JOURNAL AND PROCEEDINGS OF THE

INSTITUTION OF AGRICULTURAL ENGINEERS

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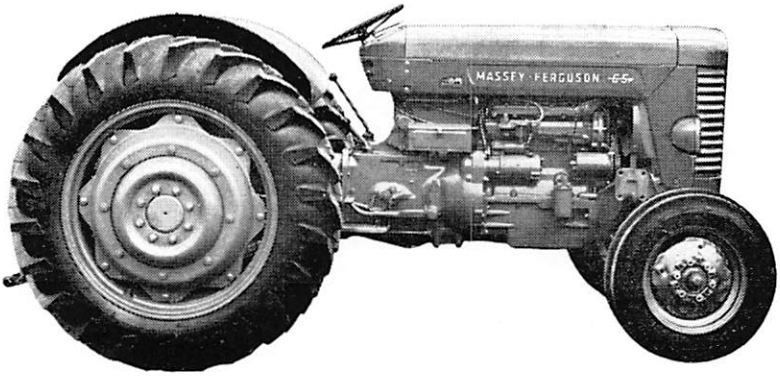

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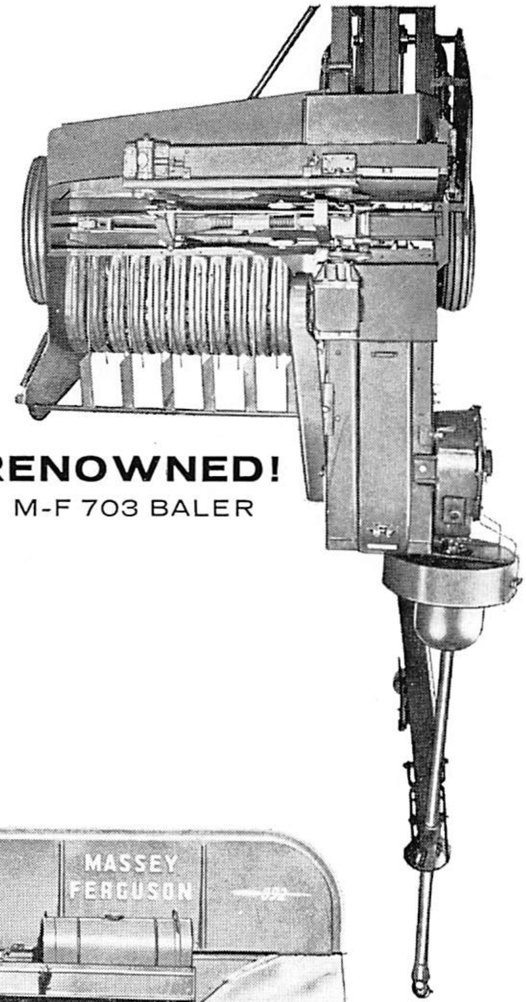

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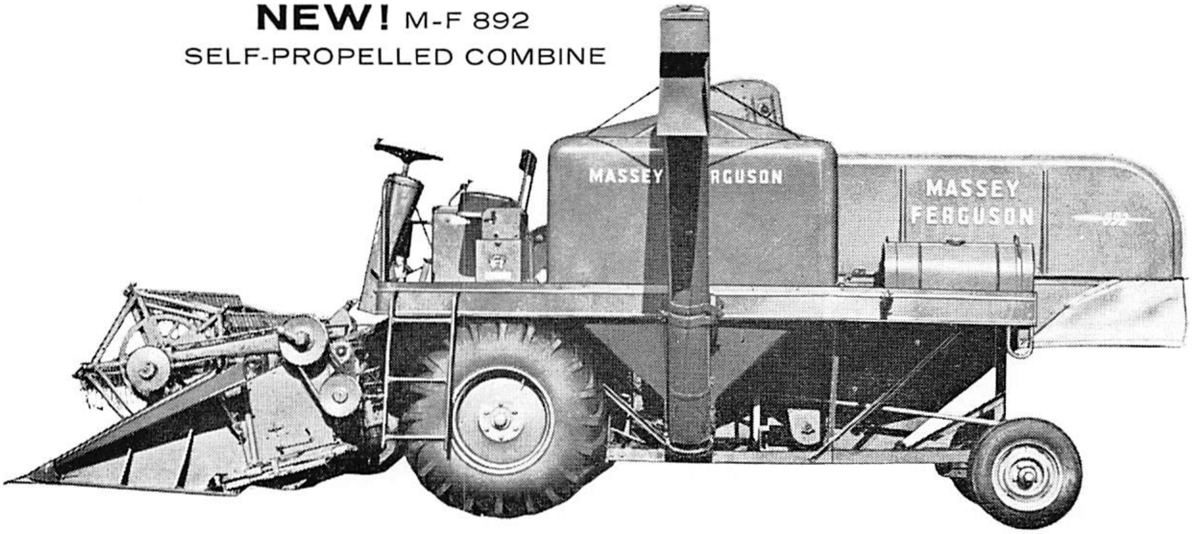

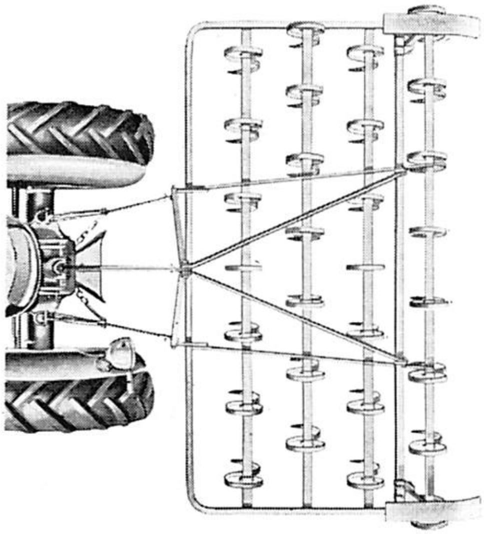

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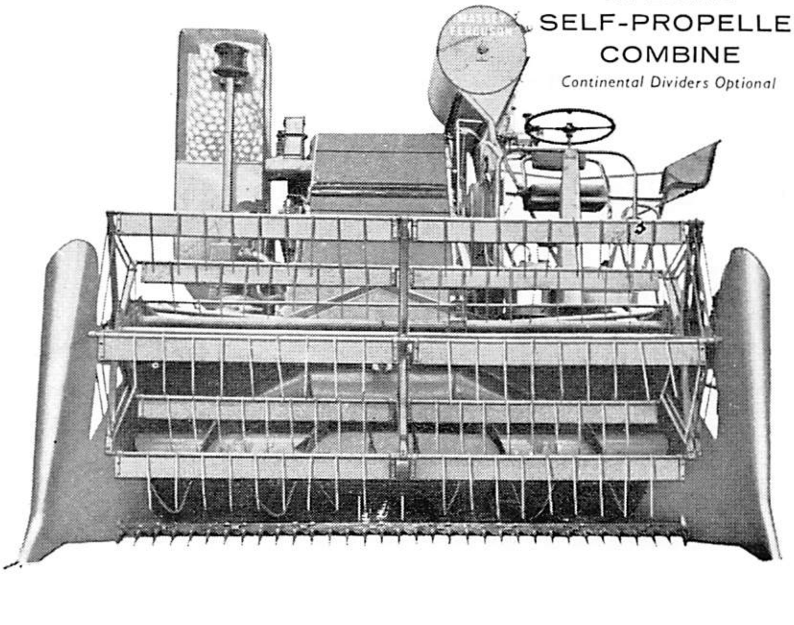

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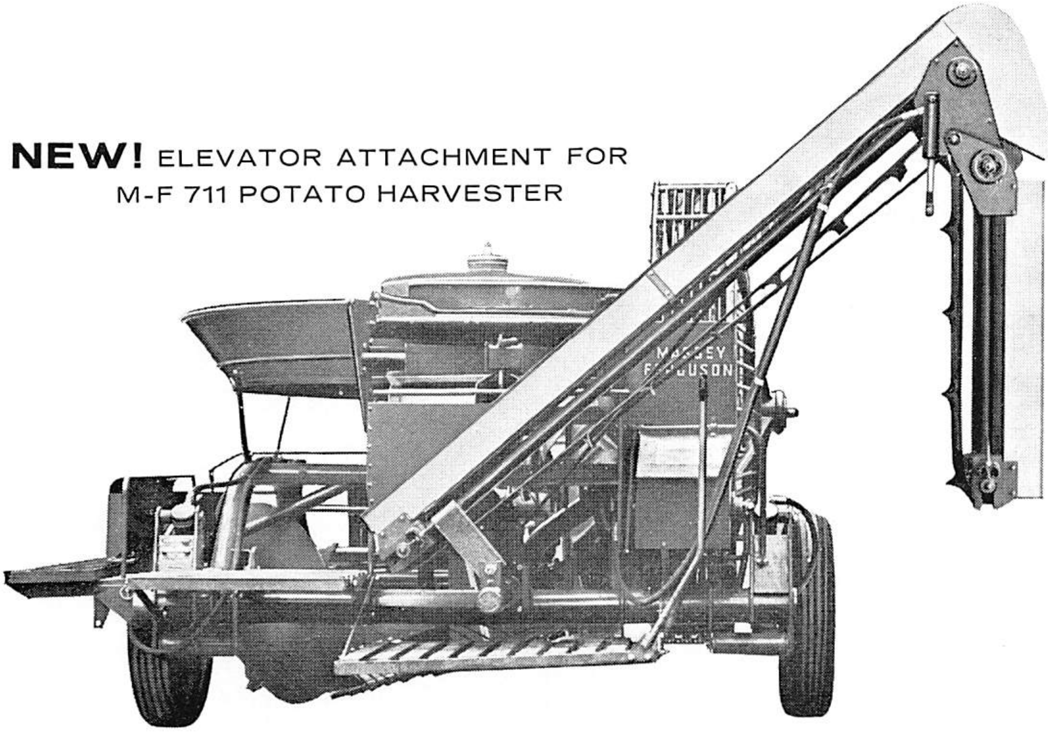

your profit pattern for '61

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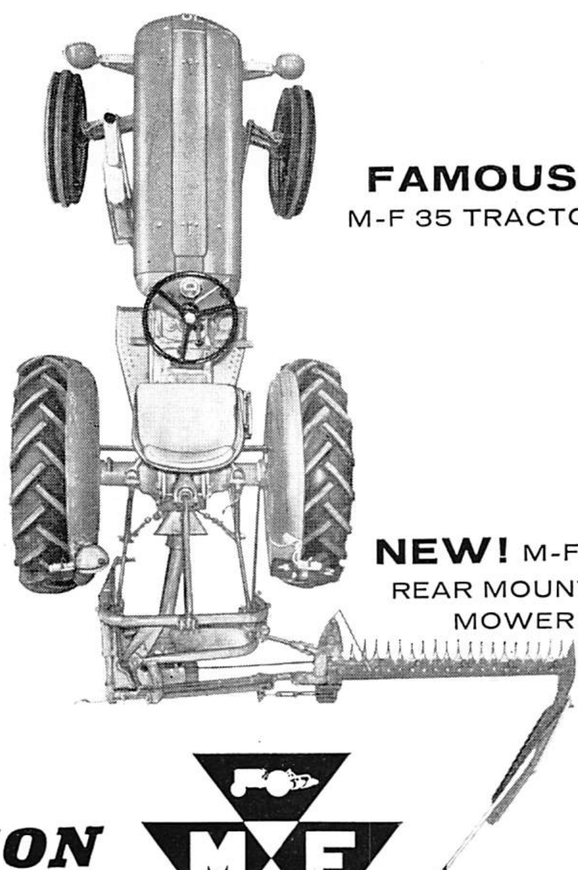

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INSTITUTION NOTES

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Annual Conference and Dinner

THE first Annual Conference of the Institution was held at the Piccadilly Hotel on April 25th. It was preceded by the Annual General Meeting, and the proceedings ended with the Annual Dinner, which was attended by some 170 members and guests. A report of the speeches at the dinner, together with the full text of the Papers delivered at the Conference, will appear in the July issue of the Journal.

Each of the three sessions of the Conference was very well supported by members, and it would appear that this form of meeting might well be repeated. The Council are to consider in the near future the question of attendance at Open Meetings, and doubtless the success of this Conference will be borne in mind.

Reduced Subscriptions for Retired Members

Those members who are nearing retirement are reminded that a special rate of subscription—£2 2s. 0d. annually—has been instituted for retired members. The Secretary will be pleased to make the necessary adjustment on receipt of notifications. A number of members have already taken advantage of this facility, but it is felt that a number of others must be eligible.

Income Tax Rebate

Members are again reminded that their annual subscriptions as members of the Institution are allowable as an expense for Income Tax purposes. The necessary form of claim (P358) may be obtained from local Tax Inspectors.

National College of Agricultural Engineering

During his speech at the Annual Dinner, the Guest of Honour, Mr. W. D. Akester (Past President, Agricultural Engineers' Association), announced that the Board of Governors of the College had accepted the offer of the Ford Motor Company of their premises and facilities at Boreham, near Chelmsford, for use by students until the new College buildings were completed.

The Board had accepted the offer, said Mr. Akester, and this meant the courses could be started sooner than had been anticipated.

" Dunlop " and " Shell Mex " Scholarship and Bursaries

Applications for the above from suitably qualified candidates for the National Diploma in Agricultural Engineering should be sent to the Secretary without further delay. Forms are available on request.

The Council has received with pleasure an intimation from the Dunlop Rubber Company that it is their intention to renew their Scholarship annually for at least five years.

Appointments Service

An increasing number of members and employers are making use of the Institution's appointments service. Enclosed with this issue is a copy of a Bulletin now prepared monthly, which is available on request from the Secretary. A form on which to make application is appended to the Bulletin.

Open Meetings in London

Replies to a letter sent to members living in the South-East of England indicate that the majority are in favour of Open Meetings being held in the evening, instead of the afternoon.

In view of this, the Council has decided that Meetings shall commence at 6.30 for 7 p.m., and it is hoped by this means that a larger attendance will be obtained to hear and discuss the Papers arranged for the 1961–62 Session.

Graduate Section

The rapidly growing number of Graduate and Student members has been noted with satisfaction by the Council, and consideration is to be given to the formation of a section to deal with the interests of these younger members.

Commonwealth Technical Training Week

Dr. P. C. J. Payne is to give a lecture on careers in agricultural engineering at 2.30 p.m. on June 2nd at 6 Queen Square. Copies of the lecture may be obtained from the Secretary.

RECLAMATION OF FARMING LAND FROM THE SEA

by Ir. B. Prummel,* L.I.

A Paper presented at an Open Meeting on Tuesday 13th December, 1960.

"KEEP your head cool and your feet dry" is one of the oldest and most typical Dutch maxims. These words are not only true for the "low lands near the sea," but are of universal application !

The weapons used in the battle against the sea have been improved, but the struggle still continues with unabated force (*i.e.*, Delta works).

The Department of Waterworks has a civil engineering section (Zuidersee works) which is in charge of building the dykes, the pumping stations and dredging the canals of the new polder. After the dyke has been closed and the water pumped out, it is still impossible to walk upon the reclaimed land because of its very wet and soft condition.

During the time of pumping (six to eight months for the polder East-Flevoland) the canals are probably silted up to about 50 per cent. of the depth. Through these shallow canals the water flows to the pumping stations, and one of the first jobs to be tackled is the cleaning of these canals.

By this time the layout of the new roads and villages has been prepared. As soon as possible, the Zuiderzee-works Authority (Civ. Eng.) start digging the necessary internal ditches. Provisionally, these ditches are made 1 metre deep, 1 metre wide at the bottom and 4·5 metres wide at the top, and 300 metres apart ; this work is done by draglines owned by contractors. Then the Board of the Wieringermeer (IJsselmeerpolders) takes over—in particular, the agricultural technical section, which is directed by agricultural engineers.

This agricultural technical section does not employ contractors, but has its own equipment, such as trenching machines, tractors, ploughs, draining machines, combine harvesters, etc., etc.

1. Draining the Land

After the main and side ditches have been dug by draglines, with a distance of 300 metres between them, work commences on the field trenches (detail-drainage).

(*a*) *The Open Trenches*

The field trenches are 60 cm. deep, 1·15 metres wide at the top and 25 cm. wide at the bottom. The distance between the trenches may be 8, 12, 16, 24 or 48 metres, depending on the type of soil. In fine, sandy soils and light loam the distances are less than in coarse sand or heavy loam. Each trench, at both ends, has its own piped outfalls into the ditches ; these 8 cm. pipe sections, of either clayware or vinyl plastic material, are 13·5 metres in length, thus allowing the provision of a headland measuring some 12 metres over which the machines and tractors can be driven.

During the first years the drainage of the land consists of open trenches, and after the land has for some years been under crop the open trenches are replaced by tile-drains 3 to 4 ft. deep. At that time the original shallow ditches are deepened to 5 ft., so that the outlets of the tile-drains lie at a distance of 8 to 12 ins. above the bottom of the ditch. Then the open trenches are back-filled by ploughing and the land levelled. Cultivation is difficult with open ditches, but the trouble can be minimised by the use of 8 metre drills and 12 ft. wide combine harvesters.

In the first polder, the Wieringermeer, most of the trenches were made by hand, because suitable machinery was unavailable, and in those years (1930–1932) there were many unemployed.

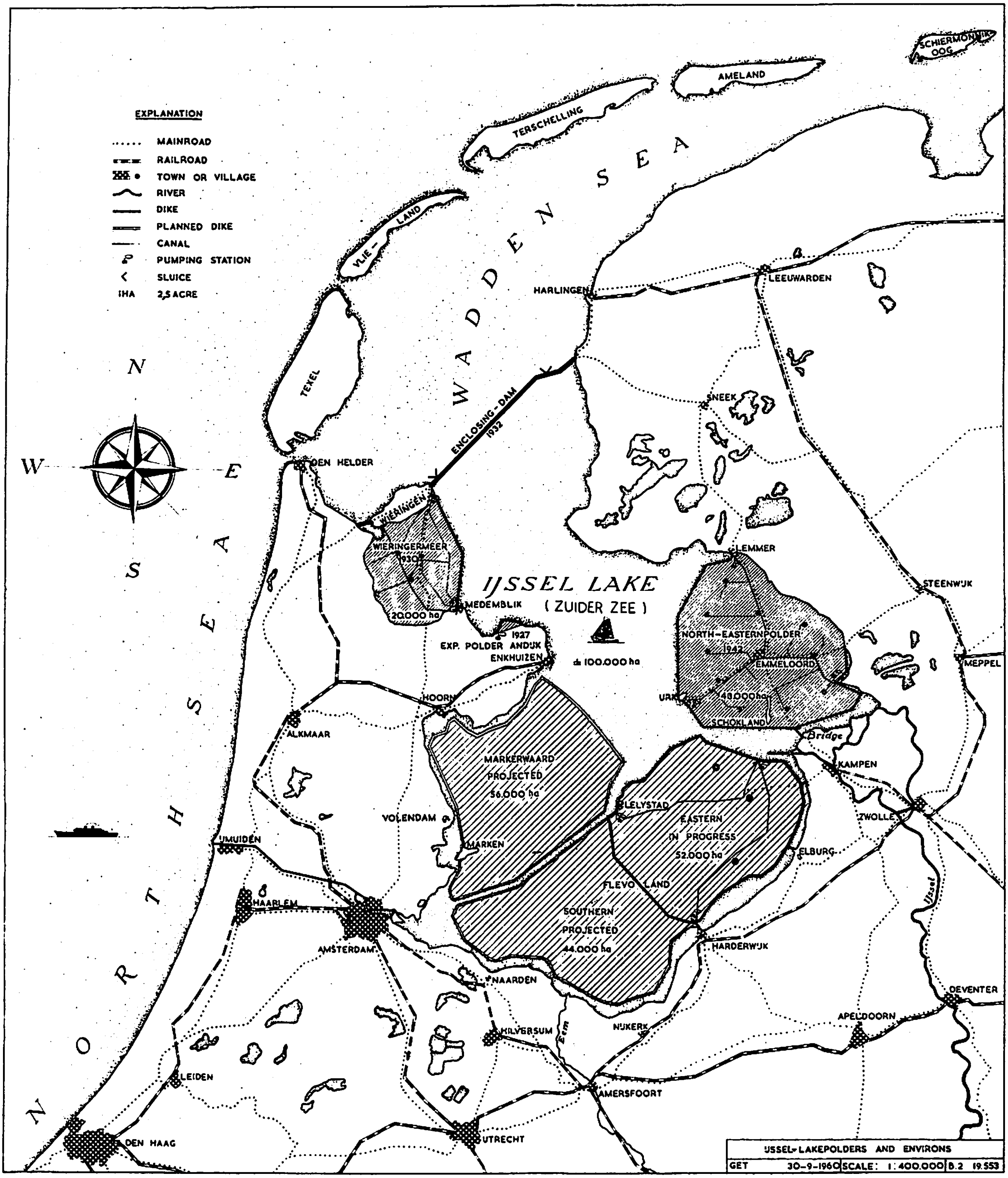
Trenching plough. Trenches are 1·15 metres wide, 60 c.m. deep and 25 c.m. in the bottom ; content, 0·42 cubic metre.

In the Wieringermeer a start had already been made with the use of trenching ploughs, and in the north-east polder, as soon as the war had come to an end, the trenching ploughs were further developed. From 1946 to 1949 the soil was firm enough to allow the operation of tractors for pulling these ploughs ; one trenching plough pulled by three crawlers (Caterpillar D4) reached a daily capacity of 20 km.

In the third polder, East Flevoland, the soil mainly consists of heavy loam and clay, which during the first year were too soft for the passage of machinery.

Then the rotary trencher was developed and operated. This trencher weighs 12 tons, but the tracks are 5 metres long and 1 metre wide, so that the soil pressure is only 120 gram per square cm., or in other words less than 2 lb. per sq. in. Another advantage of the rotary trencher is that the earth is spread directly, whereas with

* *Chief of the Agricultural Development Section of the Wieringermeerpolder, Kampen, Holland.*


EXPLANATION
MAINROAD
RAILROAD
TOWN OR VILLAGE
RIVER
DIKE
PLANNED DIKE
CANAL
PUMPING STATION
SLUICE
1HA 2,5 ACRE
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E
SCHIERMONNIKOOG
AMELAND
TERSCHELLING
VLIELAND
TEXEL
WADDEN SEA
HARLINGEN
LEEUWARDEN
ENCLOSING-DAM 1932
SNEEK
DEN HELDER
WIERINGEN
WIERINGERMEER 1930
20.000 ha
MEDEMBLIK
IJSSEL LAKE
(ZUIDER ZEE)
1927 EXP. POLDER ANDIJK
ENKHUIZEN
± 100.000 ha
LEMMER
STEENWIJK
NORTH-EASTERNPOLDER 1942
EMMELOORD
48.000 ha
URK
SCHOKLAND
MEPPEL
Bridge
KAMPEN
HOORN
ALKMAAR
MARKERWAARD PROJECTED 56.000 ha
LELYSTAD
EASTERN IN PROGRESS 52.000 ha
ZWOLLE
VOLENDAM
MARKEN
ELBURG
FLEVO LAND
IJMUIDEN
HAARLEM
AMSTERDAM
SOUTHERN PROJECTED 44.000 ha
HARDERWIJK
IJssel
NAARDEN
DEVENTER
APELDOORN
NIJKERK
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NORTH SEA
IJSSEL-LAKEPOLDERS AND ENVIRONS
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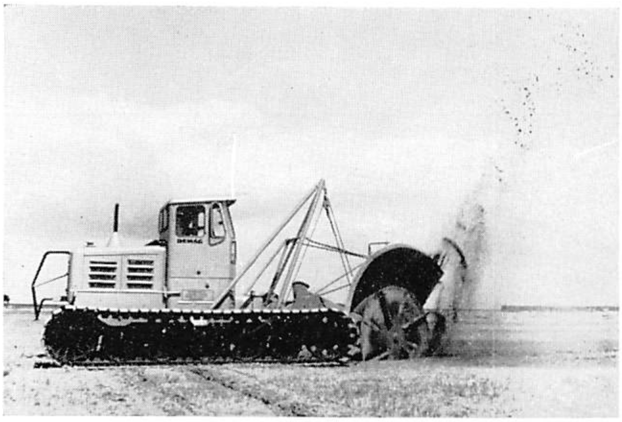


Trenching machine (frais) tracks, 5 metres long, 1 metre wide, 60-h.p.

trenching ploughs the soil has to be levelled by angle-dozers or graders.

