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | New | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 204.2 | | | | | | | | | |
| 2 | 381.7 | 236.1 | | | | | | | | |
| 3 | 552.4 | 414.8 | 238.2 | | | | | | | |
| 4 | 748.4 | 621.1 | 453.6 | 266.3 | | | | | | |
| 5 | 893.2 | 773.2 | 613.3 | 433.9 | 216.4 | | | | | |
| 6 | 1047.0 | 934.8 | 782.9 | 612.0 | 403.0 | 225.8 | | | | |
| 7 | 1184.2 | 1078.4 | 934.0 | 770.8 | 569.9 | 400.8 | 214.0 | | | |
| 8 | 1322.2 | 1223.3 | 1085.7 | 930.4 | 737.4 | 576.9 | 398.4 | 223.8 | | |
| 9 | 1460.7 | 1368.9 | 1238.6 | 1090.4 | 905.9 | 753.6 | 584.1 | 420.5 | 234.7 | |
| 10 | 1598.2 | 1513.5 | 1391.2 | 1250.4 | 1073.3 | 929.8 | 769.0 | 611.8 | 438.1 | 213.8 |

For the cost of retaining an old tractor deduct the dealer's margin.

**TABLE IV (a)**

Comparative Costs of Buying and Holding a £750 Tractor.
(rate of interest 5 per cent)

| Age at Sale | Age at Purchase (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | New | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 272.3 | | | | | | | | | |
| 2 | 463.7 | 279.5 | | | | | | | | |
| 3 | 614.1 | 461.0 | 268.3 | | | | | | | |
| 4 | 755.4 | 629.1 | 471.1 | 283.2 | | | | | | |
| 5 | 848.1 | 740.2 | 603.4 | 422.9 | 231.6 | | | | | |
| 6 | 930.2 | 839.1 | 721.8 | 583.9 | 401.5 | 234.3 | | | | |
| 7 | 1041.4 | 915.3 | 810.9 | 693.5 | 532.3 | 391.4 | 218.3 | | | |
| 8 | 1047.7 | 979.9 | 888.6 | 786.9 | 644.3 | 525.6 | 379.4 | 224.5 | | |
| 9 | 1094.0 | 1035.4 | 955.3 | 866.8 | 740.1 | 640.8 | 517.8 | 389.6 | 229.1 | |
| 10 | 1133.4 | 1082.6 | 1012.0 | 934.8 | 821.9 | 738.8 | 635.5 | 530.8 | 398.5 | 203.4 |

For the cost of retaining an old tractor deduct the dealer's margin.

**TABLE IV (b)**

Comparative Costs for Buying and Holding a £750 Tractor
(rate of interest 20 per cent)

have previously been affected by the introduction of other new models, whereas, the older the tractor is, the greater the chance that improvements have occurred before; further improvements in new models make very little difference. By the time a tractor is 10 years old it is practically certain that obsolescence will have occurred and the cost will have been borne in previous years, whereas in a tractor only one year old the probability of obsolescence is low, but if it does occur in the following year its cost will be very high. By distributing the cost of obsolescence, say £100, by the probability of occurrence a cost schedule is constructed. The cost of repairs and obsolescence, and the opportunities lost through breakdowns are combined in Table III where buying and selling prices are also shown.

From Table III the present value of future costs of holding a tractor have been calculated using the formula previously mentioned for taking into account costs over time. These are tabulated in Table IV.

### Use of the Tables

Table IV shows comparative cost figures for buying tractors of different ages and holding them for various lengths of time. Where a tractor has already been purchased the cost of retaining it for a further period can be found by reference to the table and deducting the dealer's margin shown in Table III. For example, a farmer holding a two-year-old tractor may wish to compare the costs of retaining it for a further two years with the purchase of a new tractor or a tractor one year old, both to be kept for two years. He can earn 5 per cent on capital in alternative investments. The three alternatives may be set out as follows:

(*a*) Retain the two-year-old tractor until it is four years old. The present value of the costs that will be incurred, discounted at 5 per cent, is found by entering Table IV (a) in column 'Purchase two year old tractor' and reading the figure opposite the age at sale—four years, £453.6. From this is deducted the dealer's margin shown in Table III for a two-year-old tractor, £50, because this is a cost that will not be incurred. The present value of the costs over the next two years is then £453.6 – £50=£403.6.

The alternatives may be read directly from the table because they involve the sale of the existing tractor and purchase of an alternative.

(*b*) Purchase of a new tractor for sale two years later gives a figure of £382.1 for the comparative cost.

(*c*) Purchase of a one-year-old tractor for sale when it is three years old gives £414.8.

Thus, just over £20 can be saved by trading in the old tractor for a new one. However, if the rate of return in alternative investment is as high as 20 per cent, capital is more valuable. Using Table IV (b) gives the comparative costs as:

(*a*) £471.1 – £50=£421.1

(*b*) £464.4

(*c*) £461.0.

In these circumstances the farmer would be well advised to retain his tractor and invest the money he has available in the lines of business that give him a 20 per cent return.

If a higher trade-in value can be obtained by buying new then the extra value should be deducted from the costs shown for it is equivalent to the dealer reducing his margin. The difference between costs (a) and (b) then shows how much the farmer must gain from the dealer in his bargaining if he is to break even on the purchase of a new machine.

Changes in the assumptions, particularly the incidence of repairs, during the life of the tractor, change the present value of the future costs. As the schedule was drawn up for a tractor operating 1,000-1,200 h/annum under reasonable care, greater or lesser use will affect the expected repair costs. Generally, the heavier the use of the tractor the higher the costs of retention, making an early trade-in more profitable. On the other hand, a tractor used for less than 500 h/annum can rarely have a present value of future costs greater than that of a new one, although at some stage it may be worthwhile to replace it with a second-hand model.

The variation from farm to farm in the use and treatment of tractors and value of alternative investments makes it unlikely that the optimum replacement age is the same even for farms apparently operating under similar conditions.

## III

## MACHINERY SCHEDULING

Machinery scheduling is the process of planning out machine usage day by day to ensure that work is completed on time. Priority is usually given to those jobs which affect profitability most or are likely to cause the greatest losses if delayed. Various techniques are available for estimating the capacity of a collection of equipment and determining likely completion dates for a sequence of operations. These are widely used in industry for estimating costs and planning work schedules. However, agriculture has its special difficulties in the considerable variability in the time needed to complete operations and the time available to carry out tasks. This leads farmers to carry excess capacity in their equipment which, with the unavoidable high proportion of idle time, makes machinery a costly item. Attempts may be made to reduce unit costs by adjusting cropping programmes to machinery capacity and planning out the work to ensure optimal use of machines.

A necessary prerequisite of scheduling is that the year be divided into mutually exclusive periods or seasons in which certain tasks must be done and that tasks in one period must be completed before succeeding operations on a particular crop can be carried out. Where flexibility between periods exists for jobs such as ploughing, that may be done over a range of time between clearing of the preceding and the cultivations of the succeeding crop, judicious over-lapping of periods will still allow delineation of the work periods. The tasks for the various machines may then be laid out in correct sequence and the time needed to complete the operations associated with the cropping programme ascertained. Adjustments of the cropping programme methods or the machinery complement can then be made to comply with the time allowed. However, if average times for the various tasks are used, simply adding them together and restraining the total within the time available will give no more than 50 per cent chance of completion. Such a chance may be acceptable according to the value of the crop and the cost of higher capacity equipment, but if it is not, further consideration must be given to the probability of completing the various jobs on time.

Suppose there are three jobs leading to the autumn drilling of wheat, each with an average time derived from past experience and all showing a tendency to variation from season to season. The total time for the operation may be found by adding the average values of time required for each task and a measure of variability in the total time found by adding the variances of the individual operations. Estimating the average time available for the work will give a lead to the number of acres that can be sown, but again variability in this figure will affect the certainty of the outcome. A range of 100 hours with 200 hours as the expected time from one man will give the acreage of wheat drilled with the associated probabilities shown in Table V assuming that there is no correlation in the work rates and the time available and no interference from the preceding crop.

| *Sowing Winter Wheat* | | | | |
|---|---|---|---|---|
| Man hours/acre | *Ploughing* | *Discing* | *Drilling* | *Total* |
| Average time | 1.4 | 1.0 | 0.6 | 3.0 |
| Variance | 0.5 | 0.5 | 0.3 | 1.3 |

| *Acre/man* | *Probability of Completion* |
|---|---|
| 33 | 90 per cent |
| 47 | 75 ,, |
| 67 | 50 ,, |
| 87 | 25 ,, |
| 100 | 10 ,, |

**TABLE V**

Such information can be used to decide whether men and machines could be more profitably transferred from competing operations such as sugar-beet harvesting or, alternatively, additional equipment purchased and labour hired. Problems of this kind make it imperative that the allocation of machinery is considered on the farm as a whole, to build up a balanced organisation. Individual farm requirements and machine performance, weather and crop growth data are all required for a systematic analysis and a prediction of system performance. The results can then be combined with economic information and the degree of risk acceptable to the farmer to formulate a cropping programme and machinery complement to suit.

**Choosing Machinery Sizes**

A larger machine with a higher rate of work increases the average amount of work that can be done in a given time or it can be used to increase the probability of completing the work on a given acreage. However, with tractor-drawn implements there is no guarantee that greater width will increase the rate of work. If tractor power is sufficient to pull the widest implement, increasing the working width of the implement increases the work rate in proportion, but if tractor power is a limiting factor, the work rate only increases linearly until the tractor has to drop to a lower gear to cope with the greater load. When the tractor is working at full power, further increases in width will result in lower gears being selected reducing forward speed such that the work rate does not change.

Because of the range in tenacity of soils, different widths of implements will give the best results in different areas and the optimum size can be determined by the solution of a cubic equation with data available or by the farmer experimenting for himself.

With self-propelled machines, power is usually increased for greater width and a more general guide can be formulated. The basic factors determining the optimum size of machine are the speed of operation, field efficiency, the area of crop to be handled and the time available for completion. The speed of operation is controlled partly by the machine and partly by the crop. A combine-harvester working in a two-ton crop should be able to thresh $\frac{1}{2}$-ton/h/ft of cut, although the width of cut is not always the deciding factor. This gives a speed of operation of 0.25 acre/h/ft and with a field efficiency of 80 per cent gives an effective speed of 0.2 acre/h/ft. If this simple explanation is adequate, the width of machine required to harvest 300 acres in an area of the country where 25 combining days are available is as follows:

$W = \frac{A}{SH} = \frac{300}{0.2 \times 200} = 7.5$ ft where W = width in feet, A the acres of crop, S effective speed in acre/ft/h and H the hours available.

**Risk Considerations**

However, such a formula takes no account of the risk involved. It ignores the possibility of reducing losses incurred by weather variation by employing higher capacity equipment.

It is unlikely that every year will allow 200 hours of combining time and a high degree of risk will be incurred by just being able to deal with the average year. The cost of taking this risk can be gauged by estimating that 72 acres* will be lost in a very wet year. Even if the chances are as low as 1 in 100, 1 per cent of the value of the crop at risk could be spent in extra machinery costs each year as an insurance against loss. An 8.5 ft cut machine would reduce the chances of loss by quite a large amount, but not until a 9.9 ft machine is used is it 99.9 per cent certain that no corn will be lost. The optimum size of machine lies between these sizes according to the marginal cost

* This ignores the possibility of a reduction in work rate in acre/h due to bad weather.

according to the marginal cost of providing additional capacity and the increase in average returns through the reduction in losses. Taking risk alone into account, a 9.5 ft machine would probably be the optimum where extra capacity costs £40/ft/annum.

A further increase in size of machine is difficult to justify on the grounds of risk alone. On the other hand, the time saved in having a larger machine may well be more valuable than the cost when it is applied to other farm work. By having a 12 ft machine, the harvest can be completed in a shorter time, giving the opportunity to make a start on other tasks, although, like the harvesting, this is subject to a certain degree of chance. The value of the time saved can be measured in terms of a direct saving in drying costs, or indirectly in the saving of contractors' charges for subsequent ploughing, or in increased returns from a higher acreage of a more lucrative crop that would not otherwise be grown later in the season. Thus the optimum size of machine not only depends upon the work that it is expected to do, but also the work imposed on the labour force from other sections of the farm organization at the same time.

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## DISCUSSION

MR C. V. BRUTEY (National Farmers Union) expressed surprise that Mr Camm had made no mention of machinery syndicates. If the farming community was as blind to the economics of machinery usage as Mr Camm had suggested, the machinery syndicate movement would not be expanding at its present rate, which was something in excess of 100 new syndicates in the last twelve months. Mr Brutey went on to refer to the question of labour and especially to Mr Camm's suggestion that farmers very often bought additional machinery capacity and did not dispense with workers. He wondered whether it had occurred to the speaker that in many cases the workers had gone *before* the machinery was purchased. One of the most common reasons for purchasing additional machinery these days was that labour had already left the land and the farmer had to increase or improve his machine capacity in order to replace the labour that had already gone. A further factor in the purchase of machinery was that it was not always possible to equate so many machines with so many men; there was an increasing tendency in the industry today to improve the standards of workers to something like that which was to be found in other industries. To achieve this it was necessary to purchase additional machinery simply in order to reduce the amount of effort and to eiliminate some of the more unpleasant tasks otherwise undertaken by manual labour on the farm. Finally Mr Brutey commented on a suggestion from Mr Camm that before purchasing a machine the farmer should look at alternative sources of income. 'If farmers always did this', said Mr Brutey, 'we would have no farmers—we should probably be killed in the rush from the land'.

Mr Camm said he thought Mr Brutey had treated him rather roughly. He did not think that farmers had no economic sense; on the contrary it was the farmers who were clever at this and 'we out-of-date economists' who probably wanted shaking up. Mr Camm said he had hinted at this in his suggestion that, when looking at the risk problems in machinery scheduling, it would be realised how wrong it was to castigate farmers for carrying 'excess' capacity. Of course machinery syndicates offered an admirable way of spreading costs between farmers, but this was only possible if farmers could agree; farmers, however, were a rugged lot. In practice successful operation of the syndicate system depended not so much on the machines or on the land being farmed, as upon the extent to which the farmers got along with each other. Mr Camm contested the assertion that labour had gone before machines were purchased. This was not borne out by national statistics for the period from the end of the war until some two or three years ago. The machines were always bought before the labour had gone, and during the period between 1947 and 1957 the lag between machinery purchase and a comparable labour force reduction was about ten years. The lag was diminishing as labour was going fairly quickly now. Machinery was necessary to avoid unpleasant tasks but, unfortunately, its use was very expensive. The farmyard manure spreader was probably the most expensive machine per unit of use on any farm. Were there no alloys available these days, asked Mr Camm, that would not corrode, under such circumstances? Perhaps a little education of farmers on the care of machinery might help, as most farm machines tended to rust out rather than to wear out. Nevertheless, it did not pay to put up buildings to cover machinery; it was much cheaper to let them rust out than to cover them up and incur labour costs to look after them. Mr Camm agreed that some farmers who looked for alternative sources of income would not farm, if one studied the average income of farmers. Nevertheless about a third of all farmers in Britain made double the average farmer's income and about 10% nearly treble. The average return on tenants' capital in farming was close to 20%, which was after all not a bad return, and one which any manufacturer would be pleased to take for any of his products.

CDR. F. D. BINGHAM (Association of Hydraulic Equipment Manufacturers) asked whether there was any place on the farm in this day and age for the horse. In Canada, for example, where there was a high degree of mechanization, a lot of the carting of fodder and water to stock during the winter season was done by the horse. It was at that time of the year that the staff on a large farm would not be fully employed every day, whilst on a small farm the farmer and his family might be equally short of a job. Was there not a place on any farm for the economic use of the horse for this type of work?

Mr Camm replied that Dr Dexter, who was now with the Ministry of Agriculture, Fisheries and Food, had written a Paper some years previously on the economics of horse work, and had reached the conclusion that there was a place for the use of horses for such work. Mr Camm said he doubted whether this was still true simply because a horse could not travel fast enough compared with a tractor. There were certain jobs where a horse could be useful if a driver was not needed. Milk rounds were an example of this, and Mr Camm said that he had once worked on a milk round with a horse. One could effect time savings of the order of 20% compared with the use of a lorry because as a lorry driver, one was constantly climbing in and out of the cab, whereas a horse went from house to house while the roundsman went along with his crate and picked up the bottles as required. He was sure that on a retail milk round a horse would be more economical than a lorry or a van but he doubted whether there was room on arable farms for the horse. It was not fast enough, and keeping a horse on a livestock farm displaced two or three cows or an equivalent number of other stock, which could bring in an income of £100-£120 per annum—enough to pay for a second-hand tractor.

MR E. S. BATES (British Petroleum Co Ltd) felt that Mr Camm was tending to approve the retention of an old tractor for an indefinite period although he had also stated that it would be obsolescent in 10 years, the point being that the opportunity cost of capital was the basic reason why one should not trade in the tractor too soon. Mr Bates agreed that it was always a problem when to trade in a tractor but he believed that Tables 3 and 4 provided the answer. When the total expected costs exceeded the return from the dealer on the old tractor, that was the point at which money was being lost. A scrutiny of Table 3 would show, in the case of a new tractor costing £750, that its cost in year 8 would reach £164 whilst the value obtainable from the dealer would be £160. From that point on the tractor would lose money. Reference to table 4(b) showed that by year 10 the owner would have lost £88. The divergence in values indicated by comparison of Tables III and IV(b) revealed that the correct time to change this £750 tractor was year 8, provided the estimated costs were accurate.

Mr Camm said he assumed the point being made by Mr Bates was that as soon as the cost of repairs or the cost of running the tractor for the ensuing year exceeded the trade-in value, the optimum trade-in point had been reached. In principle that would not cost very much, but if one were to look at Table IV(b) it would be seen that the cost per annum was approximately on the decline until the point was reached when the tractor just broke up. This was so only if one could invest the money at 20% elsewhere. If the owner earned only 5% on his capital it was advisable to trade in when the machine was two years' old. Mr Camm then quoted the following extract from his Paper:

> '. . . thus over £20 can be saved by trading in the old tractor for a new one. This is at the 5% discount rate. However if the rate of return in alternative investment is as high as 20% capital is more valuable, using Table IV(b) gives the comparative cost as . . .' and so on.

