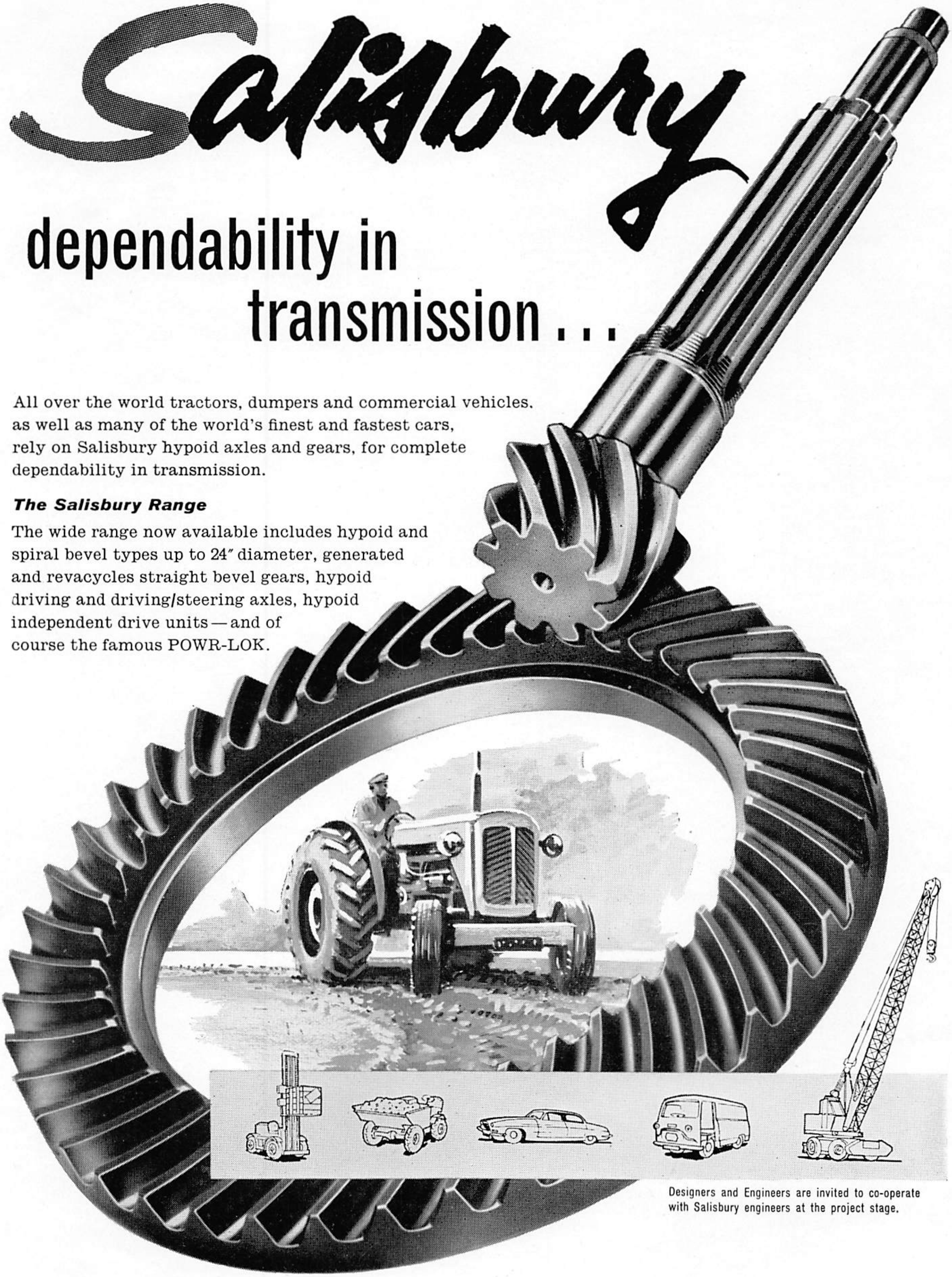
JOURNAL AND PROCEEDINGS OF THE

INSTITUTION OF AGRICULTURAL ENGINEERS

VOL. 19 NO. 1 - FEBRUARY 1963

Salisbury

dependability in transmission . . .



All over the world tractors, dumpers and commercial vehicles, as well as many of the world's finest and fastest cars, rely on Salisbury hypoid axles and gears, for complete dependability in transmission.

The Salisbury Range

The wide range now available includes hypoid and spiral bevel types up to 24″ diameter, generated and revacycles straight bevel gears, hypoid driving and driving/steering axles, hypoid independent drive units—and of course the famous POWR-LOK.

Designers and Engineers are invited to co-operate with Salisbury engineers at the project stage.

SALISBURY *hypoid* **AXLES** | Member of the **Birfield Group**

SALISBURY TRANSMISSION LIMITED · BIRCH ROAD · WITTON · BIRMINGHAM 6

A G Holland.

JOURNAL AND PROCEEDINGS OF THE INSTITUTION OF AGRICULTURAL ENGINEERS

VOLUME 19 - NUMBER 1 - FEBRUARY, 1963

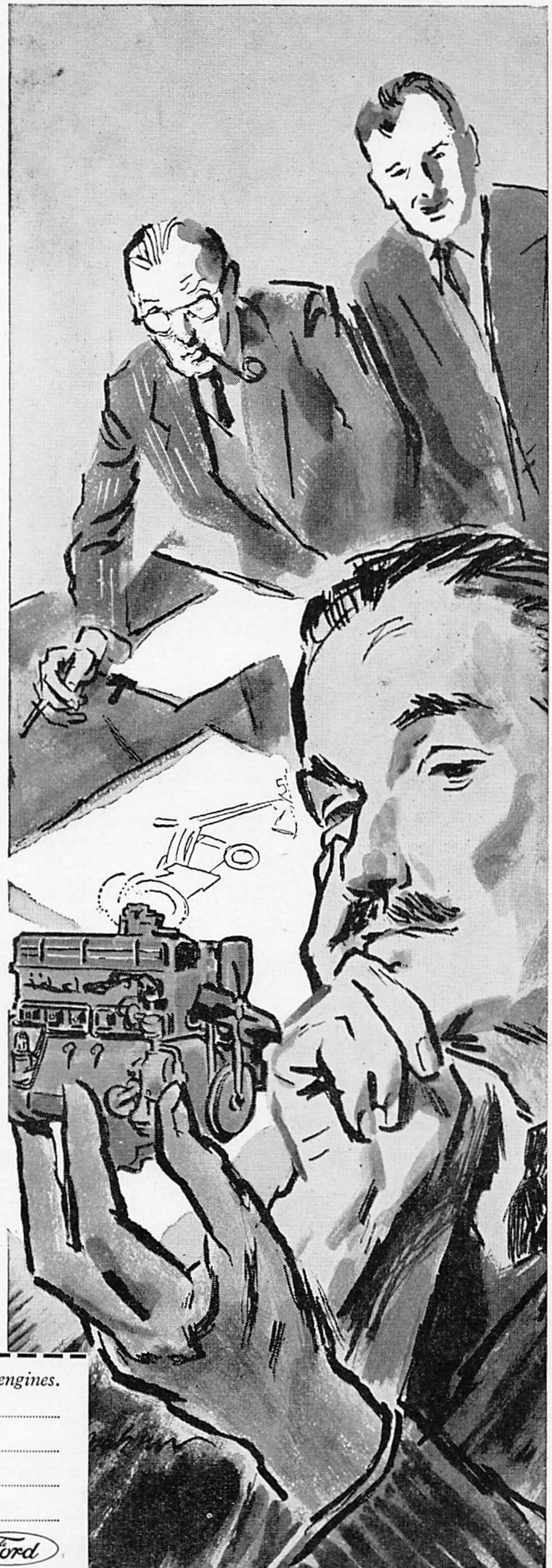
CONTENTS

Published by the Institution of Agricultural Engineers, 6, Queen Square, London W.C.1
Telephone : Terminus 0140

Price : Ten Shillings and Sixpence

Published Quarterly

A SALES MANAGER'S BEST FRIEND IS A **FORD** ENGINE



There are so many more strong selling arguments for equipment that is powered with a Ford Industrial engine! There is Ford's unchallengeable position as one of the world's most experienced builders of Diesel and Petrol engines. There is Ford's unrivalled reputation for economy, long life and reliability. Best of all, there is the incomparable Ford Service organisation—a world-wide chain of factory-trained engineers backed by stocks of genuine Ford parts.