Evolution in Reclamation Work and Saving of Man-power

In the Wieringermeerpolder about 80 per cent. of the trench-digging was carried out by hand—namely, about 11,150 km.—and the remaining 20 per cent. by trenching ploughs.

During the war, in the N.E. polder, some 15,000 km. were dug by hand, but after the war, owing to labour shortage, trenching ploughs had to do the remaining 60 per cent. of the work.

In East Flevoland manual work was only necessary at the outset on sandy soils, but 99 per cent. of the trenching scheme is carried out by rotary trenchers and trenching ploughs.

Rates of Working

1 km. digging by hand	needs 250 man hours
1 km. digging by ploughs	needs 20 man hours
1 km. digging by rotary trencher	needs 18 man hours

The capacity of the three methods is :

		Cubic Metres per hour.
By hand	4 metres p.h. =	1·7
With trenching plough	2,400 metres p.h. =	1,000
With rotary trencher	500 metres p.h. =	200

Trenching with ploughs requires the additional work of spoil spreading, while the rotary trencher as it digs spreads the spoil over a distance of 4 to 12 metres from the trench.

Another difference between the work of the rotary trencher and the trenching plough is that a rotary trencher has a 60-h.p. engine, and this means an output per h.p. of $3\frac{1}{3}$ cubic metres per hour ; trenching by plough and levelling by bulldozer or grader needs machinery amounting to 350-h.p., and $3\frac{1}{3}$ cubic metres per hour per h.p.

On the other hand, a 40-h.p. dragline with a 400 litre bucket used for digging the ditches (containing 3 to 4 cubic metres of spoil per metre) has a capacity of about 40 cubic metres per hour = 1 cubic metre per hour per h.p.

In 1932, costs of trenching and spreading the soil by hand were	33 ct. per cu. m.
Mechanical trenching and levelling	10–14 ct. per cu. m.
In 1960, costs of trenching and levelling are, by hand ..	168 ct. per cu. m.
Trenching with ploughs and levelling with bulldozer and grader	28 ct. per cu. m.
Trenching with rotary trencher	24 ct. per cu. m.

So manual work costs in 1960 about five times the price of 1932 ; mechanical work costs in 1960 about twice the price of 1932.

The outlets of the trenches were always laid by hand with 3 in. tile drains. On the soft soil of East Flevoland the transport of these tile drains was very difficult and expensive, and at times impossible. In the last two years 3 in. vinyl plastic pipes have been used ; they have a length of 13·5 metres and weigh about 7 kg., while the same length of tile drain weighs about 120 kg. An additional advantage is that this plastic pipe can be pulled in by a mole-drain plough, which requires two minutes per outlet using a 30-h.p. tractor and four men.

The pulling-in of the outlets requires only about 1 m.h. per hectare ; manual work, however, requires 33 m.h. per hectare.

Another advantage of the plastic pipe is that it can be pulled out again after the land has been tile drained and the outlet is no longer required.

(*b*) *Tile Drains* (*Drain Pipes*)

After three to five years, during which the land has been cropped, it is rented to farmers. By this time the soil has lost a great part of its water, and in clay soils aerated to a depth of 3 to 4 ft. the blue original colour has turned to grey.

Crumbing shoe and pipe layer of the Buckey drain machine.

The distance between the open trenches and the spaces between the tile-drains are not always the same ; in light soils there is generally no difference, but in heavier clay soils with many large deep cracks in the lower horizons the distance between the tile drains can be much greater.

The greater the permeability of the soil the wider the distance apart. For good drainage, a discharge of 10 mm. rainfall per 24 hours is required, and in autumn and winter the water-table in the soil has always to be more than 30 cm. (1 foot) below the surface of the field.

The shrinkage of clay soils does not stop after four or five years, but goes on for a long period, not only in the upper layers, but also in the sub-soil, and for that reason only good-quality collar-pipes are used. When the distance between drains is not more than 80 ft., 2 in. diameter pipes are used for lengths of up to 150 metres.

Careful execution of drain pipe laying is necessary. A faultless rectilinear positioning of the pipe-lines, together with a carefully calculated gradient, eases the maintenance problem. All the work is done by draining machines (Buckeye or some Dutch types).

Drains are checked with a surveyor's level after laying, thus providing the opportunity for making an accurate plan of the layout.

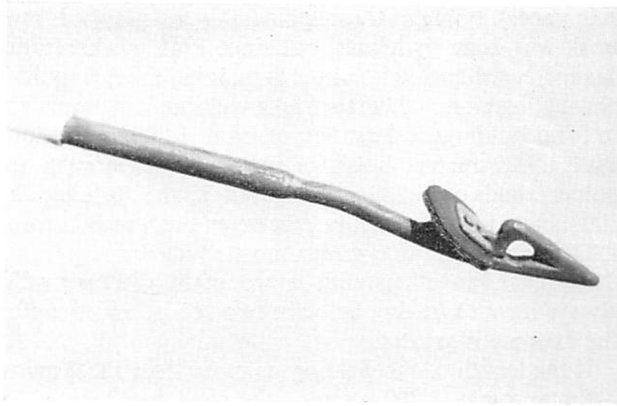
In sandy soils or soils with little clay content, the pipes

Draining machine at work ; bales of peat litter are laying by side.

are covered with peat-litter ; in heavy soils the covering is by means of aerated top soil.

To find out whether there are stoppages in the pipes preventing the discharge of water, a method for checking has been developed, which is carried out by means of bore-holes. These bore-holes are made in November–December at the highest points of the drains in the middle of the fields. When the drains are functioning, no water appears in the holes. Any stoppage is removed by rodding the drains.

In coarse, sandy soils the drainage system can be used for sub-soil irrigation, in which case the pipe-lines are laid without any slope. During a dry summer water is allowed to enter the polder through inlet sluices built in the dykes, and *via* the diversion boxes erected at the back of these gates the water is made to flow into the ditches skirting the areas to be irrigated.



Drain cleaner used for rodding the drainpipes.

The water flows from the ditches into the drains and will reach the roots of plants by rising above the sub-soil water-table through capillary action. The water level of each ditch can be controlled individually by means of dams, so that for each area the desired ground water level can be obtained. In the north-east polder an area of about 20,500 acres of drought-susceptible soils (mainly consisting of sand and peat) is supplied with water in this way.

This type of soil, if not irrigated, would not be suitable for agricultural purposes.

In a dry period the water consumption amounts to 0·3 litre per sec. per acre = 4 to 5 mm. per day.

2. Allocation of the Land

The most convenient place for a farmstead is in the middle of the holding, so that the distances from the outskirts to barn and dwelling will be small, but the supply of electricity, water, telephone, etc., will be very expensive ; moreover, the small road on the farm needs a connection with a tertiary or secondary road. Therefore, the farmstead should be built a small distance (50 metres) from the road.

When this location is decided upon, you may ask, what is the greatest distance from the furthest parts of the land to the barn. Because the transport of products and manure (organic or artificial) is expensive, the farmer prefers the distance to be small. In addition to the costs of transport are the hours spent going to and from the work by labourers, horses or tractors and other machines.

In the new polders in the IJssellake the width between ditches is fixed at 300 metres, because with 2 in. drain pipes there is a limit for the length of the pipe-line. From the middle of the land where the depth of the drain is 3 ft., there is a gradient of 0·2 per cent. to the ditch, and the outlet is there 4 ft. below the surface of the land.

By using 3 in. or 4 in. tile-drains, the length of the pipe-line could be longer, but the ditch would then have to be dug deeper and wider, and the overall costs would be greater.

When 300 metres is the general width, the size of a holding can only be changed by varying the lengths. In the first two polders, Wieringermeer and North-East polder, the length of a holding is about 800 metres (some

900 yards). When these polders were planned most work was done by horses, but since 1945 mechanisation has increased and most of the farmers in the new polders now use tractors. Due to mechanisation, it is practicable to form holdings in East Flevoland of 1,000 metres long. With 1,000 metres holdings the distance between two polder roads is 2,000 metres, but if the holdings are 800 metres long, the distance between two roads becomes 1,600 metres, and this means more roads are required in the polder, together with more main ditches, which always have to be dug between two roads, and therefore the expense is greater.

If the length of the holdings is more than 1,000 metres —for example, 1,200 metres—the road could be laid at a distance of 2,400 metres, but this means that the polder road has to be more than 3·5 metres wide and requires a better foundation ; this again is more expensive.

The average size of a holding is therefore 300 × 1,000 metres, which is 30 hectares or 75 acres ; but there are exceptions. An important feature of the holdings, when cultivated by private farmers, is again the length. A length of 100 metres may not be exceeded because of the high haulage costs which would result, especially for potatoes and sugar-beets.

The farmer would then be inclined constantly to grow potatoes and sugar-beet nearest the road, and straw crops at the opposite end, while a good rotation of all crops ensures the richness and generally benefits the condition of the soil.

3. The First Crops and Crop Rotation

During the first years when the State is developing the fields, the soil is not sufficiently fertile for growing flax and peas, and with the surface gutters at distances of 8 to 16 metres apart it is very difficult to grow potatoes or sugar-beet, particularly in a wet autumn, when transport would be impossible. So the first crops consist of grains and colza (winter rape).

After the big enclosure dam was finished in 1932, the salt Zuiderzee had, a few years later, become a fresh-water lake and the salt in the top layers of the reclaimed land had disappeared.

When the surface trenches have been made, it is possible to grow the first crop ; usually, colza is sown (12th August to 12th September). The next year's colza will be followed by winter wheat ; after winter wheat spring barley, and after this oats.

With this crop rotation, colza – winter wheat – spring barley and oats, it is possible to harvest with combines, and, therefore, less labour is required.

The drills used are 8 metres wide and are pulled by a 40–45-h.p. tractor, which goes just near enough to the trench for it to pass under the drilling machine. The capacity of a caterpillar D4 with an 8 metre sowing machine is about 30 hectares a day (75 acres).

A 12 ft. combine harvester has a capacity of some 125 hectares a year, consisting of about 30 hectares colza, 30 hectares spring barley, 50 hectares winter wheat and 15 hectares oats or spring wheat.

To get more humus in the soil, it is possible to grow clovers (yellow clovers) under spring barley or oats, which is ploughed in during the autumn ; also alfalfa, which is sold to privately-owned alfalfa drying factories.

After three years several hundred hectares are leased to flax growers for one season in order to reduce the work load at harvest time.

In 1960 a total crop was grown of 2,650 hectares colza, 2,400 hectares spring barley, 4,600 hectares winter wheat, 300 hectares spring wheat and 900 hectares of oats.

The colza is first windrowed, but almost all the grains are straight combined, which means that this year ninety 12 to 14 ft. cut combine harvesters were operated. Each combine requires six 3-ton trailers for transporting the seeds to the dryers, silos (72 Braby 100 tons al. silos) and ships.

4. The Training of Workers

There is a large machinery unit consisting of 140 wheeled tractors, 150 crawlers, 40 swathers, 90 combine harvesters, 200 4-share ploughs, 20 8-metre sowing machines, 6 rotary trenchers, 20 bulldozers, etc., etc.

Trench cleaner.

It will be appreciated that, owing to the amount of machinery available and the small amount of hard manual work needed for digging ditches and trenches, there is no need for the labourer. The need is for a skilled farmhand, mechanically minded and able to learn the operation and maintenance of the machines. It is not easy to recruit these mechanics, and often the only solution is to train farm labourers and farmers' sons for each particular job.

During the first period of their engagement the new hands are employed for manual labour, and after some months a selection is made. The selected men are sent to the training centre and take a course in wheeled tractor driving. This training lasts two or three weeks, whereafter the trainees go back to the farms to acquire some practical experience as wheeled tractor operators (haulage, harrowing, cultivating, mowing, etc.). After six to eight weeks an examination is held, and after the candidates have passed their examination they get their " own " tractor. Their wages are simultaneously increased by 5 cts. per hour. From these wheeled tractor operators the crawler tractor drivers are chosen, who then commence a new course in crawler operation and maintenance. During this course special attention is paid to ploughing with 4 and 8-share ploughs, to working an 8-metre sowing machine, etc. After a week of theory and practice the trainees return to the farms to acquire more experience and, after having passed the examination, they are entitled to their " own " crawlers and a further increase in wages of 5 cts. per hour.

Thus a course is provided on every type of machine available—combine harvesters (two types), rotary trenchers, draining machines, trench cleaners, swathers, spraying machines—to teach the men to operate the equipment efficiently.

While the State is developing the new areas, they are divided into sections of 500–600 hectares, which are supervised by a civil servant farmer. Most of them are farmers' sons and have had an agricultural education, but after some years' work in the new polder they are selected from the other workers and trained for the special job. The training for a civil servant farmer lasts about six months ; then they are placed on the various farms (500–600 hectares) as assistant supervisors, and after one or two years they are sufficiently trained and have a good knowledge of machinery, soil physics, plant diseases, manuring, weed killing, etc., and, most important, administration and personnel management.

5. The Improvement of Soil by Green Manuring and Deep Ploughing

The sea-bed, having been for hundreds of years under water, has few bacteria, the greater part of them being anaerobe and of little use to the farmer of the future. This " new " soil has also only a small humus content, and during the first years of development we try to increase this, because it means a maturing of the soil, which then gets a better structure.

While the soil supplies enough phosphate for one or two straw crops, and potash and lime are available for many, many years, it shows a small content of nitrogen.

Colza as first crop gets no phosphate or potash, but 120–150 kg./N./hectare. Winter wheat as first crop gets no phosphate or potash, and as second crop it gets 20–40 kg. P_2O_5, no potash and 60–75 kg. N./hectare ; oats and spring barley get the same amount of phsophate, but 45–60 kg. N./hectare.

In the North-East Polder, as in the Wieringermeer, where the newly reclaimed land appeared to be low in nitrogen content, large quantities of legumes were grown, such as lucerne (*Medicago sativa*) and yellow clover (*Medicago lupulina*). The seed of these clovers is treated with inoculants prepared in our own micro-biological laboratory. This was applied on a large scale, which enriched the soil with a considerable quantity of organic matter. Another responsibility of the micro-biological research scientists is to check the development of bacterial life in the recently uncovered soils.

As soon as possible, the growing of lucerne (alfalfa) and yellow clover is started, sometimes as a first crop, though generally the yellow clover is sown under spring barley or oats ; it grows very well after the straw crop is harvested and is ploughed under in November or December.

Lucerne is grown for one or two years and is sold to the drying factories in the polders or in the neighbourhood. In this way the agricultural technical section is relieved of a great deal of work, since the cutting and the transport are done by the buyer.

The lucerne and yellow clover growing is so organised that almost every holding gets one good crop of clover before it is leased out to the farmers.

Enriching the soil with organic matter is also very important because the structure of the soil is thus very highly improved and the following crop needs less nitrogen.

An alternative method of improvement of the soil is by deep ploughing. In the new polders, the top layer of the areas near the old coast line nearly always consists of sandy soil. Sometimes this sandy soil is improved by sub-soil irrigation, but when the layer of sand is no more than 1 to 5 ft. thick, and under the sand a good layer of clay or heavy loam is found, then there is the possibility of deep ploughing—an operation which ploughs under the sandy top-soil and raises the clay sub-soil. In various places this ploughing is now done up to a depth of 7 ft. with the aid of a deep plough developed by an agricultural contractor in the Wieringermeer.

Deep plough. Depth, 1·70 c.m. ; the clay is laid on top.

If a drought-susceptible, peat or sandy soil cannot be improved by deep ploughing, the land is not suitable for arable farming and grass must be sown. This means that for every hectare of grassland a cow-shed has to be built, and the costs for one cow is about 1,200 guilders. Twelve hundred guilders is also the price for deep ploughing one hectare to a depth of about 5 ft. ; the cost of deep ploughing, of course, varies according to depth, but 1,200 guilders per hectare is the average expenditure, and if the deep ploughing is done before the barn and cow-sheds are built it costs the State no money.

6. The Struggle with the Weeds

The advantage of leaving large sections of East Flevoland completely in its virgin state for a considerable length of time lies in the exposure of these mainly " heavy " soils to a natural drying process by wind and sun. On the other hand, this method will at the same time permit the growth of a ubiquitous vegetation. The experience gained in the North-East Polder has shown that a vegetation of this type will develop very rapidly and will completely overgrow the newly recovered land with a tangle of weeds in a year's time.

Seeing that many of these troublesome weeds cause great difficulties in the reclamation and the subsequent cultivation of the soil, a method has been sought to check their growth. The solution of the problem has been found in the artificial propagation of weed growth —in this case, the sowing of reeds (*Phragmites*).

This plant, which grew abundantly also in the North-East Polder, has the welcome property of considerably retarding the growth of other weeds. In point of fact, in the shade of reeds some 6 to 10 ft. high it is impossible for almost any other plant to take root. Moreover, by absorbing large quantities of water from the soil and thereby causing it to evaporate the reed will be an extremely powerful agent in the drying-up process of the soil. This property also tends to speed up the rate of fertility and to render the surface suitable for transport purposes. The reeds are fairly easy to remove at a later stage. When an intensive drainage of the soil is applied, the reed will fairly soon lose its vitality. The portion of the plant above ground can be burned, while its roots can be completely destroyed by a proper tillage of the land. These considerations have resulted in sowing the land with reed seeds from an aeroplane. Only the first sectors were not included in this operation, so that the total reed-sown area covers some 90,000 acres. In seeding this area in 1958—a small portion having already been sown in 1957—the first Dutch-made ramjet helicopter was introduced and is now being employed by the State Authority for other purposes such as spraying insecticides and weekdillers. Considering the fact that, as far as is known, no weeds have ever been sown deliberately, let alone from the air, this large-scale operation may be said to have proceeded most successfully.

DISCUSSION

MR. G. COLE (Ministry of Agriculture) said that he thought the Paper a very valuable addition to the records of the Institution. The figures given were interesting in comparison with some of our own. He emphasised how much this country owed the Dutch in land drainage and referred to the work of Sir Cornelius Vermuyden. If it had not been for him there would have been no dry Fens as we know them to-day. A major part of the £10 million Great Ouse Flood Protections Scheme followed lines recommended by Vermuyden in the 17th century.

He declared that the debt we owed the Dutch was not just due to the work their engineers had done for us, but also to their inspiration. Mr. Prummel's enthusiasm had impressed him.

If one looked at Holland, about one-third of the land was below sea level, but if the dykes went about a half of the land would be lost. On the other hand, while the Fens were a large area, the area of land left for reclaiming in this country was nothing like that in Holland. People had said that we ought to reclaim many acres and had asked why the Government did not do something. It was a matter of economics, stated Mr. Cole. In Holland they needed the land because of the pressure of population and the need to grow more food, but if someone said that a dam should be put across the Wash, that was not economic. It was physically possible, but the engineer had an obligation to do for half-a-crown what anybody could do for three shillings. In comparison with the Zuiderzee, the Wash was much deeper and had deeper channels to be crossed—so the dam would have to be enormously wide at its base. Our economic problem might change—although he could not see it happening just yet. However, we should not go ahead with anything in this country without making a proper estimate of the return on the investment.

The soil in the Wash was mostly sand. Mr. Cole said he had gone into this. Somebody had looked at some of the soil from the Wash and had said that it was lovely black stuff that would grow anything, but this was not so, for the soil scientists said it was really sand with just a thin black coating on it of decayed animal and vegetable matter of little value. There were also many strips round the coast which were potentially reclaimable —for example, round Essex and East Anglia—but the length of bank and the number of creeks to be crossed were out of proportion to the acreage that would be obtained.

Mr. Cole said he was amazed at Mr. Prummel's comments about reeds, for if they were found in reclaimed land in England the farmer hated it. But it was a question of the size of the problem, and in this country we had not got the machines to eradicate them that they had in Holland. Another point that had impressed him was the training given to workers and labourers. The Dutch carefully selected them, watching them on the land, and then training them for the task. With reference to Mr. Prummel's observations about polythene pipes, Mr. Cole said that investigations were going on in this country, but he thought that Mr. Theobald would have something to say about that.

MR. G. H. THEOBALD (Ministry of Agriculture) added his thanks to those of his colleague for the very interesting Paper. While, unfortunately, he had not succeeded in getting over to the Flevoland district of Holland, he had visited the eastern part and had been impressed by the way the Dutch take off their jackets to their projects. He had seen one case in which the soil 15 ft. down was better than the surface soil, and the Dutch had proceeded to invert the profile to bring the good soil to the top ; that was unlikely to be done in England.

He had one or two questions to put on the field drainage part of the Paper. First, about the spacing of the open trenches. It was said in the Paper that they should be 8, 12, 16, 24 or 48 metres apart, and Mr. Theobald said he would be interested to know just how it was decided which of these figures to use. Did the field engineers take measurements of the soil and use tables provided by the scientists, or did they use their own judgment and hope the scientists did not notice ?

Mr. Theobald was interested to see that in the preliminary drainage the ends of the trenches were piped to provide suitable headlands for farm traffic. This system had been used in our own country—in Wales and Monmouthshire adjoining the Severn estuary, where, because of the impermeability of the soil and its low altitude, open trench drainage was the traditional method.

Mr. Theobald said that he had tried to link the tables quoted for rates of working and capacity. According to his calculations, which were probably wrong, it seemed that a gang of about 50 men was required for digging with a trenching plough, and he wondered if this was so. Mentioning his colleague's reference to costs per cubic metre, he continued that the figures according to his reckoning were low—about 6d. per cubic yard for a rotary trencher and 7d. per cubic yard for the trenching plough. He wished similar costs obtained in England !

The method of putting in plastic pipe as shown in the slides had interested him. He had noticed that the equipment was on the front of the tractor. Was that mainly because the framework was there, or did the Dutch find it better to push the pipes in rather than pull them ? In this country people preferred to pull them in. On the subject of plastic pipes, he said that investigations were going on in England, but on rather different lines to the spiral pipe shown and described by Mr. Prummel in the course of his Paper. Here, the N.I.A.E. and Ministry were trying to devise a strip that went down the hollow blade of a kind of male plough and was zipped up below ground to form a circular drain. The work was still in the experimental stage, and Mr. Theobald said that his remarks were more of a preliminary notice than anything else.

His final point was on the method of financing the projects. Not much had been said on the subject, and he presumed the Netherlands Government financed them originally, but he would like to know how the Government eventually recovered the costs from the farmers.

MR. G. BUCHNER (Drainage Board and Consultant, Boston, Lincs.) pointed out that farmers and engineers in the Fens suffered nearly always from excess of water, which was the enemy number one. His interest was on the pumping side rather than on field or tile drainage, and he queried what was the meaning of the field discharge quoted in the Paper as 10 mm. rainfall per day. Was the same figure adopted for pumping that water ?

On the question of irrigation, he said that Mr. Prummel had referred to an area of about 20,500 acres in the north-east polder, which in dry periods consumed 4 to 5 mm. of water, and he asked whether that irrigation was carried out one day per week during the dry periods.

Returning to the subject of pumps, he said that costs for the three pumping stations in East Flevoland were about £20 per acre, which represented something like 4 per cent. of the total cost of the whole reclamation. This seemed extremely small, even though the total cost might be millions of pounds. He referred to what he called a nice Dutch habit of naming pumping stations after the people who inspired them.

Mr. Buchner asked about Mr. Prummel's statement that water in drains should never rise higher than 1 ft. below ground level. In the Fens, he said, farmers would be horrified ; they seemed to prefer a minimum of 2 ft. 6 ins.

MR. BARRAH (Essex) was interested to note that the pipes Mr. Prummel had shown to the meeting were 2 in. ones. He thought he was right in saying that they were usually 3 in. in this country, and asked Mr. Prummel if they were inclined to clean pipes more frequently in Holland. Mr. Barrah's experience in East England was that 2 in. ones clogged quickly, and he inquired whether Mr. Prummel had found in irrigating through drains that he got even benefit to crops in the land between the drains, or whether there was vigorous growth in the crop near the drains, while that in between was not so vigorous.

His third question was about the salt problem from the sea-water that had previously covered reclaimed land. Had this problem disappeared in Holland, for there was no mention of applying gypsum or using other techniques ? Wheat had been described as frequently one of the first crops, and it was not one of the best crops from this point of view.

IR. PRUMMEL, replying to these points, said that the spacing of open trenches, as queried by Mr. Theobald, was laid down by his country's scientists. The permeability of sand did not change after drainage. It could be measured by boring a hole in the soil. After the hole was emptied it could be noted how long it took for the hole to fill with water to the surrounding water-level. In clay and loam the permeability changed after drainage. These soils could become cracked and so the permeability gradually improved in some years. In heavy clays the cracks were larger and deeper.