It was necessary to perform this kind of calculation in each separate case. If a farmer could earn 20% on his capital it would probably not pay the owner to trade in his old tractor after 8 years. The estimated cost for the next ensuing year would be £229, buying an 8-year old tractor. The figure of £229.1 was too high for the farmer's own tractor; one had to deduct the dealer's margin which in this case was around £30, making the net cost less than £200. On the other hand, if one traded it in for a new one, the estimated cost would be £272.3 assuming one could make 20% on the money. A lot of money had to be earned on alternative investments before it would pay to keep tractors as long as 8 years. Table IV(a), based on the 5% discount rate, revealed that a change every two years was almost a saddle-point, simply because at the third year the repair schedule suggested that costs would rise considerably. But this depended entirely on the repair schedule, which lay in the realm of sheer guess work. Mr Camm could not agree with a further point made by Mr Bates that the right time to sell the tractor was the point at which the repair costs exceeded the amount he could get from a dealer. The short-term criterion was provided by comparison of the next year's cost of a new tractor with the cost of keeping the exisiting one.

MR J. M. CHAMBERS (New Idea Farm Equipment Ltd) referred to the suggestions that there might still be a use for the horse. He suggested that the agricultural engineering industry in North America had not adopted the British development of the unbalanced automatic-hitch trailer, which transfers the weight to the tractor and provides traction. The big advantage of the horse was its ability to stop and start, and to go forward when required. This had been necessary when farmers had binders and stooks which needed a lot of carting, but automatic loading on farms had made it no longer necessary. He could see no use at all for the horse on a British farm today, whether it was economic or not.

Mr Chambers went on to express surprise that Mr Camm had selected the manure spreader as being the most uneconomic machine on the farm. He would like to ask whether Mr Camm had ever gone into a field and tried to spread manure with a muck-fork. He thought that Mr Camm would then be convinced that some form of machine was needed. Mr Camm thanked Mr Chambers for drawing attention to the manure spreading problem. He thought it uneconomic simply because the time spent on spreading dung was not repaid by increased production of the crops that ensued. It would be more economic to set aside a small piece of land and pile the manure high rather than bother to spread it. In fact, this was what was happening these days, especially with pigs and poultry—farmers were now building lagoons into which to pump the rubbish and they then sealed it up like atomic waste. Most farmyard manure was worth less than 10/- per ton, i.e. only 30/- per round trip, and was of such little value that it could not really pay for the labour involved for transport to the field.

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*(continued from page 149)*

**VIth International Agricultural Engineering Congress**

3. Technical and economic contributions of agricultural hydraulics to planning and operations in land consolidation and re-grouping. General Reporter: R. Carbonnières, France.
4. Conservation techniques for underground water in arid and semi-arid regions. General Reporter: G. Torre, Italy.
5. Economics of irrigation—the cost of water for irrigation as a function of various parameters (method of sale of water; system of irrigation, etc.) General Reporter: G. A. Castanon, Spain.
6. Housing of livestock—Environmental control. General Reporters:
   *a.* concerning the basic and theoretical aspect—Th. E. Bond, U.S.A.
   *b.* concerning practical applications—K. Stietenroth, Germany.
7. Housing of livestock (cow-sheds)—Man-power, equipment and automation and their influence on the design and construction of farm buildings. General Reporters:
   *a.* concerning the analysis of elementary periods and basic fundamental data, C. W. Hall, U.S.A.
   *b.* concerning technical apparatus and appliances, R. Martinot, France.
8. Housing of livestock—Electrification and mechanization of work. General Reporter: L. H. Huisman, Netherlands.
9. Mechanization of the cultivation and harvesting of maize. General Reporter: W. Bockop, U.S.A.
10. Pooling of machinery in co-operative farming. General Reporter: P. Dellenbach, France.
11. Study of forage harvesting operations. General Reporter: C. Culpin, U.K.
12. Methods of agricultural work study. General Reporter: J. Piel-Desruisseaux, France.

Presentation of the general reports was in a large theatre with facilities for simultaneous translation by means of portable transistor radio equipment. The professional interpreters were fully occupied in this room, so interpretation in the other rooms, where discussion group meetings were held, had to be by the best 'consecutive' arrangements that could be devised. In most groups a good proportion of the original discussion took place in English; and in most groups someone with a knowledge of two languages was able to translate the more important contributions. Nevertheless, as with all such large international technical congresses, it was the opportunity to meet other workers in the field and to continue discussions outside the conference room that helped to make the Congress worthwhile. The General Reporters were responsible for guiding the discussion groups and for preparing a brief report of conclusions reached. The four days of the Congress were followed by three days of study tours. It is not practicable in this article to include any effective summary of the vast amount of technical information included in the 120 or so papers. As an example of the scope, the subject on which the present writer was general reporter included 12 printed papers and two late contributions, covering subjects such as swath treatment of hay, bale handling, hay wafering and bulk handling, barn drying of chopped hay, and the use of tower silos. There were 5 papers from research workers in U.S.A., and during discussion we learned of American developments which might make hay wafering practicable in a humid climate, and of effective methods of spreading chopped hay for barn drying. The German hay towers were thought to be technically effective but too expensive. There was some doubt about the economics of building tower silos. Subject 6, dealing with control of environment in livestock buildings, brought together a great deal of valuable information on a subject which is advancing rapidly in many countries.

The delegates attending the Congress consisted mainly of University teachers and research workers, members of national advisory services, officials responsible for rural electrification, drainage and irrigation services, and a sprinkling of representatives of farm machinery manufacturers.

# THE DEVELOPMENT AND APPLICATION OF HIGH POWER UNITS IN AGRICULTURE

by H. G. PRYOR, A.I. AGR.E.*

*Presented at an Open Meeting of the Institution, London on 12 October 1964.*

## Introduction

Mechanical power had by the 19th century been developed sufficiently to be applied successfully to free moving vehicles. From that time agricultural engineers and farmers have shown the greatest interest and initiative in applying it in a variety of ways to their own peculiar needs. Great ingenuity has been used and spectacular results have been achieved, probably with only a fraction of the amount of money spent on research that other forms of engineering have required.

By far the most interesting and impressive applications that have been found for mechanical power have been the larger draught units. These successful major power units have taken three distinct forms. First, the steam powered winch and cable sets. Second, the track laying vehicles and thirdly the present generation of high-powered wheeled tractors. In each case to date the most successful and typical units have used approximately 100 hp.

The need for these high-output units has been dictated by the necessity to overcome the very difficult soil and weather conditions which, whether very dry or very wet, can and frequently do occur for the whole of any of the four seasons of the year. In addition these high-powered units have been able to perform certain other special duties which were beyond the ability of smaller tractors and horses, i.e. mole ploughing, land levelling and heavy cultivating. These special duties excepted, one could summarize the success of the 'King Size' machines by saying that they have the ability to maintain output under the most difficult conditions likely to be encountered.

As engines of ample power have always been available, the designer of these units has been limited only by the amount of weight he could use to obtain traction whilst maintaining a satisfactory degree of flotation to avoid damage of the soil structure. Three other factors have been important but to a lesser degree: they are manoeuvrability, versatility and cost.

## Problems Facing the User

Before examining the various ways designers have met these challenges it may be advantageous to examine the problems which confront the potential user of a high-powered tractive unit. One of the most important problems confronting the farmer is that of investing capital in the best combination of mechanical equipment. The requirements can be affected by a great variety of conditions and circumstances, among them the production programme, the size of the farm, the type of soil, the geographical location, the availability and cost of labour in the area and the size of the fields on the farm.

Quite obviously no two farms are going to have exactly the same circumstances to overcome and it is therefore very difficult to generalize. With regard to very high-powered tractors, however, an approximate minimum output must be decided that will justify the investment. Unless contract work is undertaken to supply the balance (this frequently occurs) similar assessments have to be made when deciding the number of high-powered units necessary to operate very large holdings.

At the present time there are very few areas where there is a distinct labour shortage for operating arable farms although this situation may well change in the future. The scarcity element can therefore be dismissed and the inclusion of a high-output machine must primarily be justified on straight economic grounds.

In arriving at the answer to this equation economists have not been very successful, mainly due to their inability to assess and sometimes even to recognize the value of the 'King Size' machine as an insurance policy against breakdowns in production brought about by failures to complete operational programmes in the more difficult seasons.

Again, the importance of this risk depends very much upon the cropping programme and it is necessary to assume an average holding which will be planting a minimum of a third of its arable acreage in the autumn. These crops will carry the highest gross margins, and failure to complete the programme can very easily bring the year's financial result to a deficit.

This situation can arise from either excessively wet or dry conditions. Although the latter are very rare, high-powered units are invaluable in these circumstances for breaking up ground which is too hard to plough with a heavy cultivator. Apart from having greater penetrating power these super heavy cultivators, requiring drawbar efforts of 8,000-16,000 lb, are more robust and suffer far less damage than a mouldboard plough under the very hard conditions; they are very popular in areas where farmers are familiar with them. Wet seasons are likely to

* Farmer on own account.

occur at the rate of one in every three or four and extremely wet conditions approximately once in every seven years. Difficulties in wet years are accentuated by the fact that harvest has probably been delayed by the rain and encroached into the period of approximately 45 working days and 60 calendar days in which the prudent farmer would plan to complete his autumn sowing campaign. A further handicap in wet years is that the soil will be in poor condition and seed bed preparation will entail more operations and therefore more tractor- and man-hours. It may be assumed that the more successful farmers plan their field equipment to cope with the difficult years and are not misled by consideration of average conditions.

**Economic Considerations—Users' Requirements**

A study of large numbers of operations has shown that a minimum of 400 acres under the plough is necessary to justify the presence of a high-powered tractor and on this area it should be expected to perform all the seed bed cultivation as well. When the arable acreage reaches 800 it has been found necessary to relieve the driver from harvesting commitments so that the high-performance unit can make an early start with autumn cultivating and ploughing. With this arrangement the unit can still complete the full programme even in bad years.

Operators with over 1000 acres usually find it economic to maintain two such units. There is one large operator in Essex who uses six machines on just over 3000 acres. His circumstances are rather unusual in that he farms highly productive marshland, practically all grain is winter sown and the land responds much more satisfactorily if all working is finished before November.

A vital factor affecting the size of agricultural tractors is the average size of fields on the holding. The desirable average size of arable fields in the U.K. was generally assessed at 25 acres some twenty years ago. Today it could be said to be approximately 50 and it is likely to go on rising. Although small fields are a handicap from the angle of manoeuvrability it is really the weather hazard in climates such as those pertaining in the U.K. that demand high-capacity tillage equipment. Few treatments affect clay soil more adversely than a thorough soaking with rain after being prepared or drilled. It therefore becomes necessary to have the working capacity to cultivate most fields in less than a day so that the benefits of cross-working with tillage implements can be utilized and still allow completion of all operations in any one field within the space of two days.

From this it may be deduced that an output of at least seven acre/h with seed bed preparation implements is desirable; this, with due allowance for servicing and turns, necessitates covering a width of 16 ft at 4 mile/h. These widths are too great for public roads and farm gates, if they exist. A further difficulty with implements of such width is that they could be housed in very few existing farm buildings. To overcome these problems a toolbar has been developed to use standard 8-10 ft light cultivators and harrows, both spike and disc, with an arrangement of hydraulic jacks to fold the attachments vertically whilst in motion to facilitate transport and housing. This implement weighs over a ton and can only be operated by long tractors with sufficient weight at the front to act as counter-balance, and further a heavy-duty lift is required to boost the effort of the normal linkage.

When operating this type of equipment for seed bed preparation with wheeled tractors it is advisable to spread the weight of large tractors over as large an area as possible. This is achieved on certain machines by setting the front and rear wheels at different spacing and avoiding tracking in line. A further advantage is obtained by fitting cage wheels.

Among the problems confronting a farmer and which may be suitably reconciled by large power units, such non-reducible loads as mole draining and land levelling may be included. These operations have to date remained the prerogative of the large track laying tractor although development work is in progress to provide the larger wheeled machines with suitable wheel and ballasting equipment to enable them to perform these duties.

Mole draining would require a drawbar effort of between 10,000 and 20,000 lb. Present tractors of 100 hp would have sufficient power and are equipped with suitable gears but a gross vehicle weight of 6-10 ton is necessary. Interesting results have been achieved by the German operator of a British-made four-wheel drive tractor who has fitted $18 \times 26$ tyres at a cost of £100 per wheel. When filled with special ballast and loaded with a great number of wheel weights, this wheel equipment has enabled him to achieve a fair degree of efficiency. Quite obviously a tractor capable of pulling a mole plough would need to reduce its gross weight for most other duties and the very large wheels with their great ballast capacity offer a very promising solution. We now return to look at the ways in which designers have approached the problems involved in meeting these requirements.

**First Phase High-Power Farming—Winch Operation**

The first high-output mechanical cultivation units were the steam driven winch and cable units which first appeared in the middle of the 19th century. For the first time agriculture could use draught efforts of up to 10,000 lb with a single rope at 3-5 mile/h and 20,000 lb with a compound rope. This equipment was in many ways ideal since the power units standing at each end of the field were able to use great weight, of the order of 12-20 ton without affecting the soil structure of the main area being cultivated. Once in position there were virtually no traction problems. The power units were relieved of the task of propelling themselves over unmade surfaces and all power could be utilized for useful work. There was no wear on wheels or tracks although this was offset by the wear on two heavy cables. High outputs were obtained and very valuable heavy duty tasks such as mole draining and subsoiling became both possible and popular. The principal disadvantages were the labour force requirement of a minimum of four, the need to fuel two units each developing approximately 100 hp and the immense capital cost of the full set of equipment required. Steam-powered equipment was operated generally by contractors and reached maximum popularity early in the 20th century. One contractor on the Herts and Essex border continued until 1958 and there is at least one farmer still using this equipment.

**Second Phase—Track Layers**

The second type of high-output power unit was the tracklayer, first produced by the Holt Company (later Caterpillar Co.) before the first World War. This type of machine increased in popularity until the nineteen-fifties, when their decline from favour was brought about by the cost of track maintenance, the difficulty of carrying out overhauls on their heavy and awkward components and the improvement in efficiency of the wheeled tractor. Principal advantages of tracklaying tractors were their ability to provide flotation for a great weight on very soft ground and by virtue of a large area of ground contact, to produce a high ratio of drawbar pull to gross weight. This factor is, of course, influenced by the fact that all the weight is applied to the driving members and none is wasted on purely steering units as on most wheeled tractors. With this type of machine a good proportion of the draught load is converted to vehicle weight which in turn tends to transfer weight from the forward sections of the track to the rear sections; this has resulted in quite high pressure on the ground and in severe ground compaction by the larger models when operating on loose soil, as in seed bed preparation.

The chief disadvantage of tracklayers is the high rate of track wear, which increases rapidly as ground speed rises and appears to have restricted this type of tractor to a speed of approximately 3 mile/h for sustained loads and 4 mile/h for transport. This severely reduces their versatility, necessitating the use of large expensive implements to provide an economic load. Unfortunately track maintenance is not proportionate to size, the smaller models most useful to agriculture costing almost as much to repair as the larger machines which are used industrially.

At the present time, however, the tracklayer remains the most suitable unit for the important operation of mole ploughing, when a very high tractive effort at low speeds is required. Although the tracklaying tractor represented a tremendous step forward in comparison with other machines in the early 1940s there were certain conditions when their performance declined quite surprisingly, i.e. when soft mud filled the grousers and trackslip commenced. Mud packing in the track members further absorbs power and unfortunately under this type of condition the wear rate is at its highest. Attempts to obtain better tractive efforts under soft conditions by using open-type tracks did not find much favour as the open design allowed abrasive soil to fall through and increase the rate of wear.

Other major disadvantages of this design were that the method of steering by stopping the driving member on the inside of the turn imposed very heavy stress on the tractor frame and therefore needed a very strong and costly form of construction. This type of steering also rendered the tractor unsuitable for use with direct-mounted equipment, as any large degree of turn would be so multiplied at the rear of the implement as to result in serious damage. Further, the tracklayer is unable to travel on roads maintained for the general public without the attachment of special plates to the track shoes. This operation is so laborious that it is rarely performed, operators preferring to load the tractor on to wheeled vehicles for transportation. These factors resulted in the decline in popularity of the tracklayer as a general farm tractor and the late 1950s began to see the arrival of what may be described as the third major break-through in the design of high-output machines.

**Third Phase—Large Wheeled Tractors**

Since high output is simply the product of ground speed, and width of tillage implement being used, it was natural that wheeled machines allowing working speeds of 4-5 mile/h would be developed in every possible way. It is curious that normal plan, scaled-up, two-wheel drive machines have found considerable favour in North America whilst in the U.K. developments recently have taken the form of adaptation or coupling of standard tractors to provide greater output by fitting more or bigger engines and providing four-wheel drive.

| *Manufacturer* | *Model* | *Tracks or wheels* | *Speed mile/h* | *Weight* | *Pull* |
|---|---|---|---|---|---|
| Caterpillar | D.9 | Tracks | 2.2 | 66,025 | 44,000 |
| International | 4,300 | 4-wheel drive | 3.1 | 27,000 | 22,798 |
| Wagner | T.R.14 | 4-wheel drive | 2.27 | 21,225 | 19,357 |
| Caterpillar | D.7 | Tracks | 2.18 | 30,460 | 17,834 |
| International | T.D.18 | Tracks | 2.55 | 30,955 | 15,662 |
| Wagner | T.R.9 | 4-wheel drive | 2.28 | 18,295 | 13,618 |
| Doe | Tripple 'D' | 4-wheel drive | 2.58 | 16,247 | 13,200 |
| Caterpillar | D.6 | Tracks | 2.6 | 20,670 | 11,050 |
| County | Super 6 | 4-wheel drive | 2.65 | 13,220 | 10,300 |
| John Deere | 4020 | 2-wheel drive | 2.30 | 13,055 | 10,184 |
| Fordson | Super Major | 2-wheel drive | 2.7 | 9,745 | 5,900 |

**FIG I**

Table of comparative performances—Tracklayers, four-wheel drive and two-wheel drive

The data in Fig. 1., taken from tests at Silsoe and Lincoln, U.S.A., show comparative performances of seven different high-output wheeled tractors and four crawler machines. These tests give an indication of the potential of these units under ideal conditions. They are unfortunately not so useful for evaluating field performances under average and bad conditions, although designers have endeavoured constantly to bring the two factors closer together. It may be accepted that the tracklayer is the most efficient in such conditions, the four-wheel drive second and the two-wheel drive machine, equipped with suitable weight transfer equipment, third.

The data in the table showing performance of four tracklaying machines, five 4-wheel drive and two 2-wheel drive machines has been obtained from tests at Silsoe, England and Lincoln, U.S.A. The first machine is probaly not used for agricultural purposes, and the final machine is included for purpose of comparison as representing standard general-purpose farm tractors.