Within the range of 15 b.h.p. to 100 b.h.p. there is a Ford Industrial engine, Diesel or Petrol, 4-cylinder or 6-cylinder, to power any piece of Industrial equipment. Send the coupon below for full technical specifications.

FORD

SPELLS POWER

Please send me full details and dimensions of Ford Industrial engines.

Power range required.................................. Diesel/Petrol..................

YOUR FIRM'S NAME..

For the attention of Mr. ....

ADDRESS..

.... Ford

TO: **FORD INDUSTRIAL ENGINE DIVISION** · DEPT. G5b/SM 15 · SOUTH OCKENDON · ROMFORD · ESSEX · ENGLAND

INSTITUTION NOTES

The views and opinions expressed in Papers and individual contributions are not necessarily those of the Institution. All Papers in this Journal are the copyright of the Institution.

Mr. W. J. Nolan

Our immediate Past President has now retired from the business world and we wish him happiness in his retirement. In appreciation and recognition of all that he has done for the Institution, Council has conferred Honorary Membership upon him, and we look forward to the benefit of his statesmanlike guidance in the future as an *ex officio* member of Council. Mr. Nolan is no less industrious in his retirement, and was Chairman of the National Power Farming Conference, held earlier this month.

New Year's Honours List

Council have extended their warm congratulations to Mr. Alexander Hay, Hon.M.I.Agr.E., upon the award of the O.B.E., and are delighted at this public recognition of his work.

Annual Conference and Dinner, 25th April, 1963

The complete programme for the Conference, at the Royal Society of Arts, is as below :

a.m.

10.15 " Wear by Abrasion in Soil—a Critical Review of Current Work," by R. D. Richardson, B.Sc. (Eng.), A.M.I.Mech.E., Head of Metals and Materials Sections, N.I.A.E.

11.30 Coffee.

11.45 " Techniques for Fabrication of Tubular Structures in Relation to Agricultural Machinery," by G. B. Godfrey (Tubewrights Ltd.).

p.m.

1.15 to 2.30 Interval for Luncheon.

2.30 (*a*) " Mechanical Handling of Silage and Concentrates in the Farmyard," by R. G. Mortimer, B.Sc. (Harper Adams Agricultural College).

(*b*) " The Disposal and Handling of Liquid Manure and Farm Effluent," by W. K. Hall, N.D.Agr.E., N.A.A.S.

4.0 Tea.

4.30 Annual General Meeting.

The Annual Dinner will be at the **Café Royal, Regent Street, London, W.1,** NOT at the Piccadilly Hotel as previously notified. The time, 6.15 for 7 p.m.

34th International Agricultural Show

The Show will be held at the Parc des Expositions, Porte de Versailles, Paris 15e, from March 5th – 10th, 1963. One of the main features of the Show will be the International Exhibition of Agricultural Machinery. Here the member countries of CEMA (Comité Européen des groupements de constructeurs du machinisme agricole) will be fully represented : Germany, Austria, Belgium, France, Great Britain, Italy, Holland, Sweden and Finland. This group of countries manufacture more than 98% of the total production of tractors and agricultural machinery in Europe. Visitors from the U.K. are asked to make themselves known at the Visitors' Reception Office, which will be situated at the entrance of the Palais des Expositions and open from March 3rd.

1963 Examinations

The 1963 Final Examination for the National Diploma in Agricultural Engineering will be held at the Essex Institute of Agriculture, and the Membership Examination at the Essex Institute and at Rycotewood College, Oxon., both Examinations commencing July 10th. N.D.Agr.E. entry forms will be obtainable from the Assistant Secretary at the end of February, and Membership Examination forms at the end of March.

Second All-Day Meeting

FOLLOWING the success of the first all-day meeting, as reported in the last edition of the Journal, a second was held on Tuesday, January 15th, in defiance of bad weather and rail hold-ups, again at the Royal Society of Arts. Although weather conditions excluded many members from further afield, particularly from the morning session, some 80 visitors and members attended. The Papers and ensuing discussions are reported in this issue.

Libary

The Library Service continues to prove increasingly useful to members. Its resources are extended by availability (on request *via* the Secretary, I.Agr.E.) of the books of the National Institute of Agricultural Engineering and by a vast number of periodicals from technical organisations abroad with whom the I.Agr.E. exchanges publications in the Commonwealth, United States, Russia and Europe, a number of the foreign language publications providing digests in English.

A list of these periodicals, which are available on loan, will be published in the next issue of the Journal.

SOIL EROSION BY WATER

SOME MEASURES FOR ITS CONTROL ON AGRICULTURAL LANDS

Prepared by the Agricultural Engineering Branch of the Food and Agriculture Organization of the United Nations.

Presented by M. E. B. NEAL,* B.Sc.(Agric.), M.I.Agr.E,. *at an Open Meeting on Tuesday, 15th January, 1963.*

FOREWORD

THE STAFF of the Agricultural Engineering Branch of the Land and Water Development Division of the Food and Agriculture Organisation of the United Nations obtained the collaboration of specialists in the United States of America, Australia, Africa, Colombia, Israel, Greece, the Republic of South Africa, Rhodesia and the Somali Republic to contribute information on soil erosion by water and measures for its control. The Paper now presented is a condensation of the contributions from this team, to whom grateful thanks are given. For those who wish to pursue special aspects of the matter further, a bibliography is added.

INTRODUCTION

MUCH of the 15,000,000,000 acres of land that are available for agriculture in the world is subject to erosion by water unless it is protected in some way. Natural conditions and age-old practices afford protection in this country. So British farmers are not, as a rule, unduly concerned about water erosion. But we as a nation are concerned with agricultural land in the Commonwealth and in other countries overseas, which is as it should be, because one of the most urgent problems that faces mankind is the control of erosion on farming land.

Disastrous floods in any part of the world make headline news and we are moved to subscribe to funds for the relief of the victims. The under-nourishment, hunger and actual death from starvation of far greater numbers of people, however, every year, caused by the erosion of their land, does not make news ; but it is a much more serious matter than spectacular floods brought about by dams bursting or rivers overflowing their banks.

The economy of any country depends primarily on the soil and its products, and erosion of the soil can seriously affect the development and progress of any natoin.

The soil removed by erosion is generally the most fertile. If it is allowed to be washed into the sea it is lost for ever. The soil left behind is less productive and eventually it can become completely barren. It is difficult to work because it crusts and will not absorb water, and the vegetative cover disappears.

To give an example of soil loss by water erosion :

A badly farmed field in North America, on which the rotation was maize, wheat, grass, legumes, lost nine tons of soil per acre annually over a seven-year period. These results were obtained from a controlled experiment —observations alone in many parts of the world make it fully clear that the losses of soil by water erosion are often considerably higher than this.

When the vegetative cover is wholly or partly removed the rainwater runs off more rapidly and in greater volume and the flow over the partly eroded land becomes more intense ; the vicious circle of erosion proceeds. Less water percolates through the soil to feed underground supplies and the effects of drought are aggravated.

Occasionally in this country one can see the early stages of water erosion on sloping fields that have been ploughed up and downhill after heavy rain and before the crop is dense enough to hold the loose soil. But we do not suffer much from high temperatures, serious over-grazing, deforestation, torrential storms after long dry periods, monoculture, and soils of low organic matter content. When these conditions obtain, as they do in India, the southern U.S.A., South and West Africa, parts of North Africa, Central China and in some districts of Brazil and Argentina, vast areas have been seriously and sometimes completely damaged by water erosion.

The world's nutritional problems are growing due to the additional 50 million people a year who are being added to the population. It has been estimated that every new person needs one acre more of cropland to support him. Overcrowding, both of human beings and their livestock, is causing damage in many ways, one of the most important being by creating conditions which allow rapid erosion. Removing all vegetation and leaving the soil bare is the worst thing that can happen to the land.

Some remarkable soil and water conservation programmes in the world are proving effective in stabilising and safeguarding the agriculture in their respective countries. These and other such programmes need technicians who are trained in agriculture, forestry, and conservation practices such as contouring, strip-cropping terracing and other control methods. Contour practices designed to fit the topography of the land and combined with rotations and proper fertilising will provide protection to the soil, conserve water and raise the yields of cultivated crops in any part of the world where water erosion is a serious hazard.