In trial fields, trenches or pipe-lines were given different spaces, the water-level being measured in summer and winter. In the latter season, the water-table should not be more than 1 ft. below the surface of the land, but in summer it was much more than that, depending on the drainage of the subsoil and the seepage (spring water). Maximum yield was given in winter with the 1 ft. figure, but a water-table deeper than that did not cause a higher yield.

Good drainage was the first essential of good farming. The plastic outlet pipes for the headlands, which had been referred to, were pushed in *before* trenching. A crawler with mole equipment mounted on the " C "-frame of a bulldozer started about 30 metres from the edge of the ditch. The mole was pushed in deeper and deeper, followed by the plastic pipe. At the end of the trench the pipe was pushed in 70 c.m. below the surface, and the outlet end came out at a depth of 90 c.m. ; so there was a slope of 20 c.m. per 13·5 metres (the length of the pipe). The tractor driver had one target on the " C "-frame (the mole) and two others on the other side of the ditch, so enabling him to do the work properly. This pipe-laying was done with a crawler with a lowest speed of 20 metres per minute.

He described the cost of reclaimed land in answer to Mr. Theobald. Because of such factors as rent, the cumulative effects of taxes, etc., some economic scientists were of the opinion that the Government finally received about 8 per cent. interest on the input, and, socially-economically, the value of one hectare might be ±18,000 Dutch guilders, although the private economic value was, perhaps, no more than 7,000.

The pumping capacity per day was ±12 m.m., and so it would take three to four days to clear 40 m.m. of rainfall from the polder. The drainage system needed the same time to restore the original water-level.

Continuing his answer to Mr. Buchner, he said that the drought-susceptible area mentioned received fresh water from the IJssellake. The system was not surface irrigation, but subsoil irrigation, and the water entered the soil through pipe-lines.

On the cost of pumping, road maintenance, etc., he said it was 60 Dutch guilders per hectare (±£2 per acre), which meant 0·6 per cent. of the total cost.

There was only little control over the farmers in the new polders and also only little over the crop rotation.

When spaces between pipe-lines were not wider than 241 metres, 2 in. tiles were always used, but, for larger spaces, 3 in. ones were partly used. The length was always 150 metres with a gradient of 0·2 per cent. In subsoil-irrigated land (coarse sand) there was no difference in plant growth between two pipe-lines, using 2 in. tile drains and spaces of 12 metres—providing the farmer knew the amount of water to supply.

About the salt problem, he described how, after the big enclosure dam was finished in 1932, the water of the North Sea was prevented entering the IJssellake. The lake became nearly fresh after two or three years—fresh water coming from the River IJssel and other sources—and thus made the top-soil of the polder lose its salinity. No salt problems arose in the North-Eastern Polder and East Flevoland. In flooded land, calcium clay was changed into natrium clay by the NaCl of the sea-water. In that case, only gypsum ($CaSO_4$) was the remedy, because the Ca-ion and Na-ion changed, and Na_2SO_4—more soluble than $CaSO_4$—was washed out by the rain.

It was important not to work fresh soil too much in the first years, he concluded. Its structure improved later, however, when there was a higher humus content.

THE PRESIDENT stated that one thing the meeting had learnt about Dutch methods was their thoroughness. The way they train workers was an example. They demanded a high level of accuracy—and they had their own remedies, added the President, referring to a remark by Mr. Prummel that workers were not paid for a stretch of pipe-laying if it was not accurate enough. The President thanked the three gentlemen who had opened the discussion, said to Mr. Prummel that the Institution had been honoured by his visit, and congratulated him on the way he had presented his Paper.

I.C.T.A. ASSOCIATION OPEN MEETING

(University College of West Indies, Imperial College of Tropical Agriculture, Trinidad)

The Association will hold an Open Meeting on Friday, 21st July, 1961, at 2.30 p.m., at Uganda House, Trafalgar Square, London, S.W., when two Papers will be presented, each followed by a discussion. Any members of the Institution interested in the various problems of tropical agriculture will be welcome. The Papers and authors are given below :

Advances in the Use of Agricultural Chemicals in Tropical Agriculture
by G. WRIGLEY, B.Sc. (Hons.), A.I.C.T.A. (Fisons Pest Control, Ltd.).

Testing and Development of Implements for Peasant Farmers
by D. W. HAYNES, B.Sc. (Agric.), A.M.I.Agr.E. (Agricultural Engineer, Regional Research Station, Samaru, Northern Nigeria).

The Chairman will be H. J. PAGE, C.M.G., B.Sc., F.R.I.C., Principal of the Imperial College of Tropical Agriculture, 1947–52.

Summaries of the Papers may be obtained on application to the Secretary of the I.C.T.A., E. G. Wright, 28, Highland Drive, West Wickham, Kent.

THE DESIGN AND OPERATION OF BARN HAY DRYING SYSTEMS WITH SPECIAL REFERENCE TO DRYING IN THE BALE

by W. L. HEARLE,* A.M.I.E.E., A.M.I.Agr.E., and H. PATERSON,† B.Sc., A.M.I.Agr.E.

A Paper presented at an Open Meeting of the Institution on 14th February, 1961.

OVER the past decade increasing attention has been paid to the improvement of methods of conserving, on the farm, herbage for winter feed for livestock. During this period the traditional method of haymaking in the field—itself improved in technique—has been increasingly replaced or supplemented by silage-making and artificial drying.‡

Although " haymaking " is still applied to some 90 per cent. of the acreage of grass conserved in the U.K., it is undoubtedly the most wasteful method of the three. The authors do not, however, propose so much to discuss the relative merits of the various methods securing the grass crop as feed, but to evaluate in some detail conservation by drying hay on the farm using comparatively high air volumes and low air temperatures and generally referred to as " barn hay drying." Field haymaking is essentially a drying process, and to avoid confusion in the Paper it will be referred to as " swath drying."

Barn hay drying has been carried out to an increasing extent in the United Kingdom over the last 10 years from the ventilating of hay loose in barns on false floors to the drying of stacks of bales either in the field or in storage under cover. Although the term barn hay drying is more widely used to cover a variety of systems, its full implication and value is only understood by a relatively small number of users and specialist advisers.

Objects of Hay Drying

The theoretical function of any system of haymaking is to reduce the moisture content of the material when cut (75 per cent. to 85 per cent.) to a figure at which it will store without deterioration (16 per cent. to 20 per cent.) in as short a time as possible. The practical function of any artificial system of hay drying is to do precisely the same thing, but, by reducing the time and exposure hazard and increasing quality, to offset—if not, indeed, improve—on the relative economic value of the crop. By and large, the methods discussed do succeed in retaining in the final feed a higher proportion of the basic nutrients in the original crops as cut.

* R. A. Lister & Co., Ltd., Dursley.

† Agricultural Electrification Advisory Section, The Electricity Council.

‡ The terms hay drying or grass drying are used in this Paper as referring only to low or medium temperature methods applied to long grass or hay as distinct from high temperature " grass drying."

Losses in Swath Hay Drying

Although some losses are caused by respiration, the major loss in swath drying is that of dry matter which takes place due to brittleness and disintegration of the grass after the moisture content falls below some 35 per cent. Further dry matter loss due to heating and " burning of carbohydrates " can occur during storage if baling has taken place at moistures higher than 20 per cent.

To evaluate completely the losses which take place, the digestibility of the available nutrients in the end product has to be taken into account. The decrease in percentage digestibility is no doubt due to the fact that the leafier part of the cut crop dries much quicker than the stem and is therefore subject to more " mechanical " losses before the overall moisture content of the crop is low enough to permit baling. These losses are related to the amount of leaf and are therefore all the greater the earlier cutting takes place ; if cutting is timed to coincide with the highest yield of digestible nutrients per acre, the less will be the chance of conserving a high percentage of them. Investigations have shown dry matter losses on swath dried hay to average over 30 per cent. This means that for every potential ton of finished hay available at cutting only 11·8 cwt. of dry matter is conserved and 5 cwt. is lost (assuming a final moisture content of 16 per cent.), or a loss of half-a-ton per acre on a potential 2 ton to the acre crop. Any reduction that can be made in these losses represents an increase in the conserved yield per acre none the less significant.

Losses in Barn Hay Drying

Comparative trials have shown dry matter losses in barn dried hay to be only half those in swath dried hay ; losses in digestibility in barn dried hay are less than half those incurred with swath-made hay.

Range of Moisture Content for Barn Hay Drying

If a herbage crop is cut at the stage of maximum feeding value its moisture content will inevitably be in the range of ·75 per cent. to 85 per cent., whereas the accepted safe storage moisture content for hay is 16 per cent. to 20 per cent. To produce one ton of dry hay, therefore, not less than 50 cwt. of water must be evaporated. In barn hay drying no attempt is made to remove the whole of this moisture artificially for two very important reasons :

1. To evaporate all this moisture artificially would involve more cost in fuel than could be justified in terms of feed value produced.

2. The method of handling a crop at this moisture content would be limited to relatively small quantities because uneconomically shallow loading depths would have to be used.

The process is therefore divided into two distinct stages :

(*a*) Pre-wilting or field drying.

(*b*) Barn drying to a safe storage level.

The range of moisture content from which the material is barn dried means that only some 5 to 20 cwt. of water have to be removed by the artificial drying process, depending on the method of drying used, to produce one ton of dry hay.

Pre-wilting or Field Drying

The aim in this stage is to dry to 35/60 per cent. moisture content in the shortest possible time so as to limit the chance of the crop being subjected to rainfall as it lies in the fields. This can only be achieved by repeated movement of the swath by tedding and turning, which also ensures that there will be an even moisture content throughout the crop when barn drying commences.

As this stage of the drying process removes more water than is evaporated in the artificial drying stage, and does so more cheaply, it is true to say that it is very important and calls for good management.

The duration of the wilting period, although critical, is often variable, depending on the following factors :

(*a*) Stage of growth of crop.

(*b*) Weight and nature of crop.

(*c*) Prevailing atmospheric relative humidity.

(*d*) Amount of mechanical treatment given in the swath.

(*e*) The subsequent method of barn drying adopted.

Very young, leafy grass is very succulent or full of sap and requires a considerable amount of tedding to reduce its moisture content, whereas an older crop is more stemmy and does not require so much tedding. A heavy crop also requires more tedding and some types of grass seem to dry out more quickly than others. These factors, however, are all governed by the prevailing ambient humidity. When this is high wilting is slow, despite intensive swath treatment, but when the humidity is low wilting will progress much more quickly.

The machines available for tedding the crop have improved in design and quantity in recent years. It is probably true to say that the need for such machines to operate in conjunction with barn hay drying has also encouraged their use for all improved methods of hay making in recent years. During the field wilting stage there is little risk of damage or deterioration due to excessive movement of the swath because the crop has not reached the brittle stage. The most suitable type of tedder is one with a kicking action which will leave the swath in a " fluffed up " condition, thus assisting natural ventilation. Tedding should be commenced as soon as possible after cutting, and in some cases the tedder is hitched in tandem with the mower. Tedding should be repeated as often as possible until the moisture content has been suitably reduced. Turning in conjunction with tedding will accelerate the wilting process.

There is also evidence that the use of forage harvesters, roller crushers and crimpers reduce the wilting period, but until more is known about their use they should only be used once on any one cut of hay, as some loss of leaf might result.

The tradition of leaving the crop to lie undisturbed in the swath for the first 24 to 48 hours after cutting still dies hard, but the results of early and frequent tedding show that only by such methods is it possible to obtain quick and even wilting. The practice of earlier cutting to obtain higher quality makes immediate and intensive field treatment even more essential.

Drying Data

Drying by forced ventilation is based on the natural phenomenon that air has the ability to pick up moisture from any material which is wetter than the air with which it is in contact. The amount of moisture which air can pick up is affected by the relative humidity (R.H.) of the air and also to a lesser extent by its temperature. As the R.H. of air increases, its ability to pick up moisture decreases until either saturation or equilibrium is reached. Barn drying methods use either ambient air or warmed air or a sequence of both for drying. Air warming is carried out to reduce the relative humidity of the ventilating air, so increasing its moisture-carrying capacity. The figures in Table I show the moisture-carrying capacity of a given quantity of air, cold and with various temperature lifts, under a range of ambient temperature and humidity conditions.

The most efficient drying results in the air leaving the dryer having an R.H. approaching saturation—*i.e.*, 100 per cent.—but for practical reasons it is not usual to have exit air with an R.H. above 94 per cent.

It can be seen from this Table that, under average conditions, cold air can remove a considerable amount of moisture. Even under particularly adverse conditions, although the quantity of moisture removed is small, cold air can and is being used satisfactorily for drying where adequate airflows are used. Warming the air even by only a few degrees greatly increases the moisture-carrying capacity of the ventilating air, and whilst this increases the drying cost there are occasions when it is fully justified. Nevertheless, it must not be forgotten that it is cheaper to *move* air than to *warm* it, and generally an economic compromise has to be selected. Air warming may be necessary either to keep to a time table ; *i.e.*, batch systems or in areas where persistent high air humidities are customary. For economic operation, however, only modest temperature rises are permissible, and these are described later.

There is a definite relationship between the relative humidity of air and the moisture content of hay, and these equilibria values are shown graphically in Table II.

In most parts of the country the mean relative humidity ranges from some 70 to 80 per cent. during the months of May, June and July. Since, for most barn drying

TABLE I

Drying Capacities of Atmospheric Air and with Various Temperature Rises

Condition of Atmospheric Air.		*Relative Humidity.*	*Drying Capacity per 24 hours* of 1,000 c.f.m. (cwt. of Water).*					
Temp. ° F.			*Atmospheric Air.*	*Air Warmed 5° F.*	*Air Warmed 10° F.*	*Air Warmed 15° F.*	*Air Warmed 20° F.*	*Air Warmed 25° F.*
Dry Bulb.	*Wet Bulb.*	*Per Cent.*						
45	39	60	1·06	1·62	2·19	2·68	3·32	3·95
45	41	70	0·73	1·27	1·83	2·40	3·03	3·67
45	42	80	0·44	0·98	1·55	2·18	2·82	3·38
45	44	90	0·11	0·70	1·27	1·90	2·53	3·17
50	44	60	1·23	1·81	2·37	3·00	3·56	4·30
50	45	70	0·84	1·46	2·09	2·72	3·28	4·05
50	47	80	0·49	1·11	1·74	2·37	3·07	3·69
50	49	90	0·13	0·76	1·39	2·02	2·71	3·34
60	52	60	1·44	2·10	2·73	3·35	4·03	4·71
60	54	70	1·01	1·70	2·32	3·00	3·68	4·36
60	56	80	0·57	1·22	1·90	2·65	3·33	4·01
60	58	90	0·14	0·88	1·56	2·31	2·92	3·53
70	61	60	1·67	2·40	3·07	3·74	4·47	5·07
70	64	70	1·15	1·86	2·53	3·19	4·00	4·80
70	66	80	0·62	1·39	2·06	2·85	3·58	4·38
70	68	90	0·19	0·99	1·72	2·45	3·18	4·10

* Assuming the drying air is exhausted at a relative humidity of 94 per cent.

AIR HUMIDITY AND HAY MOISTURE CONTENT

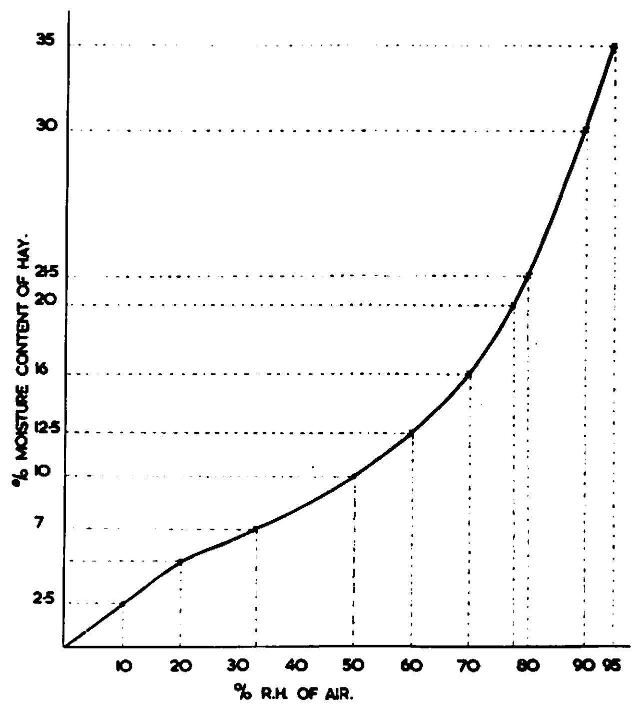


TABLE II

methods, the hay is loaded at from 35 to 60 per cent. moisture content, it can be seen from Table II that even with humidities as high as 80 per cent. a considerable amount of moisture can still be removed with cold air. In actual fact, for storage methods of drying, cold air only is perfectly satisfactory, provided there is sufficient of it. For batch methods of drying, however, where time is an important factor, since a drying time table is necessary, the use of a little warmed air in the final stages of drying is necessary. The actual temperature rise employed, however, need not be very great, but only sufficient to ensure that the volume of air used can effect the drying in the given time. There are, however, some areas in the country where high relative humidity is persistent, and in such cases air warming may be desirable for storage methods in the final stages of drying, but the temperature rise need only be sufficient to act as a humidity corrector.

Barn Drying Methods

Barn drying of hay has developed along two distinct but related lines—(*a*) the Storage method and (*b*) the Batch method. Both have been applied to hay carried from the field either loose or in bales.

(1) **Loose hay drying—storage method.** The first introduction of barn hay drying to the United Kingdom came in the early post-war years, 1945 onwards, when the Electrical Research Association carried out field trials based on the methods then used in America and known as "mow-drying." These trials proved that when the moisture content of the material was reduced to an even 35 to 45 per cent. before loading into the barn, the quality of the material dried with unheated air was vastly superior to swath-made hay under similar conditions. The results were particularly significant

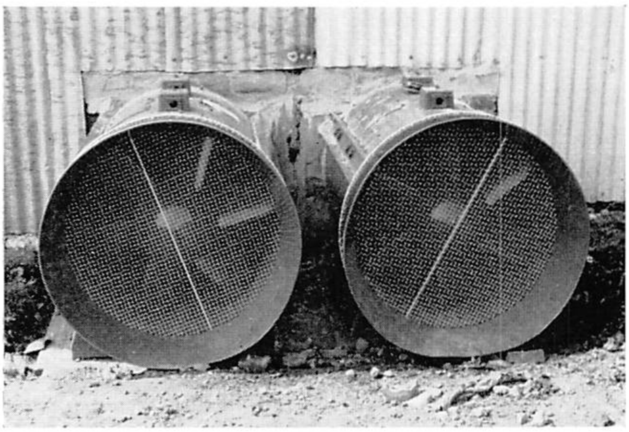


FIG. 1.
A large two-fan installation as used in figure 4, delivering 40,000 c.f.m. at 2.0 in. w.g.

with lucerne. Following this work, steady progress was made in the early 1950's in the North-West, where existing hay barns were readily adapted for this system. Although this method was a practical proposition for the small acreage farmer making some 20 tons of hay, it did not become widely popular because of the relatively small output per season. Nevertheless, a number of such installations are still being used successfully.

(*a*) *Ventilating Requirements*. Experience has indicated that airflows of 30 cubic feet/minute per square

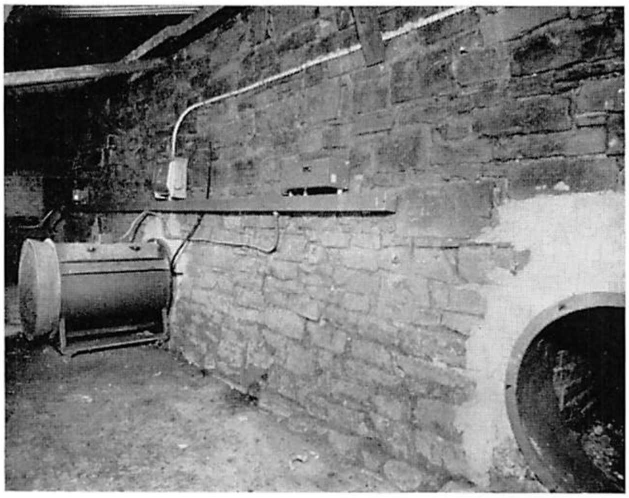


FIG 2.
Three-bay dryer, with portable fan, two bays.

foot are necessary for successful operation, calling for fans operating at pressures up to 2 ins. water gauge.

(*b*) *Structural Features*. These features are common to all methods of barn drying, with the exception of the tunnel bale drying system. Basically, the drier consists of a walled barn or section of barn with a flat false floor of some such material as Weldmesh supported on timber bearers some 24 ins. above ground level, thus forming a plenum or pressurising chamber, the fan or fans blowing air into it and upwards through the hay. The false floor must be "blanked off" to a width of 24 ins. around its outer edge. The side-walls of the drying bay should be reasonably flush and extend to the full loading depth, but adequate provision must be made for free exit of the moist exhaust air. Provision of convenient loading and unloading doors is essential, and is best achieved by making drop-in panels to fit flush with the inside of the wall. The walls of the drying compartment should be airtight to ensure vertical airflow through the hay. Since this is basically a storage method of drying the building selected should be as high as possible to make the system economic. On many installations hay can be loaded to a height of 16 ft., and this has been found economic.

(*c*) *Operation*. After wilting for some 36 hours or to a moisture content not exceeding 45 per cent., the hay is loaded on the drier to a depth of 8 ft. To ensure even and uniform drying, the loose hay must be spread lightly over the whole of the drying floor without any form of trampling. This can best be done from a loading platform mounted above the drier and preferably movable, as it is difficult to load directly underneath it. For multi-bay working, one movable platform can serve all the bays. The fan or fans should be switched on as soon as all the drying floor is covered with hay to a foot or so. After an interval of two to three days, a second loading of 8 ft. can be added. Similarly, after a further interval, a third loading can be added. In general, this would be the final loading due to the building heights available. The fan or fans should run continuously night and day until the complete filling has been dried down to under 20 per cent. moisture content. Under average conditions, this can be achieved in 14 days, but under adverse conditions it may take up to 21 days. For each 400 sq. ft. of floor area, assuming a 12 ft. settled depth, 12 tons of dried hay is obtained. Subsequent drying can be achieved either by utilising a second drying bay or by baling out the dried hay and refilling the drying bay.

(*d*) *Drying Cost.* Under average conditions, drying costs are in the region of 15s. per ton of dried hay.

(2) **Loose hay drying—batch method.** Until 1954 all the systems employed unheated air, but at this time a system of batch barn hay drying was introduced by the Electrical Research Association using higher rates of airflow per square foot and some heat for finishing. This system took the form of two-stage drying and enabled the wilted grass to be loaded at moisture contents as high as 60 per cent. This method is carried out in relatively shallow batches of 4 to 7 ft. and enables younger and more leafy grass to be handled, giving a much higher quality of finished product. These developments made some progress, particularly in areas where grass was the prime crop.

(*a*) *Ventilating Requirements.* The first stage consists of a high rate of airflow at 55 ft. per minute at 2 ins. w.g. with unheated air, followed by a low rate of airflow at 12 to 15 ft. per minute with air raised in temperature by 10° to 20° F.

(*b*) *Operation.* The moisture content of the hay in the field should be reduced to some 55 to 60 per cent. usually in a period of 6 to 24 hours. Loading should then commence and the fan or fans switched on as soon as the floor is covered. Loading of the loose hay must again be done carefully, and a loading platform will again greatly facilitate this. The cold blow should be continued for some 48 hours, by which time the moisture content of the hay will have been reduced to approximately 40 per cent. The warm blow period should then commence and continue until the hay is finally dry, usually taking a further 24 hours. The low rate of airflow for warm blowing can be achieved where a single fan is used by baffling down. Where two fans are used, one can be switched off and blanked off to prevent " blow back," while the second fan is used to provide the low rate of airflow. At the end of the warm blow the hay should be ventilated with cold air for half-an-hour to cool it before it is put in store.

The batch method has been commonly referred to as either " high-low " for the two rates of blowing involved, or " cold blow hot blow " for the two air temperatures involved.

(*c*) *Drying Cost.* As the hay is dried from 60 per cent. moisture content, the drying costs are in the region of 40s. to 60s. per ton of dried material.

(3) **Dry of hay in bales.** The drying of hay in bales has been carried out in America for some time, but it was not tried out in this country until 1956. The two methods already mentioned are both systems for drying loose hay, and this was considered by many farmers to be a serious drawback, since successful drying called for meticulous and laborious care in the loading of the hay. This, together with increasing shortage of labour and the increasing use of the pick-up baler, meant that barn hay drying became much more popular as the early bale drying experiments in this country proved so successful.