It is clear from this table that very high performances indeed can be achieved by four wheel drive tractors. Large two-wheel drive machines are very popular on the North American market and are beginning to appear in the U.K. These machines use lower link depth control to transfer weight from the implement and front of tractor to the drive wheel and might have difficulty in maintaining output under bad conditions with implements such as rolls, discs, cultivators and drills which do not allow the weight transfer system to reduce the weight on the front axle. A varying degree of transfer could, of course, be effected by raising the drawbar. This practice is, however, undesirable, the tractor being progressively more liable to overturn as the hitch point is raised. A further disadvantage these machines face in U.K. operation is that the average furrow width here is some 12 in as opposed to 16in in North America; this factor limits the rear tyre width to no more than 12 in, with a consequent effect on flotation and on the area available for tractive effort. This problem might well be overcome in the future by a monitoring mechanism to allow the tractor to follow the furrow automatically whilst running on the level. For such a device to be successful a degree of performance reserve would be required to eliminate as far as possible side slip and crabbing which would be brought about by wheelspin.

High-output tractors in production in the U.K. include four models, all having four-wheel drive. Two of these are equipped with Ackermann-type steering; two tractors steer by articulation. Two machines which are no longer in production are of interest; one of these was a large two-wheel drive machine which suffered from lack of manoeuvrability and of a suitable linkage to provide weight transfer, and may have appeared before economic conditions justified it. The other machine, a very interesting one, was a four-wheel drive machine steered by the Ackermann system, which was equipped with a lift at each end to facilitate ploughing in both directions. This machine had a high initial cost and suffered from the fact that the tyre tread was necessarily wrong on one pair of wheels for each direction of travel.

The four machines currently on the market are each of an entirely different concept and therefore provide an extremely interesting exploration of the possible ways of obtaining high performance. A further machine using clutch and brake steering, the County Four Drive, was not designed for agricultural applications, being considered too wide for ploughing, and it is not fitted with a large enough engine to be considered a high-output machine. From the same manufacturer, however, the County Super Six is produced especially for the agricultural market. This machine uses a Ford 6-cylinder engine of 330 in$^3$ capacity which, when operating at 2000 rev/min produces 95 bhp gross. A special heavy-duty clutch is used to transmit the power through a standard tractor gearbox and rear axle unit, fitted with specially strengthened gears, differential and axle shafts. Two forward-extending propeller shafts convey power to the front wheels independently, each front hub containing a bevel reduction unit. Thus a single differential unit, which can be locked for bad conditions, serves both axles.

A specially strengthened linkage is used, providing a lift effort of 2,250 lb at the ball joints with the standard lift. Booster rams can be fitted, one ram increasing the lift capacity to 3,375 lb and two rams providing a lift of 4,500 lb.

Thus very large implements can be used, up to a 5-furrow plough weighing 2,000 lb. Power-assisted steering is standard and the turning circle is 42 ft free and 18 ft with brake assistance. The static weight distribution is approximately 55% on the front axle and 45% on the rear axle. The maximum sustained pull is 10,300 lb at 2.65 mile/h on a tarmac surface, at a gross weight of 13,220 lb (N.I.A.E. Test).

The disadvantage of the Ackermann system of steering is that the steering wheels foul the main framework of the tractor if acute angles of turn are required. The County Super Six overcomes this problem by using a very short wheelbase, which in turn allows good weight distribution. The six-cylinder version of this machine has only been on the market a short time.

The other machine steered by the Ackermann system is the Roadless 6. This machine uses smaller wheels, $9 \times 24$ at the front, and a shorter wheelbase than the standard tractor from which it is developed. With this layout it has an excellent free-turning circle of 27 ft, slightly less than the parent tractor. It uses a well-tried shaft and bevel differential unit to convey the power to the front axle. Many of these machines have been sold to farmers and an interesting demonstration of the effectiveness of four-wheel drive is often achieved by disengaging the drive at the front wheels and allowing the rear wheels to dig into the ground through overload; the front axle is then engaged, enabling the tractor to pull out of the hazard. Since the drag of the extra axle gears is very small it is clear that the front-wheel drive is a distinct advantage, becoming increasingly beneficial as conditions deteriorate, even when engaged in such operations as ploughing when weight transfer, through the linkage, may be expected to render the front-wheel drive less advantageous than it would be for such operations as rolling, cultivating, discing and general transport. An interesting version of the tractor is the model which can be supplied with hydrostatic transmission at an extra cost of £500. When so equipped the stress on the transmission is considerably reduced, thereby permitting uprating of the engine by 20%. This should result in a greater output, which in turn offsets the extra initial cost.

The gross weight of this tractor is 8,400 lb. Unfortunately, N.I.A.E. test figures are not yet available for this machine.

The other two high-ouput machines are steered by articulation. This permits the use of a long wheelbase whilst retaining a small turning circle, the long wheelbase being advantageous in reducing jolting on rough ground and in improving tractive effort where occasional wet or soft spots occur. It also provides, by virtue of the weight at the front, an enormous counterbalancing force for operating super-heavy mounted implements.

Of the two machines steered by articulation, the Doe Triple-D, uses the major components of two standard tractors coupled by a turntable and trunnion bar to form a single four-wheel drive tractor. The practice of coupling two draught units together for heavy-duty operations was, of course, quite widespread in the days of animal power when our forefathers made a great success of the trace horse. This tractor has the advantage that spares and service are available through the normal trade channels and a large measure of standardisation with tractors already on the farm is automatically achieved. The factor of familiarity has no doubt influenced prospective operators, who can readily see and understand and therefore feel confident of the main components. The machine was developed after, and largely as a result of, the very wet autumn of 1956. Its popularity has steadily increased and there are now over 100 such units working in one county (Essex) alone.

The tandem-tractor concept of high-powered tractor design may well have a very important place in the future. Accurate speed synchronization has been found to be unnecessary; the two units will operate, even in different gears, without harm, efficiency, of course, being much reduced. A major factor in the success of this type of machine is the reliability of the modern diesel engine which requires so little servicing that there is little disadvantage in the fact that two units are used rather than one large motor. Further, it is unlikely that any 440 in$^3$ engine could be purchased for much less than the cost of two 220 in$^3$ units benefiting from such large-volume production.

An important feature of a machine constructed from two standard engines and transmission units is that the need for a centre or third differential is eliminated, the absence of which in some designs results in high tyre wear on abrasive surfaces.

Many machines of the tandem type have been constructed throughout the world. In North America design has been dominated by the proposal to split the machine into two single tractors at certain times of the year. Little interest has been shown for this feature in this country, it being generally held that no driver is available for the second tractor and that on most farms light or medium tractors are usually available. The more widespread use of automatic or hydraulic transmission would, of course, be a great advantage to this purpose and would greatly facilitate the break-down of tandem-constructed machines to separate units. It is probable that if hydrostatic transmission was a standard fitting a tandem tractor could be so constructed that the front unit could be recovered for light work in approximately four hours by one man.

The static weight of this tractor, as tested (Test No. PS/NIAE/64/2), was:

| | |
|---|---|
| Rear wheels | 6,561 lb |
| Front „ | 9,686 „ |
| Gross „ | 16,247 „ |

giving a weight distribution of 60% front and 40% rear. Turning circle without brakes, 21 ft 6 in. Maximum drawbar pull: 13,200 lb at 2.58 mile/h (limiting factor wheel spin); 9,500 lb in third gear at 3.67 mile/h.

Two types of linkage are available: the standard linkage with a single booster ram cylinder provides a lift of 4,800 lb, and is suitable for 5-furrow single way plough and cultivator etc; for the 4-furrow two-way plough and twin disc tool bar, a special twin-ram lift assister is available, providing a lift of 6,500 lb at the end of the lower link arms.

The other high powered tractor employing steering by articulation is the 'Matbro Mastiff' manufactured by Messrs Matthew Bros. This machine employs the rear axle and differential units of a well-known standard tractor to transmit approx 100 hp supplied by a single large engine of 330 in$^3$ capacity. The drive is taken from a single specially strengthened gear box by a triplex chain to a common shaft connecting the two axles, which are standard units in very large volume production. Directional variation results from articulation by two-way hydraulic jack and the drive deflection is accommodated by two in-line universal joints.

This layout provides all the advantages of long wheel base with manoeuvrability, and the initial cost is little higher than that of alternative machines. The weight on the front axle is sufficient to counterbalance the heaviest implement available for mounting on the strengthened linkage.

No test figures are available for this tractor to date. The draw bar pulls should be very high.

Two types of lift assistance are provided: (1) a single ram cylinder providing a lift of 4,800 lb at the end of the lower link arms, and (2) the Doe twin-cylinder lift assister can be supplied to provide 6,500 lb lift for use with 4-furrow two-way ploughs and twin disc tool bars.

To take full advantage of the tractive effort provided by these high-powered wheeled tractors, a new generation of implements has been developed. These are of two distinct types, mounted and semi-mounted. Mounted implements are limited to a maximum weight of approximately 1¼ tons by lift and linkage capacities and to 15 ft length by counterbalancing and weight distribution problems. It would appear, therefore, that as tractor power continues to increase further development will be concentrated on the semi-mounted types.

Among the mounted machines at present on the market are: 5- and 6-furrow ploughs weighing approximately

18 cwt, 3 and 4-furrow two-way ploughs weighing approximately 25½ cwt, heavy duty cultivators 8-9 ft wide for 'busting' hard ground, weighing approximately 16 cwt, subsoiling attachments for fitting to the same bar for pan busting up to 24 in, lighter cultivators up to 16 ft wide and hydraulically folding bars for operating two disc or spring tine harrow frames up to 20 ft wide. This very popular implement weighs approximately 22 cwt when fitted with discs.

The semi-mounted implements available include 5-8 furrow ploughs for right hand only work weighing 33 cwt and 4-5 furrow two-way ploughs; little experience of these types has been obtained but they are certain to play a very large part in agriculture of the future.

This new generation of high-powered wheeled tractors can be well justified economically in comparison with both lighter and cheaper wheeled tractors and heavier and more expensive tracklaying machines, and it is significant that a very high proportion of those machines at present in use are being operated by the more successful farmers.

Their challenge to the normal-size units has arisen from the constant increase in drivers' wages. This increase has been approximately £25/annum for the last twenty years. It is probable that this rate of increase will accelerate rather than decelerate.

The inclusion of a high-output tractor usually coincides with a reduction in the labour force and therefore effects a saving of approximately £700/annum. Economists usually accept a figure of 20%/annum of the purchase price as the operating overhead cost of a tractor. The £2,500 high-output machine, therefore, carries an annual charge of £500 which, together with driver at £700, results in a £1,200/annum operating cost. This may be compared with two normal-sized units at £800 each initial cost and £329 annual overheads and two drivers at £1,400, total £1,720; a saving of £520. Each system of mechanization will, of course, have its own peculiar seasonal advantages, the two smaller units being better suited to lesser productive operations such as haulage, hoeing, spraying, fertilizer spreading, hay making, etc. The heavy duty equipment, however, would show to advantage in the more vital times of the year, in particular during the autumn ploughing and sowing campaign.

A direct economic comparison between four-wheel drive tractors of approximately 100 hp with tracklaying tractors is very difficult and must be only approximate but it could be reasonably considered that a four-wheel drive tractor would cost initially about half as much as a tracklayer of similar output, the tracklayer also costing double for general wearing parts. A set of tyres costs £180 (12×36) and for the tracklayer a set of track chains and sprockets and rollers would cost £750. A set of tyres might be expected to complete 2,500 hours and the track parts approximately the same. From this it may be assumed that it would cost approximately three times as much per hour to operate the tracklayer for wearing parts and twice as much for capital depreciation; drivers' wages would of course be the same.

The tracklayer would have a very important advantage by virtue of its ability to handle a mole plough but would have the disadvantage in circumstances when it was necessary to travel on highways.

To summarize the various developments during the past 100 years it can be said that there has been a constant reduction in the initial and running costs of operating high-powered tractors. Versatility has been constant. The particular conditions existing in the U.K. have resulted in the development of the various styles of four-wheel drive tractors now appearing on the market. Their future appears very promising, especially in the heavier soil conditions throughout the world.

## Factors Affecting Future Design

Any consideration of future developments must be dominated by the knowledge that wages and costs will continue to rise, resulting in a continuing demand for increased output per man/hour. There are two ways in which this demand can be met: either by constantly increasing the power and weight of manned equipment or by developing automatic machines. Should automatic machines become practicable, they will undoubtedly be very much smaller than present-day machines, and probably single-furrow ploughs would be the more usual. Traction would be achieved either by a single wheel or by a winch and cable with permanent anchorage, supplied by a rail laid flush with the ground. This could possibly be utilized to supply mains electrical current for the power unit, which could provide the great power reserve that would be necessary, without unduly increasing the running costs. Steering would probably be achieved by the machine laying its own guidance cable on the preceding run. If this system were susceptible to a cumulative error of as little as ⅛ in per run, particularly on side hills, it would be unacceptable. At present there appears to be little likelihood of this problem being overcome and since supervision of the implement working the soil is the principal function of the human operator it appears that future development will be directed to the improvement of man-operated machines.

Speculation on the form future high-output power units may take can be guided by reviewing the shortcomings of present day designs and by the knowledge that very high initial prices can be and will readily be accepted. A pair of steam engines equipped with winches and 800 yard cables together with plough, cultivator and mole plough, in 1914 would have cost approximately £3,000. Technical developments and modern manufacturing methods enable the production of equipment capable of similar output at a very similar price today. From this comparison it may be assumed that investments of up to £20,000 would be made on equipment provided its operation was economic.

Present day standard tractor designs can be said to suffer from three quite serious faults: (1) the Ackermann system of steering, utilizing two free-running wheels of narrow section carrying approximately 40% of the units' weight, represents a method of steering which has to be supported by power assistance to reduce driver fatigue, differential braking to prevent forward sliding and an elaborate system of linkage to transfer as high a proportion of the 40% weight to the driving wheels as can be permitted without affecting the machine's stability. The remaining weight and wheel drag act as a very serious adverse factor in the production of tractive effort. This transference of weight from front to rear is only possible with certain types of load, ploughing and hauling providing quite good results. Such operations as disc cultivating and rolling give quite poor results, sometimes with very serious effect indeed on the tractive effort. (2) Driver comfort. Very little attention is paid to the driver's comfort on any tractor. This fault is common to both standard and high-output tractors. Cabs are available for weather protection; these are never a part of the original design and in most cases are mounted on the existing mudguards which are a most unsuitable foundation and make exclusion virtually impossible. Entry and exit are also made very difficult indeed. Further, a large quantity of heat is produced by the engine and is allowed to waste to the surrounding air; this could quite easily be directed to the task of warming a suitable cabin for the driver. Driver fatigue is also induced by the fact that most operations take place behind the driver so that he has constantly to turn through 180° to supervise the results of the tractor's effort. It may well be uneconomic to provide the driver with a riding position behind the implement; this concept should not, however, be discarded by the designers as it is a feature which may ultimately become possible. Conversely, driver interest is well catered for by present-day designs. This aspect of tractor design is quite important, as it is quite a pleasant form of occupation, particularly for the younger operatives, to control an agricultural tractor under all but the worst conditions.

The third major disadvantage of present day design is the use of draught control for maintaining the implement depth.

This system is quite efficient under ideal conditions but it is unsatisfactory when soil conditions are variable and the tougher sections cause the implement to be raised at a time when it is most important for depth to be maintained. Draught control does, of course, with conventional designs make possible higher drawbar pulls for a given weight of tractor and for this reason it may well be the standard practice for a very long time. However, with prime movers having all wheels power driven it is unnecessary and likely to be superseded by a simple wheel control of implement depth.

All the four-wheel drive designs on the market at present make possible the elimination of the first and third defects. Weight on the front axle becomes an advantage and present designs are arranged to provide as much as 70% of the vehicle weight on the forward axle when static, thereby providing an excellent counterbalance for very heavy implements. With the drawbar effort to load the rear axle, correct weight distribution in motion is obtained, implement depth being regulated on most of the present designs by arranging the linkage to float the equipment in support of the draft control, the larger and heavier implements using depth control wheels.

The problem of driver comfort will probably receive considerable attention during the next ten years; its progress is likely to be accelerated by the increased speed at which farm operations are likely to be conducted. Substantial improvement will probably only be made when the designers regard driver comfort as essential and plan the entire layout to provide it from the very earliest stage.

To meet the continuous demand for more output the speed factor is certain to be still further exploited. Doubling a tractor's speed may be assumed for practical purposes to have the same effect for flotation and traction purposes as doubling the size of track or wheel equipment to carry twice the weight and pull an implement correspondingly increased in size. A penalty must be paid in increased draught, and shock loading will be greatly increased as a direct result of increased speed. Wear will also increase from soil abrasion. The result, however, greatly favours the use of the highest practicable speed. Implements will need to keep pace with tractor development to permit these higher speeds. To date, the wearing surface appears to have received more attention than shape of soil moving member. As the highest practicable operating speed is approached, attention is bound to turn towards wheel equipment which is larger both in diameter and tread width. Furrow size is a factor at present limiting wheel width and since furrow width is unlikely to increase in the U.K. it follows that ultimately tractors will run on the land out of the furrow. Very good traction is obtained by the furrow wheel and therefore moving to the top will probably require an immediate increase of tyre width by as much as 100%.

The success and popularity large wheeled tractors have achieved during the last five years is sufficient to justify the conclusion that they will be important in agriculture during the coming two or three decades at least. The various concepts, i.e.: four-wheel drive, two-wheel drive, Ackermann or pivot steering may well each find a large market as each has certain detail advantages to suit the various applications. It is probable that a wheel tractor of approximately double the present 'King Size', i.e. 200 hp and over 20,000 lb in weight, could be used principally by contractors for such tasks as mole ploughing and land levelling. The existing high-power units are operating between 8,000 and 12,000 lb pull on held operations. This figure may well rise to 10,000 or to 15,000 lb by the middle 1970s and it may be assumed that farm, field and implement size will always be developed to maintain a balance.

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E. Doe & Sons Ltd.
Deere & Co.
International Harvester Inc.
F. W. D. Wagner Inc.

## DISCUSSION

Mr Pryor was asked by MR J. M. CHAMBERS (New Idea Farm Equipment Ltd) how the figures for 'Weight' and 'Pull' in Figure I had been obtained, and whether soil and ground conditions were similar in both sets of data. He also asked for information about the tyre pressures used in these large tractors. Mr Pryor explained that the data in Figure I were taken from tests conducted at Silsoe and Nebraska. There was a real possibility that conditions were not the same in each case. It was not easy to follow the test methods. Apparently they had been conducted on tarmac test circuits but it was difficult when reading the reports to establish whether the term 'pull' meant 'maximum pull' or 'maximum sustained pull'.