To induce farmers to discard the harmful ways of using their land involves obtaining the confidence of at least a small number of farmers who are willing to

* *Land and Water Development Division, Agricultural Engineering Branch, F.A.O.*

become innovators and who will in turn persuade their neighbours to follow the conservation practices which have been proved successful.

PROCESSES INVOLVED IN AND TYPES OF WATER EROSION

Types of Erosion

There are two major types of erosion :

(1) Geologic.

(2) Accelerated.

In its broadest sense, geologic erosion is a normal process, in that it happens without the influence of man. It has been going on ever since the Continents were lifted from the sea and is caused mainly by the action of water, wind, temperature changes, gravity and glaciers. Geologic erosion has formed the soil on which crops are grown.

Accelerated erosion is induced by man's activities which bring about changes in natural cover and soil conditions. The main causes are the action of water and wind. So far as water erosion is concerned, there are three main types :

(1) Sheet and micro-channel,

(2) gullying, and

(3) sedimentation.

Sheet and Micro-channel Erosion

This is more or less the removal of a thin sheet of soil from the surface of sloping land. Two processes are involved :

(1) Detachment, and

(2) transportation.

Particles of soil are detached mainly by falling raindrops. A raindrop falling on wet soil forms a small crater, the displaced water and soil being thrown into the air in a circle around the crater. The particles may splash 2 feet into the air and almost simultaneously move horizontally as much as 5 feet on level surfaces. On sloping land more than half the splash moves downhill. Since raindrops come in rapid succession and hit the soil all over the surface, during heavy rains the soil is subjected to rigorous and repeated loosening and lifting.

When the rainfall exceeds the rate of infiltration of water into the soil, the water starts to flow over the surface of the land. It is at this stage that the second erosion process, transportation, takes place. The flowing water carries the loosened particles of soil, often in the form of a thin sheet, across the whole land surface. This is called sheet flow. The eroding and transport power of sheet flow are functions of the depth and velocity of water run-off for a given size, shape and density of soil particles or aggregate. Studies show that the maximum movement of soil particles occurs when the depth of flow is about equal to the diameter of the particles.

Micro-channel or Rill Erosion

Sheet flow occurs mainly when the surface is smooth, but this condition rarely exists in arable fields. Consequently, as water from the rain accumulates it concentrates in depressions, and when these depressions fill up, the water begins to flow along the paths of least resistance. The surface flow, with fine soil in suspension, moves into micro-channels or rills.

The detachment and transportation of soil particles are both greater in rill than in sheet erosion. The amount of soil particle detachment is in proportion to the square of the water velocity. Thus if the velocity is increased from 1 foot per second, which is the common speed of sheet flow, to 2 feet per second, its soil-detaching power is increased four times.

The ability of moving water to transport the soil varies as the fifth power of its velocity. Thus an increase in velocity from one to two feet per second increases the transporting power of water 32 times.

Rill erosion is most severe when heavy rains fall on soils which have high run-off characteristics and which erode easily. Rill erosion moves some topsoil, but once the rills are formed much of the cutting is downward and may extend into the subsoil.

Apart from splash erosion, the soil cannot erode without run-off water, and soils with large stable particles seldom erode. A soil with a moderate organic matter content may contain aggregates that are relatively stable, but they cannot withstand the double impact of wetting and raindrop impact ; the aggregate will disperse and cause surface sealing. Surface sealing, combined with the natural decrease in infiltration, will cause the water intake rate to drop below the rainfall intensity during very heavy rainstorms.

When run-off begins, the aggregates have not been completely broken down, so, for a short time, a large quantity of small aggregates is washed away. When the film has been completely formed the rate of erosion is reduced. When this condition is reached, the amount of erosion depends on the soil properties ; in coarse and sandy soils with little clay the infiltration rate remains fairly high ; run-off and consequently erosion is lower than on fine-texture soils.

The rate of infiltration into a dry soil is very rapid for a short time, but as the soil gets wet the rate decreases rapidly until equilibrium is reached. This depends on soil characteristics, such as texture and structure.

The decline in infiltration rate occurs regardless of the manner in which the water is applied. Surface sealing caused by raindrops speeds the rate of decline and lowers the equilibrium rate. A mulch or vegetative cover on the surface will prevent surface sealing and keep the infiltration rate higher, and therefore the run-off and erosion are decreased.

Infiltration also depends on the moisture content of the soil at the beginning of the rain. The storage capacity of a soil that is set to begin with is nearly filled and water enters the soil from the beginning at about the rate of the water movement through wet soil. Water moves through soil in direct proportion to its wetness, the greatest movement being at saturation point and falling off as the soil gets dry.

A dense layer of soil near the surface slows water movement because it has a low porosity. This slowing does not result in a decrease in the infiltration rate immediately, but the moisture in the overlying more porous layer moves into the more dense layer in time, due to the greater tension in the latter.

Gullying

A gully is a channel that is cut so deeply into the soil that the surface cannot be smoothed out with ordinary tillage implements. It occurs where the run-off increases sufficiently in volume or velocity, or where the water flows long enough in the same channel to cause deep cuts. Gullies can develop from rills which are allowed to go unchecked. They are sometimes started by ruts or tracks made up and downhill by vehicles or livestock. They vary greatly in size, depending on where they are located, their age and the many conditions contributing to their development. Some are narrow and only two or three feet deep, others go down as much as 40 or 50 feet and can be 100 feet wide. It is very costly to repair and stabilise existing gullies.

Sedimentation

The soil that has been eroded from its original location is always deposited somewhere else. It might be nearby, be carried right out to the sea, or it might settle somewhere between these two extremes. The distance that soil particles travel depends mainly on their size, density, shape and the velocity of the run-off water. Coarse sand moves the shortest distance and settles first. Fine sand and silt are deposited next, and some very fine silts settle only in standing water. Clay and humus stay suspended in the water indefinitely. Some eroded soils may be deposited as small fans when the channels in which it is carried undergo abrupt changes in gradient. Some might settle on lower areas where the flood water spreads out and decreases in volume and velocity ; yet others are deposited in drainage and irrigation ditches and in reservoirs.

Much of the damage caused by local sediment deposits results from this silting of waterways and the like. Other damage is caused by the burying of growing crops and by decreases in the fertility of fields.

Once the sediment reaches a stream it is carried in one of two ways—(1) as a suspended load and(2) as a bed load. The first is distributed throughout the cross-section of the stream and it consists chiefly of clays and colloids. The bedload is made up of coarse material, such as sand, gravel and even stones. It is called bed load because it moves along the bed of the stream. If the material that is deposited is of suitable texture and fertility, it can increase the productivity of the lower land.

Aggregation and Surface Sealing

Soil aggregate stability is most important in reducing erosion. Aggregate formation depends mainly on the organic matter in the soil. Those soils devoid of organic matter have very unstable aggregates. The mechanism of aggregate formation is not yet very well understood.

Top Soil Depth

If the top soil is thin and sub-soil is mixed with it by cultivation, the organic matter is lowered and this results in a lower aggregate stability and high erosion.

Water Holding Capacity

The texture of the soil largely determines its water holding capacity ; soils erode differently because of differences in infiltration, percolation and detachability.

PRINCIPLES OF CONTROL

From what has been said about the causes of erosion by water action, the main principles involved in erosion control are not difficult to deduce. These are :

(1) The prevention of particle detachment, when raindrops fall on bare surfaces, by covering the soil with vegetation, crop residues or other forms of mulch.

(2) Improving the infiltration with a vegetative cover, mulching, opening up the soil to rain infiltration with cultivating tools, and in other ways by preventing surface sealing of the soil.

(3) Preventing water run-off by retention terraces, absorption ditches, banks, walls and other retaining devices.

(4) Slowing down run-off to non-erosive velocities where the rainfall is so intense that water infiltration or retention is not sufficiently controlled by the structures mentioned in (3) above.

CONTROL MEASURES

Many erosion control measures are closely related to ordinary methods of good husbandry. The common ones are the proper use of the land, sound cropping systems, cover crops, fertilizers and manures, and tillage methods.