Bale drying was carried out originally by the batch method, either in an enclosed drying bay or in tunnels, cold air being largely used with only a little heat in the final stages of drying. While these systems are still being used with increasing success, there is an even greater interest in the storage method of bale drying which eliminates double handling.

Bale Drying—Field Techniques. All that has been stressed previously on the importance of field work applies equally to the bale drying techniques. Most types of pick-up baler will handle hay at 45 per cent. moisture content, but it is essential that the density should not be too high, 12 to 13 lb. per cubic foot being the aim. At 45 per cent. moisture content a full-size medium density bale measuring 36 × 18 × 14 ins. should weigh no more than 70 lb. Where the handling of bales of this weight presents any difficulty, most pick-up balers can be adjusted to produce a bale of shorter length, and it has been found that a length of 27 to 30 ins. is ideal. This reduces the weight before drying to only 56 lb. As bales of hay at 45 per cent. moisture content would seriously heat if left in the field for long, mechanisation of bale handling to enable speedy transport to the drier is desirable.

Theoretically, low-density bales or trusses should have been ideal for drying, but in actual practice it has been found that they need particularly careful stacking to ensure uniform airflow ; this is mainly due to the irregular shape of such bales and also to the fact that the density is so low.

" Rotobales " or round bales have been dried satisfactorily, stood up on end, two and three layers deep in batch driers. They have not, so far, been tried in storage-type driers.

Methods of Drying in the Bale

(1) **Batch Drying—Mesh Floor.**

(*a*) *Ventilation Requirements.* Experience has shown that the provision of an airflow of 45 to 50 ft. per minute with cold air is adequate for batch bale drying. The resultant back pressure is 2·5 ins. w.g. For economic throughput some warming of the air is necessary either by a low temperature rise of up to 5° F. continuously, or a rather higher temperature rise of 10 to 15° F. in the final stages of drying, preceded by a cold blowing period.

(*b*) *Structural Features.* For this system of drying the blanking-off strip need only be some 18 ins. wide. It is also desirable that the loading doorways should be wide enough to accommodate an elevator for ease of handling and should be placed as near as possible to the centre of the longset side.

(*c*) *Operation.* The hay should be wilted down to at least 45 per cent. moisture content before baling takes place. The bales should be stacked with their cut edges downwards, packing them from wall to wall as tightly as possible to minimise air leakage between the bales. The bales in each successive layer should be laid at right-angles to those immediately below, giving a cross-bonding effect, thus preventing continuous vertical seams between the bales. It has been found that the loading depth should be restricted to five layers deep, because depths greater than this will involve an excessively long period of blowing to dry the top layers. Blowing should commence as soon as the first complete layer of bales is on the drier. On average, the drying time for a batch is six to seven days. Cold air blowing should continue for five days at least. If the ambient conditions are good on the sixth day, cold blowing could continue, using heat only on the seventh day. If, however, conditions are not suitable for cold blowing on the sixth day—*i.e.*, if the humidity is above 80 per cent.—warm blowing should be started. Alternatively, a low temperature rise of up to 5° F. can be used continuously throughout the drying period. As for batch drying of loose hay, on the completion of drying the bales should be ventilated with cold air for half-an-hour before put in store.

(*d*) *Drying Cost.* Under average conditions, the drying cost for this method ranges from 15s. to 30s. per ton of dried bales.

(2) **Batch drying—tunnel method.** The successful technique for drying grain in sacks by the tunnel method led to the development of a tunnel drying system for baled hay.

(*a*) *Ventilation Requirements.* For satisfactory tunnel drying of bales, an airflow of 45 cubic feet per minute per bale is required, and the back pressure will be up to 2·5 ins. w.g. Warm air is again needed in the final stages of drying, and the requirements are the same as in the other batch bale drying method.

(*b*) *Structural Features.* Tunnel driers can be constructed for either single-tunnel or multi-tunnel working. Where any quantity of bales is to be dried, multi-tunnel working is much more adaptable and flexible. Single-tunnel working calls for the absolute minimum of constructional work, the only requirement being a short connection duct between the fan and the tunnel of bales. Multi-tunnel working requires a little more constructional work, involving the provision of an air-duct with several 2 ft. by 2 ft. openings at 15 ft. centres. The fan or fans blow into the air-duct and *via* the openings to the tunnels. For satisfactory tunnel drying the building should not be less than 12 ft. high, and to facilitate bale handling there should be access for trailer loads of bales to be drawn right up to the building face of the tunnel.

Where a mobile drying unit is used, "tunnel stacks" of bales can be built and dried in the field. This has particular acvantage where the distance to the place of storage is great. Mechanical handling by connected buckrake and hydraulic front loaders can assist in

FIG. 3.
Tunnel stack drying of bales in the field.

conveying the bales from the field to the drying stack in very quick time. This system lends itself to situations where the bales are lft in the field for stock feeding.

(*c*) *Operation.* The hay should be baled at not more than 45 per cent. moisture content and tunnel construction should commence immediately. The tunnels are really hollow clamps, the ventilating air blown into the cavity and forced outwards through the bales. There are several methods of tunnel construction, but the two in most common use will be shown in detail on slides. Immediately the tunnel is completed, ventilation should commence. The drying programme is then exactly the same as for the other batch bale drying method described earlier. It should, however, be recognised that satisfactory tunnel construction requites much more careful supervision than stacking bales in a drying bay.

(*d*) *Drying Cost.* For tunnel bale drying the drying cost ranges from 20s. to 30s. per ton under average conditions.

(3) **Storage drying.** While batch and tunnel bale drying methods are successful, they do involve double handling, and consequently a storage method of bale drying, eliminating double handling, was the next development.

(*a*) *Ventilation Requirements.* An airflow of not less than 40 to 45 ft. per minute through the bales is required for storage bale drying, the back pressure being 2·5 to 3 ins. w.g. Since this is a storage method of drying and no time table is involved, cold air only can be used, and it is therefore preferable to keep the airflow through the hay as near 45 ft./min. as possible.

(*b*) *Sructural Features.* The construction is exactly the same as for storage drying of loose hay. The building must be as high as possible to give an economic output. The false floor must be suitably supported to carry a considerable weight of bales. Since the ventilating air may have to pass through anything from 12 to 18 ft. of bales, it is important that the drying compartment walls be as air-tight as possible.

(*c*) *Operation.* Baling should commence when the hay has been wilted to 45 per cent. moisture content, but not before. Immediately one complete layer of bales is on the drier, blowing should commence. Three to four layers can be loaded on the first day. Successive loadings can be added every two to three days until the drier is full. Blowing should be continuous, and under no circumstances should this stop until drying is completed, otherwise the bales will almost certainly start heating. Under average conditions, ventilation will have to continue for up to 10 days after the last filling is placed on the drier. Where, however, the power unit is an internal combustion engine and waste heat can provide a temperature rise of up to 5° F., this period can be reduced by several days. The criterion with storage drying is not so much the time factor, but rather the capacity of the building converted. Where either a duct system is used to convey air to a number of storage bays or a mobile fan unit is available, the storage system can cope with relatively large tonnages in a comparatively short time.

(*d*) *Drying Cost.* For storage drying of bales the drying cost ranges from 10s. to 20s. per ton.

Ancillary Equipment

For all methods of barn drying there are one or two items of ancillary equipment which, while not essential, can assist in the satisfactory operation of the drier. A simple manometer fitted to the drier will indicate the back pressure, thus preventing the drier from being overloaded. A wet and dry bulb thermometer is a useful method of determining humidity, and even more useful is the provision in the air duct of a stem-type hygrometer, which will show at a glance the humidity of the ventilating air. This is particularly useful in batch drying for determining when heat is essential. The temperature rise employed can be simply checked by the use of two thermometers, one measuring ambient temperature and the second measuring the warm air temperature.

Choice of System of Barn Drying

Although a farmer may have a preference for a particular system of drying, there are several practical factors which he must consider before finally deciding which system is most suited to his conditions. These factors are :

(1) *Quantity of Hay Required.* For large tonnages of hay the storage bale drying method lends itself. Where tonnages are smaller—say, not exceeding 60 tons per season—then batch bale drying can be used, provided there is no objection to double handling.

(2) *Quality of Hay Required.* Quality must always be considered in conjunction with quantity. Where quality is of prime importance, irrespective of quantity, then the batch method for drying loose hay would be the obvious choice, since this system would incur the absolute minimum of field losses. On the other hand, where it is desired to make as much hay as possible with a high feeding value, bale drying methods can be used to advantage, as they allow larger tonnages to be dealt with while still maintaining a fairly high feeding value. For conditioning of large tonnages the storage method of bale drying should be used.

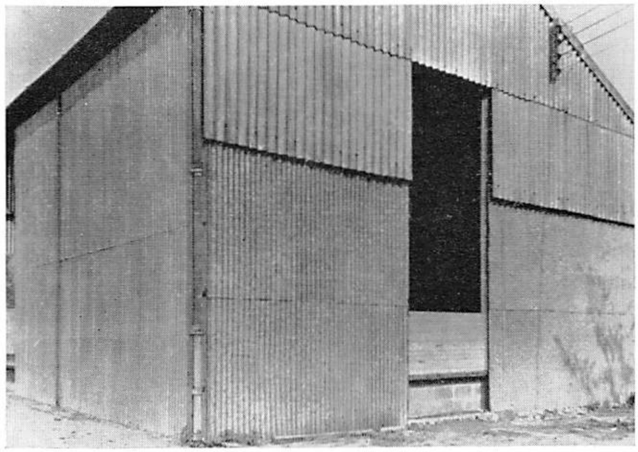


FIG. 4.
A typical drying bay, showing loading doors.

(3) *Suitability of Buildings.* Storage methods of drying require buildings with as much headroom as possible. If these are not available, either new buildings would have to be built for the purpose or batch methods, with a lesser requirement for headroom, would have to be used. Buildings can be adapted to match the size of a ventilating unit where one is already available, or, alternatively, a unit can be specified to suit any particular building.

(4) *Labour.* Loose hay drying has a higher labour requirement than bale drying. Therefore, where labour presents a problem, bale drying, particularly by the storage method, is a better proposition, since this obviates double handling.

(5) *Locality.* Where humidities of above 90 per cent. are persistent cold air drying methods can be considerably slowed down, and in addition the field wilting period can be protracted with increased loss of dry matter. Batch drying of loose hay would be most satisfactory under these conditions, since it calls for the minimum of field wilting and heat is available to counteract the high humidity. The degree of field wilting which can be effected in a given time must always be considered.

(6) *Availability of Buildings.* Where all suitable buildings are utilised for other purposes, the tunnel method can be used with advantage, and where a mobile fan unit is available the tunnel drying can be carried out in the field.

(7) *Cutting Programme.* This is particularly important where high quality hay is the aim. This will entail

cutting early in the season, and cutting will have to be staggered throughout the growing season so that each cut is obtained when the crop is at its peak feeding value.

(8) *Baling Facilities.* Where baling is by contract, experience has shown that successful drying can only be achieved when the farmer

(*a*) has absolute priority over the contractor and
(*b*) supervises the actual baling.

(9) *Number of Stock.* Experience has shown that for winter feeding approximately one ton of barn dried hay is needed for each cow in the milking herd, and the drier must therefore be of adequate capacity to provide the total tonnage required.

(10) *Multi-Purpose Aspect.* This is a very important factor, since a drier which is multi-purpose allows the capital equipment to be utilised over a longer period of the season. By suitable planning in the initial stages, barn drying systems can also be used for drying grain in the sheaf, in sacks or in bulk and also for ventilation of ware potato stores.

Many other factors could, no doubt, be added to this list, as there is such a wide range of conditions under which barn drying might be expected to operate, but those given above are considered to be the most important ones governing the choice of method.

Economics of Barn Hay Drying

Trials have indicated that 15 to 20 per cent. extra weight of dry matter can be obtained by using barn drying methods as compared with swath drying, which means that an extra 4 cwts. of dry matter valued at 40s. can be conserved for every ton of dry matter swath dried. This in itself may cover the whole cost of drying, quite apart from any increased value due to quality.

Feeding trials have also shown that barn-dried hay yielded additional milk worth 30s. from each ton as compared with similar swath-dried hay. Therefore, a total saving of some 70s. per ton can be achieved. These figures relate to average samples of barn-dried hay, and where high-quality hay is made the financial saving will obviously be greater.

While swath-dried hay is normally used for the maintenance ration, barn-dried hay can be used for maintenance and part of the production ration thereby effecting a considerable saving in concentrates. Many farmers claim that this saving amounts to £10 per cow over the winter season, and in some cases these savings have more than paid for the drier over a period of two years.

The economic factors mentioned above are shown diagrammatically in Fig. 5.

It is important to recognise that correct utilisation of barn-dried hay has an important bearing on the economics. It should not be treated as a roughage, otherwise the increased feeding value will not show its full financial return. Chemical analyses of barn-dried hay greatly assist in compiling rations so that the barn-dried hay is used to its best advantage.

Selection of Equipment

To a large extent, the selection of equipment for barn hay drying is governed by the choice of system, but the

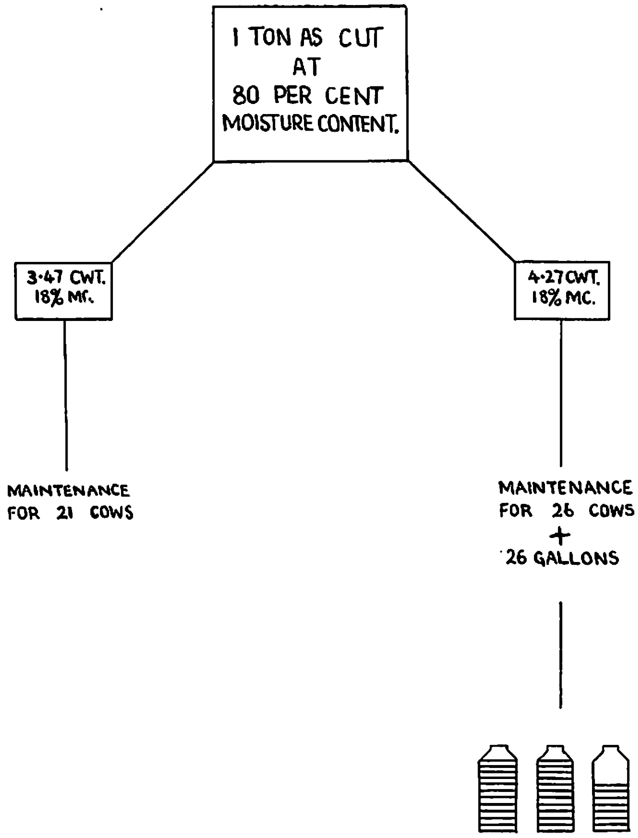


FIG 5.

following factors also influence both the size and type of machinery selected :

(1) Capacity and type of electricity supply available, as well as the cost per unit of electricity, recognising that there are generally crop drying tariffs available.

(2) Capital costs, if any, required to make provision of an adequate electricity supply.

(3) Multi-purpose aspects of the project—*i.e.*, grain drying in sack, in sheaf or in bulk and ware potato storage ventilation.

(4) Mobility requirements for use with scattered buildings or for drying in the field.

(5) Proximity to residential buildings where noise level could be a problem.

All these factors are somewhat interdependent as well as being basically dependent on the system chosen.

(*a*) *Fans.* Both centrifugal and axial flow fans are commonly used for barn hay drying and there is a wide range available. The power required per 1,000 cubic feet of air delivered and the cost per 1,000 cubic feet varies considerably. In general, the lower the horse-power requirement per 1,000 cubic feet of air per minute the more costly are the fans, and this applies particularly to centrifugal fans. As a general rule, the selection of fans for barn hay drying is a compromise between maximum volume with minimum power and maximum volume with minimum capital cost.

Axial flow fans with electric motors direct coupled and built into the fan casing provide a very efficient means of air movement. As the motor has adequate cooling, being in the airstream, the frame size and therefore the cost can be kept to a minimum. The temperature rise provided by the motor, although only small, does provide some additional T.Bh.U.'s which contribute to greater moisture removal per unit of time. Single-stage axial flow fans running at 3,000-r.p.m. synchronous motor speed are used up to 24 ins. diameter and produce adequate air volumes up to 2·75 ins. water gauge. Above this diamter, the fans have a high horse-power requirement per 1,000 cubic feet of air, and they have a high noise level due to the high tip velocity of the impeller. Two axial flow fans in series or a two-stage contra-rotating fan can be used for higher pressure developments. Axial flow fans in parallel can be used for developing higher volumes, but care must be taken to keep the fans in balance.

Centrifugal fans of three main types are commonly in use—namely, forward curved, backward curved and paddle bladed. Where in bin grain drying is considered in conjunction with barn hay drying, pressures up to 6 ins. w.g. will necessitate the selection of a fan with a wide range of duties. The backward curved centrifugal fan has a non-overloading characteristic and is particularly suited to this combined duty.

More recently, portable fan units comprising large single-stage axial flow fans, direct coupled to internal combustion engines, have been used. Such fans have a wide range of duties and can work at pressures up to 6 ins. w.g.

(*b*) *Heaters.* Electric duct air heaters, oil-fired units and coke-fired units, each with heat exchangers, and waste heat units are being used to provide the heat required for batch methods of drying. Despite their higher running costs, electric air duct heaters are widely used, probably on account of their low capital cost and their simplicity of design and operation. Loadings of 20 to 50 kW. (68,000 to 170,000 B.Th.U.'s) have proved adequate on most installations. Oil-fired heat exchangers for batch barn hay drying with outputs of up to 250,000 B.Th.U.'s have recently been developed. Most recently portable fan units, utilising the waste heat from the air-cooled diesel engine, have been introduced with outputs of 140,000 B.Th.U.'s.

Multi-Purpose Aspects

Perhaps one of the most important aspects in layout and design is that the equipment selected and the way it is arranged should provide flexibility and continuity of operation. To illustrate this point, the following examples are therefore taken and described in detail :

(1) Batch Drying

Requirements : To dry hay in bales with a capacity of up to 100 tons per season, and to dry corn in sack or in sheaf.

Building Available : Two bays of an existing four-bay Dutch barn, each bay measuring 21 ft. by 15 ft.

Method : Batch drying since double handling is not objected to.

Electricity Supply : The supply available is three-phase with a 50 kVa. transformer on the farm.

Conversion of Building

(*a*) *Walls :* Two bays are walled up using 9 in. concrete blocks, with one common dividing wall, to a total height of 10 ft.

(*b*) *Drying Floor :* Four inch by 3 in. timber cross-bearers at 3 ft. centres and 2 ft. above ground level are supported at the intersections by 9 in. concrete block pillars. The timber framework is covered with 3 in. square 5-gauge Weldmesh, which is stapled down.

(*c*) *Loading Doors :* In the centre of each 15 ft. wall, on the front of the building, 6 ft. wide gaps are left for loading and unloading. During drying, these gaps are filled with 6 ft. by 3 ft. flush fitting " drop in " doors.

Fans : Three 5-h.p. axial flaw fans, each delivering 8,000 c.f.m. at 2 ins. w.g., are required. These are arranged so that one fan delivers air to Bay 1 and a second fan delivers air to Bay 2. The third fan is installed in line with the central dividing wall between the bays and is connected through a two-way air duct so that air can be blown to either bay.

Heater : The heater is a 30 kW. portable duct air heater arranged to operate on either of the fans serving Bays 1 and 2.

Operation : In view of the fact that the first stage of drying is carried out with a high volume of cold air utilising two fans, and the second stage with a reduced volume of warm air utilising one fan with heater, the equipment has a high load factor, since continuous operation is possible. This is particularly important, as maximum throughput per week is vital.

Each bay, if loaded to five layer deep, will yield approximately 10 tons of dried bales per week, but as there is an overlap after the first week due to the two stage procedure, unloading and reloading can take place every five days. The target of 100 tons can therefore be achieved over a period of 2 to 2½ months.

Capital Cost : For an installation of this type an average figure for the fans, heater, control gear and wiring would be £420. In addition, building conversion, which can be grant aided under the farm improvement scheme, would also cost approximately £420, giving a total capital cost of £840.

Such an installation could handle, in addition, 150 to 200 tons of grain in sack or, alternatively, grain in the sheaf can be dried. By the use of suitable mesh flooring and with the right fans in bin grain drying and barn drying can be combined. Where no grain needs drying, both bays could be filled with bales 10 layers deep at the end of the season, so utilising the bays for storage.

(2) Storage Drying

Requirements : To dry between 80 and 100 tons of bales *in situ* per season. Hay is the only crop to be dried.

Building Available : A four-bay Dutch barn, each bay measuring 24 ft. by 15 ft. Both ends of the building and one side are already sheeted up to eaves level.

Method : Due to a shortage of labour, there is a definite objection to double handling, and since hay is the only crop to be dried, the storage method of drying is adopted.

Conversion of Building

(1) The barn is divided into two equal area of 30 ft. by 24 ft. by erecting a dividing wall of corrugated sheeting in the centre.

(2) A false floor of Weldmesh on a timber framework as already described for batch drying is installed in each section.

(3) The open side of the barn is sheeted up, leaving two 6 ft. wide loading and unloading doorways, one for each section.

To ventilate one section of 720 sq. ft. at 40 ft. per minute per square foot, a total volume of 28,800 c.f.m. would be required against a back pressure of 2·75 ins. w.g. As it is unlikely that both sections will be filled and dried simultaneously, a fan with this duty is adequate. An all-electric unit can be used with an air duct delivering the air to either bay or a portable unit can be used and moved from bay to bay. Such units, using the waste heat principle, can supply a slight temperature rise, which is very useful in shortening the drying period.

From 80 to 100 tons could be dried and stored, providing the building is 18 to 20 ft. high to eaves level, allowing some 10 or 11 layers of bales to be accommodated. The acreage providing this quantity would be cleared in less than one month under average conditions. Capital expenditure would be approximately £800 for ventilating equipment and constructional work.

(3) **Tunnel Drying of Bales in Barn or Field**

Both examples given above involve capital expenditure on adapting buildings, but the tunnel drying system involves little expenditure over and above the cost of the fan unit. All-electric fan units could only be used in the barn and would necessitate an air duct for multi-tunnel working. A portable fan unit, consisting of an engine-driven axial flow fan, providing an air volume of over 30,000 c.f.m. at 20 ins. w.g., would cost £650. The 40-h.p. diesel engine would give a temperature rise in the form of waste heat equivalent to 40 kW. of electricity. Such a unit enables tunnels of some 800 bales to be dried at a time, and can be used for multi-tunnel working in barns or for tunnel drying in the field.

Conclusions

In this Paper the authors have endeavoured to outline the theoretical requirements of barn hay drying and at the same time show how these are interpreted by practical examples.

It will be noted that there is a wide variety of methods of application both in batch and storage drying, but it is the opinion of the authors that a compromise between batch and storage drying will become the most popular, since this will achieve a high seasonal throughput per £100 of outlay and will minimise double handling.

There is no doubt that a very live interest in quality hay exists, and the use of barn hay drying is bound to increase, as its value is more widely known and appreciated. The rate of development, however, is bound to be governed by the number of enthusiasts and advisers amongst farming circles who are able both to sell the idea and co-ordinate the various functions of building conversions, equipment requirements and grant aid applications. At the present time the number of such advisers is small in relation to the potential that exists.

Further research into methods of application might well produce ideas which involve less capital expenditure, particularly on building construction. At the present time, developments in the U.S.A. would appear to be concentrated on the drying of chopped hay. In this country, however, drying in the bale would appear to be the speediest way of handling and drying large quantities at a time, which is an essential feature, since the growing crop will invariably tend to overtake the drying facilities.

During the presentation of the Paper, the authors gave some extra figures for comparing field-made with barn-dried hay. Stating that 5·8 tons of grass at 80 per cent. moisture content would yield 1·2 tons of dried matter, which represented 1 ton of field-made hay at 18 per cent. moisture content. On the other hand, 5·8 tons of grass at 80 per cent. moisture, reduced to 40 or 45 per cent. in the field, then baled, would result in 1·2 tons of hay at 18 per cent. moisture content if it were barn dried. So there was an extra 4 cwt. for every ton of hay made. In addition, there was the question of quality. One ton of field-made hay maintained a dairy cow for 125 days, whereas 1·2 tons of barn-dried hay maintained the cow for 150 days and provided for 150 gallons of milk. To obtain 150 gallons of milk required 600 lb. of concentrate, which cost £8, and, after adding the 0·2 tons of hay providing maintenance for the extra 25 cow days, the overall saving was the £10 per ton mentioned in the Paper.