On the subject of tyre pressures for the super-heavy machines, Mr Pryor said that so far as he knew pressures of 12 lb/in$^2$ were used in the U.K. He reiterated the point in his Paper that doubling the speed was just as effective as doubling the area. Obviously, if a machine were to travel four miles on a tyre of 12 in width, it would use the same amount of soil to support itself as a machine which had travelled half that distance on a tyre of twice the width. Mr Pryor believed that this speed factor had been much neglected. Very little test information was available on the relationship between speed and flotation. He did not know what tyre pressures were used in the big machines generally; they all seemed to achieve roughly the same drawbar pull, at about 80% of their gross weight.

MR C. V. BRUTEY (National Farmers Union) referred to Mr Pryor's remarks on the effectiveness of the furrow wheel from the point of view of traction. He asked whether Mr Pryor would agree that it was also very effective with regard to compaction. His own experience in this field had been in contracting on very heavy land in Nottinghamshire where most of his business had been gained because he had a fleet of crawlers. The local farmers, many of whom possessed their own tractor fleets, had employed Mr Brutey's crawlers solely to avoid compaction in the furrow. Mr Pryor agreed that the furrow wheel was undoubtedly effective in this respect. The difficulty appeared to arise from the glazing effect of slipping tyres and consequently an adequate reserve of performance was a great help in reducing compaction. He thought that eventually all tractors would run on the unploughed land but at present they used the furrow, with its clean and comparatively dry surface, in order to obtain a large measure of the required traction. An advantage of wider implements such as the 5- or 6-furrow plough was that the tractor wheel ran in the furrow only once in every 6 ft, instead of once in every 2 ft as with the old two-furrow plough.

MR J. V. FOX (Bomford & Evershed Limited) said he was interested in problems of shock loading, particularly of cultivation implements. He wondered whether Mr Pryor could indicate to what extent he thought the difficulty of protecting implements at higher speeds would be a limiting factor in the development of this type of tractor. He also invited Mr Pryor to comment on the suitability of pivot or centre-point steering when used in conjunction with the conventional three-point linkage system. Mr Pryor agreed that shock loads, which must be related to the speed of operation, would impose limits on the operating speed. Few machines at present appeared to use any sort of trip protection, although this would probably be developed. The pneumatic tyre was, of course, a very good safety device in that it spun more readily than some of the other forms of tractive equipment and this had been a large factor in enabling higher speeds of work to be attained. Shock loading, nevertheless, remained a problem; it meant that the implement had to be proportionately stronger and heavier. Mr Pryor had noted very intensive use of heavy cultivators during the current autumn work. These implements could withstand shock loads from hard ground—they did not suffer as ploughs would—and they were extremely popular in the areas where people were acquainted with their performance.

In answer to Mr Fox's second point, Mr Pryor said that the machines using pivot steering were all operating with the normal three-point linkage and as far as he knew no defects were being revealed. The only troubles were those due to the large increase in the power and tractive effort available, and some linkages were breaking because they were just not big enough. Mr Pryor believed that Category 3 linkage was now being fitted to some of these machines. He added that they did not appear to suffer any tendency to slew in the fashion of a crawler. If the load was heavy the front unit appeared to carry the slewing effort rather than the rear one.

MR K. J. BENFIELD (Cambridgeshire Farm School) said Mr Pryor had suggested in his paper that 400 acres was the area necessary to justify the use of a high power unit. Whilst Mr Benfield felt that this was perfectly legitimate for a four-wheel-drive tractor costing under £2,000, he was concerned at the extra cost of the equipment necessary to make a number of the American tractors useful. In the rate of working suggested by Mr Pryor for 400 acres a quick calculation indicated that one should be able to get all the arable operations done in around 300 h/annum. He wondered whether Mr Pryor thought this was an economic use of such a high capital expenditure, and added that he would welcome Mr Camm's comments also on this question. Mr Pryor replied that he was quite certain that one would not get the work done at anything like that rate. The ploughing capacity of these machines appeared to be somewhere between 1-1½ acre/h, which alone provided almost 400 hours of work. His reference to 7 acre/h had been in connection only with the twin toolbar. This hydraulically-folding toolbar covered a width of 20 ft at approximately 4 mile/h. A hundred high-powered tractors had been at work in Essex this year, and they included some in use on 400-acre farms. The operators were shrewd businessmen and he believed they were finding their use well justified. Mr Camm said that, from the figures he had seen for these large tractors, there was no doubt that they were economic provided they could displace two conventional tractors and thus employ just one man instead of two. Even the very high cost of their introduction in the first place was more than amply covered by the saving of cost in other directions.

MR H. J. NATION (National Institute of Agricultural Engineering) asked Mr Pryor for his views on driver comfort and whether he had made any assessment of the driver ride on these large units. In his reply Mr Pryor said that the bigger wheels were better able to absorb the unevenesses of the surface. A second factor was the length of the wheel-base; the longer the wheel-base the more comfortable it was to ride on. Both these considerations were important in improving driver comfort.

## JOHN FOWLER 1826-1864

*In Memoriam*

The news of John Fowler's death reached a shocked and bewildered Smithfield Show on its opening day December 4th in 1864. His death following a fall in the hunting field ended a career at its brilliant peak of achievement.

At Nacton in April 1856 he had shown that mechanized soil tillage, about which men had theorized since the 17th century, was a practical reality. His earlier demonstration of land drainage by steam power in 1854 had influenced the council of the Royal Agricultural Society in making their offer of a prize of £200, later increased to £500, for 'The Steam Cultivator which shall in the most efficient manner turn over the soil and be an economical substitute for the plough or the spade'. In spite of his successful demonstration at Nacton in 1856 it was not until the Autumn of 1858 that Fowler received the award. It was withheld on grounds of relative economy but in 1858 the cost of ploughing with Fowlers 'tackle' was estimated to be 5/6d per acre while the cost of horse ploughing in the same conditions was estimated to be 7/-.

At the Royal Show at Worcester in 1863 Fowler demonstrated a double-engined set establishing the broad principles of design, for both engines and implements, which remained unchanged until steam power was gradually displaced by the internal combustion engine during the period between the two world wars.

Shortly before his death the 1864 Royal Show was held at Newcastle. Here he received first and second prizes for 'The best application of steam power to the cultivation of the soil'; first prize for 'The best application adapted to small occupations'; first prize for 'The belt plough for steam power'; first prize for 'The best cultivator for steam power'; the prize for the best windlass and a high commendation for a rope porter. These awards were the culmination of 14 years of intensive work involving alternative failure and success, work calling for high courage in the face of all the difficulties which are the common lot of the pioneer. Regrettably Fowler's work has never received the recognition it deserves. George Stephenson who fathered the mechanization of transport has an unassailable place in history. Fowler who fathered the mechanization of food production is almost unknown.

D.R.B.

# SIGNIFICANT FEATURES OF FUELS AND LUBRICANTS FOR THE WINTER USE OF DIESEL-ENGINED TRACTORS

by J. D. SAVAGE, A.M.I.MECH.E., A.M.I.AGR.E., A.M.I.R.T.E.*

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## INTRODUCTION

With many European and North American mass-produced tractors, often the only features of their operating specifications that are varied to suit local conditions are the characteristics of the petroleum products employed. The role of petroleum products is therefore a very significant one, more especially for diesel-engined tractors operating in the colder areas. This paper is written in an attempt to guide users in the care and application of fuel and lubricants, and to provide designers and manufacturers with information on the quality of fuels and lubricants for agriculture in various areas of the world.

Reference is also made to fuels and lubricants for the protection of engines in storage.

## THE DIESEL-ENGINED TRACTOR

During the twentieth century tractor designers have made use of almost every kind of internal combustion engine. At first gasoline- and kerosine-fuelled engines were the most popular, and in certain areas of the world they still are. But, after World War II, the diesel engine took an increasingly prominent place, first in Europe and then in America. Today almost all the current British tractor production is diesel powered with only a few gasoline-engined tractors being built for Denmark and some Middle East countries where there is a lower tax on gasoline used for agricultural purposes.

In North America the diesel engine has grown in popularity to the point where, in 1962, it accounted for 50% of the tractor production in competition with gasoline-, kerosine-, and LPG-fuelled engines.[1]

The diesel engine is therefore of growing significance in the mixed range of engine types in the world-wide tractor fleet, and as far as winter operation is concerned, it is certainly of great interest because its fuel and lubricants must be suitable for low ambient temperatures.

The case in favour of the diesel engine for powering agricultural tractors argues advantages of fuel economy, good low-speed torque characteristics and close engine-speed governing. In many instances these advantages would be outweighed by the higher first cost and greater complexity of the diesel engine, but by standardizing on the diesel engine the tractor manufacturer has achieved lower unit costs which have further encouraged its use in agriculture. This has occurred despite the diesel engine's unjustifiably poor reputation for cold starting; in fact, when correctly fuelled and lubricated it can be reliably started at the lowest ambient temperatures encountered in farming territories. Correct design, construction and maintenance all play their part in achieving reliable cold starting.

In areas where farm machinery is regularly used at low ambient temperatures, in Canada and Finland for example, serious difficulties are not encountered frequently when compared with the incidence of troubles in the more temperate climates. This is because the equipment designers and manufacturers know that at very low temperatures reliability must be built into the machine and paid for in the interest of convenience, economy and even survival. When standard equipment is purchased for the colder areas the local agent and the farmer know that they must take precautions and prepare for the winter and, should they be 'caught out' by an early cold snap or a particularly cold spell, they know what emergency steps to take to get out of trouble.

It is reasonably safe to predict that within the foreseeable future the diesel engine, which is currently so popular, will continue to be the preferred power unit for agricultural machines, especially tractors, and it will remain in agriculture long after more sophisticated engines or electrical systems have replaced the diesel engine in other fields. The disadvantages of the diesel, i.e. noise, smoke, odour and vibration are far less worrisome in agriculture than in other industries such as passenger transport, where customer comfort is important, and road transport generally, where congested roads and city streets attract attention to the diesel's presence. Furthermore, no tractor manufacturer will 'tool up' for a novel tractor until the cost of his existing plant has been written off. Indeed at this moment, several major tractor plants in Europe and North America are being constructed for diesel tractor production. Presumably they will have to produce at peak output for five to seven years to make an adequate profit on the investment. As tractors have a service life of at least twelve years, a long future is ahead of the diesel engine in agriculture, and it is therefore well worthwhile considering the various features of the petroleum products that contribute to its trouble-free use, especially in the difficult months of winter.

* Diesel Engineer, Technical Services, Marketing Dept., British Petroleum Co. Ltd.

## FUEL STORAGE AND HANDLING

Diesel fuel systems are unable to tolerate abrasive contaminants, or water in the fuel. When diesel fuel is delivered to the farm, it is clean and free from water. In the stages of storage and handling on the farm, it may, even with the best of care and good intentions, collect some contaminating material.

Whether in the Arctic or the Tropics, correct fuel storage and handling is therefore a vital first requirement. Recently a farm in the United Kingdom with 30 tractors was equipped with new, properly designed fuel storage tanks (Fig. 1). Within six months all fuel system troubles


Fig, 1

were eliminated, yet these had previously been the greatest cause of engine failure.

The elementary requirements for adequate fuel storage are:

1. Properly designed and installed storage tanks.
2. Regular cleaning and servicing of the tanks.
3. The correct use of dispensing equipment and techniques.
   (See Appendix 1 for References to fuel storage recommendations).

### Tractor Fuel Tanks

Whatever precautions are taken to protect the fuel from contamination in storage, the greatest risk occurs in the tractor's own fuel tank. To allow for displacement of the fuel, the tank must be vented to the atmosphere, so inevitably dust and air are drawn in through the breather, and condensate forms on the inner walls of the tank. Rust follows and ultimately some of the contaminants will find their way into the fuel system itself, unless an adequate filter is incorporated. If fuel filtration is inadequate, troubles may range from annoying starting difficulties to catastrophic fuel pump failure.

Filtration systems vary tremendously in style and efficiency. This is partly due to the differing needs of different fuel systems, but it is also due to the fact that the best of the latest techniques have not been adopted by all engine manufacturers.

Three filters should feature in any diesel engine fuel system.

1. THE PRIMARY OR PRE-FILTER
   This filter is usually made of gauze, and is situated between the fuel tanks and the fuel lift or feed pump. Its three-fold function is to protect the lift pump from damage by large particles, to prevent the pipes from becoming blocked and to assist in removing water from the fuel. Many preliminary filters incorporate a proper water trap.
   
   Because the pre-filter is often located in an exposed position away from the engine's heat, the pre-filter readily clogs with wax if the fuel temperature is lower than the cloud point of the fuel. Consequently, there is a great temptation to remove the gauze during very cold weather, and then it often remains out of use for the rest of the year!
   
   This problem can now be overcome by installing a non-choking sedimenter that has ample accommodation for particulate matter, ice crystals and wax crystals without blocking and without the efficiency of the unit changing as collection and sedimentation continues (See Fig. 2).

2. THE MAIN FILTER
   This consists of a conventional felt, cloth or paper filter situated between the primary pump and the main injection pump. Its task is to prevent smaller particles proceeding through the fuel system. The filter element should be renewed regularly.

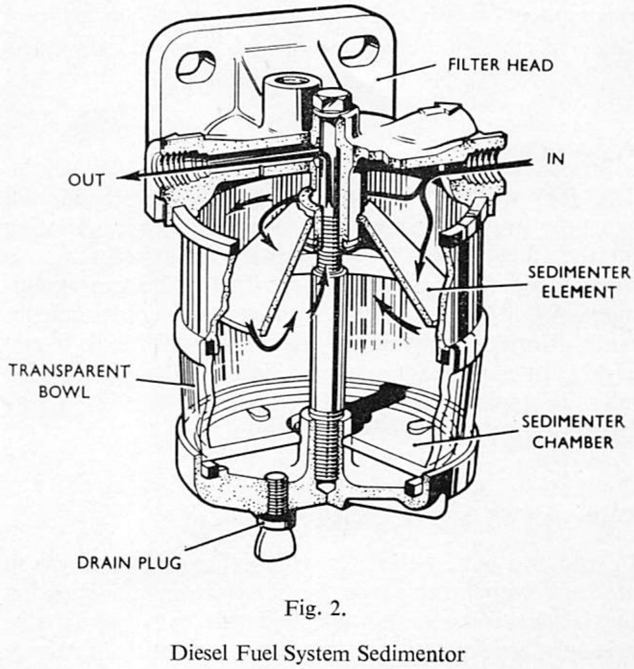


Fig. 2.

Diesel Fuel System Sedimentor

3. THE FINAL FILTER
This filter should be situated between the main filter and the fuel injection pump, and is preferably of a pleated paper type. It should not be disturbed between major tractor overhauls as servicing may allow dirt to pass into the fuel pump.
As water droplets entering the fuel pump can cause corrosion and seizure, a water separator can be embodied in the final filter (Fig. 3). This unit offers the added advantage in cold weather of protecting the filter from blockage due to the formation of ice crystals.

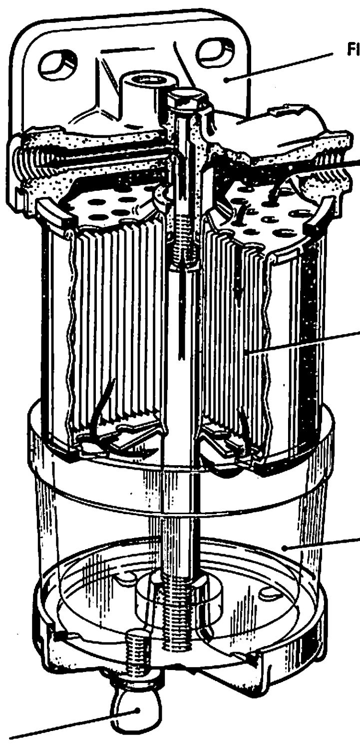


Fig. 3.
Combined Fuel Filter & Sedimenter

**Water in Fuel**

The fuel storage precautions already mentioned will generally prevent an excess of water from accumulating in the fuel tanks—very necessary in all climates to prevent the rusting and seizure of fuel injection equipment. An additional hazard from water in cold countries is the formation of ice crystals which will block filters, and in hot countries it may provide a breeding ground for micro-biological fungus type growth, which is a particularly effective filter blocking material.

**Water in Fuel in Cold Climates**

In cold and humid climates with rather wide changes in ambient temperatures (e.g. the U.K.) water condenses on the inside of the tank walls and this can lead to surprisingly large quantities of water accumulating in storage and service tanks. Although good housekeeping rules offer the best overall protection, water will inevitably appear in the fuel tanks and this is why most manufacturers now fit water traps of one kind or another, as previously shown in Figures 2 and 3. These should not be neglected, and in the event of excessive quantities of water regularly appearing in the trap, the reason for the presence of water should be determined and remedial action taken, because the capacity of the water traps and sedimenters is usually rather limited.

In Canada, where diesel engine operators were at one time plagued by clogged filters due to water in the fuel, a remedy was developed using isopropyl alcohol in the diesel fuel in winter months. The dosage employed varied between 0.25% and 0.5% by volume.

Care must be taken to see that the water which is precipitated and accumulates in the bottom of the fuel tank is drained off regularly. If 'slugs' of free water from the bottom of the tank are fed into the fuel system, they are likely to do more harm than evenly dispersed water in suspension in the fuel.

**Water in Fuel in Tropical Regions**

Although it is intended that this paper should deal principally with low temperature aspects, attention to water-in-fuel problems in mild and tropical areas is not unrelated and is worthy of brief mention.

In warm and humid climates with wide fluctuations in ambient temperature, condensate will form on the inner walls of the fuel tank. Here the problem that is most acute is the possible formation of a sludge at the interface of the fuel and water. This sludge is a form of fungus which very effectively blocks filters, especially the paper type. Good housekeeping again offers the most practical preventive solution, but when this sludge does occur, the fuel can be effectively treated with the boron type biocides, of which there are several proprietary versions. These are used at concentrations that vary from 30 p.p.m. to 300 p.p.m. according to the exact formulation and the proportion of boron in the additive.

The micro-organisms that attack the fuel in this way may be carried to the fuel from the atmosphere, from water for tank cleaning or rain water. Studies have shown that microbes can live for months in essentially anhydrous fuels, waiting only for the presence of free water to produce a 'population explosion'. These micro-organisms may then feed on the hydrocarbon fuel itself in addition to the water. Hence, apparently clean fuel may develop a sludge at any stage during its storage if water is allowed to accumulate in the tank.

**LOW TEMPERATURE CHARACTERISTICS OF DIESEL FUEL**

The low temperature flow characteristics of diesel fuel are usually specified in terms of the cloud point and the pour point. The cloud point is defined as 'the temperature at which paraffinic wax or other solid substances begin to crystallize out or separate from solution when the fuel is chilled under prescribed conditions'. (ASTM D-97 procedure). The pour point is defined as 'the temperature at which a petroleum fluid will not flow when it is chilled under prescribed conditions'. As a general but not infallible rule the cloud point can be expected to be about 8-15°F (4.4-8.3°C) higher than the pour point.