Vegetation provides erosion protection in the following ways :

(1) It cushions the soil against the beating action of the rain.

(2) It offers resistance to moving water and it slows down its rate of run-off.

(3) Plant roots help to hold the soil in place.

(4) Plant roots and crop residues improve the soil structure, making it more porous and able to absorb the falling rain. Whatever kind of crop is grown, it will provide the greatest protection when it is vigorous, fast growing and high yielding.

Well-managed soils become granular in structure, porous and they tend to remain open to absorb the rain.

These are the main crop husbandry methods used to control erosion :

Cover Crops

A cover crop is one that is grown to protect the soil from erosion when the seasonal crops have been removed. They are most valuable in areas where the winters are mild and heavy rains fall in the winter and early spring. They should be sown as soon as possible after harvesting the main crop.

Green Manure Crops

These are generally legumes which are grown and ploughed into the soil to improve its texture and to add humus and nitrogen.

Interplanting

Crops, such as a grass-legume, sown between a main row crop, will protect the soil between the main crop from erosion and also establish a valuable pasture.

Mulch Tillage

This consists in covering the soil surface with crop residues. Experiments in the grass-growing areas of North America have shown that mulch tillage will reduce soil loss by as much as one-half. They reduce splash erosion and surface sealing and they enable the water to soak more easily into the soil. They also tend to retard the surface flow of water.

Minimum Tillage

Minimum tillage is the use of specially designed or modified implements for growing row-crops with the expenditure of less work and in a shorter time than is required by the conventional methods. The object of minimum tillage is to loosen the soil as little as possible, yet sufficiently to prepare an adequate seed-bed and to retain the maximum amount of erosion-resisting crop residues on the surface.

In minimum tillage the area between the rows of crops must be cultivated in a way which prevents erosion, yet increases rain absorption and provides a good storage for water in the lower layers of the soil. A rough, cloddy surface with many small depressoins will achieve this.

ADDITIONAL CONTROL PRACTICES

Contour Farming

This is the practice of planting crops or operating farm machinery along the contours of the field. This helps to conserve both soil and water because each row, furrow or implement mark acts as a barrier to the flow of water. Soil losses on slopes of between 4 to 6 per cent. can be reduced by 50 per cent. with this method. The loss of water by run-off is also cut by about one-half.

Strip Cropping

With this method, fields are also cultivated and cropped on the contour, pasture and grain crops being grown in alternate strips. This also greatly reduces soil loss as compared with cultivating up and downhill.

Terraces

A terrace is an earth embankment, or a combined channel and embankment built across a slope at a predetermined distance from contiguous terraces. Terraces control erosion by reducing the slope length and by conducting run-off water to a suitable outlet at a non-erosive velocity.

Types of Terraces

The most common in humid areas is the channel or *drainage terrace*. This is generally made by moving earth downhill to form a channel with a low ridge. The channel is graded to a suitable outlet to carry run-off water away without causing erosion.

In areas where the rainfall is low or poorly distributed, terraces are generally made level so as to absorb as much of the precipitation as possible, as well as to control erosion when the rain is very heavy. To construct, the earth is moved from both the downhill and uphill sides to form a very broad-based ridge. This is called a *ridge-type terrace*.

Yet another type, the *bench terrace*, is designed to control erosion, increase the water storage in the soil and to allow furrow irrigation to be done. Bench terraces are made by moving earth to form a series of level strips, or benches, of land at intervals across the slopes.

A *basin terrace* is also level and is best suited for areas which have highly permeable soil. This is a very broad terrace generally located on steep land below permanent meadows. Its main purpose is to hold run-off water and to keep it from flowing across cultivated areas lower down.

Outlets

All terraces should be provided with suitable outlets, which might be a natural field drain or a specially constructed exit designed to carry surplus water away without eroding the land.

Construction of Terraces

Terraces can be constructed with a plough and other suitable tillage implements or with heavy earth-moving equipment. The bulldozer is a popular machine for this purpose.

Diversions

A diversion is an individually designed channel cut across the slope of a field to conduct water to a safe outlet. It has two main functions :

(1) To divert run-off water from a hillside and prevent it flowing over fields lower down, and

(2) to divert water out of active gullies into a safe outlet.

MACHINERY USED FOR EROSION CONTROL

Every type of soil-loosening and soil-moving tool, implement and machine is used to make ditches, terraces, dams and other erosion control structures. Terracing machinery is classified according to the method of transporting soil as follows :

Lift and Roll.	*Lift and Carry.*	*Throw.*	*Scrape and Push.*	*Carry.*
Mouldboard plough Disk plough	Earth scoop	Whirlwind terracer	Motor patrol Bulldozer V-drags Towed blades	Elevating grader Rotary scraper Carry-all

A whirlwind terracer is a tractor-drawn mouldboard plough having a vertical power-driven cutting rotor fitted instead of the wing of the mouldboard. The high-speed rotor pulverises and throws the soil to one side for a distance of 3 to 6 feet.

The motor patrol is a power-operated blade for moving soil, used in the construction and maintenance of terraces and for cleaning and repairing the sides of ditches.

Elevating graders, rotary scrapers and carry-alls, as seen at work on the new roads being built in various parts of the country, may all be used for terrace construction.

As would be expected, the larger and more powerful machines have a greater output than the smaller. Relative rates of construction for terraces on loam soils with a 5 per cent. slope are :

Mouldboard plough	1·0
Disc plough	1·2
Whirlwind terracer	2·8
Motor patrol	3·2
Elevating grader	4·0
Bulldozer	6·4

Rates of terrace construction decrease as the slope increases. Typical rates for a 5 per cent. slope are : 100–250 feet per hour with a mouldboard plough ; 250–350 feet per hour with a whirlwind terracer ; and 300–600 feet per hour with motor patrols, bulldozers and elevating graders.

When ditches and channels form part of erosion control measures, the various scoops, excavators, conveyors, back-hoes, draglines and like irrigation and drainage machines are used, depending on conditions and the rates of work required.

Because the establishment of a vegetative cover is important, machines to broadcast or drill herbage and other seeds form part of erosion control equipment. The various drills and seeders on the market for ordinary farm purposes are used, the seed being sown in accordance with good crop husbandry practices.

Lister drills and semi-deep furrow drills are excellent machines for seeding row crops which are grown in ridges and drilled on the contour.

EROSION CONTROL IN TROPICAL AFRICA

A system of tillage based upon the construction, by the plough, of broad lands has achieved considerable success in several parts of Africa.

The broadland, which is very similar to the Essex Stretch, is the nearest approach yet devised to a self-contained unit, the construction, maintenance and cropping of which gives the farmer an effective system of soil conservation and drainage. It has application over a wide range of conditions of soil, climate and topography. It gives lengthy protection against surface wash, considerably improves the drainage, and provides a compact, workable unit suited to a large range of cropping conditions whether rain-fed or irrigated.

A method of mechanised tie-ridging and contour cultivation of annual crops in semi-arid areas of East Africa was suggested by officers of the National Institute of Agricultural Engineering, and implements to do the cultivations were designed by the N.I.A.E. Fairly extensive field trials were conducted with the equipment. Although all the results have not yet been published, the evidence points to the fact that the methods and the implements are most successful.

SOIL AND WATER CONSERVATION IN THE SOMALI REPUBLIC

In the Northern Region of the semi-arid Somali Republic, arable agriculture is possible only on a small area. It is necessary in this part of the country to hold as much of the available rainfall as possible. To this end, a system of earth banks has been developed. With assistance in laying out the contour lines, these banks can be built by local farmers with a simple ox-drawn scraper. These earthworks at least double the yield of sorghum, the common crop of the district, and make farming possible in apparently impossible areas.

EROSION CONTROL IN AUSTRALIA

The various soil conservation services are a function of the State Governments in Australia. In general, it is considered that crop rotations and tillage practices which maintain fertility and promote water absorption are of greater importance than earthworks.

Banks or terraces, sometimes level, but more usually on a grade, are used where necessary, the spacing and capacity depending on rainfall intensity and erosion hazard. Large absorption-type banks are used in the zones where the rainfall is about 20 in. a year. In the high rainfall areas, large-capacity graded terrace systems are used. These latter have grassed waterways to dispose of the run-off water.