Capital costs varied according to the convertibiltiy of existing buildings and the type of system required. Operating costs were inversely proportional to capital ones. The initial capital outlay could be described as about £10 a ton, so this could be recovered in one year. It was normally the second season before full benefit was gained from the technique, and they had therefore erred on the side of caution.

After making the case for barn drying, the authors summarised the various methods outlined in the Paper, commenting on field work, dual-purpose aspects, drying costs and labour costs, which are certainly no more for field-made hay in a normal season and less in a bad season.

BIBLIOGRAPHY

(1) "Barn Hay Drying," by C. A. CAMERON BROWN and P. G. FINN-KELCEY. E.R.A. Report No. W/T17.

(2) "Barn Hay Drying. Recommendations for the Construction and Operation of Farm Installations," by C. A. CAMERON BROWN and P. G. FINN-KELCEY. E.R.A. Report No. W/T17a.

(3) "The Operation of a Barn Hay Drying Installation," by P. G. FINN-KELCEY. E.R.A. Report No. W/T28.

(4) "The Development, Design and Operation of an All-Electric Multi-Purpose Farm Drier," by P. G. FINN-KELCEY and V. M. OWEN. E.R.A. Report No. W/T34.

(5) "An All-Electric Multi-Purpose Farm Drier—Design and Operation," by P. G. FINN-KELCEY and V. M. OWEN. E.R.A. Report No. W/T34a.

(6) "Greencrop Drying." Farm Electrification Handbook No. 7. Electrical Development Association.

(7) "Artificial Ventilation of Baled Hay," by G. SHEPPERSON. Reprinted from Agricultural and Horticultural Engineering Abstracts, Vol. 9, No. 1, 1958.

(8) Session 12b/4, 8th International Grassland Conference, 1960. G. SHEPPERSON.

DISCUSSION

MR. S. CULPIN (N.A.A.S., Drayton) said that he would like to think about the Paper from the farming point of view and to say something about the developments that one hoped would take place. He found himself so much in agreement with what had been said that he was not going to criticise matters of detail ; there were many places in which results at Drayton fitted into the picture given that afternoon.

However, it was obvious to everyone that the improvement of haymaking by any method could make a major contribution to farming in general. From what was known about silage and hay, the room for improvement was greater for the latter. This was because silage used a part of the crop for its own fermentation, which gave a bare minimum of losses below which one could not go, that figure being about 15 per cent. of the dry matter—perhaps fractionally lower under ideal conditions. At present, these losses were about 25 to 30 per cent. in good conditions ; so the possibility of improvement for silage making was from 25 to 30 down to 15 per cent. As had been said, there was a bigger prospect of improvement in haymaking than that. Another advantage was that everyone liked hay, whereas not everyone liked silage.

Mr. Culpin agreed almost exactly with the sort of picture of the increase in quantity of hay that could be collected. The Drayton figures showed an increase in dry matter collected of 14 per cent. when using the barn method rather than that in the field. Under their conditions, it had been possible to provide by barn hay drying 20 per cent. more than by ensilage. This meant that their field haymaking had given them just a little more dry matter to feed to the stock than silage making.

At Drayton they had found barn hay drying a process they could manage from the farming point of view. He felt that one of the major improvements required was to make barn drying thoroughly reliable at the silage-making season of the year. So far, most of the comments that were made about barn drying were really concerned with drying hay during the haymaking season. The danger in introducing the process at the silage time of the year or even earlier was that, instead of the costs of drying that had been quoted, the large quantities of water would make operating costs somewhat higher. They had had some very high figures at Drayton for the cost of extraction because they had been working early in the year, and Mr. Culpin quoted figures of 45, 50 and 60s. per ton of hay produced. That was where he, as a farmer, would expect some help from the engineer.

Nevertheless, it did not always happen that the crop dried early was the most expensive one, because the cost was a function of the weather. However, the quality of early hay was an important point.

He thought that one of the biggest advantages found with barn drying was that the process came to the rescue just when it was needed most. Their experience ran from 1958 to 1960. The maximum benefit was obtained in 1958, when they had had the worst of the weather and when it had been most important to have a quality feed to give to the stock. It was very beneficial to be able to keep a level production of feeding stuffs for the stock.

He was dubious about the extra value one could put on a ton of barn-dried hay. On Mr. Hearle's £10 per ton figure, he said that if they were going to make comparisons of that sort they must think of the alternatives that one could adopt, because the value attributed to the hay depended on the value of the product—milk, liveweight gain, etc. If one compared the barn hay with field hay plus barley, the answer might come out differently, and he asked the authors to recalculate on that basis.

Their experience was that barn drying of hay made more difference to quality in a difficult season. Using their 1959 hays they were unable to demonstrate any difference on a production basis. This year, although they were only partly through the hay, with young cattle aged about 11 months and weighing something like 6 cwt., they had found that the cattle were gaining weight 20 per cent. faster on barn-dried than field-dried hay.

MR. P. FINN-KELCEY (Electrical Research Association) recalled the history of barn hay drying, going back to the time when he and Mr. Cameron-Brown had been concerned with starting the technique in this country. It had been Mr. Finn-Kelcey's job to read the American literature and build a system. The air-flow given in that literature had been 12½ cubic feet per min., and it was said that one could load to 8 ft. depth and that it did not matter if one trampled on the hay. When he had come to construct his system, however, he used 20 cubic feet per min., and even that was not enough. Also, he discovered that one could not trample on the hay. Doubtless the reason was the different weather conditions in the two countries. In 1946 to 1947 they had made all the mistakes possible, and out of 12 built only one plant was thoroughly successful. The prospects for barn hay drying at that time were not good, and if it had not been for Mr. Hearle's enthusiasm he doubted if there would have been many barn driers to-day.

Temperature rises of 20 or 25° F. had been mentioned by the authors, and Mr. Finn-Kelcey had a word of warning about that. If fairly wet material was being loaded and that temperature rise was put on at the start of drying, the depth being 7 or 8 ft., there was the danger of moisture transference from the lower to the upper layers. So his advice was not to put on that amount of heat at first.

He was sorry to note that the authors had insisted on putting the bales on edge, which made them more difficult to handle, and he could not think it made any difference to the drying ; it only rather made life more difficult. He preferred to see 2 in. rather than 3 in. " Weldmesh " used in the construction, because it was safer to work on and made it easier when carrying sacks.

One of the problems with barn hay drying was the feeding of the product, and he hoped that the N.A.A.S. would help farmers in this respect, for, being a more valuable and more costly material, it must be carefully rationed, without waste.

There was tremendous scope for barn hay drying overseas, especially in dry areas where irrigation was used and where tremendous yields of lucerne were possible, but leaf loss was excessive in haymaking. A tumble storage type of drying was becoming popular in America, in which bales were just dropped into the drier and, being almost cubic in size, would just roll down and load themselves. . Such an arrangement would probably be attractive over here.

MR. G. SHEPPERSON (N.I.A.E.) thought that, although field treatment had been mentioned, it could not be overemphasised, especially when we had field machinery that could get hay down to less than 30 per cent. in under 24 hours. In the work his organisation had carried out this year they had obtained good results with a crimper ; its use gave a 10s. to 18s. a ton advantage in artificial drying costs when compared with a tedder. Mr. Shepperson considered that one could be satisfied with driers which were low in relative efficiency, provided the farmer knew how to operate the one he had on his farm. Once the design of drier had been decided on, the method of handling, including the handling of the material out to the animal, would make or break the system.

It was cheaper and produced better results in his opinion to blow a lot of air than to blow a little and heat it to a high temperature. Although results were not complete, they indicated that if a small airflow and a very high temperature was used (140°–150° F.) uneven drying and high costs resulted. If the airflow was high and a high temperature (100°–120° F.) was used, then drying was more even, but costs were still high. Most satisfactory costs per ton were achieved when a large airflow and little or no heat at all was used.

He questioned whether it was necessary in a storage drier to ventilate from beginning to end. It might be possible to do so for a few days and nights and then to switch off the fan and merely blow during the day time, perhaps switching on at intervals during the night to prevent over-heating.

Work that this organisation had carried out had been reported in a Paper given to the National Grassland Conference, and it showed that one could get a greater drop in the potential feeding value of the hay by delaying cutting for three weeks than from the worst possible methods of haymaking. It would, he added, have been, perhaps, more helpful if the capacities of the driers had been given on a volume weight basis. Lastly, he wanted to know if the authors had found how to get the top layer and the outside of tunnels really dry without condensation.

MR. HEARLE, replying to these speakers, said to Mr. Culpin that the authors had thought that their claims of £10 per ton increase would be queried. However, they had studied carefully the feeding values of field-made hay as opposed to barn-dried hay. About Mr. Culpin's point that it was important to cut the crop as early as that for silage, Mr. Hearle said that somewhere there was an optimum yield of digestible nutrients per acre, but that further research was required on this. There were problems in cutting earlier if one was going to dry it in the bale, but the biggest problem of all was the wilting time. If hay was cut in early May, even with crushers and crimpers, it was going to take two to three days to get the moisture content low enough for baling and subsequent drying. Mr. Culpin's figures on silage were very interesting, as they clearly indicated that on animal production per acre basis barn-dried hay would give a greater yield than silage.

The authors had rather copied the Americans about putting the bales on edge, and Mr. Hearle told Mr. Finn-Kelcey that he had never examined the results of one rather than the other. Perhaps Mr. Finn-Kelcey was right. He paid to that gentleman a tribute for his work on the subject of barn hay drying.

Answering Mr. Shepperson's question about the need for continuous blowing, he stated that perhaps the authors had been wrong to emphasise that it should be continuous, but that it was better to err on that side rather than the other. If farmers were told that they could shut down at night they would shut down during the day as well, and it could be overdone. On the question of the top layer problem, he knew of one case where a new barn for storage and batch drying had been set up and bales of bracken had been placed on top of the hay bales, the same bracken bales being used every season. The blowing time for the last layer of hay bales could otherwise increase the overall time quite a bit.

MR. PATERSON felt very strongly about starting cutting early in the season, and thought it essential that barn hay drying should be started at the earliest date. However, the crop might have to be handled loose at that time of the year, and if a farmer had handled bales on a drier for only one season it was often difficult to persuade him to revert to loose hay drying earlier in the season.

Taking up Mr. Shepperson's declaration that it was the handling of material that would make or break a drier, he agreed and added that it was important to site new buildings for drying near the feeding space to minimise handling.

MR. E. C. CLAYDON (East Anglian Branch) had a historical correction to make. It had been mentioned in the Paper that the drying of hay in bales had not been tried in this country before 1956. However, one farmer had tried it in 1951 and another in 1955. (Report of the 1956 E.D.A. Rural Electrification Conference refers.)

With regard to technique, had the authors any comments to make on the use of differential humidity controllers for hay drying ?

MR. WRIGHT (N.I.A.E.) felt that evenness of wilting was extremely important for successful barn drying, and the authors agreed that this was so, particularly for drying in the bale.

MR. SCOTT (Nu-Way) suggested that it might be better to use heat continuously and also to use a greater temperature rise than recommended in the Paper. The authors felt that while this would speed up the drying process, the drying cost would be considerably increased, and stressed that much of the drying could be done with cold air.

MR. MOFFAT (Rothamsted) felt that cutting early in the season was not desirable under all circumstances, but he did feel that barn drying was a good insurance policy.

PROCEDURES FOR SPRAYER TESTING

by P. HEBBLETHWAITE,* M.S., B.Sc., N.D.A., A.M.I.Agr.E., and P. RICHARDSON,* N.D.H.

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The ultimate criterion of sprayer performance is the net economic return. Direct assessment of this is not feasible in test work with sprayers, and in any case is only of value if investigated over a number of years for a number of pests. The aim instead is to produce a balanced picture of the physical performance of the machine with the final user always in mind. The biologist cannot yet give a precise specification of the type of coverage required for each pest, but progress in this direction has started and this must eventually be the meeting point with the engineer.

In reading the Paper, Mr. Hebblethwaite said that for fruit spraying the comparison machine used was usually a hydraulic sprayer. This was used as a yardstick because there was such a variety of types amongst fruit sprayers in the air-blast category. Referring to the air speed and volume figures quoted for air-blast machines, he thought that converting these to air horse-power was a useful way of reducing to a single figure for approximate comparisons between machines.

Introduction

SPRAYERS are subjected to routine test at the N.I.A.E., along with other classes of machines and tractors. The present Paper is complementary to an earlier one by McLaren[1] on the testing of root crop harvesters, to which reference should be made for details of the function of the N.I.A.E. Testing Service as a whole. Two other Papers to this Institution have referred to the testing of crop driers[2] and tractors[3] within the framework of the same Testing Service.

The first part of this Paper deals with the practical significance of sprayer test data, together with alternative test methods, and should be read in conjunction with Part II, which covers the test procedure currently in use at the N.I.A.E.

PART I

Standard Tests for Sprayers

Sprayers may be entered for test singly or several at a time ; whichever is the case, it is clearly desirable that successive tests be as comparable as possible. This raises the question of " Standard Tests "—a term which appears to have considerable popular appeal, but one which must be used with caution in the context of implement testing.[1] For implements, it is only in relation to test procedure (including test conditions) that some standardisation is attempted at the N.I.A.E. ; with a few relatively minor exceptions,[4] performance standards (*i.e.*, acceptable levels of performance) cannot conveniently be laid down at the present time. Even the moves towards " procedure standardisation " (the phrase " establishment of preferred test procedures " might be more appropriate) which the N.I.A.E. have made still leave the test procedure flexible so that the Testing Service is of the fullest possible use to entrants, many of whose machines are still developing rapidly and may exhibit radical changes in principle.

The question of " standard " tests also assumes considerable importance for sprayers intended for export. One or two countries insist on the production of a test certificate for all potential imports, and for others such a document is of real help in gaining acceptance.

One of the major obstacles in the way of laying down a rigid standard test for sprayers is well illustrated by making a comparison with tractor testing. Many of the important measurements in a tractor test are engineering measurements with a high order of repeatability, and thus standard tractor tests have been achieved.[5] By the same token, certain aspects of a sprayer test such as the bench testing of nozzles[4] or pumps[6] can be standardised ; it is when the biological aspects of crop or field conditions have an important influence on the measurements that standardisation must assume a different meaning.

A further feature of a test which can be fully standardised is that when a measurement is made of, say, fuel consumption or the flow of water delivered by a pump, the reading obtained can, by calculation, be corrected to standard temperature and pressure conditions for the material involved (in this case, fuel or water). In contrast, an assessment of spray coverage obtained in a test orchard where the leaf cover is excessive cannot be corrected mathematically for leaf deckage ; however, in writing the conclusions on such a test, one can and must take into account the effects of this divergence from " ideal " conditions.

A start has been made on an international standard test for sprayers under the aegis of O.E.E.C.,[7] but the problem in this case has all the complications of a national standard, with the added difficulties of varying units and terminology.

Another attempt at standardisation—again on the international level—is the W.H.O. document[8] on hand-operated sprayers for public health work. These standards describe test procedures and also list acceptable levels for certain test results. However, some aspects of these standards have been criticised as inflexible in respect of certain arbitrary methods of assessing the durability of a sprayer.

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Duration of Tests

In all cases a routine N.I.A.E. test on a sprayer is based on a single season's spraying ; on the other hand, there is much to be said in favour of continuing for two, three or more seasons, which would then make it possible to include biological assessments. Only the one season's work is possible, because in the present context a test is essentially an unbiased evaluation of a commercial product and, as such, it derives most of its value for the manufacturer and the farmer from its topicality.

Range of Crops and Conditions

If exact repeatability is to be obtained in tests carried out in successive years, they should really be done under identical conditions. This is impossible at the moment, and instead the N.I.A.E. rely on carrying out their field work under a range of representative conditions. The tests are carried out on commercial holdings, and the logic governing the selection of sites is the same for all types of test—the range goes from difficult conditions at one extreme to easy ones at the other. Because tree sprayers are working in perennial crops, there is the chance of returning to the same orchard for several years in succession, and in the case of mature trees they are likely to change little in form. To this extent, selection of test sites for sprayers is easier than for other implements. On the other hand, degree of foliation and weather conditions will not remain constant from year to year, and the different systems of pruning make possible a wide range of tree form—a variable not encountered in a crop like wheat.

As an indication of the degree of foliation, leaf deckage can be estimated in potatoes, but, unfortunately, no method suitable for use in routine test work has been devised for such an estimation in tree crops. Currently, the areas of potato leaflets are determined by laying a sample on a sheet of clean paper and applying a fine spray of dye solution. This produces silhouettes on the paper, which are then planimetered. Eventually, it is hoped to make use of a photometric method of area measurement.[9]

For certain phases of a test, particularly where measurements of deposit are to be made, there is much to be said for making use of an artificial tree. Such a " tree " would have aerodynamic characteristics similar to a natural tree, and sampling could be carried out at identical points in successive tests. Initial work on the development of such a tree shows some promise.[10] Used under still air conditions, an artificial tree would be only of limited value as a test tool. It would, however, be of great value if it could be used in the field under stated wind conditions or, better still, in a wind tunnel. Unfortunately, the achievement of this latter ideal would be expensive.

The behaviour of sprayers (particularly fruit sprayers) on sloping fields is investigated in a test because the outfit's ability to maintain speed up hill and the handling characteristics are important to many growers.

Quality of Work—Assessments under Controlled Conditions

Calibration and Durability Test of Pump. The output of a pump over its full range of working pressures is important to the user, because it often has a direct bearing on the rate of work which can be obtained, and similarly the pressure which it can maintain affects droplet size and penetration. Under test, a sprayer pump should have an output at maximum pressure considerably in excess of its requirements for delivery and agitation, so that it may continue to meet requirements even after wear has started to reduce its efficiency.

One difficulty with measuring the output of a pump when it is installed on a sprayer is the danger of confusing water delivery to the booms with total output. For the duration of the calibrations, overflow valves and pressure lines returning to the tank must be located and closed, and the output pressure controlled by a simple gate valve.

The estimation of pump durability or resistance to wear is not straightforward, because exact definition of the abrading medium is required and is difficult to achieve. In an N.I.A.E. test, copper oxychloride is the suspension used for all pumps. There are probably other more abrasive substances in regular use, but copper oxychloride has the advantage that it is well known and is easily available commercially in a more consistent physical form than many other insoluble spray materials. Some years ago the authors carried out an investigation using a laboratory rig to compare the abrasive properties of certain suspended spray chemicals and to compare the resistance of metal components to wear. A high degree of repeatability was not achieved and the work only served to emphasise the need for close control over test conditions and the particle size of the abrading medium.

Something of a paradox occurs when rotary sprayer pumps are used with water alone ; the rate of wear encountered has sometimes been greater than when pumping a spray solution such as M.C.P.A. Presumably, something in the latter formulation has either lubricating properties or has an influence on cavitation.

Relatively small quantities of suspended material in the water supply can have a marked effect on the rate of wear. This is important both in wear testing and in practice.

Calibration of Nozzles. The procedure laid down in B.S. 2,968 is straightforward for this phase of the test, although a difficulty encountered in the past serves as a warning ; a set of nozzles were calibrated using a reciprocating pump in the supply system. The results obtained were not in good agreement with a calibration of the same nozzles carried out at constant pressure—an error which may well have been attributable to the inability of the Bourdon gauge to give a true mean pressure on a pulsating supply. Nozzle calibrations are repeated at the end of the test to give an indication of the wear[11] which has occurred. Although currently this only represents the wear taking place in the field work of an N.I.A.E. test, it would be possible in the interests of repeatability to convert this to a bench test. Other effects of nozzle wear which have considerable practical significance are the change in droplet spectrum and distribution pattern. Time does not allow a repeat measurement of these factors in an N.I.A.E. test. However, it would be very helpful if an investigation could be carried out for each of the main types of nozzle to relate change of nozzle output to deterioration in pattern and change in droplet spectrum. Such an investigation would make possible a statement such as " no more than *x* per cent. increase in output should be allowed for fan nozzles because the pattern is usually unsatisfactory after this stage."

It has been shown that water temperature has relatively little effect on the output of spray nozzles,[12] and it is unlikely ever to have any significance in field work. However, the range of 5° F. has been suggested in Part II for the pre- and post-field work calibrations, because errors due to temperature change would be more apparent when the difference between two runs is being measured.

Evenness of Distribution from Hydraulic Nozzles. The performance of a nozzle in a patternator test is a realistic indication of one aspect of its behaviour in use. Unless a nozzle gives a good performance on the patternator, it cannot apply chemicals in the most economical way possible. This bears upon the question of optimum dosage, because once the correct weight per acre has been decided upon it is wasteful to apply excess spray to some plants and to underdose others.

Many different forms of patternator have been used, ranging from a sheet of corrugated iron as the simplest possible design. The latter can be most unsatisfactory, because the air stream which the droplets always carry with them is bent into the horizontal plane as it approaches the surface of the sheet, and in so doing carries some of the droplets sideways. Thus the true pattern is distorted and is in fact " squashed in the middle." The perfect patternator has yet to be designed, because dead-straight, knife-edge partitions are difficult to construct. The use of glass partitions seems to be a promising approach. An N.I.A.E. patternator (Fig. 1) is similar to the British Standard specification, but differs in that the collecting gutters are not connected to the partitions (which are in the form of an inverted V). This arrangement allows much of the air stream to pass down through the patternator as it would in a cereal crop.

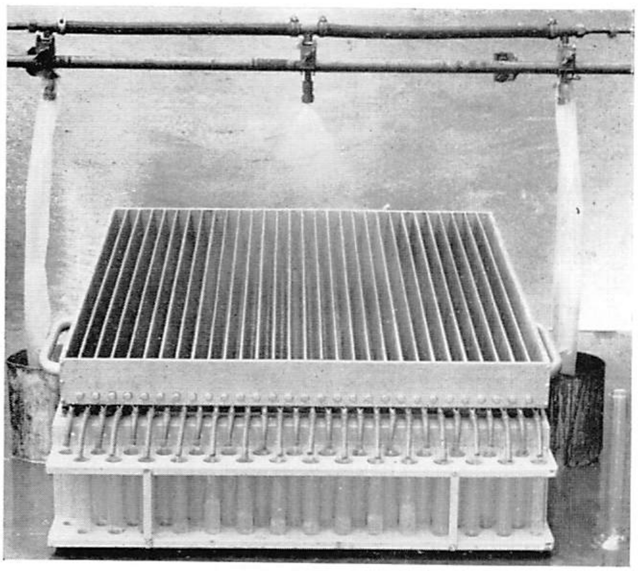

FIG. 1.
An N.I.A.E. Patternator ; the divisions are 1 in. wide. The adjacent nozzles on the boom have been shrouded in polythene tube.

Two-dimensional patternators which measure the evenness of distribution in both the longitudinal and transverse directions are of value in connection with initial design and development ; they are not normally used in routine testing because they do not give a direct picture of the effect on the crop in the way that the B.S. type does.

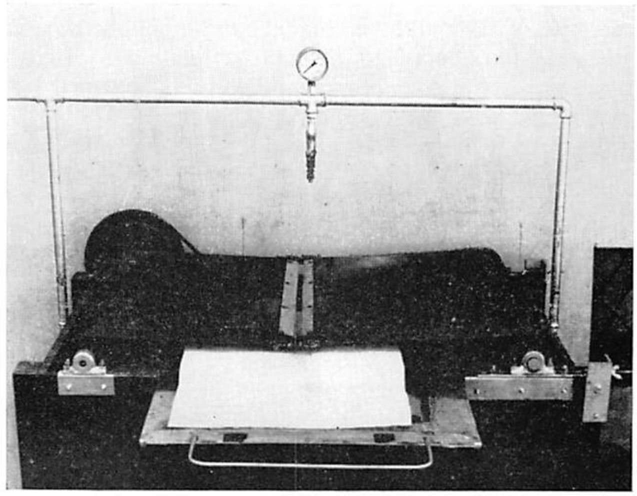

FIG. 2.
A version of the Riley Sprayograph ; the spray pattern on the paper has been partially drawn out of the belt for purposes of illustration.

The sprayograph (Fig. 2) is an enlarged version of a focal plane camera shutter with absorbent paper in place of a film. The only complication relating to its use is the disturbance of the air stream caused by the motion of the slit. The droplets collected on the paper thus often represent a biased sample of the spectrum ; the chief function of the sprayograph is similar to that of a two-dimensional patternator.