In practice, the cloud point indicates a temperature at which wax crystals may start to block filters, and the pour point indicates the temperature at which the fuel may fail to flow through pipes, ports and galleries.

Investigations[2] have suggested that neither pour point nor cloud point give a precise correlation with the temperature at which vehicles fail to function in service because of wax formation and deposition, but cloud point is now preferred as a criterion in the fuel specifications because it tends to err on the safe side. The factors which influence the actual rate of build-up of wax in the fuel system and the extent to which deposits cause fuel starvation are numerous, and their individual significance can only be evaluated under genuine operating circumstances. For this reason, the author's company conducted a programme of tests on a number of diesel-engined tractors and vehicles. The results of the tests have previously been described in References [2] [3] and [4] but they are summarized again in the paper for the convenience of the agricultural engineering industry, because the author feels that they offer useful supplementary information for the designers of diesel-powered agricultural machinery.

**Results of Service Tests**

A survey of the more popular makes of diesel tractor and trucks showed that fuel systems generally fall into one of about five basic arrangements. These range from the simplest system, in which fuel is drawn from a tank through a single filter direct to the high pressure injection pump, to the more complex arrangement of water trap, primary and final filters, feed pumps and injection pump. Six different makes of tractor and truck were selected for tests. They incorporated the most frequently used fuel system designs. Two of each model were obtained, and thermo-couples and pressure gauges were installed at various points in their fuel system to give an indication of any restrictions which might occur due to wax build-up.

A series of tests was conducted on a private road in central Sweden where ambient temperatures down to -20°F (-28.9°C) could be expected with reasonable certainty. Each day an estimate was obtained of the minimum temperature expected for the following day, and two fuels were blended up, one with cloud point and the other with pour point, corresponding to the expected temperature. After draining and flushing the complete fuel systems, each pair of vehicles was filled with the two test fuels. The vehicles were left outside overnight. The next morning they were started and driven around the test track until either blockage of the fuel system caused the vehicle to stop, or it became evident from the fuel temperature that it was clear of the critical region. It was found that if blocking was going to occur it would take place within 30 minutes of start-up, and consequently tests were limited to this duration.

From these tests a pattern of performance was thus built up from which it was possible to isolate the critical features of each fuel system, and to obtain a relationship between the fuel characteristics and the temperatures at which blockage occurred for each particular fuel system lay-out.

It was found that all vehicles operated satisfactorily at temperatures down to the cloud point of the fuel, but failures occurred when the fuel temperature lay between the cloud point and about 4°F (2.2°C) below the pour point. The precise temperature at which failure occurred depended on the design and layout of the particular fuel system concerned. Features of the fuel system that were found to be of particular importance included:

1. Size and Type of Suction Screens
   Suction screens were particularly prone to blockage, and the smaller their size and finer their mesh, the more critical they were, whether positioned in the tank or water/sediment trap.
2. Location of the Main Fine Filter
   The tendency to block was greatly reduced if it was sited close to a warm part of the engine so as to pick up maximum heat as soon as possible after starting. In one make of truck the fine filter was situated immediately behind the cooling fan, and this proved to be a particularly severe operating condition. Use of a radiator blind made it less critical.

By the attention of these two features up to 10°F (5.6°C) improvement in low temperature performance can be achieved.

On the basis of a programme of work in Norway and Sweden, Flynn and Pukkila[5] reached similar conclusions in which they wrote:

> 'As would be expected, the design of the vehicle fuel system has an important effect on the low temperature performance. Fuel filters should be located where they receive some engine heat. In this way, even though some wax is accumulated in the filter during the first few minutes of the vehicle's operation, it quickly melts as under-hood temperatures rise. Conversely, filters located in the vehicle tank or on the chassis tend to present cold weather operating problems. Also, if vehicles are fuelled with cold fuel from outside drum storage, the filter screen in the vehicle tank inlet pipe may plug with wax particles. Therefore these should be removable if used at all.'

From the operator's point of view, this work has resulted in improvements from two quarters. Firstly, engine builders have been provided with information to supplement their knowledge of the requirements of fuel systems to enable them to function at the lowest possible ambient temperature, and secondly, fuel characteristics have been made to match more closely the climatic conditions encountered in various parts of the world.

**Winter Fuel Quality**

As equipment designers do not always adopt the most favourable fuel system features, for which realistic recommendations are made in Reference[4], the fuel supplier must provide a product with a cloud point low enough for the ambient temperatures likely to occur in a given district.

Fuels with adequate or even generous margins, can be produced from all crudes but, with the exception of material from special crudes of limited availability, this is done at some sacrifice to:

1. Cost.
2. Yield.
3. The quality of other characteristics, (e.g. Specific Gravity and Ignition Characteristics).

A combination of all three sacrifices usually occurs if fuel with special low temperature characteristics is produced and its cost, as a combination of 1 and 2, can be considerable. Tables I and II show the characteristics of fuel supplied for particularly low temperature operation.

**TABLE 1**

*Diesel Fuel Canadian Specification* 3-GP-6b *Type A*

| | | |
|---|---|---|
| Viscosity at 100°F (37.8°C) | | |
| Centistokes | —Min. | 1.8 |
| Centistokes | —Max. | 4.3 |
| Sulphur % wt | —Max. | 1.0 |
| Carbon Residue (Ramsbottom on 10% residue) | | |
| % wt | —Max. | 0.20 |
| Centane Index | —Min. | 40 |
| Pour Pt °F | —Max. | —40 |
| Pour Pt °C | —Max. | —40 |
| Cloud Pt °F | —Max. | —30 |
| Cloud Pt °C | —Max. | —35 |

**TABLE II**

*Fuel used for Diesel Engines in the Commonwealth Trans-Antarctic Expedition* (1957)

| | |
|---|---|
| Specific Gravity | 0.788 |
| Viscosity 100°F (Centistokes) | 1.4 |
| Sulphur % wt | 0.04 |
| Carbon Residue (Ramsbottom on 10% residue) % wt | 0.02 |
| Cetane Number | 45 |
| Pour Pt °F | —50 |
| Pour Pt °C | —45 |
| Cloud Pt °F | —50 |
| Cloud Pt °C | —45 |
| (Kerosine Type Fuel) | |

Hence, fuels are marketed that have adequate and realistic low temperature characteristics to suit the prevailing ambient temperatures.

## Selecting Cloud Points

As different parts of the world have different climates there is a need for fuels with different cloud points. Nothing is achieved by having cloud points pitched at a lower level than is required by the ambient temperature or the vehicle population. For similar reasons most fuel suppliers offer summer and winter grades of fuel having their cloud points adjusted to suit the ambient temperature.

To set realistic cloud points it is necessary to study meteorological data collected over a period of at least ten years. It is not possible to base cloud points on *average* temperatures for a given period, as much lower temperatures will occur from time to time. On the other hand *minimum* temperatures are not suitable because the fuel in the vehicle tanks takes some time to cool to the level of the ambient temperature. Hence it has been necessary to consider a temperature between the two and in consultation with the British Meteorological Office the author's company has adopted a formula to obtain a Minimum Critical Winter Temperature which is the mean of:

1. The average of the lowest temperature recorded each year over a number of years.
2. The lowest average monthly temperature for the winter season.

Although this approach is aimed to take the above mentioned factors into consideration it is fully appreciated that other methods might be equally satisfactory and indeed other companies probably adopt a different approach. Whatever method is used to arrive at suitable cloud points, it is wise to ignore 'cold sinks' and sparsely populated areas when collecting the basic meteorological data.

Examples obtained with our method for a number of locations are given in Table III. With cloud points set to these levels there is a risk that fuel system troubles will occur if the abnormally low temperature is experienced, but the number of days that this will happen will be very few and in most years there will be no trouble at all. Just

**TABLE III**

| *Country* | *Minimum Critical Winter Temperature* *Town* | °F | °C |
|---|---|---|---|
| Australia | Melbourne | 32 | 0 |
| Greece | Volos | 27.5 | − 2.5 |
| New Zealand | Christchurch | 26 | − 3.5 |
| U.K. | Kew | 20 | − 7 |
| Italy | Milan | 17.5 | − 8 |
| Denmark | Copenhagen | 14 | −10 |
| Belgium | Antwerp | 14 | −10 |
| Holland | Winterswijk | 11 | −11 |
| France | Nancy | 9 | −13 |
| Germany | Nuremberg | 4 | −15.5 |
| Austria | Innsbruck | 1.5 | −17 |
| Norway | Oslo | 0 | −18 |
| Switzerland | St Gothard | 0 | −18 |
| Canada Ontario & Quebec | Toronto | − 8.5 | −22.5 |
| Sweden | Umea | −16 | −27 |

See Table IV for typical examples.

as it would be unreasonable and uneconomic to design and build a tractor that would never fail, so it would be equally unrealistic and uneconomic to set cloud points so low that they would not give trouble at even the lowest of ambient temperatures.

Examples of fuels meeting the Minimum Critical Winter Temperature are given in Table IV. From the

**TABLE IV**

*Typical Cloud and Pour Points of Winter Grade Fuels*

| Country | Samples | M.C.W.T °F | M.C.W.T °C | Cloud Pt. °F | Cloud Pt. °C | Pour Pt. °F | Pour Pt. °C |
|---|---|---|---|---|---|---|---|
| New Zealand | A<br>B | +26 | − 3.3 | —<br>— | —<br>— | 0<br>+10 | −17.8<br>−12.2 |
| Holland | A<br>B | +11 | −11.7 | +10<br>+10 | −12.2<br>−12.2 | + 5<br>+ 5 | −15.0<br>−15.0 |
| Germany | A<br>B | + 4 | −15.6 | + 6<br>+ 6 | −14.4<br>−14.4 | + 5<br>− 5 | −15.0<br>−20.6 |
| Norway | A<br>B | 0 | −17.8 | 0<br>− 5 | −17.8<br>−15.0 | −25<br>−10 | −31.7<br>−23.3 |
| Switzerland* | A<br>B | 0 | −17.8 | +8.0<br>+16 | −13.3<br>− 8.9 | + 5<br>+10 | −15.0<br>−12.2 |
| Canada (Ontario & Quebec) | A<br>B | − 8 | −22.2 | −12<br>−12 | −24.4<br>−24.4 | −30<br>−25 | −34.4<br>−31.7 |
| U.K. | A<br>B | +20 | − 6.7 | +14<br>+14 | −10.0<br>−10.0 | + 5<br>+10 | −15.0<br>−12.2 |

* (See text for comment about Switzerland)

table it can be seen that the cloud point of Swiss fuel is higher than the M.C.W.T. and this has been confirmed by the examination of other samples. Yet there are no problems of filter blocking in service. This is attributed to the fact that operators are familiar with the precautions necessary in cold weather and they take the necessary action as a matter of course.

New Zealand provides an example of the situation where, due to limited areas having low temperatures, it is necessary to market a diesel fuel with low temperature characteristics suitable not only for the local area but, from practical distribution reasons, for the whole of the marketing area.

In the U.S.A. most current diesel fuel specifications require the pour point to be 10°F (5.6°C) lower than the lowest expected ambient temperature. Bearing in mind the fact that there is usually a difference in the order of 10°F (5.6°C) between the pour point and the cloud point, the American requirement is fundamentally similar to relating the M.C.W.T. to *cloud* point.

It must be recalled that while an adequately low cloud point ensures satisfactory performance with the most critical of fuel systems, many systems will operate satisfactorily on fuels with a cloud point several degrees above the ambient temperature. Hence fuels with a cloud point at least as low as the M.C.W.T. offer a substantial safeguard in all fuel systems, even those which are badly designed and so are critical in this respect.

Despite the considerable effort that in recent years has been expended in an attempt to understand and overcome the difficulties associated with the blocking of fuel systems at low ambient temperatures, circumstances are bound to occur occasionally when the low temperature characteristics of a particular batch of fuel are not adequate for its intended application.

Possible circumstances in these categories are:

1. Carry-over of summer fuel into the winter.
2. Unexpectedly early cold weather.
3. Unexpectedly severe cold weather.
4. Vehicles with critical fuel systems.

In any attempt to make use of fuel that would otherwise cause blockage in fuel systems, consideration must be given to the use of additives to improve the low temperature performance.

**TABLE V**

*The Effect of Kerosine addition to Diesel Fuel on Pour Point and Cloud Point*

| % Kerosine | FUEL A Cloud Pt °F | FUEL A Cloud Pt °C | FUEL A Pour Pt °F | FUEL A Pour Pt °C | FUEL B Cloud Pt °F | FUEL B Cloud Pt °C | FUEL B Pour Pt °F | FUEL B Pour Pt °C |
|---|---|---|---|---|---|---|---|---|
| 0 | 22 | − 5.6 | 10 | −13.3 | 26 | − 3.3 | 15 | − 9.4 |
| 20 | 16 | − 8.9 | 5 | −15.0 | 22 | − 5.6 | 10 | −12.2 |
| 30 | 14 | −10.0 | − 5 | −20.6 | 18 | − 7.8 | 5 | −15.0 |
| 40 | 10 | −12.2 | −10 | −23.3 | 16 | − 8.9 | 0 | −17.8 |
| 50 | 8 | −13.3 | −10 | −23.3 | 12 | −11.1 | − 5 | −20.6 |

### Use of Additives (including Kerosine)

Several chemical compounds exist that effectively depress the pour point of diesel fuel, but a liberal quantity of kerosine is the only established reliable method of reducing the cloud point of an existing fuel without impairing its other properties. (See Table V.)

An additive which only depresses the pour point is unlikely to reduce the lowest operating temperature of an engine. But the actual response of different fuel systems to a fuel's low temperature characteristics can vary so much that only practical tests can prove the true value of any particular pour point depressant in a particular base fuel and particular fuel system. Therefore a good deal of work along these lines has been conducted. Reference[4] summarizes a number of these tests and concludes:

> 'At the present time these additives do not provide a general solution to low temperature problems with a diesel fuel system'.

Nevertheless, a number of these compounds are marketed under proprietary brand names. Generally, their claims for pour point reduction are valid in terms of originally high pour point material, but their practical effect on the minimum operating temperatures of vehicles and tractors is uncertain. These additives should therefore be used with some caution.

### Emergency Action for Diesel Fuel Systems in Cold Weather

If the temperature suddenly drops below the cloud point of the fuel in stock, kerosine can be added in the proportions given in Table V. If fuel systems actually block with wax before the fuel is blended with kerosine, the filters and fuel lines should be warmed with hot water directed onto the critical parts or by using exhaust gas from a running engine. Temporary removal of the preliminary gauze filter is well worthwhile under these circumstances, but the engine should not be run without the main fuel filter, as irreparable damage can be done to the fuel pump even during a short period of operation. The addition of kerosine to the main filter bowl will often enable a machine to be driven home.

## CRANKCASE LUBRICANTS

Many European and North American tractor manufacturers are unable to state the ultimate destination of any particular tractor on the production line. The tractor is often built to a standard specification whether it is to be sold in the Arctic or the Tropics. Hence, it is quite possible to find a tractor operating in Nigeria with only one feature of the manufacturer's operating specification different from an otherwise identical model working in Finland. This one feature is the viscosity of the crankcase

Supplementary starting aids are fitted to some tractors as a standard feature, and others are available as special versions for Arctic use, but whether starting aids are fitted or not, the speed at which the engine is rotated by the starter must be kept above a certain minimum for satisfactory starting, and the viscosity of the oil used will significantly affect the cranking speed.

### Cold Starting Problems

Difficulties with cold starting usually arise during abnormally cold weather in the temperate zones where starting is normally easy. In the event of particularly cold weather, the user is surprised to find that the engine will not start, and frequently complains bitterly to the tractor dealer or manufacturer. Tractor manufacturers try to ensure that the starting capacity of the engine has a good deal 'in hand' when it leaves the factory, because experience has shown that the engine will be neglected in service 'just as long as it starts'. In colder regions the experience of the user has taught him to take care of the battery, starter, starter leads, earth connections and auxiliary starting aids. He also learns the importance of correctly following the starting instructions, including the use of the recommended crankcase oil viscosity.

**TABLE VI**

*Examples of tractor manufacturer viscosity recommendations—SAE Grades*

| °F | °C | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 90 | 32 | | 30 | 30 | | 30 |
| 80 | 27 | 30 | | | | |
| 70 | 21 | | | | 30 | |
| | | 20W | 20W | 20W | 20W | 20W |
| 30 | − 1 | | | | | |
| | | 10W | | 10W | 10W | 10W |
| 10<br>−10 | −12 | | 10W | | | |
| | | | | 5W | | 5W |

1. Massey-Ferguson
2. Deutz
3. Ford
4. Chamberlain
5. John Deere

### Crankcase Oil Viscosity

All engine and tractor builders include a list of recommended or approved lubricants in the instruction manual. Either branded oils or oil by specification or designation are listed, and guidance is always given as to which viscosity level is most suitable for a given range of temperatures. (See Table VI for examples.)

Using the SAE classification of viscosities (Fig. 4), it is possible to say that a reduction of 10°F (5.6°C) in minimum starting temperature will be achieved by changing to the next lower viscosity grade (e.g. 20W to 10W). This is because the lower viscosity reduces the resistance to cranking, and hence lowers the load on the starter motor sufficiently for it to maintain the minimum satisfactory cranking speed. This is usually about 100 rev/min but some particular engines need a somewhat higher cranking speed. At very low temperatures supplementary heating of the combustion air will also be necessary or a starting fluid may have to be used in order to ensure that the spontaneous combustion takes place. A reduction in starting temperature of some 10°F (5.6°C) is also possible by using heavy duty electrical equipment, and this is a practice often adopted when tractors are sold as special units for continual operation at low temperatures. Such equipment can only be provided at some extra cost, whereas there is little if any difference in the price of the different viscosity oils.

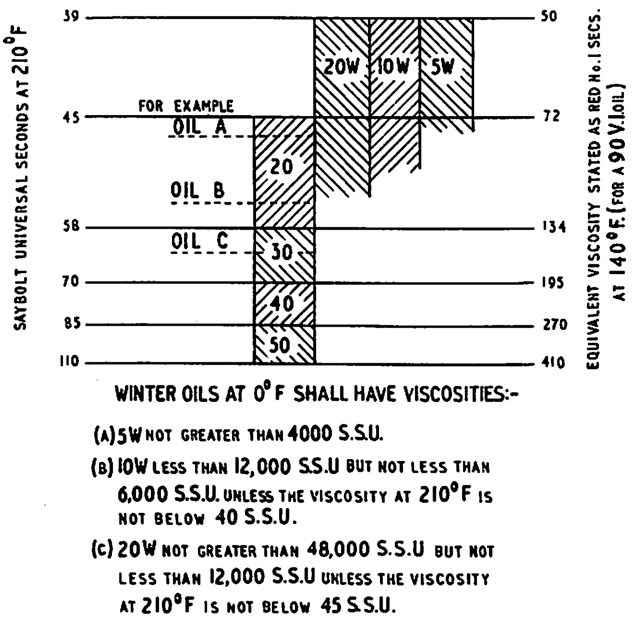


Fig. 4.