Most of the earthworks on arable land are associated with cereal crops, mainly wheat, although some row crops, such as maize and peanuts, are grown.

For the large banks, bulldozers of 40 to 60-h.p. have been found the most economical and versatile.

Erosion is controlled on grazing land by improving the pastures to the maximum with fertilisers and seeding improved species, and by controlling the grazing.

In New South Wales, large absorption banks or terraces are used extensively. These terraces have sufficient capacity to hold up to 2 in. of run-off from an individual storm, and in conjunction with suitable structures they will eliminate soil loss completely and add as much as 5 in. effective rainfall to the area. They also are of great importance in controlling the floods from large rivers.

Mechanical control measures of pasture lands tend to be of greater value in the lower rainfall areas. This is due to the fact that pasture improvement is usually so effective in higher rainfall districts as to render mechanical devices unnecessary. Pasture furrows are proving most effective in helping to re-establish the bush cover in the drier (9–12 in. of rain) pastoral region. These furrows serve to concentrate both seeds and moisture to form a suitable environment for the establishment of the shrubs.

SOIL EROSION CONTROL MEASURES IN RHODESIA

The principal measures in use for the protection of arable land in Southern and Northern Rhodesia are :

(1) Storm drains.
(2) Contour ridges.
(3) Grass waterways.

Definite procedures are laid down by the Conservation Department for the laying out of contours and storm drains. These depend on factors such as the characteristics of the soil, the slope, the existing pattern of erosion, rainfall, and so forth.

All arable land is contour ploughed, and whether or not special contour ridges are made depends on the soil conditions. Ordinary farm implements such as the disc and mouldboard ploughs are used for building these banks.

Unless special equipment is available, the construction of storm drains is undertaken by hand labour. The dimensions of the drains, when they have to be made by hand, are kept down as much as possible, but frequent discharge points, normally into grass waterways, are provided. It is found that the provision of additional grass waterways is generally less than the cost of long and very large drains. Also a grass waterway can be used for grazing.

When the slope of arable land is such and it is considered that erosion will occur during heavy storms, grass stripping is sometimes used. The strips are either of indigenous grasses or other species which have been found satisfactory. They are generally about 15–20 in. wide and laid out on the true contour.

Drop inlet spillways are used to cope with the trickle flow from farm dams which flow can cause much erosion unless protected in this or some other suitable way.

Dry-packed masonry structures are being tried out for gully control in Southern Rhodesia. It is still too soon to say whether they are entirely effective, but investigations show that there is great promise in this kind of structure for the stabilisation of gullies.

Concrete drops are also used to some extent for gully control; they reduce the velocity of the flow and thus the erosive power of the water.

A comprehensive programme of erosion research is in operation in Southern Rhodesia and the results obtained are freely available to all the farming community.

SOIL EROSION CONTROL IN THE REPUBLIC OF SOUTH AFRICA

Agricultural land in South Africa falls into two main categories :

(1) That privately farmed mainly by people of European stock, and

(2) that Bantu Area where shifting cultivation has been practised for generations.

Acts of Parliament lay down comprehensive rules for the conservation of existing and the reclaimation of despoiled areas. Appropriate Divisions of the responsible Government Departments have the functions and the technical staffs to implement the enactments that were drawn up to preserve the natural soil resources of the country. Great success is attending the programmes that have been operating during the past decade or so.

The erosion control techniques used follow those evolved in the U.S.A., with modifications to fit South African conditions. Animal-drawn implements and powered machines both play their part in the work that is carried out.

The legislation to deal with private farms anticipated the co-operation of the farmers themselves. This, in fact, has been obtained through Land Conservation District Committees, organised on lines rather similar to the County Agricultural Executive Committees here during the last war.

ISRAEL

The State of Israel is faced with soil erosion problems that are as great as those in most other countries. The task of reclaiming what are virtually desert areas and of getting the maximum use from the better land is being under taken with energy, skill and the application of techniques developed in other countries, adapted to suit Israeli soils, crops and climate.

A general land use survey was completed about ten years ago and a detailed survey of all grazing and arable land will be finished in a few years. All land use is based on these surveys.

Crop rotations and high soil fertility are given great importance in soil conservation programmes.

Mulching, no-tillage, contouring and terracing are practised where appropriate. Heavy structures are avoided as much as possible, and all plantations are laid out to satisfy the Soil Conservation and the Plantation Crops Divisions.

REFERENCES AND BIBLIOGRAPHY

The following is a list of some institutions and agencies engaged in soil and water conservation activities who publish reports, Papers and similar information :

Hydrogeonomy Service, Athens, Greece.

Departamento de Conservacion del Suelo y Agua, and Instituto Mexicano de Recursos Naturales Removables, Mexico, D.F.

Soil Conservation Service, Ministry of Agriculture, Israel.

Natural Resources Board, Southern Rhodesia.

Department of Soil Conservation and Extension, Union of South Africa.

Soil Conservation Service of New South Wales, and Soil Conservation Authority of Victoria, Australia.

Commonwealth Scientific and Industrial Research Organisation, Soils Division, Adelaide, Australia.

Soil Bureau, Department of Scientific and Industrial Research, Wellington, New Zealand.

Soil Conservation and Rivers Control Council, Wellington, New Zealand.

International Institute for Land Reclamation and Improvement, Wageningen, Holland.

Federacion Nacional de Cafeteros, Centro Nacional Investigations, Chinchina-Caldas, Colombia.

Ministerio de Agricultura, Bogota, Colombia.

Servicio de Conservacion de Suelo, Ministerio de Agricultura, Madrid, Spain.

Soil Conservation and Farm Irrigation Division, Ministry of Agriculture, Ankara, Turkey.

The Nature Conservancy, Merlewood Research Station, Grange-Over-Sands, England.

Division of Soil Conservation, Bureau of Soils, Manila, Philippines.

Institute Sperimentale par la Studio e la Difesa del Suolo, Firenze, Italy.

Conservator of Forests, Hyderabad-Deccan, India.
Soil Conservation Project, Rawalpindi, Pakistan.
Inter-African Bureau for Soils and Rural Economy, Pubilshing Headquarters, Paris, France.
Divisaõ de Conservacaõ do Solo, Secretaria da Agricultura, Saõ Paulo, Brazil.
Soil Conservation Service, Department of Agriculture, United States of America.
Prairie Farm Rehabilitation Adminstration, Federal Government of Canada.
Ontario Department of Planning and Development, Ontario, Canada.