Air Output and Evenness of Distribution. The amount of energy contained in the air stream delivered by an air blast sprayer is some indication of the machine's ability to spray tall trees and work under adverse wind conditions. This statement applies only to broad differences, however, and it should not be implied that a sprayer delivering 5,000 cu. ft./min. at 90 m.p.h. is necessarily inferior in practice to one delivering 5,500 cu. ft./min. at the same speed. A better shape of delivery spout could well nullify the numerical difference between the two machines. It is not yet possible to state categorically whether a high volume, low-speed airstream is better than the converse, although broad limits can be indicated.[13] Pending further research, however, it is safe to say that with the possible exception of drift spraying a grower who has an extensive spraying programme necessitating working under adverse conditions should not select a machine which delivers only a low air horse-power.

In accordance with the B.S.[14] on the subject, sprayer air outputs are measured at the N.I.A.E. by passing the air stream through a straight length of pipe. The frictional resistance of the pipe to the air stream introduces a slight bias into the velocity measurements. An arbitrary correction is therefore made, based on the further reduction in air velocity brought about by the addition of a second and similar length of pipe.

Peak air velocities can easily be measured without the need for the ducting mentioned above, but if a rough estimate of the output is thus derived it should be used with caution, because without the ducting a reliable mean velocity and the corresponding cross-sectional area of the air stream are often difficult to obtain.

In many instances the shape of the air stream(s) when it has left the sprayer is of interest. Accordingly, attempts are currently being made at the N.I.A.E. to feed a large volume of smoke into the sprayer's air inlet and to record photographically the development of the cone or arc formed by the moving air.

Droplet Size Measurement. The measurement of fine particles and droplets is a very wide subject and almost a science in itself.

Anyone testing a sprayer, whether he be working with his own prototype or carrying out an official test, must strike a balance between a cursory visual examination of the droplets and a detailed analysis, which might well take up the whole time available for testing, to the exclusion of all other aspects of performance.

Collecting Media for Droplets. Several factors such as impaction velocity, spray liquid, ambient conditions, and droplet size govern the choice of droplet collecting media, and more specific works on the subject must be referred to for details.[15] [16] A few generalisations can, however, be made relating to the choices listed in Part II.

Impaction velocity : Harder, more highly-polished surfaces (*e.g.*, siliconed slides) are likely to cause large droplets to break up on impact. Plaster of Paris plates[17] and particularly the vaseline/paraffin mixture[18] are more tolerant of changes in velocity. Where the spread factor for a collecting surface has to be determined, it is important that this calibration be carried out at approximately the impaction velocity for which the surface is to be employed. Where possible, sampling should be carried out at a point where the droplets have lost most of their kinetic energy.

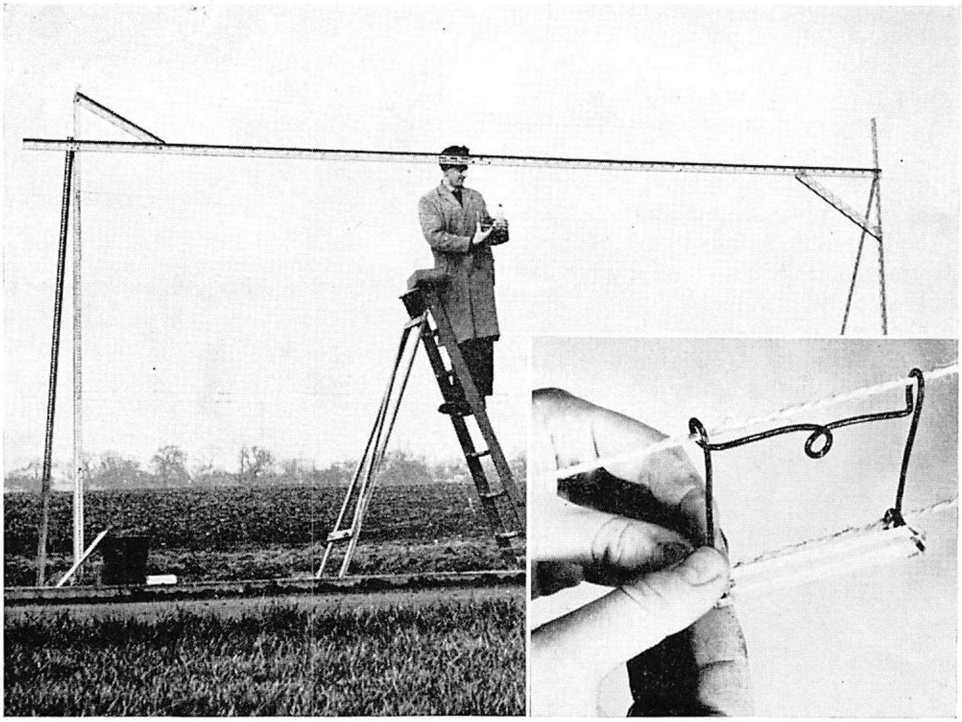

FIG. 3.
The structure used at the N.I.A.E. to carry vaseline/paraffin droplet collecting slides in a test of a fruit sprayer. *Inset :* One of the slides.

Spray liquid : Although the choice of collecting surface for oil is more difficult than for water, the problems of size change due to evaporation are absent with oil.

Ambient conditions : Working under conditions of high humidity and low temperature helps to keep size change due to evaporation to a minimum, and this is of particular importance where very small droplets are concerned.

Droplet size : There is always the danger with small droplets that either due to an over-large collecting surface or because of wind conditions they will fail to impact on that surface. It is for this reason that the narrow slides (Fig. 3) have been designed for test use, Wetting agents are omitted as a matter of routine during this phase of the test because this helps to maintain repeatability. It must be remembered, however, that in practice normal formulations will contain wetting agents, stickers, emulsions, suspensions, etc., and these are all likely to have some influence on droplet size.[19]

Sampling. A knowledge of the factors involved is essential in sampling droplets if large errors are to be avoided. The errors which would be introduced by using one slide, to collect droplets from one point in the pattern of a hydraulic nozzle, are well illustrated by Furmidge,[20] who showed that at different points in the pattern the mass median diameter (M.M.D.) changed from 190μ to 110μ and to even less on its fringe. Sampling with the nozzle in motion relative to the target is one step towards a representative sample, and a logical arrangement of slides across the width of the swath is another component.

Droplet Sizing. Complete automation of this operation has been achieved in a number of applications.[21]

The electronic counter which was developed at the N.I.A.E. has now been superseded by improved commercial machines which size by diameter instead of by

Fig. 4.
An operator using the projection microscope and dictating machine for droplet sizing.

the chord intercept method used in the N.I.A.E. machine. Regular use and a single operator who can keep a regular check on the machine's calibration seem to be essentials for this type of equipment. No doubt, electronic counting will be used in routine testing in the relatively near future ; in the meantime, the task of sizing by eye is made as simple as possible by supplying the operator (Fig. 4) with a dictating machine with a foot-operated control. As he measures the size of a droplet he works the control, calls out the dimension concerned, then removes his foot from the pedal until he has measured the next droplet. This arrangement allows him to have both hands free for measurement, and when the end of the tape on the dictating machine is reached, he takes a rest from counting and enters on a bank of tally counters the dimensions which have been recorded. With the majority of sprayers the droplet spectrum to be estimated is a broad one, and this automatically means that unless a very great number of droplets can be counted any averages which are derived must be approximate. Where droplet sizing is done by eye, the man hours involved limits the number of droplets which can be dealt with (using a projection microscope, one man sizes 1,000 to 1,400 droplets per hour).

There is much to be said for estimating droplet size with little or no greater accuracy than the accuracy with which practical requirements are known. At the moment there are very few cases of pesticide applications where an exact optimum size can be quoted with confidence, but it is true to say that it is quite often possible to state limits of acceptable droplet size. There is probably a great deal of truth in the suggestion made by a number of authors that the broad droplet spectra commonly encountered are useful when a sprayer has to deal with changing conditions of crop and weather. As conditions alter—for example, increasing wind—so can the optimum size alter, and a broad spectrum will insure that at least some of the droplets in the spray are of the optimum size.

Presentation of Results. The choice of a single statistic to express average droplet size has been the subject of much discussion[22] [20] and there are more than half-a-dozen averages from which to choose. However, two facts must be borne in mind—firstly, no average is ideal for all purposes or in relation to all pests, and thus different ones will be chosen in different cases ; secondly, no average contains as much information as the frequency distribution curve (whether by number, surface or volume). To work with the frequency distribution is best if possible, and although these are plotted on linear scales in reports intended for popular consumption, log/probability plots are useful to those carrying out the test. Amongst the averages the volume–surface mean diameter can be used fairly widely, and a logical justification of its use has been made.[22] The arithmetic mean diameter suffers from its unnecessary sensitivity to changes in the frequency of small droplets, whereas the M.M.D. changes considerably with the introduction of only two or three very large droplets (say, 300–500μ) in a spectrum containing thousands of smaller ones.

Quality of Work—Assessments in the Field

It is as well not to lose sight of the fact that there is only one ultimate criterion of sprayer performance—the net economic return on the spraying operation. Estimation of this on the basis of one year's experiment would be difficult and, what is worse, in a lot of cases misleading to the tester and the development engineer. Largely because of the time factor, the tester can go no further than physical measurements, and research must bridge the gap and show the effects of alterations in coverage upon the economic return. The intermediate step of estimating the effect of the spray on the pest (disease or insect counts) introduces the efficacity of the spray chemical as a further complicating factor. It has not so far been used in N.I.A.E. tests, but it has shown promise in a few instances : Butt[23] demonstrated the range of action of single spray droplets, and Courshee[24] subjected sprayed plants to controlled exposure to Phytophthera infestans.

The word micro-distribution will be applied to the distribution of spray on one surface of one leaf ; macro-distribution is the way the spray is divided between different surfaces and regions of the plants.

Distribution on Individual Leaf Surfaces. In routine tests only a limited number of the available techniques have been utilised. For example, plaster of Paris casts which make possible examination of deposits on twigs and fruitlets[25] have not been used, nor have cellulose acetate and gelatin films or auto-radiographs. These are excellent techniques to allow the research worker to examine deposits in detail, but the tester must limit his armoury to some extent.

Leaf printing has proved very valuable in test work, and the rapidity with which prints can be made (one operator, 200 leaves per hour) satisfies the need for a large number of replicates. It seems likely that all the possibilities for printing techniques have not been exhausted and, in fact, development of the converse of copper printing is under way at the N.I.A.E. This will involve the formation of a similar coloured copper complex, but the thiocarbamate will be the spray chemical and the copper the solution on the paper.

Fluorescent tracer techniques are very valuable in spraying, but it is important to sound a note of caution—there is a great deal of difference between comparing by such a technique the distribution of spray throughout one tree and the comparison of two treatments which may differ in droplet size, gallonage, tracer concentration, and so on. The eye, and the camera, can be misleading if this second type of comparison is made without coupling this visual technique with quantitative measurements on coverage. The quantitative measurements are currently made by techniques other than fluorimetry, although the latter has been used both for oil deposits[26] and aqueous sprays.[27] Fluorimetric methods are capable of further development if one or two inherent snags such as non-linearity and interference from trace impurities are overcome. An aspect of this type of tracer work which requires attention is a logical method of adjusting tracer concentration with spray application rate. In certain cases, it can be argued that tracer concentration should be varied in inverse proportion to the diameter of the smallest droplets which are of interest. Where very fine suspensions or true solutions of tracer are concerned there are difficulties associated with both the " constant weight of tracer per acre " basis and the " constant concentration " approach. A compromise between the two extremes is usually necessary, particularly where photographic recording is used.

Scoring Leaf Prints and Tracer Patterns. The first impression of this method is that it must be highly subjective ; in fact, however, close agreement is regularly reached between operators working quite independently, but from the same set of standard prints. The observations made in the previous paragraph about the danger of comparing treatments as distinct from variation within a treatment still apply under the present heading.

Distribution throughout the Target Area. In routine tests it is usually sufficient to measure the deposit of spray on groups of several leaf discs ; however, techniques are available for measuring separately the deposit[28] on the tops and bottoms of leaves. In a majority of cases, the aim of a spray application is to produce even cover throughout the plant ; in others a specific plant region has to be treated. Whichever is the case, the majority of treatments must apply a minimum dose per unit area to kill the pest and often have to remain below a maximum—governed by phototoxicity. Examination of the macro-distribution in this light, particularly if the lethal dose (L.D.) or L.D.$_{50}$ levels of the spray chemical are known, will reveal whether the treatment is likely to be deficient. Harm has been done to many people's understanding of spray problems by suggestions put about by individuals with a compound to sell that " a mere smell of it " will kill the pest. For each chemical–pest relationship there is an L.D.$_{50}$ or corresponding figure—microgramme quantities in many cases, it is true—but the point is that halving or further reducing this dose on certain areas of the plant by patchy spraying *will* reduce the kill obtained. Some recommended application rates contain a considerable safety factor, D.D.T., M.C.P.A., whereas others—*e.g.*, D.N.B.P. on peas—have to be used with narrow limits ; this, coupled with the chemical's systemic properties, if any, sheds further light on the interpretation of the macro-distribution of a spray.

New Methods. The analysis of the deposit of actual spray chemical on the leaf surfaces is, with few exceptions, lengthy. The biologist often requires such data, but in the testing context measurement of the distribution of the water is usually sufficient. Dyes have proved very useful and a further batch of dyes are currently being screened at the N.I.A.E. in the hope of finding one which is cheap and which has a higher tinctorial strength than Nigrosine. Nigrosine appears to cause no harm to plants other than the shading effect ; however, if a red or green dye can be found it will be pleasanter to handle.

Radio-active tracer techniques have been used in the laboratory and to a limited extent in the field.[29] The possibility of simultaneously obtaining auto-radiographs and rapid quantitative estimations is very attractive. However, as N.I.A.E. tests are carried out on a wide range of commercial holdings, such techniques have not so far been used. The need for close control with the appreciable quantity of tracer in a tankful of spray, and also a number of administrative complications associated with the use of these materials, mean that they are unlikely to be used in routine tests in the near future.

Statistical Analysis. In a majority of cases the data on macro-distribution can with advantage be subjected to an analysis of variance treatment. Not only does this provide an objective way of comparing the deposits in different regions, etc., but it emphasises the adequacy or otherwise of the replication—a most important point with such widely-scattered figures as dosage data. Although apparently not always appropriate, the $\log_{10} (D + 10)$ transformation for dosage data[30] is interesting in this context.

Range and/or Penetration of Spray. A high level of repeatability is difficult to achieve with measurements under this heading. At least a proportion of the work must be done under wind conditions which are less than ideal, because it is this aspect of performance in which the user is often interested. Up-currents of air could enable a low-powered machine to achieve some cover on the tops of tall trees ; such conditions, upon which potential users cannot rely, have therefore to be avoided. It is particularly important to obtain a realistic figure for the range of drift sprayers on ground crops because this is directly proportional to the machine's rate of work.

Rate of Work on Fuel Consumption

The majority of this Paper has been devoted to the assessment of quality of work only because of the variety and specialised nature of the techniques involved. In an N.I.A.E. test, and indeed in any test where a balanced picture of a machine is required, equal weight must be given to those aspects of performance subsequent to the topic " Quality of Work " in Part II of this Paper. It is a general principle in N.I.A.E. tests that the test machine is under observation all the time it is at work. The continuous time record which is obtained is useful not only as an indication of the speed of travel which is practicable under each condition, but also to show the causes and the amount of time spent on stoppages. Thus a realistic overall rate of work can be quoted.

Labour Requirement and Handling Characteristics

Under this heading and the one which follows occur those features which, if deficient in a particular machine, cause the greatest annoyance to the user. Measurement is used where possible, but there are obviously certain features, such as safety arrangements and the siting of controls, which can only be commented upon with, where necessary, reference by the officer in charge of the test (O. in C.) to a comparison machine(s). Adequate guidance in the form of a good operator's manual is another important feature.

Noise measurement has not so far been included in routine tests, but popular interest in the abatement of noise has quite rightly been aroused, and manufacturers must pay some attention to this point both from the point of view of the operator and " the neighbours." Official Australian tractor tests already include a measurement of noise level ; perhaps this will point the way to a more general scrutiny of noisy farm machinery.

In the testing of knapsack sprayers, objective assessment of items under this heading becomes difficult. The use of comparison machines and a number of operators of different stature helps, but there will always remain certain aspects of handling which are only the subject of personal preference ; it is the task of the tester to attempt to differentiate between these and objective points of difference.

Construction

Approximately 30 to 50 hours are spent in actual spraying under farm conditions, although there are exceptions to this. Such a period may appear short, but as anything from 5 to 10 or more tests sites will be involved, the achievement of this total, together with the detailed measurements, usually represents a full season's work.

Obviously, there will be cases where potential fatigue failures are not detected in the 50 hours' work, particularly as the corrosion/fatigue relationship may be involved with sprayers. However, this period of work has proved to be adequate for detecting the vast majority of mechanical faults. Even if the component concerned does not actually fracture, inspection at the end of the test will locate the weakness.

Resistance to Corrosion. Again this is a separate subject in itself, and the examination of the reaction of the various components to a relatively short list of typical chemicals (selected so that it contains one or more acid, base, oil, etc.) cannot possibly give a comprehensive answer. Fortunately, the chemical industry is now beginning to show more consideration for the engineer, so that, in the future, paint strippers and tank solvents are less likely to be found in spray formulations. However, even with careful grouping of chemicals, it will always be virtually impossible for the tester to state categorically whether a given tank lining is proof against *all* spray chemicals.

PART II

A DETAILED PROCEDURE OF TESTING FOR SPRAYERS

Scope of Test

The test will be carried out in a range of crops and/or conditions to assess the following features :

1. Quality of work. Assessments under controlled conditions :
   (*a*) Calibration and bench tests of pump and nozzles.
   (*b*) Measurement of air output (air blast sprayers).
   (*c*) Estimation of droplet spectrum.
   (*d*) Efficiency of agitation.
   Assessments in the field :
   (*e*) Quantitative and qualitative assessments of coverage.
   (*f*) Range or penetration of spray through foliage.
   (*g*) Comments on spray drift (ground crop sprayers).
2. Rate of work.
3. Power requirement (or fuel consumption).
4. Labour requirement and handling characteristics.
5. Suitability of construction.

Pre-Test Check

On arrival at the N.I.A.E. the machine will be examined to ensure that it is undamaged and correctly assembled. Notes will be made for reference at the completion of the test.

If it is decided to have the machine, or some components (*e.g.*, the pump), dismantled and measured before the test, the manufacturers will be invited to be present when the machine is re-assembled. After thorough lubrication, the sprayer will be run-in in accordance with the manufacturer's instructions, and they will then be invited to demonstrate it.

Choice of Tractor

The manufacturer will be asked to state the makes or horse-power range of tractors suitable for use with the machine. Before use, measurements will be made to ensure that selected tractors are capable of providing the speeds, pump pressures, etc., specified by the manufacturer. The suitability of the recommended tractors with reference to both performance and dimensional relationship at the points of attachment to the sprayer (particularly for mounted machines) will be noted.

Range of Crops and Conditions

Test work will be divided into several parts as follows :

1. Work under controlled conditions.
2. Field work.

(*a*) General farm work, during which rate of work, handling characteristics, suitability of construction and, to a limited extent, quality of work will be assessed.

(*b*) Detailed work on the quality of work during which the officer in charge of the test (O. in C.) will select the test sites so that conditions remain within stated limits.

Crops. The test machine will be operated under a representative range of conditions. The crops involved can be divided into four main groups :

(i) Tree crops (represented by apples and/or plums).
(ii) Bush or plantation crops (represented by blackcurrants).
(iii) Ground crops (represented by potatoes and/or cereals).
(iv) Glasshouse crops (represented by tomatoes and/or chrysanthemums).

The detailed field work on quality of work will normally be done on one or more of the crops mentioned in brackets. In the case of the routine field work, where only a visual check of coverage will be made, other crops may be used in order to examine the machine's general performance under as wide a range of conditions as possible.

Definition of Conditions. Within each of the above-mentioned groups, commercial crops will vary in regard to height, row width and density of foliage, etc. Test sites for detailed work on the quality of work will be carefully selected to avoid extremes. For example, for fruit sprayers the following points will be observed :

(*a*) Tree height will, where necessary, be restricted to conform to any limits suggested by the entrant.

(*b*) The trees will be in full leaf.

(*c*) The trees selected will have been pruned in accordance with good commercial practice (*i.e.*, trees which are excessively dense or excessively thin will be avoided).

(*d*) Planting distances will be such as to allow easy access for the spraying outfit.

In the case of all the crops mentioned for detailed work on coverage, with the exception of cereals, the regions of the plant will be designated as shown in Fig. 7.

Terrain. Field slope and other relevant data about the ground surface on the test sites will be recorded.

Meteorological Conditions. Wind speed and direction relative to the crop rows will be recorded during field work. During general farm work it will be estimated on the Beaufort Scale. When detailed work is being done, the speed will be measured using a cup anemometer at 3 ft. and at 6 ft. above ground level. Wet and dry bulb air temperatures will be recorded.

Comparison Machine

Crop conditions vary from year to year, and therefore to provide a " yardstick " a comparison machine will, when appropriate and at the discretion of the O. in C., be operated side by side with the test machine. The comparison machine will be of a type which is widely used in commercial practice, but it is not in any way implied that the comparison machine is necessarily the best in its class. Data obtained with the comparison machine will not normally be published in the test report.

Quality of Work—Assessments under Controlled Conditions

Calibration of the Pump. Calibration of the pump will be carried out on the sprayer or on a separate rig. A newly-calibrated gauge will be fitted. Total discharge rate (for tap water) will be measured, usually by weight, at a number of pressures ranging from the maximum to the minimum as stated by the manufacturer. If the pump may be used at various speeds, the measurements will be made at three speeds, including maximum and minimum recommended speed. As far as possible, the tests will be made in accordance with the British Standards on Pump Tests[6] and Flow Measurement.[31] This test will normally be carried out prior to the field work, but a run at maximum working pressure will be repeated after its completion to give an indication of the wear which has occurred.

Pump Durability Test. A bench test of the pump will be included at the discretion of the officer in charge of the test. This work may be carried out on the sprayer's own pump before or after the completion of the field work, but preferably will be done with an identical new pump supplied by the manufacturers.

Before the start of the bench test, the pump will be run-in for half-an-hour using a solution of M.C.P.A. salt (1 per cent. acid equivalent) in tap water. Throughout the remainder of this phase of the test the pump will be operated at the maximum working pressure recommended by the entrant. The stages in a pump test are as follows :

Table I

PUMP DURABILITY TEST

Stage	*Duration, hours*	*Material*	*Remarks*
1	$\frac{1}{2}$	M.C.P.A. salt	Running in
2	Measurement of output at maximum working pressure		
3	20	M.C.P.A. salt	Period increased to 50 hours if stages 5 and 6 are omitted
4	Measurement of output at maximum working pressure		
5	50	1% Cu oxychloride*	May be omitted in the case of sprayers designed only for true solutions
6	Final measurements and recording of output at maximum working pressure		

* If wear is only slight at Stage 6, a second period of 50 hours may be added.

Where appropriate, precise dimensions of the pump's components will be recorded before and after the test to supplement the index of wear provided by the change in output at maximum working pressure.

During the test the pump will be operated in a closed circuit and the charge of spray will approximate to the pump's output at maximum pressure during a period of three to five minutes. Heating of the spray liquid will generally occur and, where necessary, means for preventing an excessive temperature rise will be provided. The suspension will be changed half-way through the test period ; *i.e.*, after 25 hours.

Calibration of Nozzles. With each set of nozzles provided for the sprayer the manufacturer will be asked to supply two to four additional nozzles (additional to spares normally provided), which will be used for reference at the end of the test. They will be marked for identification, as will the nozzles which are fitted to the machine. Before the field work is started the output of all the nozzles will be measured at normal working pressure either on the sprayer (Fig. 5) or on a separate rig (the pressure and water temperature will be recorded), and three or four randomly chosen nozzles will be calibrated over the complete range of their working pressures. The recommendations of B.S. 2,968, referring to test procedure, will be followed.

At the completion of the field work, nozzle wear will be estimated by repeating the runs at normal working pressure (using water $\not>$ $\pm 5°$ F. different from that used initially). Repeat runs on the unused reference nozzles will be carried out to make certain that the setting of the pressure gauge has not altered since the beginning of the test.

Evenness of Liquid Distribution from Hydraulic Nozzles. In the case of ground crop sprayers, two or three nozzles taken at random from each set will be tested on the N.I.A.E. Patternator and on a Riley Sprayograph[32] (Fig. 2). New nozzles will normally be run-in with water for about one hour to remove burrs prior to these tests.