## Low Viscosity Oils

Figure 5, based on manufacturers' recommendations, shows that SAE 10W oils are suggested for tractors at temperatures as high as 32°F (0.0°C). On the other hand SAE 10W oils are recommended for use in some makes of tractor down to the lowest ambient temperatures likely to be encountered in farming territories, and 5W oils, the lowest viscosity grade available, are only necessary in a few tractors at temperatures below 0°F (-17.8°C). Consequently, SAE 5W oils are only in limited demand and are not too readily available, even in Scandinavian countries. In North America SAE 5W oils and SAE 5W/20 multigrade oils are commonplace.

Kerosine is recommended as a crankcase oil diluent by some manufacturers, particularly to lower the viscosity of the oil to achieve higher cranking speed, and partly to reduce the pour point of the oil. The pour point does not affect the cranking speed but it does influence the pumpability of the oil. Hence the addition of kerosine can minimise the risk of bearing failure if tractors are brutally started at temperatures below the pour point of the undiluted crankcase oil. Figure 6 gives examples of the

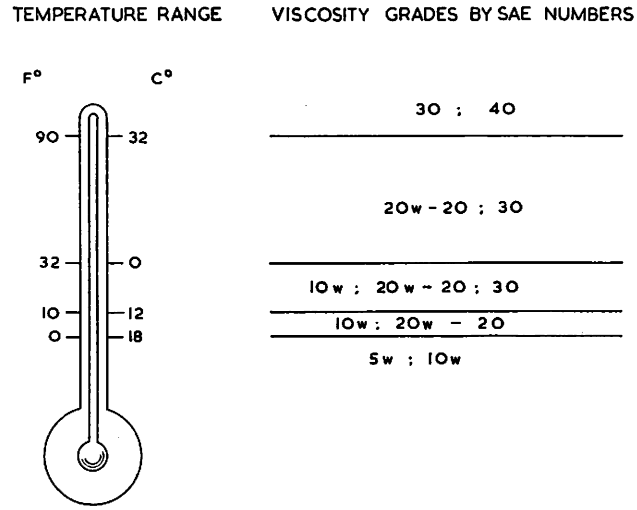


Fig. 5.

Range of Viscosities based on Tractor Manufacturers' Recommendations.

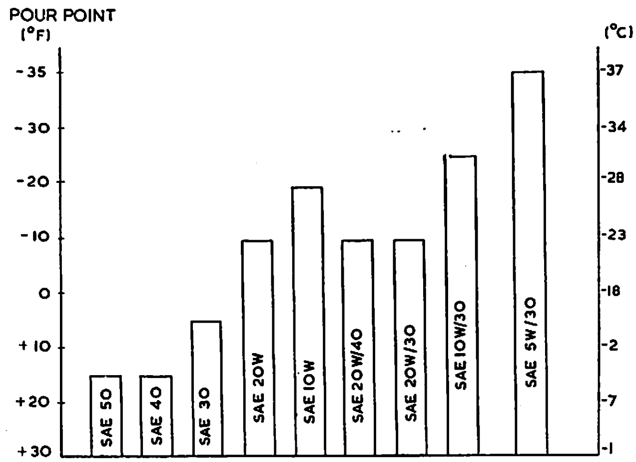


FIG.6.

Comparison of Pour Points of Various Oils

range of pour point to be expected with different viscosity grades.

By and large, engine manufacturers appear to avoid recommending SAE 5W oils, presumably because of the increased risk of external leakage, increased oil consumption and the fear of damage to bearings. These fears are unfounded in the case of engines in good condition, but if an engine is worn, a sudden change to a lower viscosity is at least likely to result in higher consumption and increased leakage. This has led to interest in multigrade oils that offer low viscosities at low temperatures of starting, but retain their relative thickness at the higher temperatures of engine operation.

## Multigrade Oils

As multigrade oils are so commonplace today, it would be unjustified to devote space to the subject in this Paper. For agricultural purposes, multi-grade oils marketed as 'universal' oils were fully described to the Institution of Agricultural Engineers by Bates in 1955, Reference[6].

## Universal Oils

The concept of 'universal' type multigrade oils that can be used in the engine, gearbox, transmission and hydraulics of the conventional wheeled tractor is now firmly established in most countries with advanced farm mechanization. Tractor manufacturers have, nevertheless, been reluctant, mainly for commercial and policy reasons, to promote the use of these grades. The first choice of lubricant listed by almost every tractor manufacturer is the single viscosity grade; detergent or HD. As most major and many minor oil companies now market 'universal' oils, it is a pity that the tractor manufacturers cannot adopt a more open-minded attitude to the universal grade, and at least list them as being of equal status to the conventional oils. In fact the advantages of universal oils should logically make them the first choice for new tractors, especially as they have been expressly formulated for modern tractors and are often quite superior in quality to the earlier tractor oils.

Furthermore, in the interest of maintaining a good reputation for its products, an oil supplier must ensure that the viscosity chosen for a given marketing area is suitable for the climatic conditions. For this reason, branded universal oils are often varied in viscosity to suit local conditions and the manufacturer, in recommending such an oil, does not have to bother himself or the user with the problem of matching viscosity to the local ambient temperatures—if universal oils are chosen, this is done by the oil company.

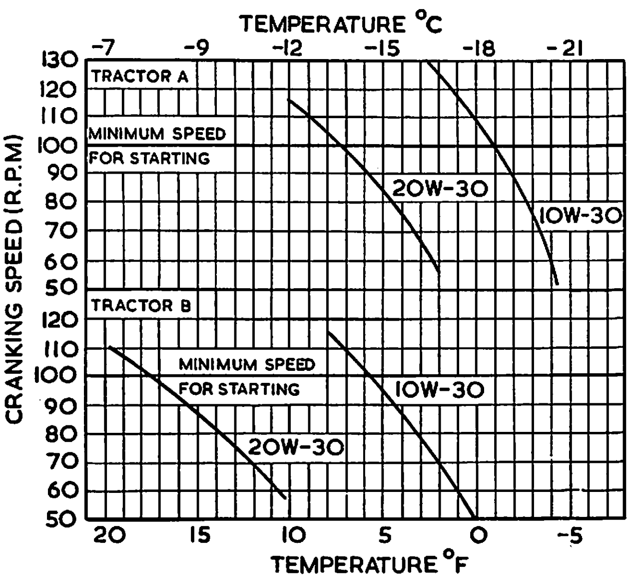


Fig. 7.

## Matching Viscosities to suit the Climate

Whether single-bracket or multigrade oils are used at low temperatures, some thought must be given to the most desirable level of viscosity for the expected ambient temperature. Sometimes the choice of viscosity is the responsibility of the supplying oil company, sometimes it is the tractor manufacturer who makes a recommendation; on other occasions the user is faced with choosing a suitable viscosity on the basis of his own experience.

Tests conducted by many manufacturers and by independent testing organizations (for example see Fig. 7) during the last few years have shown that with most tractor engines a cranking speed of 100 rev/min is desirable to ensure a satisfactory cold start. New tractors and engines are now always tested in cold chambers to ensure that starting will be adequate for the ambient temperature to be encountered. If the tests reveal that the starting performance is inadequate, different electrical equipment or different starting aids are fitted, and the most suitable crankcase oil viscosity is specified. Because of the variations in specifications for starting equipment and the difference in inherent resistance to cranking of different engines, a wide range of viscosity recommendations results. The temperature ranges for which different grades are recommended are by no means standardized either. Reference back to Figure 5 is an indication of the spread of viscosity recommendations based on a survey of tractor instruction manuals.

To simplify the problem of selecting a viscosity grade —either a single grade or a multigrade universal type, a broad generalization can be made, namely, if an engine will crank at 100 rev/min with an SAE 30 grade at 30°F

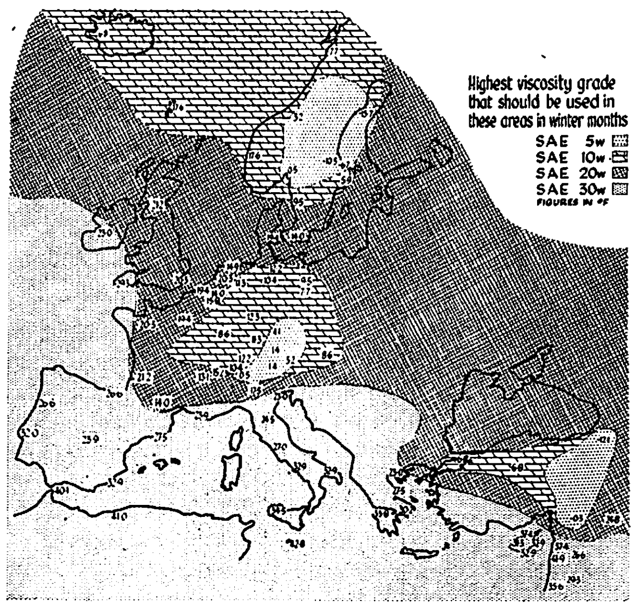


Fig. 8.

Choice of Viscosity Grades for Winter Use

(-1.1 °C), it will crank at approximately 100 rev/min if a 20W oil is used at 20°F (-6.7°C). Similarly, a further reduction to a 10W oil will ensure that a cranking speed of approximately 100 rev/min will be obtained down to 10°F (-12.2°C). Hence it is possible to draw up a simple table:

| *Degrees Fahrenheit* | *Degrees Celsius* | *SAE Grade* |
|---|---|---|
| 30 | − 1.1 | 30 |
| 20 | − 6.7 | 20W |
| 10 | −12.2 | 10W |
| 5 | −15.0 | 5W |

This table can be used to select the maximum low-temperature viscosity of a multigrade oil, i.e. a 10W/30 in place of a 10W oil, or a 5W/20 in place of a 5W oil.

If this 'rule-of-thumb' guide is related to distribution of ambient temperatures in Europe, it is possible to determine maximum viscosity levels for particular areas (Fig. 8). A significant feature revealed by this diagram is that SAE 5W oils should only be required in the north of Scandinavia and in a limited area of Central Europe.

## PROTECTIVE FUELS

Normal diesel fuels are not expected to remain in engine fuel systems for lengthy periods. Consequently, fuel specifications tend to deal with operating performance rather than storage characteristics. While some fuels fortuitously offer ideal protection of the fuel system in storage, others may not, and it is not usually possible for diesel engine users to evaluate storage characteristics of a particular fuel. If a fuel allows corrosion to take place in the fuel system, or if it oxidizes to form gum or other deposits, components in the injection equipment will stick and seize, causing malfunctioning or complete failure of the engine. When long periods of storage can be predicted, it can be of real practical value to avoid such problems of replacing the normal diesel fuel with a special protective fuel.

Protective fuels are designed to have good inherent stability, together with properties that will protect the fuel system units from the effect of air and water entrained in the fuel. This protection can be achieved in two ways:

1. By the use of selected fuels.
2. By adding certain materials to normal fuels.

Special fuels refined from selected crude oils are produced and sold as storage fuels or 'run-out' fuels. In addition to their use for protective purposes, they are also extensively used for testing fuel injection equipment. They are particularly suitable for this work, because their physical characteristics are very closely controlled so that variations in performance of the equipment is unlikely to result from variations in the characteristics of the test fluid.

When 'run-out' fuels are used by engine manufacturers the normal diesel fuel is replaced by the 'run-out' fuel just towards the end of the test and running-in period. The 'run-out' fuel purges the fuel system of normal fuel, and at shut-down the engine is actually running on the special fuel. Hence, the fuel system remains filled with it for the idle period that inevitably follows despatch of the engine until it goes into service—often many months later when overseas shipment is involved.

A similar procedure can be followed when an engine is stored after a period of service. However, understandably, users are reluctant to drain fuel from vehicle tanks and then run the engine for a long enough period to ensure that all the normal fuel in the fuel system has been consumed. An alternative procedure therefore is to drain the main filter and to fill the bowl with protective fuel. The engine is then started to ensure that the protective fuel has been drawn into the system. Oils for protection of engine crankcases can also be used for this purpose, but special inhibiting fluids are preferable, as smaller quantities are needed and it is not necessary to drain the fuel system in order to make use of them.

Certain vegetable and animal oils offer protection when diluted with diesel fuel. Products are available as concentrates of these materials for adding to the fuel already in the fuel tank. Application procedures vary according to the exact nature and strength of the inhibiting additives. Usually a total of one part of additive to ten parts of fuel is required. The additive may include a proportion of protective crankcase oil, or the user may be instructed to mix inhibiting fluid with a protective oil and to add the blend to the fuel in the system.

## CRANKCASE PROTECTIVE OILS

Oils that protect the engine from the effects of combustion products which find their way into the crankcase are not always the best oils to protect it from the corrosion that occurs when an engine is stored for a lengthy period. So oils are specially produced for storage purposes.

To enable engines to be run for limited periods on these special protective oils they usually contain some detergent properties but they are particularly blended with additives that inhibit corrosion. Such oils are usually tested against the specifications MIL-L-21260 or BS-1133 Section 6.

Protective oils are often used by engine manufacturers for first-fill purposes and running-in. Recommendations usually suggest that first fill oils should be drained out after a period of use of up to 50 hours when normal engine oil and new filters should be used.

When an engine that has been in service is to be stored for a period of several months, the oil should be drained out when the engine is warm and the filter bowl should be emptied. Protective oil should then be put into the crankcase and the engine idled for a few moments. The practice of removing injectors and spraying protective oil into the cylinder is not recommended unless first-class skilled labour is available, otherwise injector problems that arise from incorrectly tightening the holding-down bolts and the high pressure fuel pipe unions are likely to be greater than the corrosion problems.

## PROVING, SERVICE AND FIELD TRIALS

In the preceding sections of this paper a great deal of accumulated information has been summarized in an attempt to present some practical guidance on the winter use of petroleum products in mechanized agriculture. Often the information is initially available as theory only, and broad assumptions would have to be made in relating the theoretical information to practical operating conditions, unless practical proving facilities are available. Most major oil companies conduct service and field trials on new and improved products in territories where the most arduous operating or climatic conditions can be expected. The author's company regularly conducts local tests and trials in almost all the countries in which it markets, and in the last few years field trials on products for mechanized agriculture have been carried out in Scandinavia, Greece, Australia and North Africa prior to their introduction on a world-wide basis. Experience of general farming has been obtained by liaising with a 500-acre farm in the Midlands. Limited field trials and tests have been conducted by the farm personnel to obtain unbiassed but nevertheless informed views on products and service.

Recently an agreement has been reached with a large estate in the U.K. (Fig. 9) to enable the company to monitor and control the use of all the estate's petroleum products. This will ensure that technical and commercial personnel in the company have access to, and are familiar with, the day-to-day and overall problems of farm mechanization and the use of petroleum products in agriculture. In aaαition to the very valuable general experience and background data that is being obtained, the estate offers what is perhaps a unique opportunity for practical testing procedures under realistic farming conditions. Its 32 tractors (see Table VII) and other mechanical equipment are divided into six farm units ranging from a two-tractor unit to an eight-tractor unit. Each tractor is always driven by the same driver, and each farm unit is under the supervision of the senior tractor driver. The estate's farming is managed by the General Farm Manager who co-ordinates the overall operation. Forestry and gamekeeping activities are managed separately.

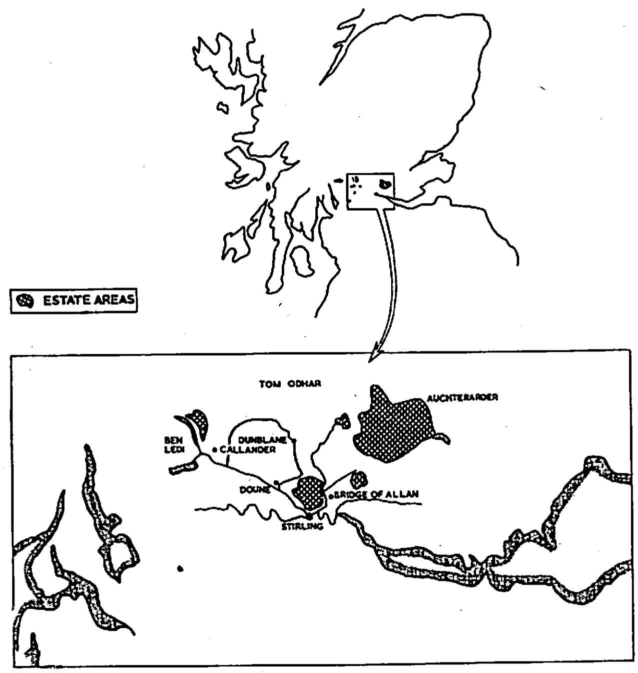


Fig. 9.

Keir & Cawder (Estates) Ltd., Keir, Dunblane

**TABLE VII**

*List of tractors and mobile mechanical equipment on the Keir and Cawder Estate*

| | |
|---|---|
| Massey—Ferguson 65 | 13 |
| Massey—Ferguson 35 | 8 |
| Fordson Major | 4 |
| Fordson 4×4 | 2 |
| T V O Tractors | 5 |
| Combine Harvester | 5 |
| Land Rovers | 6 |
| 5 cwt Vans | 4 |
| 10 cwt Vans | 9 |
| 7 ton Trucks | 2 |
| Shooting Brakes etc. | 6 |
| Mobile Crane | 1 |

Tractors and drivers may be temporarily posted to other farm units when work loadings are unequally distributed, but each driver takes his tractor back to his home farm each night when it is fuelled, lubricated and greased as necessary. Hence it has been possible to run the tractors at different farm units on different fuels and lubricants with the knowledge that there will be no mixing of products if the particular tractor is working away from its base. Similar facilities could be obtained by using a number of different individual farms, but the advantage of having the whole operation under one management is proving to be an extremely attractive feature.

### Operation of Estate Field Trials

In order to obtain a pattern of the lubricating oil consumption of the various tractors with a top quality 'universal' type oil, most of the tractors are using an SAE 10W/30 Supplement 1 oil in the engine, gear box, differential, final drive and hydraulics.

Each tractor driver has been provided with a logbook for fuel and oil consumption records (Figs. 10 and 11). Periodically the individual fuel and lubricant log entries are written onto a master card (Fig. 12). Analysis of the logbook records has already shown that lubricating oil consumption is substantially influenced by the topping up procedures adopted by the individual drivers. Oil changes are carried out unfailingly by some drivers at the recommended period and almost ignored by others (Fig. 13).