Publications

"Soil Erosion in New Zealand," by K. B. Cumberland. The Soil Conservation and Rivers Control Council, Wellington, New Zealand.
"A History of Land Use in Arid Regions." UNESCO, 1961.
"The Conservation of Natural Resources," by Richard C. Haw, Salisbury, South Rhodesia. Faber & Faber, London.
Encyclopedia Britannica Year Books articles entitled "Soil Conservation," from 1945 to 1962.
"Soil Conservation," by Hugh H. Bennett. McGraw-Hill Book Co., New York, 1939.
Proceedings of the United Nations Scientific Conference on the Conservation and Utilisation of Resources, Vol. VI, "Land Resources," 1949.
Manual on Soil and Water Conservation. In English, Spanish, French, Portuguese, Turkish. The Soil Conservation Service, United States of America, 1945–1951.
Frevert, R. K., Schwab, G. O., Edminster, T. W., and Barnes, K. K., "Soil and Water Conservation Engineering." John Wiley & Sons, New York. 1955.
Gottschalk, L. C., and Jones, V. H., "Valleys and Hills, Erosion and Sedimentation." *Water*, 1955 Year Book of Agriculture, U.S. Dept.Agr., 135–143.
Kohnke, Helmut and Bertrand, A. R., "Soil Conservation." McGraw-Hill Book Company, Inc., New York, 1959.
Osborn, Ben., "How Rainfall and Run-off Erode Soil." *Water*, 1955 Year Book of Agriculture, U.S. Dept.Agr., 126–135.
Laws, J. O., and Parsons, D. A., "The Relation of Raindrop Size to Intensity." Am.Geophys.Union, Trans., 24 : 452–459. 1943.
Moldenhauer, W. C., Burrows, W. C., and Swartzendruber, D., "Influence of Rainstorm Characteristics on Infiltration Measurements." 7th International Congress of Soil Sci., Proceedings. 1961.
Osborn, Ben., "Effectiveness of Cover in Reducing Soil Splash by Raindrop Impact." Jour. Soil and Wat. Conserv., 9 : 70–76. 1954.
Smith, D. D., and Wischmeier, W. H., "Factors affecting Sheet and Rill Erosion." Am.Geophys. Union, Trans., 38 : 889–896. 1957.
Beasley, R. P., "A New Method of Terracing." Univ. of Missouri, Ag.Exp.Sta.Bull., 699. April, 1958.
Hays, O. E., "New Tillage Methods reduce Erosion and Runoff." Journ. Soil Wat. Conserv., 16 : 172–175. 1961.
Jacobson, Paul, "A Field Method for Staking Cut and Fill Terraces." Agr.Eng., 42 : 684–687. 1961.
Jacobson, Paul, and Weiss, Walter, "Farming Terraced Land." U.S. Soil Conservation Service. Leaflet No. 335.
Larson, W. E., Beale, O. W., "Using Crop Residues on Soils of the Humid Area." U.S.D.A. Farmers' Bull., No. 2155. 1961.
Peterson, A. E., Berge, O. I., Murdock, J. T., and Peterson, D. R., "Wheel-track Corn Planting." Univ.Wis., Agricultural Extension Service. Cir. 559. 1958.
Ree, W. O., Palmer, V. J., and Lau, Jr., W. P., "Handbook of Channel Design for Soil and Water Conservation." SCS TP 61. 1947.
Schaller, F. W., Hull, D. O., Willrich, T. W., and Jacobson, Paul, "Grassed Waterways and Terrace Outlets." Iowa State Univ., Agr. Extension Service. P-166. May, 1958.
U.S. Department of Agriculture, "Applied Mulches and Mulching." ARS 22–7. 1961.
U.S. Department of Agriculture, Soil Conservation Service. Engineering Handbook for Soil Conservationist in the Corn Belt. Agr. Handbook No. 135. 1958.
Frevert, Richard K., Glenn, O. Schwab, Talcott, W. Edminster, and Barnes, Kenneth K., "Soil and Water Conservation Engineering." John Wiley & Sons, Inc., New York. 1955.
U.S. Department of Agriculture, Agricultural Research Service. A Universal Equation for Predicting Rainfall-Erosion Losses. ARS 22–66. 1961.
Wischmeier, W. H., "A Rainfall Erosion Index for a Universal Soil-loss Equation." Soil Sci.Soc.Amer.Proc., 23 : 246–249. 1959.
Beale, O. W., Nutt, G. B., and Peele, T. C., "The Effects of Mulch Tillage on Run-off, Erosion, Soil Properties and Crop Yields." Soil Sci.Soc.Amer. Proc., 19 : 244–247. 1955.
Carreker, J. R., and Hendrickson, B. H., "The Measurement of Soil and Water Losses with Run-off Plots." Soil Conservation Service, U.S. Dept. Agr. (Watkinsville, Ga.) Report. 1952.
Copley, T. L., Forest, L. A., McCall, A. G., and Bell, F. G., "Investigations in Erosion Control and Reclamation of Eroded Land, Central Piedmont Conservation Experiment Station, Statesville, N.C., 1930–1940." U.S.Dept.Agr.Tech.Bul. 873. 1944.
Ellison, W. D., "Some Effects of Raindrops and Surface-flow on Soil Erosion and Infiltration." Trans. 26th Ann. Meeting Amer. Geophysical Union, Part III : 415–424. 1945.
Free, G. R., "Erosion Characteristics of Rainfall." Agr.Eng., 41 : 499–455. 1960.
Peele, T. C., Latham, Earle E., and Beale, O. W., "Relation of the Physical Properties of Different Soil Types to Erodibility." South Carolina Agricultural Experiment Station Bul. 357. 1945.
Smith, D. D., and Whitt, D. M., "Estimating Soil Loss from Field areas of Claypan Soils." Soil Sci.Soc.Amer.Proc., 12 : 485–490. 1947.

DISCUSSION

The President said that the Council had invited the Institution of Civil Engineers to nominate a member to open the discussion, and it was his privilege to welcome as their nominee Mr. Gerald Lacey, Companion of the Indian Empire, Bachelor of Science, Member of the Institution of Civil Engineers, who was Consultant to Sir Murdoch MacDonald and Partners.

Mr. Gerald Lacey, C.I.E., B.Sc., M.I.C.E., said that it was with some trepidation that he had accepted the invitation to open the discussion on Mr. Neal's interesting and valuable Paper, for he was an irrigation engineer and not an agricultural engineer. But he thought it was now quite evident that irrigation engineers and agricultural engineers were for the greater part agriculturalists with their feet firmly on the ground, he hoped, among the healthy vegetative cover.

Agriculture and irrigation were two facets of a many-sided problem—that of efficient land and water use. Note that—use, not abuse. Efficient land and water use was a means of increasing food production, and that was very largely the function of the Food and Agriculture Organisation of the United Nations, of which the author was a member, performing such sterling service in Tunisia. Mr. Lacey had been fortunate enough to be engaged by the F.A.O. in 1956 as Co-Director of a Training Centre and Study Tour of drainage and irrigation works in the U.S.S.R. During his briefing in Rome he learnt much about F.A.O. activities, and while in the U.S.S.R. found that the problem of soil erosion was receiving attention. The great work of the F.A.O. in the field of food production was not, he thought many would agree, sufficiently recognised in this country. Mr. Neal's valuable summary of the steps taken to check erosion with a view to growing more food in so many countries gave some idea of the activities which the F.A.O. engaged in, and of the extent to which they were spread over the world.

Mr. Lacey had for eight years been Drainage and Irrigation Adviser to the Colonial Office and during his visits to the Colonies had become familiar with agriculture in semi-arid countries. The successful prosecution of agriculture under minimum rainfall conditions was of vast importance. In Tunisia the need for that had, he thought, been recognised for some time, but a larger field where these possibilities were now being explored existed in parts of the Sudan.

The world shortage of food arose quite simply from the stark fact of the unbalance or lack of balance between human fertility and soil fertility. By better husbandry the production of food could be increased, and possibly the size of the families could be somewhat reduced. This was a plain fact, and one with which all the world was threatened.

Regarding land abuse, the author had dealt with soil erosion from the agricultural viewpoint, but soil erosion due to deforestation, shifting cultivation and the depredations of the ubiquitous goat had also to be considered. These factors had very great repercussions on irrigation, because deforestation led to floods of greater intensity and shorter duration, and the reservoirs in the hills which irrigation engineers were now constructing on a vast scale would sooner or later be filled with sediment from those deforested hills. Unless something was done to check it, it would be very much sooner rather than later.

Mr. Neal had said that unfortunately soil lost by erosion was usually the most fertile, and that it found its way to the sea, where it was wasted. However, that was not always the case. Egypt had for centuries relied on soil erosion. But if soil erosion was entirely geological erosion, Egypt would eventually find itself without the very fertile silt upon which it relied.

Mr. Lacey mentioned British Guiana as an example of a territory which relied for its arable soil on silt or sediment from rivers ; that is, littoral drift probably from the Orinoco, or even indeed the Amazon itself. In British Guiana the only soil that was really productive was a coastal belt about ten to twenty miles in width, extending along the whole length of the shore, which was marine clay brought down by rivers.

In England there had been some reclamation of soil in the Wash, on a very small scale. There they were reclaiming by trapping what they call the warp in the Wash, which was very fine silt derived from erosion along the coast.

A few years ago Mr. Lacey had seen a striking case of soil waste on a scale comparable to that mentioned by Mr. Neal. He had flown up the Tana river in Kenya from its mouth right up to its source in the Kenya highlands. To begin with he flew a little bit out into the Indian Ocean and saw a great fan of red fertile soil, stretching for many miles in extent. That was during the rains. He followed the course of the river up to its source and there saw the same fertile soil being washed out from fields and gullies into the river. That had been a wonderful illustration of what was actually occurring, seen not by measurement over the centuries, but seen within twenty-four hours.