Patternator. The N.I.A.E. Patternator (Fig. 1) is similar to that described in B.S. 2,968, and the method of testing described in that Standard will be followed. The results of the Patternator test will be reproduced in the test report, and these, taken in conjunction with the output tests, and dimension checks, will enable a statement to be made as to whether the test nozzles appear to conform with the Standard.

For ground crop sprayer nozzles a test of the overall distribution of spray will be included (with a minimum of three nozzles operating on a boom), and when appropriate the effect of altering working height will be investigated. This is additional to the tests mentioned in the British Standard.

Sprayograph. This test, which produces on absorbent paper (Whatman No. 1) a plan view of the spray pattern, will be carried out using an aqueous solution of Nigrosine* ($\frac{1}{2}$–1 per cent.). Normal working pressure will be used or, in the absence of recommendations from the entrant, the standard pressures mentioned in B.S. 2,968

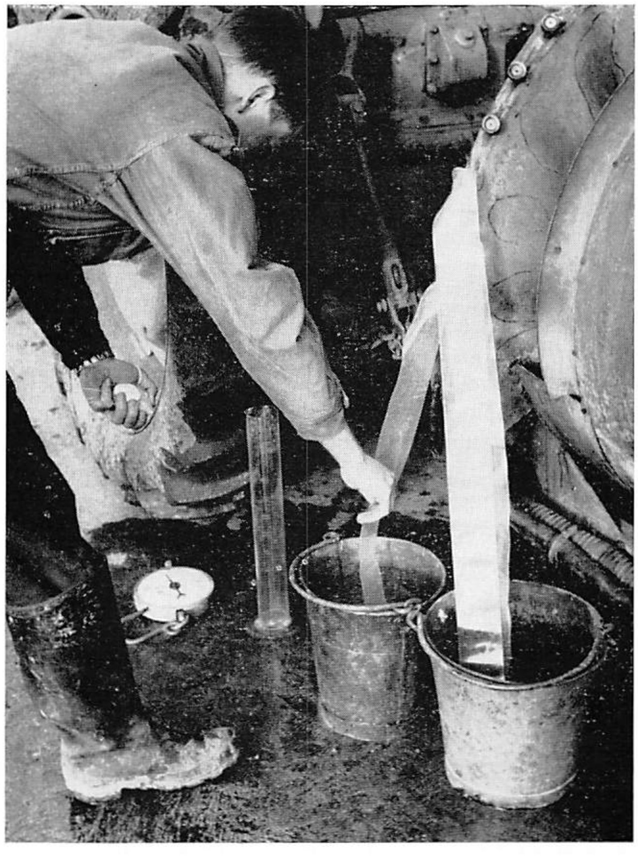

FIG. 5.
In situ calibration of nozzles ; only the water from one nozzle is in this instance being collected for measurement.

will be used.[4] Height settings will also conform with this Standard if the entrant does not give specific instructions. The length of time for which the paper is exposed in the Sprayograph will be adjusted so that there is little coalescing of stains. In certain cases a sampling box[33] may be substituted for the Sprayograph.

* Nigrosine G.140 water soluble crystals (I.C.I. Dyestuffs Division).

Air Output and Evenness of Distribution. The air output (cu. ft./min.) and velocity of discharge of air blast types of sprayers will, as far as the design of the fan housing allows, be measured in accordance with the British Standard on Testing of Fans.[14] When a machine is equipped with a number of outlets the total air output and the quantity of air delivered from each nozzle will be measured.

Droplet Size Measurement. An estimate of the droplet spectrum will be made for all nozzles not primarily intended for use at or above the run-off point. In the latter case, droplet size is less important and the measurement may be omitted after consultation with the entrant. This phase of the test will be carried out with tap water, to which $\sim$ 1 per cent. of a water soluble dye such as Nigrosine has been added to facilitate identification of the droplets. No wetting agents will be added to the water unless the entrant makes special recommendations to this effect in his instruction book. The effect of pressure changes on droplet size will not normally be investigated ; instead, droplets will be measured only at normal working pressure. Determinations on replicate nozzles may be required.

Occasionally the droplet spectrum produced when spraying oil will be measured if this is an important practical aspect of the machine's work.

Collecting Media for Water Droplets. The normal technique which will be used whenever practicable will be to collect samples of the droplets on the surface of a mixture of $\sim$ 25 per cent. vaseline and 75 per cent. medical paraffin[18] which has been stored over watei (the mixture can be adjusted to suit test conditions). Conditions of low ambient humidity or high temperature will be avoided for this work, and in any case the collecting slides will be flooded with further medical paraffin (also stored over water), if possible, within one minute of droplet collection (this will prevent further evaporation). When collection of droplets from a tree sprayer is undertaken, trough-like slides (Fig. 3) measuring $\frac{3}{8}$ in. by 3 in. will be used to hold the paraffin/vaseline mixture (they can be mounted in any plane), and for ground crop sprayers either these slides or Petri dishes are suitable. By this method the collected droplets are maintained in spherical form and true spherical diameter is measured. When samples taken as described above have to wait their turn to be measured ($\not>$ 24–48 hr.), they will be stored in a box in which the humidity approaches 100 per cent.

In certain cases, alternative collecting media may be required and several are available—glossy art board*[34] which has a spread factor of $\sim \times 2\frac{1}{4}$; plaster of Paris plates,[17] spread factor $\sim \times 3{\cdot}8$; and silicone treated glass slides[35] (which require an increase in Nigrosine concentration to $\sim$ 2 per cent.), spread factor $\sim \times 1\frac{1}{2}$. These surfaces will be used for rapid preliminary determinations and/or where a permanent record is required.

Collecting Media for Oil Droplets. Depending on droplet size and method of dispersal, oil droplets will be collected on either a magnesium oxide film[36] (for small droplets) or on glass slides treated with an oleophobic material.[37] An oil soluble dye will be included in the spray fluid, which will be one of the commercially available spraying oils (*e.g.*, Shell Risella 17). The art board previously mentioned may be used during preliminary work.

Location of Collecting Slides during Sampling. In all cases the aim will be to collect a representative sample of the spray droplets in the vicinity of the sprayer's normal target (plant or tree) ; the droplet spectrum in this region will not necessarily be identical with that of the spray in the immediate vicinity of the nozzle.

Droplet Sampling—Ground Crop Sprayers. For low-volume nozzles the collecting surfaces will be placed on the floor of a sampling box and the sprayer boom driven over them at normal working height and speed (4 m.p.h.) under still air conditions. When slides are used the long dimension will be parallel to the boom. Suitable positions will usually be selected by carrying out preliminary runs over strips of white paper placed parallel to the boom, and in any case the several collecting slides used will be placed on such a strip (further information about sampling positions will be provided by the sprayograph patterns obtained earlier).

The coalescing of droplets on the collecting surfaces will be avoided by reducing the width of the slit in the sampling box. In certain cases, a nozzle under test may be removed from the sprayer and mounted on a separate rig.

Droplet Sampling—Automatic Tree Sprayers. Preliminary runs will be made using paper strips as targets to indicate suitable positions for the collecting surfaces. The latter will be mounted on strings (Fig. 3), which will be arranged on a light structure in such a way that they will draw a representative sample from most of the spray arc from the horizontal upwards. Each collecting surface will be arranged so that it is approximately normal to the path of the droplets and/or air stream at that point. The distance between the sprayer and the collecting surfaces will approximate to the normal working position of the sprayer relative to a row of apple trees. The sprayer will be driven at normal working speed (usually 2–3 m.p.h.) past the structure which holds the slides. The work will be carried out under fairly calm conditions outdoors (wind preferable, $\not>$ Beaufort Force 2) or indoors if practicable.

Droplet Sizing and Expression of Results. The droplets in suitable areas of the collecting surfaces will be measured using a projection microscope (Fig. 4). The classification of sizes will usually be in steps of $\sim$ 20 microns. The number of slides resulting from each run will depend upon the configuration and homogeneity of the droplet spectrum over the sprayed area. Thus the number of droplets counted per run will vary, but will usually be in the region of 1,000 to 3,000. When 50–100 droplets in a particular size group have been counted, this generally constitutes an adequate sample ; where a group contains less than 10, further counting is advisable. High numbers are usually reached first in the small size groups. When this occurs, subsequent counting can be confined

* "Priority White Art Board." Spalding & Hodge Ltd., Russell Street, London, W.C. 2.

to larger droplets only—say, $\not> 200$ or 300 microns diameter,[38] the area scanned for these large droplets being a known multiple—say, 4 to 10 times—of the area initially scanned.

The results of the counts will be reported as frequency histograms (by number), and three averages will be calculated :

1. The arithmetic mean diameter.
2. The volume–surface mean diameter $= \dfrac{\Sigma\, nd^3}{\Sigma\, nd^2}$
3. The mass median diameter—a calculated diameter such that 50 per cent. of the volume of the spray is contained in drops smaller than that diameter.

Agitation in the Sprayer Tank. Except in the case of simple ground crop sprayers intended only for use with true solutions, the efficiency of the test machine's agitation system will be investigated. The test suspensions will be commercial samples of :

Ground crop sprayer—copper oxychloride (1 %).
Fruit sprayers—lead arsenate (1 %).

The first test will measure the machine's ability to maintain a full load of freshly prepared suspension without appreciable settling out. The machine will be left running with the booms turned off for half-an-hour, after which time three separate 100 ml. pipette samples will be drawn from 6–10 in. below the surface of the liquid in the tank (washing out the pipette between each sample). The concentration of the three samples will be determined in the laboratory ; all three samples should have the same concentration and should correspond with the original concentration if agitation is satisfactory. In many cases this can be checked by draining the tank quickly at the end of the half-hour period and examining the bottom of the tank for sediment.

The second part of the test will measure the machine's ability to re-suspend the mixture after settling times of 1, 2, 4 and 24 hours. At the end of each settling time the sprayer will be started up, and single pipette samples taken at 1, 3, 5 and 10 minutes after the start of agitation. In the case of hand sprayers, this phase of the test will simply be a check on the sediment left in the bottom of the tank after spraying out one load of each of the above materials.

Quality of Work—Assessments in the Field

Before starting the field work, as much as possible of the indoor work will be completed, as it will usually help the test team to obtain optimum results in the field. No biological assessments of coverage will be made. Physical assessments will, however, be made, and in most cases quantitative measurements of the evenness of distribution of the spray to the different regions of the target (macro-distribution) will be made simultaneously with qualitative assessments of distribution on individual leaf surfaces (micro-distribution).

Selection of test sites has been discussed earlier ; at least one set of runs will be done in tall trees so that some indication of the practical maximum working height can be given.

Estimation of Leaf Deckage in Potatoes. An estimate of " leaf deckage "[39] (an indication of the density of potato foliage) will, if possible, be made in the fields where quantitative work is carried out. The leaves stripped from three to five 5 ft. lengths of row will be dried in an oven and weighed. Simultaneously, 30 or 40 leaves will be planimetered and also oven-dried and weighed to give an estimate of " leaf area per unit dry weight." From these two figures the leaf deckage (acres of leaf plan view per acre of field) will be calculated.

Distribution on Individual Leaf Surfaces. Where practicable, preference will be given to those methods which involve the use of leaves rather than artificial targets.

Leaf Printing. Several substances in common use as spray materials produce a dark-coloured stain on a white background if the sprayed leaves are pressed between sheets of suitably sensitised paper. These methods will be used whenever practicable to indicate the distribution of spray chemical on individual leaf surfaces and the relationship between the coverage on the top and bottom surfaces of the leaves.

(*a*) Leaf prints with copper sprays. This method will be used with any copper-containing spray, but it is principally intended for use with those sprays which contain ~ 50 per cent. metallic copper and which are applied at the rate of 5 lb./acre. When the spray has dried, 40 to 50 leaves (leaflets in the case of potatoes) will be picked at random from each of the plant regions and will be treated as follows :

1. Two foolscap sheets of Whatman No. 1 filter paper will be marked (with Biro) with identification numbers and then dipped in a solution of 0·5 g. bis-cyclohexanone oxalyldihydrazone in 50 ml. methanol, 48 ml. water and 2 ml. glacial acetic acid, and briefly allowed to drain.*
2. Surface moisture will be removed from the sheets by blotting them between sheets of clean newspaper.

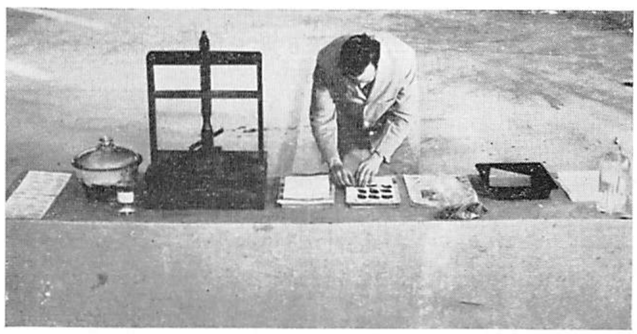

Fig. 6.
Making leaf prints with a copper fungicide. The process is arranged in order from the operator's left to his right.

3. Sample leaves will be arranged on one sheet of moistened paper and the other sheet placed on top. This sandwich is then placed between sheets of dry newspaper, and this in turn is sandwiched between two sheets of $\frac{1}{2}$ in. sponge rubber and pressed for $\sim \frac{1}{2}$ minute in a letter press (Fig. 6).

* This method has been developed from the original, but unpublished method suggested by Pizer, N. H., and Dewis, J. W., of N.A.A.S., Cambridge.

4. The pressure is released and after discarding the leaves, the two sheets of filter paper will be put into an ammonia atmosphere for ~5 minutes to " develop " (0·88 ammonia solution in the bottom of a desiccator). Particles of copper show up as permanent blue stains on the paper.

(*b*) Leaf prints with lead arsenate. When this insecticide is in use, usually on fruit trees, prints will be obtained by forming a brownish-black lead sulphide stain.[40] Best quality typing paper is substituted for the filter paper and the first treatment for this paper is a dip in 5 per cent. sodium hydroxide solution for one minute. Excessive liquid will again be removed on clean newspaper (great care is needed in handling the paper at this stage, as it is on the point of disintegration. Except for an increase in pressing time to 1 minute, steps 2 and 3 are the same as for the preparation of copper prints, and are followed by :

4. Removal of the sandwich from the press, discard of leaves and development of the prints to completion in a 5 per cent. solution of lime-sulphur.
5. Washing the prints gently in clean water and then drying them slowly between sheets of newspaper.

(*c*) Leaf prints with lime-sulphur. A reaction similar to the above has been developed for use with lime-sulphur sprays. Steps Nos. 1 to 3 are the same as for the copper printing method, except that a 1 per cent. solution of lead nitrate or silver nitrate is substituted for the cyclohexanone solution. The prints develop in the press without the need for further treatment.

Fluorescent Tracers. Techniques involving the addition of fluorescent materials to the spray fluid[41, 42] will, at the discretion of the O. in C., be used in place of leaf printing techniques to indicate the distribution of spray on the leaves. A useful pigment is Saturn Yellow (0·2 to 0·02 per cent. suspension), although other colours[42] and true solutions[43] are available where necessary. To ensure wetting, the powder will be creamed with a liquid wetting agent prior to adding it to the sprayer tank. Under certain circumstances, it will be necessary to increase the concentration of tracer where photographic recording of fine droplets is required. Preliminary examination of the coverage obtained will be carried out with the leaves *in situ* either by using an ultra-violet lamp at night or in sunlight by examining the leaves in a darkened box fitted with a Wood's glass top.[42]

Fluorescent tracers will not be mixed with dark-coloured spray solution (*e.g.*, Nigrosine, because of the masking effect of the dye).

Artificial Leaves—Tree Sprayers. A permanent indication of the coverage obtained during tree spraying can conveniently be obtained simultaneously with quantitative work involving the use of Nigrosine dye (at a concentration ~½ per cent.). Artificial " leaves " measure 1½ × 2 ins. and have a small hole punched at the centre of one of the short sides. The " leaves " are made of either absorbent paper backed with a self-adhesive polythene film, or of the art board mentioned previously. They will be tied to the trees with string, and prior to attachment identification letters giving details of the spray treatment, which surface is uppermost, and of the tree region in which they are placed will be marked in the top left-hand corner. After the spray has dried, the tags will be collected and trimmed down to 1½ in. square and are then available for photographing if necessary.

Artificial Targets—Ground Crop Sprayers. When spraying cereals with herbicides at typical rates per acre, a qualitative indication of the machine's performance will be obtained by placing strips of paper (1½ × 10 ins.) on the ground beneath the crop. The strips will be placed at random, some between the crop rows, others across them. A Nigrosine solution (~½ per cent.) will be used in the spray tank. After the spray has dried, the strips will be collected and the consistency of coverage assessed visually. Absorbent paper will be suitable for this work for low-volume applications where fine droplets may be involved, and art board will be used for higher volumes. At the discretion of the O. in C., a comparison machine will be tested in the same way.

Quantitative measurements of the amount of spray penetrating the crop foliage will not be made as a matter of routine, but methods are available if this becomes necessary.[44]

Scoring Leaf Prints and Tracer Patterns. Although leaf prints and the work with fluorescent tracers will be used mainly to assess coverage on individual surfaces, a scoring technique will generally be applied which will provide information to supplement the quantitative measures of distribution throughout the tree. The technique consists of selecting from the leaf prints, or from the leaves treated with fluorescent tracer, a set of " standards " which are a series of leaves arranged in ascending order of quantity and completeness of spray cover. The ten leaves are awarded marks from 1 to 10 ;

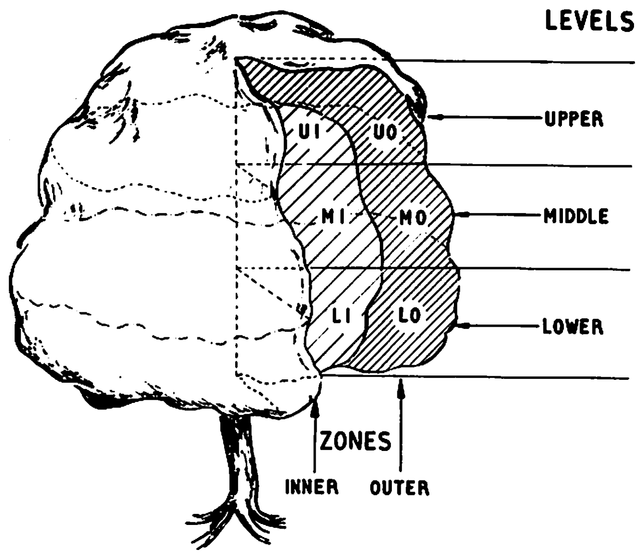

FIG. 7.
Sketch of tree showing the designation of the regions from which samples are taken.

the leaf marked 1 shows only a trace of deposit, 5 is generally just below an arbitrary " acceptable " level, and 10 represents fully adequate cover. Marks in excess of 10 will not be awarded to leaves on which the cover is excessive. Once these standards have been established, two observers working independently " score " a large number of leaf prints using the standards for comparison and noting the regions from which they come. The average mark for each tree region is then calculated. Photographs of the Standards are, where appropriate, available for reproduction in the report, but as they are only arbitrarily chosen, the scores are intended only as an indication of the distribution throughout the tree. It should be emphasised that direct comparisons between different gallonage rates, sprays with different droplet spectra, or between different sites, cannot normally be made on this basis alone.

Distribution throughout the Target Area. The distribution of spray throughout the target area will be measured in terms of the quantity of material deposited on leaves in the different plant regions (Fig. 7). Leaf discs 1 in. diameter will be cut from the leaves (Fig. 8)

FIG. 8.
Cutting leaf discs from the leaves of plum trees prior to measuring the amount of dye on them.

without removing them from the plants (using special discing pliers). As soon as each sample (from 1 to 10 discs) has been taken, it will be ejected from the pliers into a chemically clean sample bottled and sealed, or, when ashing is to follow, the samples may be wrapped in ash-free filter papers. The number of leaf discs per sample will vary with circumstances and must be sufficient to provide a measurable quantity of chemical from most of the samples.

With copper-based sprays conventional analytical techniques may be used. In other cases, tracer dyes such as Nigrosine will be used. In either case, samples of the spray fluid will be taken from the nozzles just before or during spraying in order that the concentration of the tracer material can be determined.

Copper Analysis. The quantity of copper on the leaf discs will be determined by a colorimetric method[45] involving ashing the discs and the use of a cyclohexanone derivative to develop a coloured complex.

Tracer Dyes. Dye concentration will be adjusted to facilitate analysis. The dye solution in the sprayer tank must not contain any dye in suspension.

The leaf discs will be washed in clean water, to which a small amount of a liquid detergent has been added. The strength of the solution thus obtained will be determined in an absorptiometer. A calibration curve will be obtained using dye solutions of known concentration and, using this, spray dosage will be expressed in terms of μl/sq. cm. For comparative purposes, this will usually be brought to the common denominator of " μl/sq. cm./100 gal./acre applied."

In all quantitative work of this type " blank " determinations will be done on samples taken before spraying. Thus absorptiometer readings can be corrected for errors introduced by dissolved sap and dust from the surfaces of the leaves.

Range and/or Penetration of Spray. The quantitative estimations of dosage distribution under the previous heading will provide an indication of the ability of tree and potato sprayers to force spray through the foliage of the crop being treated. The work will be done under relatively calm conditions and repeated when there is a stronger wind, and on progressively taller trees until the limit is reached.

The range of drift sprayers will be investigated initially by using fluorescent tracers, or dye solution and artificial leaves. Quantitative estimations of the dosage on successive rows will follow the preliminary work.

Spray Drift. Due to the difficulties associated with reproducing a particular set of conditions which produce drift, measurements of it will not be included as a matter of routine in sprayer tests. Excessive drift is most serious in relation to ground crop sprayers. If such a machine under test appears to produce either an unusually high or unusually low amount of drift in relation to the comparison machine, the drift raising from the two machines will be measured when applying herbicide to cereals. The two machines will be operated in quick succession under conditions which are as nearly as possible identical.

Rate of Work and Fuel Consumption

The following information will be recorded during field work :

(1) Site conditions—planting distances, heights of plants, degree of foliation and weather.
(2) Total working time, excluding operations connected with filling.
(3) Turning time and any other stopped time and the causes.
(4) Accessibility for cleaning and maintenance.
(5) Spot readings of forward speed.
(6) Fuel used by self-engined sprayers.

Power Requirement

In the case of p.t.o.-driven machines, the power consumption will be measured using the N.I.A.E. strain gauge torque-meter.[46] The tractor will be stationary and measurements will be made over the full designed range of p.t.o. speeds and pump pressures. Where possible, the power requirement for the fan and for the pump will be measured separately.

The draught requirement of trailer machines will be measured on the flat, in work, with the tank full.

Labour Requirement and Handling Characteristics

Observations on the following topics will be recorded :
(1) Ease of setting and adjustment (including timings).
(2) Ease of filling with water and chemical.
(3) Dimensions of turning circle with specified tractor.
(4) Accessibility for cleaning and maintenance.
(5) Adequacy of guards and other safety devices.
(6) Working conditions for the operator (noise and spray drift).
(7) Accessibility of controls.

Particular attention will be paid to observations under this heading when a knapsack sprayer is being tested. Ease of operation and carrying and operator fatigue will be assessed by allowing several operators to use both the test machine and a comparison machine.

Suitability of Construction

Any faults, distortions or breakages which occur during the test will be noted. On the completion of the test the machine will be dismantled and the components examined in detail for signs of excess wear or distortion.

Resistance to Corrosion. The spray materials used during the test will conform with any restrictions imposed by the manufacturers in their instruction book. Inspection during and at the end of the field work will reveal whether any of the materials used have given rise to undue corrosion.

During the field work it may not be possible to arrange to use the sprayer with certain materials which may be important from the corrosion point of view ; consequently, some further tests will be carried out after the field work. A list of twelve spray materials which are widely used, and which represent important chemical groups, has been drawn up, and, with certain reservations, the sprayer tank will be filled with each of these in turn and allowed to stand for 72 hours with occasional agitation (with cleaning out and inspection before each new material). The liquid temperature will be within the range 50–65° F. The list of chemicals, which will be used at the concentration shown is :

1. M.C.P.A. salt, 1% acid equivalent.
2. D.N.C. (herbicide), ½%.
3. Sodium chlorate, 20%.
4. Copper oxychloride, 1%.
5. Wettable sulphur, 1%.
6. Lime sulphur, 20%.
7. Organo-mercury fungicide, 0·5%.
8. Lead arsenate, 1%.
9. D.D.T. emulsion, 1·5%.
10. Tar oil (insecticide), 5%.
11. T.C.A., 2%.
12. Sulphuric acid, 10%.