BP

**TRACTOR FUEL RECORD**

BP

Tractor Type ..................... Number ...........

| Date | Meter Reads | Gallons | G.P.H. | Nature of Work |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

N/RS

Fig. 10.

BP

**BP Tractor Trial**

**Oil and filter change reminder**

BP

Tractor Type ..................... Number ............

| Oil to be changed:- | Date | Meter Reads | E,T, R or H* | Oil | | Quantity |
|---|---|---|---|---|---|---|
| | | | | Change+ | Top-up+ | |
| Crankcase every ........... hrs. | | | | | | |
| Transmission every ........ hrs. | | | | | | |
| Final reductions every .... hrs. | | | | | | |
| Hydraulic every ........... hrs. | | | | | | |
| Air cleaner every ......... hrs. | | | | | | |
| Fit new crankcase-oil filter every ............ hrs. | | | | | | |
| | | | | | | |

* E = Engine T = Transmission R = Final Reductions H = Hydraulic

+ Tick as appropriate

N/RS

Fig. 11.

Some understanding of these personal influences is important if a comprehensive or detailed study of conditions is to be made at any later stage. It is evident that the practices of topping-up and changing the engine oil can be vastly altered merely by asking each driver to record what he does!

A fully equipped farm service vehicle has been installed on the estate to facilitate the company's activities there and a Service Centre with comprehensive lubricant handling and dispensing equipment has been constructed to provide practical experience in the various ways in which the petroleum products can be handled and dispensed. Eventually, demonstrations will be given, and advisory and training films will be made at the Centre.

A mobile dynamometer has also been installed on the estate so that objective evaluations of the tractor's performance can be obtained before, during and after each particular test programme.

## CONCLUSIONS

Theoretical studies, fields trials and practical service have shown that current fuels and lubricants for diesel engines in agricultural applications and other vehicular applications are of an adequate quality level for their purpose, provided that they are correctly selected, stored, handled and applied. Improved qualities are already being developed, yet full advantage has not always been taken of these. Examples of the agricultural engineering industry's reluctance in adopting progressive techniques of advantage to the user can be seen in:

1. Fuel systems that, at no extra cost to the manufacturer, could be designed to give 10°F (5.6°C) lower operating temperature before the onset of filter blocking problems.
2. Lack of support for the use of 'universal' type oils that can adequately lubricate a complete conventional tractor and ensure adequate cranking speeds for effective cold starting down to all but the lowest ambient temperatures, for which special low-viscosity oils are marketed in the appropriate territories.

In view of the practice of producing standard tractors for use in all parts of the world, careful thought should be given to the quality of petroleum products selected for them for use in widely different climates to ensure their most effective performance.

## ACKNOWLEDGEMENTS

The author wishes to thank the Chairman and Directors of The British Petroleum Company for permission to present this paper and to express his grateful appreciation of the considerable help in preparing this paper given by a number of colleagues in BP and the Tractor Industry.

## APPENDIX I

**Publications on Fuel Storage**

INSTITUTION OF AGRICULTURAL ENGINEERS
'Annual Year Book'

MINISTRY OF AGRICULTURE LEAFLET NO. 29
'The Tractor Fuel Store'

CAV LIMITED. LUBRICATION NO. 513
'The Storage & Filtration of Diesel Fuel Oil'

TEST NO. PES 588

| BP Trading Ltd. - Tractor Trials | |
|---|---|
| Test Oil:- UK 86 | Fuel:- |
| Name of Farmer ...K & C...... | Name of ~~Manager~~ Driver ..DAVENPORT |
| Address of Farm:- ARDOCK | |
| Tractor Make M-F   Tractor Type 65   Serial No. | |
| Engine Make   Engine Type   Engine No. | |
| Age of Tractor ....1962...... Years ........2815..... Hrs. Run | |
| Condition, and details of any major repairs or modifications since new. | NONE |
| Nature of work usually undertaken. | General Farm Duties – Arable Farming |
| Farm Conditions, Soil, Terrain etc. | Sandy Loam Flat. |
| Grade of oil used prior to test:- Engine ......... Transmission ......... Hydraulic ......... Final Drive ......... | UK. TOU |
| Average engine oil consumption in last year prior to the test (approx.) | Not Known. |
| Remarks:- | |

| Date | Motor Reads | E.T.R or H* | Oil Change+ | Oil Top-up+ | Quantity | Observations: Filter changes, samples taken etc. |
|---|---|---|---|---|---|---|
| 2.12.63 | 2815 | E | ✓ | – | 13 pt | |
| .. | .. | TH | ✓ | – | 6 ½ gall | |
| | | R | ✓ | – | 3 pt | |
| 12.12.63 | 2821 | E | – | ✓ | 1 pt | |
| 13.12.63 | 2828 | E | ✓ | – | 13 pt | |
| 15.12.64 | 2835 | E | – | ✓ | 1 pt | |
| 20.12.63 | 2858 | E | – | ✓ | 1 pt | |
| 3.1.64 | 2880 | E | – | ✓ | 1 pt | Ploughing. |
| 8.1.64 | 2900 | E | – | ✓ | 1 pt | |
| 13.1.64 | 2910 | E | – | ✓ | 1 pt | |
| 15.1.64 | 2933 | E | ✓ | – | 13 pts | |
| 26.1.64 | 2960 | E | – | ✓ | 1 pt | |
| 1.2.64 | 2988 | E | – | ✓ | 1 pt | |
| 11.2.64 | 3024 | E | – | ✓ | 1 pt | |
| 12.2.64 | 3036 | E | – | ✓ | 1 pt | |
| 16.2.64 | 3048 | E | – | ✓ | 1 pt | |
| 20.2.64 | 3063 | E | ✓ | – | 13 pt | |
| 23.2.64 | 3081 | E | – | ✓ | 1 pt | |
| 8.3.64 | 3121 | E | – | ✓ | 1 pt | Ploughing. |
| 11.3.64 | 3139 | E | – | ✓ | 1 pt | |
| 18.3.64 | 3165 | E | – | ✓ | 1 pt | |
| 19.3.64 | 3194 | E | ✓ | – | 13 pts | |
| 2.4.64 | 3215 | E | – | ✓ | 1 pt | |
| 4.4.64 | 3228 | E | – | ✓ | 1 pt | |
| 10.4.64 | 3259 | E | – | ✓ | 1 pt | |
| 13.4.64 | 3284 | E | – | ✓ | 1 pt | |
| 20.4.64 | 3298 | E | – | ✓ | 1 pt | |
| 28.4.64 | 3323 | E | ✓ | – | 13 pts | |
| 4.5.64 | 3369 | E | – | ✓ | 1 pt | |
| 11.5.64 | 3379 | E | – | ✓ | 1 pt | |

*E = Engine; T = Transmission; R = Final Reduction; H = Hydraulic
+Tick as appropriate.

Fig. 12.

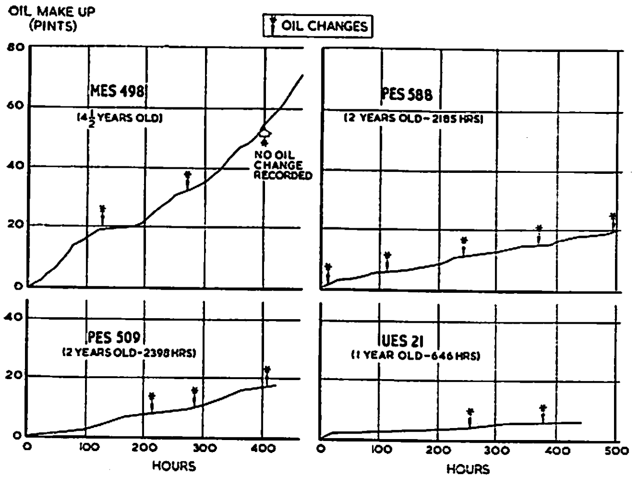


Fig. 13.

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## DISCUSSION

MR A. C. B. HOPEWELL (Shell-Mex and BP Limited) said that some manufacturers disliked recommending a universal oil for their tractors and he invited Mr Savage to comment on the difficulties manufacturers experienced in exporting tractors to countries overseas where perhaps a particular type of oil was not available. Mr Savage described this as a 'chicken and egg' problem. The greater the support for the product by the users, the greater would be its availability. In fact, he believed that most countries importing British-built tractors now had universal oils available. He could not understand why tractor manufacturers did not simplify the user's task by listing as a first choice an oil that would satisfactorily lubricate the whole machine whilst, in the places where this was not available, the alternative of three oils—hydraulic, transmission and engine—would have to be adopted. At present instruction books tended to list the three oils as the first choice and then one would find in small print that universal oils were also accepted, a practice that had tended to discourage their use. Mr Savage confessed that he did not know what more could be done to instil confidence in universal oils among the tractor manufacturers. He recognised that there might be special cases such as tractors that required some particular kind of lubricant even for normal service, and there was a minority of borderline cases where tractors needed special lubrication for particularly severe duty. A very large number of tractors currently in production could be so simply lubricated that it was surprising to him that manufacturers did not adopt this simple approach and specify the use of universal oils. In fact the contrary had been the case.

MR R. J. SIMS (Surrey Farm Institute) mentioned that he had been using universal oils fairly extensively in his tractors and he had experienced a certain amount of trouble in the form of severe wear in the hydraulic system. The local agents of the tractor manufacturer had advised him not to use universal oils, alleging that these were responsible for the difficulty. He asked Mr Savage whether there was any published evidence confirming that universal oils possessed a film strength comparable with that of gear oils. Mr Sims also referred to the failure of the hydraulic system fitted to a very old crawler tractor. On inspection the hydraulic pump was found to be worn out and to be blocked by a fibrous substance giving the appearance of grease that had been deposited from the oil.

Mr Savage replied that so far as the film strength, load-carrying properties of universal oils were concerned, there was quite a lot of evidence, mainly in connection with transmission systems, where the oil had to do the most work. It was not possible to analyse the wear problem mentioned by Mr Sims without probing deeply on the spot to find out exactly what had happened in that one particular case. In his experience, continued Mr Savage, universal-type oils had not led to the general incidence of wear in hydraulic systems. Certainly, if in an old tractor of the type that operated on a thick oil in the combined transmission/hydraulics circuit, wear had occurred while running on that oil, a problem might arise on changing to a universal oil because of the substantial change in viscosity. On the other hand he knew of many tractors which had started life on universal-type oils and had lived satisfactorily through many years of arduous operation.

Mr Hopewell said he believed the National Institute of Agricultural Engineering at Silsoe had published quite exhaustive reports on tests of universal oils. Mr Savage agreed, but said that one of the two documents published related to the transmission system, and consisted of a fairly severe endurance test. The other, described the advantages in terms of rate of work, having regard to improved viscosity characteristics and that, of course, was essentially a short-term operation which would not reveal any wear or anti-wear characteristics of the product. The companies that marketed universal oils could probably provide further evidence. MR L. K. O. COX (Esso Petroleum Co Ltd) said that the terms 'multigrade' and 'universal' as used in Mr Savage's paper seemed to be synonymous. Generally speaking, in the motoring world the viscoscity index of multigrade oils was pitched in the range of 130-145. There was an intermediate range of 20W/30 oils for which the viscosity index was 123-125 and there were the straight mineral oils which could have a viscosity index of 100-105. Mr Cox suggested that not all universal oils were in fact multigrade oils. Whilst he did not dispute that there were some universal oils which happened also to be multigrade oils, he believed that there should be a clearer division in the classification of universal oils. Mr Savage said that the point made by Mr Cox highlighted two difficulties he had experienced in assembling his paper. First, he had not wanted to dwell on multigrade oils at too great length, and secondly he had not wished to repeat in detail what had been said elsewhere about the use of oils of this type. He could well understand that this had led to a possible confusion of terms. However, went on Mr Savage, all universal oils, to the best of his knowledge, were in fact, multigrade. It might be that some oils were sold as single-bracket oils, and this was unfortunate because the user would need to change from summer to winter grade even when using such a 'universal' oil. The true universal oil, in Mr Savage's view, was basically a multigrade engine oil, in that it would lubricate the engine throughout the year over the range of ambient temperatures likely to be encountered and it would equally well lubricate the transmission and serve as the hydraulic fluid.

MR E. ATKINSON (Shell Mex and BP Limited) said that one must sympathize to some extent with manufacturers in their lack of full recommendation of universal oils in agriculture, bearing in mind that a large proportion of their equipment went overseas and arrived in many markets which were small by oil company standards and where in consequence the problem of supplying recommended grades was well-nigh insurmountable from the distribution point of view. Mr Atkinson noted Mr Sims' remarks on the performance of universal oils in tractors. He personally knew of many instances where tractors had operated for periods from 7,000-10,000 hours on universal oils, and to date these were still working admirably. Where machines did not perform well in the field, the factor concerned might be a simple one, such as dirt. The adverse effects arising from silica or metal in oil were well known, but he believed field results showed clearly that universal oils in tractors had the advantages Mr Savage had mentioned.

Replying to further points made by Mr Atkinson, Mr Savage said that it was gratifying to receive support for his contention that hydraulic pumps operated satisfactorily on universal oils. Where the problem of freezing water droplets contaminating the fuel was encountered, this would show itself very soon after the temperature had dropped below the freezing point of water. Difficulties that occurred at much lower temperatures might be associated with wax and he believed that the figures shown for Switzerland in his Paper (Table III), were in the range where wax was the problem. So far as the United Kingdom was concerned Mr Savage agreed that the cloud points of material marketed in this country would always be low enough to meet the winter conditions that one could expect to find here. He believed that the only time there had been any trouble had been during the winter of 1962/63; during the ten years or so prior to that occasion, the winters had been fairly mild. The diesel engine had been growing in popularity and its fuel system had become increasingly complicated, but it took a very severe winter to bring the whole situation to a head. In consequence cloud points would be lower in future—probably unnecessarily low for nine years out of ten.

MR E. S. BATES (British Petroleum Co Ltd) said he would like to raise a matter which was in a sense a corollary to Mr Savage's welcome Paper. The Institution's President, Mr W. J. Priest, was on record as having said that an agricultural engineer must be a little of an agronomist and an economist as well as being a designer. Everyone would recall that the Suez crisis had revealed clearly how dependent European countries were on Middle East crude oils. These crudes by comparison with products from the Western hemisphere, were high in wax content. Normally wax was removed by mechanical means and as the quantities of fluid products increased it became less and less attractive to remove wax by mechanical means. The erstwhile market for wax no longer existed, as plastics were taking the place of conventional wax products. Electricity was making sure that wax candles were no longer required—except at Christmas time. Two of the products to which Mr Savage had referred—winter grade diesel fuel and universal-type oils—had to have this wax removed in order to provide the qualities mentioned in his Paper. The interesting point for the future was that scientists in the oil industry were now on the verge of employing micro-biological cultures to consume the wax in a way which would be very economical for the oil industry and result in a high-protein foodstuff, edible both by human beings and livestock. Mr Bates said he thought it was worthwhile to refer to this development as advertisements and articles were appearing in the Press about it. It was a matter connected with the oil industry which would eventually have some major long-term effects upon the agricultural engineering industry.

# BIN STORAGE AND DRYING

by W. G. COVER, M.I.E.E., M.A.S.A.E., M.I.AGR.E.*

*Based on a Paper presented in Norwich at the Annual Conference of the East Anglian Branch of the Institution, in November 1963*

## Introduction

Everybody, whether in industry, commerce or agriculture, is today very conscious of labour costs. The introduction of the combine-harvester reduced labour costs in the field, and brought with it the problems of dealing with bulk grain. It is generally agreed that the farmer must make provision for storing this grain on the farm and he wishes to handle the grain crop from the time of combining to the time of sale or use with the minimum labour force and at the lowest possible cost. At the same time, he wants to ensure that the grain is kept in first-class condition. The farmer requires a drying and storage system that will allow for changes—whether of a temporary or permanent nature—in crops harvested and to allow the grain to be consumed on the farm or sold at a time to suit the farmer and when market prices are right. The well-established system of drying and storage in bins or silos is the only system which fully meets the farmer's requirements, for the following reasons:—

1. Grain is taken from the wet grain pit, through the pre-cleaner and into the bins with the absolute minimum of labour requirements.
2. Rate of intake is controlled only by the capacity of the elevating and conveying system and/or the cleaner.
3. Different varieties of grains may be segregated.
4. The floor space required is at a minimum.
5. The farmer may be sure that the grain will keep in first-class condition.
6. Management is simple with a properly planned installation.
7. The farmer has the choice of bins for installation indoors or outdoors.

Experimental work with bin or silo drying started some twenty years ago when the National Institute of Agricultural Engineering was at Askham Bryan, Yorks. Mr W. H. Cashmore was in charge of the section dealing with grain drying and storage, and Mr W. F. Williamson was very much concerned with the detailed investigations. Much progress has been made since those days. The first commercial installation of bin drying and storage was on a farm at Pitstone Green in Bedfordshire. The plant was completed for the 1947 harvest, which was exceptionally dry, and was first used in 1948, safely drying grain of 24% moisture content. Installations on other farms commenced in 1949 and bin driers of all types have been in use in all parts of the British Isles for many years. The system of drying in bins is one that has proved itself under practical conditions for many years. It is a system which fully meets today's requirements of dealing with the grain from high-capacity combine-harvesters.

* Director, The Simplex Dairy Equipment Co. Ltd.

**TABLE 1**

**GRAIN DRIERS IN EASTERN REGION MARCH, 1961 (CENSUS)**

| | *Drier* | | | |
|---|---|---|---|---|
| | *Bin* | *Sack* | *Tray* | *Continuous* |
| Beds | 130 | 70 | 30 | 125 |
| Cambs | 140 | 45 | 15 | 75 |
| Isle of Ely | 65 | 50 | 20 | 95 |
| Essex | 185 | 135 | 60 | 425 |
| Herts | 125 | 55 | 30 | 190 |
| Hunts | 125 | 60 | 15 | 70 |
| Lincs (Holland) | 145 | 110 | 10 | 50 |
| Norfolk | 230 | 65 | 55 | 395 |
| Soke of Peterborough | 15 | — | 5 | 5 |
| Suffolk | 290 | 130 | 35 | 275 |
| TOTAL Eastern Region | 1450 | 720 | 275 | 1705 |
| (England & Wales) | (5170) | (4140) | (1945) | (6100) |

Silo grain drying is a system using a large volume of air with a temperature rise not exceeding 10—12°F and where the grain will not be damaged by overheating.