In the Paper it was stated that a farm which was very badly cultivated in parts of the United States could lose as much as nine tons per annum per acre. Mr. Lacey wondered if anyone had taken the trouble to work out exactly what this really amounted to in terms of inches or fractions of an inch of soil lost. He knew exactly what inches of rainfall were, since the measure was universal, but he thought it was very puzzling to the layman to tell him that so many tons per acre or tons per square mile had fallen on the ground. He preferred inches of water as the only measure, and wanted to know the depth of the soil which was lost. He asked if Mr. Neal could detail how many inches or fractions of an inch was represented by nine tons per annum per acre.

Mr. Lacey had already referred to the indirect evils which arose from soil erosion, and in particular reservoir silt. Much discussion was going on, notably in America at the United States Bureau of Reclamation, as to how long it was going to take their big reservoirs to silt up. It might be fifty years, seventy-five years, even a hundred years.

Mention had been made of a great many remedies for soil erosion and some of these measures could be overdone. Terracing and contouring had been practised for ages in many countries, such as India and Japan. In India for very many years they had had small field embankments. With only about ten or fifteen inches of rainfall a year, if the slopes were flattish and not too severe, the whole of the rainfall on a given bit of arable land could be conserved merely by dividing the land up into chequer patterns.

Reference had also been made to the " new " theory of no tillage, or minimum tillage. In Africa the plough was not used very frequently, the hoe was used instead. A hoe would break up the surface without producing little furrows for the water to run along. While in this country and elsewhere the ploughman took a pride in his furrows, elsewhere the furrow could be undesirable. By avoiding deep ploughing the Indian farmer had been able for centuries to maintain at least his low standard of productivity, with very little in the way of fertilisers. While we talked of teaching the cultivator, often he could teach us a good deal. Finally, Mr. Lacey felt that it was too much to expect farmers using improved methods to try to persuade their neighbours to follow their example—farmers were not generally receptive of such advice.

MR. NEAL, replying to Mr. Lacey, said that while he personally could vouch for a case of soil erosion in Tunisia where twelve inches of soil had been eroded by rainfall in one day, a loss of nine tons per acre would in fact represent a small fraction of an inch. Measurement of soil was extremely difficult, and one could not normally measure an average loss of soil in terms of depth. On an average basis, a figure of so many tons per acre had more meaning.

In many of the under-developed countries attempts had been made to popularise the use of improved native implements which were basically similar to the hoe. The F.A.O. had tried to popularise and was continuing to try to popularise the use of cultivators—the rigid tine cultivator, the spring tine cultivator and the stump-jump cultivator—for basic tillage work instead of the plough. The creation of a rough surface was known to be extremely valuable in preventing soil erosion, both by water and wind.

On the subject of extension methods, Mr. Neal disagreed with Mr. Lacey. In his experience the majority of farmers did not mind in the least being given advice and listening to other people's opinions, but they were like any other person given advice—they would only take it when they could see that it paid to do so. Agricultural consultants had in fact told Mr. Neal that their profession was a paying proposition, much better than being an adviser in a free advisory service ! There were some farmers at any rate who took advice when it's given.

MR. LACEY said that Mr. Neal had misunderstood him. He fully agreed that farmers will readily accept advice tendered by an expert extension service, but that did not imply that a farmer was easily persuaded by his neighbour.

LT.-COL. W. N. BATES (Kent) said that in many years' experience of farmers in quite a number of parts of the world, he had found that they would take advice from another farmer, once he had been bold enough to try out a new method and found that it works. If one could get two or three of them to do the same thing, then bit by bit that became known. They certainly would not take advice, as both speakers had said, f om another farmer who was only talking about something that he had seen and not practised.

He had been interested in Mr. Lacey's remarks about the amount of soil that was carried down to the sea. He had been lucky enough once or twice to fly up the east side of South Africa. There were five major rivers between the Cape and the Limpopo, and flying up the coast at five or six thousand feet on a clear day one could see a fan of yellow water going out into the sea for a distance of up to five or six miles.

COM. D. BINGHAM (A.E.A.) said that his Association received many letters from dry land areas, saying that they must have specific types of dry land cultivator equipment mentioned by Mr. Neal. In a number of cases the mouldboard plough was severely criticised as an accelerator of soil erosion. He would like Mr. Neal's views on the use of the mouldboard plough in dry areas.

MR. NEAL replied that he thought the mouldboard plough and the disc plough will continue to be used for many many years, and in fact in his opinion there was not going to be a complete revolution even if something to replace the mouldboard plough and the disc plough could be found. In dry land areas where soil erosion by mobile inland water was to be controlled, one pre-requisite was to have a cloddy surface. A cloddy surface could be kept weed-free better with a cultivator than with a plough in many cases. Secondly, crop residues should be left on the surface, and not buried, since when left on the surface they could contribute to effective control of erosion. This was one reason why the cultivator was being advocated in place of the plough, either mouldboard or disc. One danger that had been experienced all over the world where the cultivator had replaced the plough, in abnormally wet years—especially in a year when it was abnormally wet in the spring—was very great difficulty in obtaining weed control. So far we had found nothing, in any country, which was more effective than the plough for weed control.

Apart from that one point, the cultivator was giving these excellent economic results. With the cultivator tillage could be effected far more quickly and cheaply than with the plough. In low rainfall areas low yields were usually obtained and costs of production must be minimised.

MR. R. A. JOSSAUME asked if Mr. Neal had had any experience with the continuous use of artificial fertiliser on soils causing the soil to break down and increasing the tendency for erosion by water to occur. A second point was that no mention had been made of ripping the soil at one- or two-yard intervals with a heavy tine, to let the water go in after heavy showers. He had seen crops in Africa grown right through to the harvesting stage just with the use of a chisel plough. In other fields, crops had dried out during the dry season.

MR. NEAL said that he had never seen or read of fertilisers, applied in normal farming quantities to a soil, affecting its structure to an extent that it would have an effect on soil erosion. He had, however, a large amount of information showing that by judicious use of fertilisers on poor soils one had been able to get better crops and better plant residues and to improve the structure of the soil.

Ripping was one of the measures which had been often carried out, and was often advised particularly to enable the first rains, in countries with seasonal rainfall, to penetrate into the soil. He was a little doubtful as to the general applicability of this. In many areas, after a ripper had been used, the channel was sealed up with the first rain. In Nigeria what they called vertical mulching had been developed on a small scale. In this process, cracks in the soil were filled with ground nut shell ; this had been giving excellent results. There were areas in which ripping did effect infiltration of the first rains, but this type of opening could not be applied in general, because many soils sealed immediately in the first few minutes of the first rain.

MR. HARRIS (Middlesex) asked Mr. Neal if he could give some figures on nutrient uptake by the plant in relation to that lost by erosion. He thought that in controlling soil erosion by water one should dissipate the energy of water at all stages throughout the process by having plants that could break its flow, by utilising wide channels and thus the resistance of the soil, using low velocities, having high friction losses in channels—and then by barrages and dams further down the river. He asked if Mr. Lacey could give an indication of the most suitable channel shapes, frequency of barrages, water velocities and so on. Further, he referred to the fitting of wings to the bottom of the chisels on a chisel plough, so that as well as opening up a vertical slot, each tine disturbed the earth below ground, and he asked for information on this point.

MR. NEAL replied that the loss of minerals from the soil by erosion had been discussed in many publications. These showed the amount of soluble mineral materials in run off water, and references to this subject were included in Mr. Neal's bibliography. Mr. Neal agreed that dissipating the energy of the falling or moving water was the main principle of the whole of control of soil erosion by water.

Referring to the use of sweeps or wings on chisel points, Mr. Neal said that in Australia there was a new mounted cultivator on to which sweeps could be fitted, for weeding purposes. There was also a subtillage sweep which was used as a tillage tool rather than as a weeding tool. It was very effective and widely used in areas where surface mulching was carried out to control erosion.

MR. SCHULTZ (South Africa) referred to grazing in semi-arid parts of South Africa, where it was not exclusively sheep country. In a number of cases where the farmers paid particular attention to increasing the effective grass cover on the downs by judicious grazing methods there was a tendency for the quality of their stock to deteriorate. Many farmers were somewhat opposed to adopting the recommended grazing procedures for this reason. In the long term this was very harmful to the soil, but was actually beneficial as far as the immediate health and condition of the sheep was concerned.