The materials will be used in this order with the omission of those materials which (*a*) have been encountered during the field work, (*b*) the manufacturer specifically requests be excluded and which will be noted in the report, and (*c*) are inappropriate for the sprayer under test—*e.g.*, M.C.P.A. in a fruit sprayer.

ACKNOWLEDGMENTS

The authors wish to acknowledge the continuing help given to them by their colleagues in the Horticultural Engineering Department of the N.I.A.E. ; in particular, Mr. R. J. Courshee and Mr. J. B. Byass.

REFERENCES

1 McLaren, D. I., "Testing of Agricultural Machinery, with special reference to Root Crop Harvesting Equipment," *J.Inst.Agric.Eng.*, 1958, 14 (3), 98.

2 Bailey, P. H., "The Testing of Green Crop Driers," *J.Inst Agric.Eng.*, 1951, 8 (1), 15.

3 Manby, T. C. D., "Recent Developments in Tractor Testing Technique at the N.I.A.E.," *J.Inst.Agric.Eng.*, 1957 13 (3), 3

4 "Hydraulic Spray Nozzles," British Standard 2,968 : 1958.

5 "Tests for Agricultural Tractors," British Standard 1,744 : 1960.

6 "Pump Tests," British Standard 599 : 1939.

7 "The Testing of Farm Machinery on an International Basis." Report of an International Demonstration by the E.P.A. of O.E.E.C., June, 1956.

8 "Manual of Specifications for Insecticides and for Spraying and Dusting Apparatus," W.H.O., Geneva, 1956.

9 Miller, E. E., *et al.*, "Use of an Optical Planimeter for Measuring Leaf Area," *Plant Physiol*, 1956, 31 (6) 484.

10 Byass, J. B., *et al.*, "A Low-Pressure Air-Blast Nozzle and its Application to Fruit Spraying," *J.Agric.Engng.Res.*, 1960, 5 (1), 94.

11 Westerman, A., "Hydraulic Spray Nozzles," Proc. 3rd Brit. Weed Cont. Conf., 1956, p. 119.

12 Hebblethwaite, P., Underdown, P.J., "The Influence of Temperature on Output Tests of Agricultural Spray Nozzles," N.I.A.E. Dept. Note 44, 1955.

13 Byass, J. B., "How Airspeed affects Penetration," *Commercial Grower*, 1960 (3345), 323.

14 "Testing of Fans," British Standard 848 : 1939.

15 May, K. R., "The Cascade Impactor—an Instrument for Sampling Coarse Aerosols," *J.Sci.Inst.*, 1945, 22 (10), 187.

16 Furmidge, C. G. L., "The Measurement of Spray Droplet Size in the Field," Long Ashton Annu. Rep., 1954, p. 118.

17 Courshee, R. J., Valentine, R. W., "Use of Plaster of Paris for Recording Spray Drops," *J.Agric.Engng.Res.*, 1959, 4 (1), 62.

18 Courshee, R. J., Byass, J. B., "A Study of the Methods of Measuring Small Spray Drops," N.I.A.E. Report No. 31, 1953.

19 Metcalf, R. L., "Advances in Pest Control Research," *Interscience*, New York, 1958, 2, p. 426.

20 Furmidge, C. G. L., "The Evaluation of an Average Droplet Diameter in Sprays," Long Ashton Annu. Rep., 1954, p. 106.

21 Trickett, E. S., Courshee, R. J., "A Spray Deposit Analyser," N.I.A.E. Report, No. 27, 1953.

22 Courshee, R. J., "A Tree Spraying Machine," N.I.A.E. Report No. 36, 1954.

23 Butt, D. J., "The Range of Fungicidal Action of Micro-Deposits of Captan on Artificial Surfaces and on Leaves," Long Ashton Annu. Rep., 1955, p. 127.

24 Courshee, R. J., "Experiments on Applying Copper for the Control of Late Blight," Proc.Int.Agr.Aviat.Conf., Cranfield, 1960.

25 Martin, J. T., "Distribution of Copper Fungicide Deposits on Plant Surfaces," *Nature*, 1953, 172 (4,372), 313.

26 Hebblethwaite, P., "The Application of Electrostatic Charging to the Deposition of Insecticides and Fungicides on Plant Surfaces," Mich. State Univ. Thesis., 1952.

27 Liljedahl, L. A., Strait, J., "Spray Deposits Measured Rapidly," *Agric.Engng.*, St. Joseph, Mich., 1959, 40 (6), 332,

[28] HEBBLETHWAITE, P., "A Colorimetric Method for Measuring Dosage Distribution in Potato Spraying," *Plant Pathology*, 1956, 5 (1), 26.

[29] NORDBY, A., STEENBERG, K., "Application of Radio-active Plant Protection Chemicals for Illustration and Quantitative Evaluation of Spray Deposits," *J.Agrc.Engng.Res.*, 1959, 4 (2), 174.

[30] YEO, D., COUTTS, H. H. "Dosage Distributions on Coffee Plants," Col.Pest.Res.Unit, Misc.Rep. No. 250, 1959.

[31] "Code for Flow Measurement," British Standard 1,042 : 1943.

[32] SHANKS, G. L., PATERSON, J. J., "The Riley Sprayograph," *Agric.Engng.*, St. Joseph, Mich., 1952, 33 (7), 428.

[33] COURSHEE, R. J., "Investigations on Spray Drift, Part I," *J.Agric.Engng.Res.*, 1959, 4 (2), 144.

[34] YEO, D., COUTTS, H. H., "The Use of Glossy Paper for the Determination of Droplet Sizes," Col.Pest.Res.Unit, Misc. Rep. 171, 1956.

[35] COURSHEE, R. J., BYASS, J. B., "Preparation and Calibration of Glass Slides for Sampling Sprays," N.I.A.E. Report No. 32, 1953.

[36] MAY, K. R., "The Measurement of Airborne Droplets by the Magnesium Oxide Method," *J.Sci.Instrum.*, 1950, 27 (5), 128.

[37] BROWN, A.W.A., "Insect Control by Chemicals," John Wiley and Sons, New York, 1951, p. 458.

[38] HEDDEN, O. K., "Spray Drop Sizes and Size Distribution of Pesticides," Amer.Soc.Agric.Eng. Paper No. 60-602, 1960.

[39] LARGE, E. C., "Field Trials of Copper Fungicide for the Control of Potato Blight—II, Spray Retention," *Ann.App.Biol.*, 1946, 33 (1), 54.

[40] HAMILTON, C. C., "A Colorimetric Method for Showing the Distribution and Quantity of Lead Arsenate on Sprayed or Dusted Surfaces," *J.Eco.Ento.*, 1925, 18, p. 502.

[41] SHARP, R. B., "The Detection of Spray Deposits using Fluorescent Tracers," N.I.A.E. Tech. Memo, 119, 1955.

[42] STANILAND, L. N., "Fluorescent Tracer Techniques for the Study of Spray and Dust Deposits," *J.Agric.Engng.Res.*, 1959, 4 (2), 110.

[43] SHARP, R. B., "An Experimental Fluorescent Tracer Solution," *J.Agric.Engng.Res.*, 1960, 5 (3), 340.

[44] HEBBLETHWAITE, P., "A Tentative Method for Investigating the Influence of Application Rate on the Penetrative Power of Herbicide Sprays," *J.Sci. of Food and Agric.*, 1955, 6 (10), 582.

[45] SOMERS, E., GARRAWAY, J. L., "Modification in the Method of Determining Copper with BIS-cyclo-hexanone Oxylyldihydrazone," *Chem. and Ind.*, 1957 (13), 395.

[46] RICHARDSON, R. D., FILBY, D. E., "A Tractor Pulley Torquemeter employing Electrical Resistance Strain Gauges," *J.Agric.Engng.Res.*, 1959, 4 (1), 16.

DISCUSSION

MR. R. M. FOULDS (Technical Adviser to the Kent Engineering and Foundry, Ltd.) opened the discussion by remarking that he had been pleasantly surprised at the vast amount of good, sound common sense in the Paper, and that he was even more pleasantly surprised now that the authors had given their personal opinions.

He first took up a remark of Mr. Hebblethwaite's, who had said : "Testing and the evaluation of test results is in a non-man's land between the engineer and the biologist." Mr. Foulds said that time and time again during the reading of the Paper one came down to the hard, acid test, which was that, although the engineer could produce equipment for special circumstances, in this case he did not know what the circumstances should be. This was no criticism of the biologist, but was a question of whether the whole job was being properly done.

To crystallise these points, he was interested to note that an hydraulic machine was used as a standard comparison, and the point was also made that this was not a modern sprayer. However, he thought that as the majority of fruit sprayers were air-blast sprayers, an hydraulic sprayer did not really form quite as good a comparison as it should—it was of interest, but not a good comparison. On the interpretation of air output figures, he said that air horse-power would be very handy and an accurate standard of comparison.

With regard to droplet size, there had been a lot of good sense spoken on the subject that day, and there had been a lot of rubbish or unproven comment talked about it elsewhere. To-day they had received good advice, although once again the biologist did not tell the engineer exactly what was wanted.

Mr. Foulds warned about the dangers of fluorescent tracer work. They all knew what a pretty sight it was, but it could be potentially rather misleading to the farmer. He agreed with a remark of Mr. Hebblethwaite's on the dangers of using leaf discs with high-volume work. Leaf discs were ideal for low-volume measurements.

He thought that there was an ever-increasing use of systemic chemicals. It was pretty obvious in his own mind that when more and better systemic chemicals came along this was going to affect materially the whole technique of assessment. Even now there were many growers who could get away with bad application by using systemics. About field usage of machines, he declared that this was very important. They could assess facts and figures, but these were not simple and understandable to the user, being technical problems. The assessment of sprayers always rested on the man who used them. Sprayer operators were called tractor drivers nowadays, which indicated how little attention this skilled job received. More attention should be paid to the fact that it was upon the man operating it that a machine could depend. He thought handling characteristics were terribly important and did not think opinions should be subdued on that, but that comments must be made.

MR. RICHARDSON answered Mr. Fould's point on the use of an hydraulic comparison machine by saying that he agreed that a lot of air-blast sprayers were used. It was surprising, however, how many hydraulic machines were still in use. On the question of selecting the right air-blast machine for comparison purposes, which one should they use ? Air-blast sprayer design had not stabilised sufficiently for a comparison machine to be selected with confidence, although during test work on commercial holdings the opportunity of making comparisons with the growers' own air-blast machine would always be taken.

MR. FOULDS agreed with these comments, but said he would have thought that from their experience they would have been able to rig or manufacture a standard air-blast sprayer—because the devil one knew was better than those one did not.

MR. RICHARDSON confirmed that it would be possible to do this, but in testing the N.I.A.E. tried to use machines which were commercially available. Using their own air-blast sprayer would be to make comparisons with a machine with which only they would be familiar.

MR. R. F. NORMAN (Fisons Farmwork, Ltd.) : The authors are to be congratulated on the breadth of the Paper they have presented. It is an extremely difficult task to cover ground crop and fruit machines in one Paper. There are many differences between the machines and this raises some doubts as to the wisdom of the Institution covering both types of machine in one Paper.

The droplet size situation was summed up by the speaker in a very realistic manner, but it would appear that the uniformity of the spray pattern across the boom is more important than the uniformity of droplet size where ground spraying is concerned.

In the testing procedure safety considerations are, no doubt, examined. It is difficult to be objective on this matter, but it is important that the machines should not present any hazards to the operators.

Some suggestions have been made concerning the pest/droplet size relationships, and it would be of value to know of any work covering this matter.

The 50-hour running time employed by the N.I.A.E. to test pumps is probably adequate for farm sprayers, but our experience has shown that there seems to be an operating period of 300 hours before breakdown occurs. An extended length of pump test might therefore be advantageous.

The current use of systemic insecticides does enable operators to obtain a satisfactory result with a low standard of work. This in many cases is due to the fumigant effect of the materials.

MR. HEBBLETHWAITE told Mr. Norman that the authors were guilty—they had attempted to mix fruit and ground crop sprayer testing, and this mixture could give rise to certain difficulties. However, so many of the testing techniques were common to the two groups that they had found it economical to make this combination. He did agree that dangers arose in relation to the interpretation of results if this was attempted under a common heading, and he added that the N.I.A.E. always regarded them as quite separate in this context. He agreed with Mr. Norman's comment on the evenness of distribution across the width of a spray boom ; this the N.I.A.E. checked with their Patternator and tested the evenness obtained with several nozzles in action, not a purely mathematical combination of several patterns. Safety features were examined in all tests and more and more legislation was being aimed at improving machine safety. However, it was often difficult or impossible to say whether a machine did or did not comply with the law ; this decision had to be made in a court of law. Nevertheless, they were doing their best in relation to safety and, as on any other farm, there would be bad language amongst operators at Wrest Park if a power take-off guard could not be fitted to a particular machine. The 300-hour figure was interesting. In their experience, 50 hours was almost equally mystical, but he agreed that there was something to be said for increasing the period.

MR. J. PLEASANCE (Overseas Spraying Machinery Centre) asked whether the speakers had had any more success than he had in selecting nozzles to give consistent results. Were there any conclusions on the type of air blast to be produced—high velccity and low volume, or low velocity and high volume, bearing in mind a recent Norwegian Paper.

MR. HEBBLETHWAITE said that he was aware of the difficulty in getting consistency in nozzles and referred to the British Standard on the subject. He had heard the opinion from a number of people that it was difficult to make nozzles that complied with the Standard in all respects. It might have been better if the tolerances in the Standard had initially been wider ; then, when there were a number of nozzles on the market which complied, the tolerances could be tightened up if it was found to be necessary. But he would like the comments of manufacturers on this. He would not enter into the discussion on velocity and volume ; it was not his field, and there might be a contribution from the floor on the subject.

MR. G. SPEAR (N.A.A.S., Kent) mentioned the comparison of fruit and ground crop spraying, saying that he appreciated the difficulties of having the two in one Paper. However, more progressive farmers were experimenting with the possibility of using modern fruit sprayers as ground machines and getting over the ground more quickly. Could Mr. Hebblethwaite forecast whether it was possible to have a machine which could be adapted in this way ?

MR. R. F. NORMAN : Mr. Spear's suggestion that drift spraying might well be a useful technique in this country must be viewed in the light of present chemicals, many of which are not of a suitable type for this work. It would need a change in formulations to achieve the degree of catch that is necessary under the weather conditions normally to be expected in the United Kingdom.

MR. HEBBLETHWAITE commented on the difficulty of forecasting, but added that one of the machines illustrated in their slides was designed to work on both fruit and on drift spraying ground crops. The majority of work on drift spraying in the U.K. had been on potatoes, and he saw little hope of drift work on cereals because of the drift hazard for other crops where herbicides are involved. In addition, a fruit sprayer was a very expensive machine to use on cereals, and there was always the problem of the thorough cleaning of a herbicide contaminated tank.

DR. R. D. BELL (Wye College), in a written statement, said that he would like to compliment the authors on the detailed and comprehensive study presented. He referred to the technique of leaf area measurement, for they were just conducting trials of an air-flow planimeter at Wye College.

The machine was to a design by Dr. Payne, based on a unit by Jenkins of Adelaide (reported in *Plant Physiology*, Sept., 1959), and was, in fact, a comparator. Air was drawn through a grid and the manometer showed a depression. If leaves were placed on the grid the depression was increased. The adjustable orifice was set to return the manometer to its original position. The adjustable orifice carried an arbitrary scale, calibrated against known leaf areas placed on the grid. The method had shown itself to be quick and reasonably accurate. If it proved as successful as the trials suggested they would consider making it automatic in operation, apart from the placing of leaves in the grid.

MR. HEBBLETHWAITE was very glad to hear that this work was under way at Wye, and as soon as the N.I.A.E. could construct or purchase an automatic planimeter they would do so.

MR. NORMAN declared that if they were going to drift spray on, the present formulations in this country were quite unsuitable. A high degree of catch was wanted, and it was unlikely that the present attempts to drift spray would be successful in this country unless these were coupled with a change in formulations. He said that Mr. Hebblethwaite knew of the work of his concern on this in the Sudan, where formulation had been important.

THE PRESIDENT wanted to hear more about the corrosion aspect, for in the oil industry they got questions from farmers about what to do with machines when not in use.

MR. HEBBLETHWAITE, in reply, asked how much interest there was among farmers in the special dewatering and corrosion-resisting fluids that are available. The N.A.A.S. had advised them about these fluids, but he had the suspicion that sales must be very low indeed.

MR. R. J. COURSHEE (N.I.A.E.) gave two reasons why the use of an air-blast sprayer as a drift machine for ground crops was, perhaps, not a good move—it might be less efficient, and there was the question of hazards from toxic materials landing in nearby fields.

MR. R. H. LEE (Development Engineer) did not agree that the tolerances in the British Standard were too tight. He had had some slight hand in drafting that specification and if the tolerances had been any wider they would have been rather ridiculous. It had given the manufacturer something to aim at.

MR. HEBBLETHWAITE reminded the audience that he was quoting other people in his remarks on this matter. But he did not fully agree that the way to tackle this Standard was to provide a difficult target at which manufacturers should aim. It was better to set an initial Standard that people could reach, and tighten it up later on.

BOOKS RECEIVED

Agricultural Engineers' Handbook. McGraw-Hill Book Company, Inc.

This American Handbook aims to include under one cover the basic theory and practice for the various areas of agricultural engineering, and the application of engineering to the problems of agricultural production. A review will appear in the next issue of the Journal.

The Green Book (British Tractors and Farm Machinery). Norman Kark Publications, Ltd.

A comprehensive directory and useful source of reference for all interested in agricultural engineering.

ELECTIONS AND TRANSFERS

Approved by Council at their Meeting on 28th March, 1961.

ELECTIONS

MEMBERS

Hawkins, J. C. .. Beds. Mitchell, F. S. .. Beds.

ASSOCIATE MEMBERS

Cobbold, T. E. ..	Wilts.	Haines, D. R. ..	Warwicks.	Lovegrove, H. T. ..	Salop.
Deveria, N. E. ..	N. Ireland	Lightwing, W. B. ..	Salop.	Mouser, G. C. ..	Oxon.

Overseas

Chadda, H. S. ..	India	Ghosh, B. N. ..	Kenya	MacDonald, L. ..	Iran
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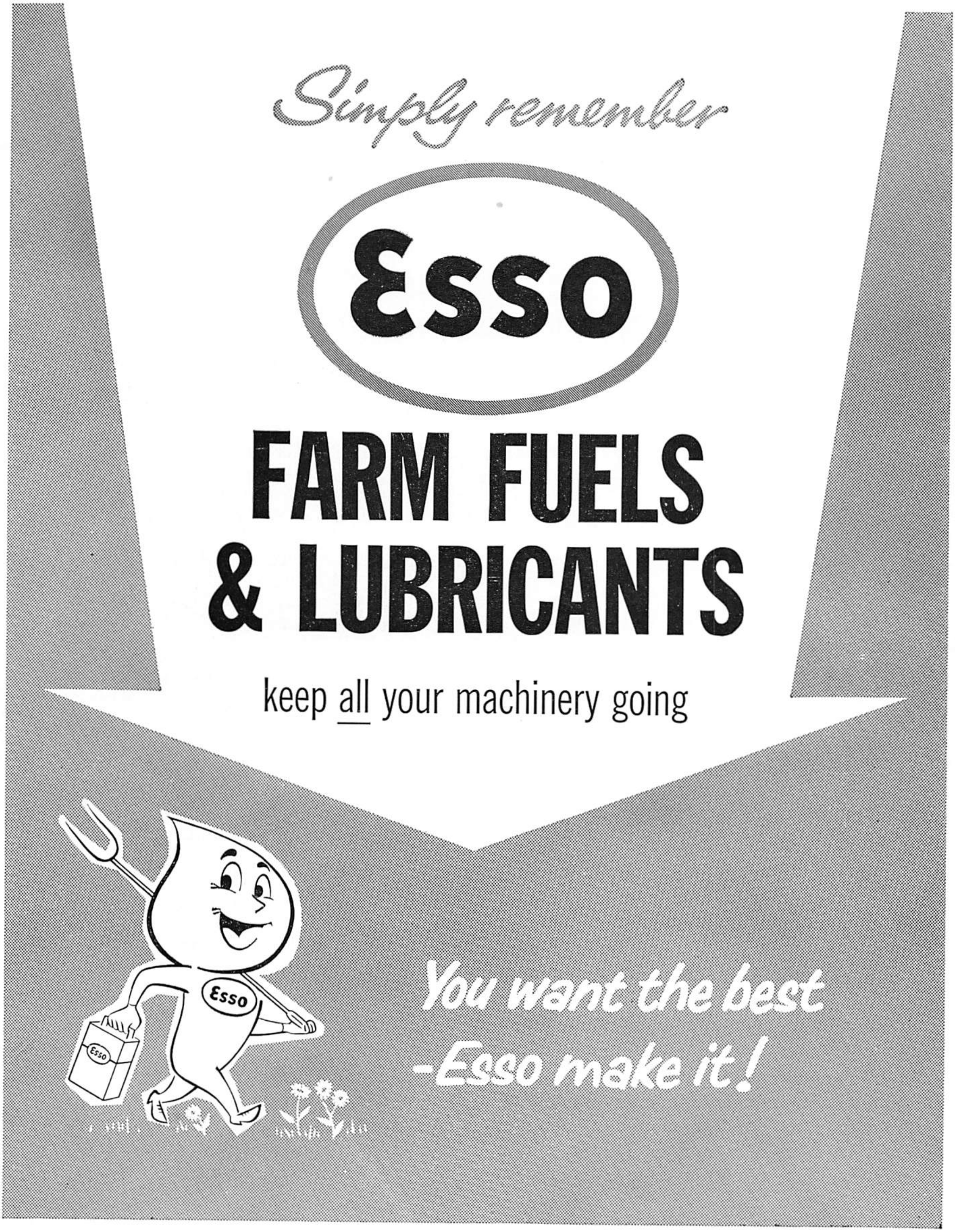
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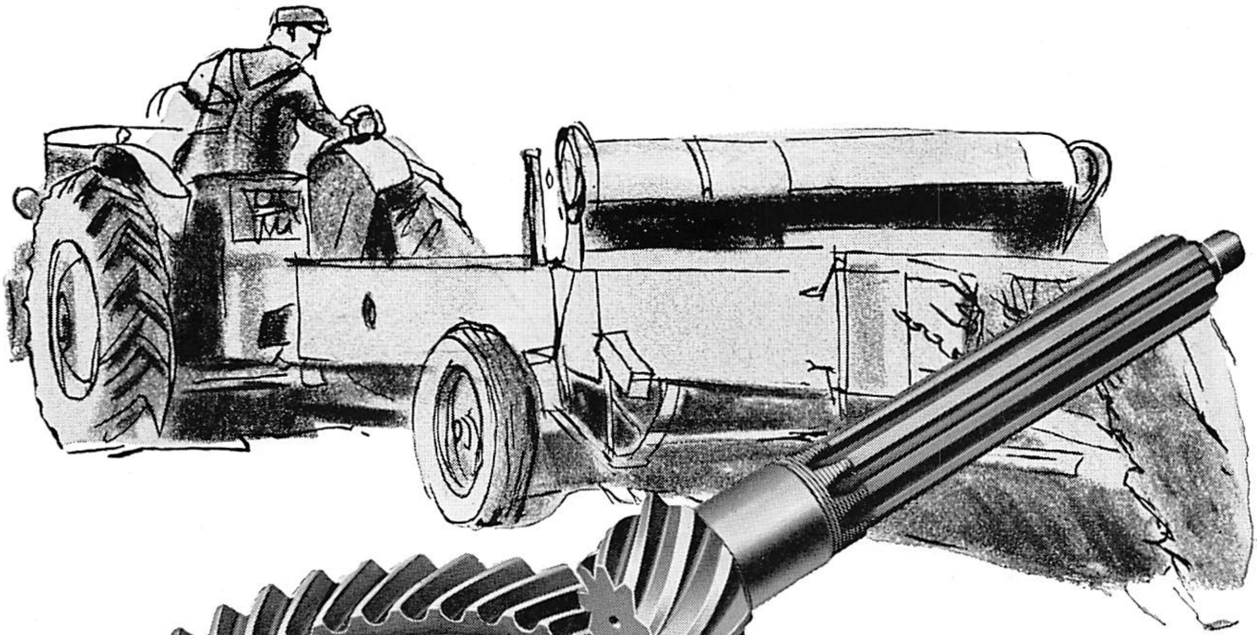

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