## Bins or Silos for Storage

The advantages of bins for storage have been appreciated for many years; bins provide a most popular, convenient, and satisfactory method of storing grain safely. The Ministry of Agriculture, Fisheries and Food recommend the facility of being able to turn grain at short notice and only bins really meet this requirement. Different grains may be kept separate and are always instantly available. Bins may be round or rectangular, have solid or perforated walls and be installed inside buildings or outdoors with individual roofs. Some have a large number of panels which have to be assembled with many nuts and bolts, and some circular silos have large panels with angle-iron uprights; assembly of a complete silo is only the work of a few man-hours. Thus there is a type of storage bin to suit all requirements. The great majority of bins are manufactured from steel which is galvanized, although aluminium and wooden bins are also available. Comparative prices should always be considered in terms of cost per ton stored; it will be appreciated that larger silos or nests of silos will give lower prices per ton. Table 2 gives a selection of typical prices.

Thus indoor silos can be obtained at prices from £1.825 to £12.6 per ton stored and outdoor silos with roofs from £2.75 to £11.55 per ton stored, which gives a range to suit all pockets. With all solid-walled silos the grain must be stored at the moisture contents recommended by the

TABLE 2

STORAGE SILOS—GRAIN
(TYPICAL PRICES PER TON STORED—(EXCLUDING ERECTION)

RECTANGULAR WITH CORNER POSTS—STEEL GALVANIZED
(unlimited combinations 8 ft, 9 ft or 10 ft sides)

| FOR USE IN EXISTING BUILDINGS (Examples capacities from 14 to 892 tons) | WITH OWN HIGH PITCH ROOF (Examples 880 tons and 528 tons) |
|---|---|
| Row or Bank 1 to 10 bins £6.75 to £3.8<br>Nest (2 rows) 4 to 12 bins £4.9 to £3.3<br>Nest (3 rows) 6 to 18 bins £4.65 to £3.2 | 2 Banks of 10 bins £5.27<br>Nest (2 rows of 6) 12 bins £4.7 |

CIRCULAR BINS

| | *Corrugated Sheets Galvanized Steel* | *Plain Galvanized Sheets with angle iron uprights* | *Expanded Galvanized Sheets with angle iron uprights* | *Wooden with perforations* |
|---|---|---|---|---|
| **Measurements** | | | | |
| Height | 10 ft to 18 ft | 8 ft to 18 ft 6 in | 7 ft 10 in to 18 ft 0 in | 9 ft 10 in to 19 ft 8 in |
| Diameter | 12 in to 18 in | 7 ft 4 in to 21 ft 10 in | 7 ft 4 in to 14 ft 7 in | 6 ft 7 in to 13 ft 2 in |
| **Capacities** Tons | *26 to 103 | 7.5 to 150 | 7.5 to 63.5 | 7.2 to 60.5 |
| **Price per ton** | | | | |
| Indoor £ | 3.68 to 2.12 | 5.6 to 1.825 | 8.2 to 4.53 | 12.6 to 5.64 |
| Outdoor with roof £ | 5.9 to 2.8 | 8.95 to 2.75 | 11.55 to 5.6 | Not Available |

*NOTE—Smallest standard bin 26 tons

Ministry, of 14-16% depending on the period of storage. The writer is advised that grain loaded at moisture contents of up to 18-19% has been safely stored during the winter in silos with expanded metal walls. One farmer wrote in May 1963, 'The... system of 12 expanded metal bins is just super. The corn has stored perfectly; one bin of barley was only dried down to 19½% and with occasional turning has kept perfectly. This was done as an experiment.'

The reduction in drying costs and the gain in grain weight is clear. This point will be developed later in the Paper.

### Bins or Silos for Drying

It must be borne in mind that drying bins are also storage bins and so serve a double purpose.

There is a relationship between the relative humidity of the drying air and the grain moisture content.

Grain at 14% MC is in equilibrium with air at 63% RH
" " 15% " " " " " 71% "
" " 16% " " " " " 78% "
" " 18% " " " " " 87% "

Therefore, if air at 60-65% RH is continuously passed through a bin of grain, the whole mass of grain in that bin will be reduced to 14% MC.

Between the middle of August and the end of October the mean daily atmospheric relative humidity in this country is between 80 and 85%, which is in equilibrium with a grain moisture content of around 17%. If air at 80-85% RH is heated by 6-7°F, its relative humidity is reduced to approximately 65%. In some years, when we have a fine harvest period, the daytime relative humidity of the ambient air is sufficiently low for no heating to be required. In any case, it is strongly recommended that if the grain moisture content exceeds 20-22% when it is put in the bin, the initial drying should be by cold air only. This not only avoids damage to the grain, but leads to more efficient and economical drying. When the grain moisture content is below 20%, sufficient heat should be added to the drying air to reduce its relative humidity to a figure approximately in balance with the desired safe storage grain moisture content.

The system of silo grain drying which is most widely used, and has been thoroughly tested, is that of blowing air either vertically through silos which have porous floors, or radially through silos having porous walls. The air path through grain in a silo having a perforated floor should not exceed 10 ft in length. At this depth, the maximum economic rate of drying is 0.5% per day. With the radial airflow silo, the centre drying cylinder and the silo walls are perforated. The grain fills the space between the two, and therefore, the length of the air path through the grain is constant. In practice, depending upon the silo diameter, this air path varies from 2 ft 5 in to 6 ft 3 in and drying rates of 3% per day are obtainable; if desired, faster drying rates can be achieved.

100 tons of grain at 16% moisture content becomes 98.82 tons at 15% moisture content, i.e. losing 1.18 tons; at 14% moisture content, it is reduced to 97.67 tons, i.e. losing 2.33 tons. By storing grain at 1% higher moisture content the saving amounts to 1.18 tons per 100 tons, which at £25 per ton is worth £30. It is possible safely to store grain at higher moisture contents in silos having expanded metal walls. It can, therefore, be calculated that by storing the grain at 1% higher moisture, an

additional capital outlay of £10 per ton stored can be justified.

Losses due to spillage and vermin are at an absolute minimum in bin storage. These, together with losses in weight through further natural drying and respiration have been estimated at 0.5% per month for in-sack and on-the-floor storage, a further very considerable loss which would justify increased capital outlay.

**Grain Handling**

A simple auger or a system of elevators and conveyors may be used for handling. The costs will depend upon the extent of mechanization and the importance of labour saving. All labour has to be paid for, sometimes in the form of extra overtime, sometimes as casual labour, or it may be that other work has to be curtailed, delayed or perhaps carried out at overtime rates in order to provide labour for grain handling, supervision, etc., and to a busy farmer, the cost may be considerable. Therefore, always plan the installation to require the minimum of labour and supervision.

When designing a plant layout, provide an ample-sized wet grain pit to receive the grain from the field. From the pit an elevator will take the grain to a pre-cleaner, and then on to the top conveyor and to the bins. The rating of the elevators and conveyors should be related to the size of the installation: 20-25 ton/h equipment is commonplace and will repay any extra cost by improved efficiency. A 1,000 ton installation of 16 expanded metal bins put in for this harvest with ample Volair fan power and 20-25 ton/h handling equipment enabled the farmer to complete the harvest and dry his grain in 14 days—a drying rate during the fourteen 24-hour days of 3 ton/h removing some 5% of moisture.

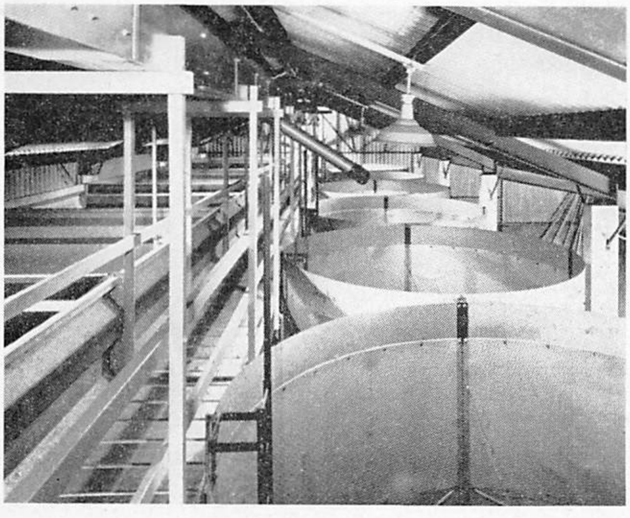

Fig. 1

Simplex Expanded Metal Drying Silos together with Sawston Grain Storage Bins and 20/25 ton per hour chain and flight conveyor supplied to Barnsley and District Co-operative Society

At the other end of the scale, a farmer with a small tonnage of grain can deal with this very satisfactorily by providing storage and drying bins around a pit, using an auger for grain handling. It is worth noting that a new twinspeed $5\frac{1}{2}$ in auger was introduced this harvest, with a slow output for feeding to the cleaner, and a higher output for filling bins, etc. This auger is portable and adjustable for height, and as the drive is at the intake end, there are no problems about lengthening the auger at a moment's notice. Adequate grain handling equipment enables the grain to be moved from storage with a minimum of labour. All these points add up to real advantages which can only be associated with bin drying and storage.

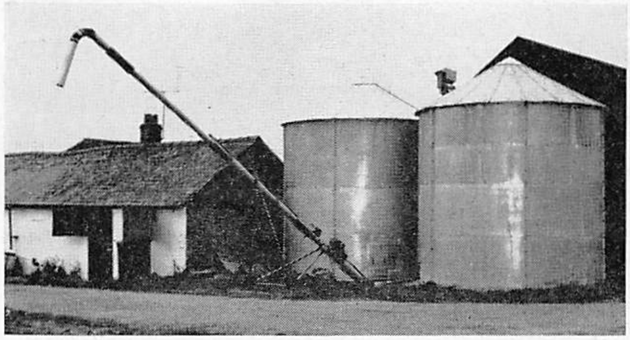

Fig. 2

2—Cambridge 53 ton Outdoor Storage Bins being an extension to an existing Drying and Storage installation. Note portable 'Twin-speed Torrent' Auger for grain handling.

**Floor Drying and Storage**

Floor drying and storage was first introduced into this country some 10 or 12 years ago, but in the author's view has few advantages when compared with a well-planned bin drying and storage plant.

Let us consider the comparative floor areas for floor or bin storage. A floor area, 10 ft by 10 ft with a 4 ft grain depth gives 400 ft$^3$ which at 4 ft$^3$/ton gives a capacity of 8.7 ton.

A 9 ft 10 in diameter silo will stand on an area 10 ft square; if it is fitted with a 24 in drying cylinder and is 11 ft 8 in high, the grain capacity is 19 ton and the length of air path is 3 ft 11 in. A 4 ft grain depth on the same floor area offers less than half this storage volume. In a 9 ft 10 in diameter silo 18 ft high with a 24 in drying cylinder, the capacity is 28 ton, which is more than three times the tonnage of grain to a depth of 4 ft over the same floor area of 10 ft $\times$ 10 ft.

A building 120 ft long $\times$ 60 ft wide, having a 6 ft average grain depth and assuming that the whole area is used for grain storage, would have a capacity of some 850 ton. A building 120 ft long and only 30 ft wide would hold the same tonnage of grain in expanded metal silos 18 ft high; if the tonnage was reduced to some 800 ton, there would be a spare silo to allow for turning the grain. So far as floor storage is concerned, it is not easy to cover the whole area evenly; furthermore, it is not easy to turn the grain unless there is considerable spare floor space, and this has to be paid for. We must also think of the cost of the labour involved.

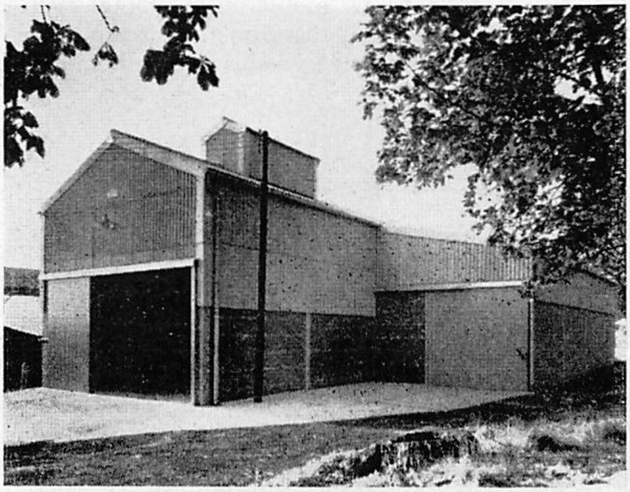

FIG. 3
414 ton Drying and Storage Plant in a Simplex Building at Home Farm, Wilsic, Nr. Doncaster.

Comments received from farmers who have floor drying and storage installations give the impression that they find the drying rate slow and unpredictable, and they consider that the grain depth during drying should not exceed some 4 ft which, of course, reduces the capacity of the store by up to $33\frac{1}{3}\%$ and increases the capital cost per ton stored. Many farmers wish they had put in bin drying storage and some are planning bin drying to supplement the floor conditioning.

An examination of costs for floor storage, of installations between 400 and 1,000 ton, appears to indicate that the price per ton before grant is between £7.5 and £10 per ton, and after grant between £6 and £7 per ton. For a 500-ton installation, this would give the following approximate figures:

Before grant: £4,200 After grant: £3,100

A competitive comparative installation could be:—

Eight—14 ft 7 in diameter × 18 ft high expanded metal drying bins with drying cylinders, etc, each having a capacity of 62.5 ton;

One—35/28 Volair centrifugal fan 35 hp 60 kW 26,000 c.f.m. at 4 in s.w.g.;

One—$5\frac{1}{2}$ in twinspeed auger;

One—$3\frac{1}{2}$ in auger;

One building 39 ft wide × 60 ft long × 18 ft to eaves and allowance for concreting over whole area, grain pits, and air ducts.

The gross cost would be about £5,700, and the after grant price £4,270, which gives costs per ton stored of: before grant, £11.5 per ton, after grant, £8.5 per ton. The extra cost of bin drying and storage (after grant) is, therefore, about £1,150. For this one obtains all the advantages of a bin drying and storage installation. Furthermore, one can assume that the grain on the floor should be stored at 14%. In the expanded metal silos it can be stored at 16% or more. The difference in weight between 16% and 14% is 2.33 tons per 100 tons or nearly 12 tons on 500 tons. 12 tons at £25 per ton equals £300. The bin system offers an additional profit of £300 per year for an additional capital outlay of £1,150, and at the same time leads to savings in management and labour and eliminates losses by vermin, etc.

It is sometimes claimed that floor storage buildings can be used for other purposes when not required for grain storage. The fans and air heating components of bin drying and storage plants also have multiple uses and many have been installed to deal with ware potatoes and also hay. It has been the writer's aim for many years to spread the usefulness of equipment and plant installed for grain drying and storage and one can contend that this facility is given with bin drying and storage, always provided that the installation is properly planned and adequate fan power and grain handling equipment is used.

**TABLE 3**
**DRYING SILOS—GRAIN**
**TYPICAL PRICES PER TON DRYING CAPACITY**
**including Drying Floor or Cylinder (excluding Erection)**

| | *Corrugated Sheets Galvanized Steel* | *Expanded Galvanized Sheets with angle iron uprights* | *Wooden with perforations* |
|---|---|---|---|
| **Measurements** | | | |
| Height | 13 ft 0 in to 18 ft 0 in | 7 ft 10 in to 18 ft 0 in | 9 ft 10 in to 19 ft 8 in |
| Diameter | 12 ft 0 in to 18 ft 0 in | 7 ft 4 in to 14 ft 7 in | 6 ft 7 in to 13 ft 2 in |
| **Capacities** | | | |
| Drying Tons | *26 to 60 | 7.1 to 62.5 | 7.2 to 60.5 |
| Storage Tons | 32 to 103 | 7.1 to 62.5 | 7.2 to 60.5 |
| **Price per ton** | | | |
| Drying capacity | | | |
| Indoor £ | Prices unknown | 11.3 to 5.35 | 15.6 to 5.64 |
| Outdoor £ | 18.5† to 12.7† | 15.0 to 6.48 | Not suitable |

*NOTE—Smallest standard bin 26 tons
†Including 3-phase Fan and Heater

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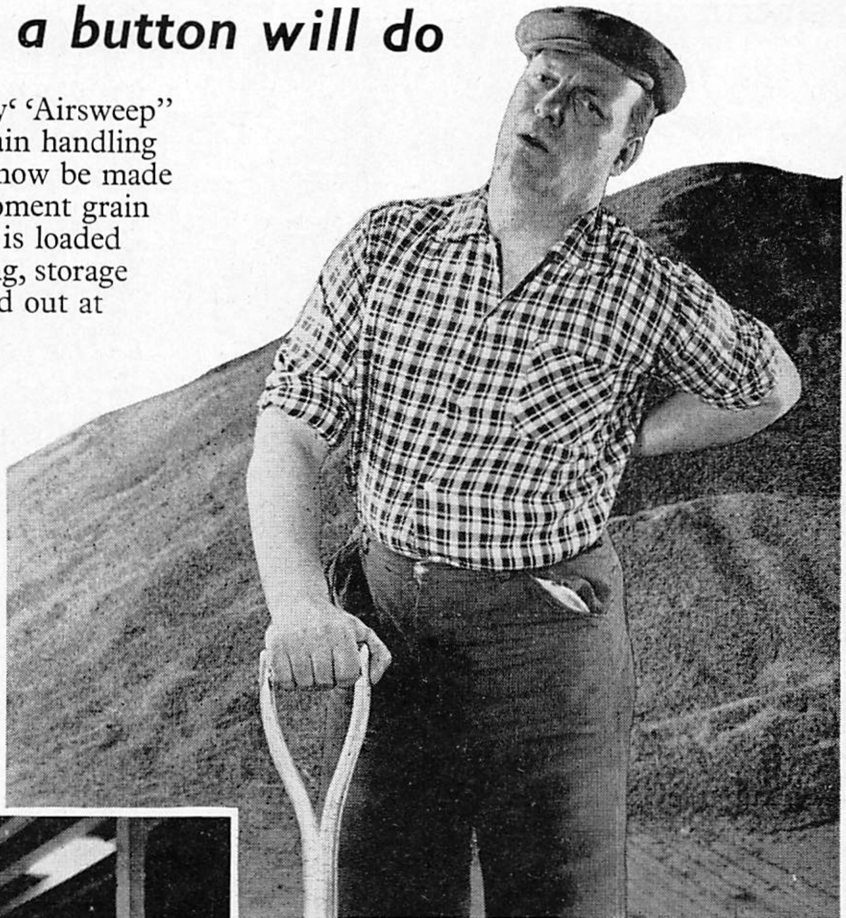

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Above: 760 ton all-Simplex grain drying and storage installation. Photo by courtesy of Messrs. Bayly Bros., St. John's Farm, Swingfield, Nr. Folkestone, Kent.

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