MR. NEAL said that the question of control of grazing has been put forward as one of the most effective means of cheaply preventing soil erosion by water and by rain. Grazing control had given very spectacular results in many many countries, South Africa included. One always tended to run into disease troubles when one increased the livestock population and naturally control measures had to be taken—it was just the same with the plant population. From the economic point of view he did not think there was any question that given improved grazing, the animal would do better, but the farmer would probably have to take more precautions. Usually the cost of the precautions was far less than the increase in output, so that it was a paying proposition. Certainly, from the point of view of the soil, controlled grazing was one of the most important and most effective methods of erosion control.

MR. J. C. HAWKINS (N.I.A.E.) agreed that water should not be allowed to move from a field as long as there was plant growth to make use of it. He felt that suitable methods of cultivation would make it possible to resist soil erosion over the maximum area, but the shape of the storms to be dealt with, and intensities as high as three to five inches of rain per hour, make conditions very difficult due to the sheer volume of water moving.

Secondly, because of the climate in question, there was little chance of building up organic matter to any extent in the soil. Termites, the high temperatures, high moisture contents associated with the high temperatures, were all factors causing loss of organic matter.

Attention was therefore being focussed on the problem of pinning water down, for example on the surface shape or condition of the soil—perhaps the use of basins—that would hold water until it had time to run into the rather impermeable soil.

There was always a risk that too much water might be held on the land and that it would suffer from waterlogging. Mr. Hawkins thought that basin methods of holding water must therefore be associated with growing the crop up on some form of ridge. Very often there was local opposition to the idea that one should not run some of this water off, on the grounds that not all of it was actually needed by the crop, but Mr. Hawkins felt this was a very serious mistake. Water in soil in the tropics could mean money in terms of a crop, and in his view there was very much less of the world where one could afford to run water off than many people had thought in the past. The usual answer to the person who said there is too much water is to ask him to find out where the water table was, and it might prove to be 90 or 100 feet down. He asked Mr. Neal if he thought more should be done on such micro soil conservation rather than on macro soil conservation.

MR. NEAL said in reply that the comparatively recent development of ridge culture methods was showing great promise in many areas, including Africa. But unfortunately ridge culture was not applicable to many of the crops grown in these semi-arid areas. The greatest area through North Africa and the Middle East is covered by cereals—not maize—and he had not yet seen the successful growing on a ridge of low yield crops, like wheat, yielding three or four bushes an acre. In the higher rainfall conditions, as in equatorial Africa, there was ridge cultivation of main crop maize, groundnuts, etc.

The principle of retaining moisture on the soil where it fell was undoubtedly extremely sound, but in very heavy storms of two or three inches an hour, or even greater intensities of rainfall, it was impossible to get the water into the soil and it simply had to run off. A lot of trouble had been experienced in Tunisia, in North Africa, with the total retention system of terracing, where terraces were constructed to retain all the moisture on the spot. Under extreme conditions they were physically incapable of holding it, and—as had happened only two months ago in Tunisia after 200 mm. of rain in 16 hours the whole town was washed out, and 6,000 houses disappeared—an absolute disaster. In these conditions provision must be made for adequate run off at non-erosive velocities. This had been done for centuries by nomadic tribesmen who spread the water coming off hillsides and planted wheat on it, often forming the sole piece of vegetation in a desert.

Finally, Mr. Neal acknowledged the thanks of the President for his excellent Paper by saying that the agricultural engineering branch of F.A.O. much appreciated the interest shown by the Institution in the work of his organisation.

NOTE: **It is regretted that owing to a printer's error in the last issue the title National Institute of Agricultural Engineering appeared at the head of the article on the Institution Examinations. The Examination is of course administered by the I.Agr. E. not the N.I.A.E.**

FACTORS AFFECTING THE PERFORMANCE OF AGRICULTURAL POWER UNITS IN SERVICE

by E. Atkinson,* A.M.I.Mech.E., A.M.I.Agr.E., A.F.Inst.Pet., Assoc.I.Loco.E.

A Paper presented at an Open Meeting on January 15th, 1963.

Introduction

FROM the title of this Paper it will be apparent that the subject can be handled in an infinitely wide variety of ways. Characteristics of design, production methods and engineering materials, as well as the properties of fuel and lubricants, have their respective effects on the performance of engines. Excellent Papers have been written on these several aspects and reference is made to some. Usually, however, sections have been dealt with exhaustively and separately. In this Paper it is hoped to emphasise key features among those factors which influence the performance of tractor power units to a marked degree.

Scope

Starting with the assumption that the manufacturer provides the best engine he can in the economic conditions of our day, the author will select a few and only a few features and appraise their significance in terms of their effect on engine performance. This selection will be made against two fundamental truths.

First, that in normal service life a greater sum will be spent upon fuel and lubricants than upon the capital cost of the engine, and second, that all machines deteriorate in service.

The first fundamental provokes a re-assessment of the current importance of certain fuel properties, such as Cetane Number and Sulphur Content in fuels used in modern engines, which have changed in significance with the development of engines and lubricants.

If one accepts the second fundamental, it is logical to bring into perspective the significance of the deterioration of mechanical components, particularly fuel injection equipment. Naturally, there is an inter-relationship with the properties of fuels and lubricant and additionally the environment in which the engine operates must be considered.

Through technical advance over the years, some characteristics, formerly critical, have been brought under control. Conversely, because of higher engine ratings and longer life, other features, such as the condition of mechanical components and engine environment, have gained significance.

It is well known that between the wars, spark ignition engines designed to burn gasoline or vaporising oil respectively were the power units adopted by agriculture. As, however, practically all farm tractors leaving British factories are now diesel engined, it is proposed only to consider this type. Table I illustrates this trend.

Table I
TRACTOR PRODUCTION IN THE UNITED KINGDOM, INCLUDING EXPORTS

Wheeled Tractors	1958	1960
Vaporising	3,636	1,768
Gasoline	7,110	6,210
Diesel	130,372	173,003
Total	141,118	180,981
Ratio Diesel to other types ..	12·1 : 1	21·7 : 1

Engine Characteristics

All tractors which might be described as of farm size in the U.K. are fitted with in-line water-cooled normally aspirated engines. The four-cylinder engine is most common, although three-cylinder versions with the same basic cylinder dimensions as the four-cylinder engine are offered by several manufacturers as lower powered units. Six-cylinder engines are also used in large crawlers.

The engines fall into two groups distinguished by combustion chamber differences. These are engines with a separate combustion chamber or ante-chamber cast into the cylinder head or carried in an inserted member fitted into the cylinder head, and direct injection engines with a hemispherical or toroidal shape chamber cast integrally in the piston crown. Both have a place, dependent upon the type and size of tractor concerned. Classically, the separate chamber engine has been said to be less restrictive in terms of engine r.p.m. at optimum efficiency than the direct injection engine and also unable to match the best specific fuel consumption of the direct injection engine. In practice, as the tractor engine is normally governed to a modest maximum r.p.m., these differences have really been of academic interest, but in any case due to development of the direct injection engine they no longer apply.

The separate combustion chamber is still exclusively used in engines below, say, 50 cu. in. per cylinder. This is because where a small volume of fuel is injected it is

* Shell-Mex & B.P., Ltd.

more difficult to mix fuel and air mechanically by atomisation and distribution of the fuel through the injector. Consequently, some assistance is obtained by air movement in the separate combustion chamber.

Dieselisation of wheel tractors was based on the existence of suitable separate chamber engines in the power and speed range required. It must also be well known that this type of engine was used by the American Company which first mass-produced Crawler tractors. However, significant numbers of direct injection engines are now used in current British production and are normal in the medium tractor range.

Engine Development

As in so many aspects of engineering evolution, the early engine designers had a knack of getting their basic facts right. Fuel injection pump characteristics and the adoption of cylinder liners are two examples.

Subsequent development has not changed the outward appearance of engines, although much work has gone into detail development. This is chiefly apparent in the serviceability of component parts realised through improvements in metallurgy, notably in the characteristics of piston rings and bearings and in the quality and control of surface finish. Chrome-plated piston rings, or piston rings with better sealing characteristics, or both, copper lead bearings with lead–tin or lead–indium overlay have become widely used. Chrome-plated rings are not, however, universally used, and now aluminium–tin bearings have been added as an alternative to copper–lead bearings. The adoption by engineering of one type of material or another and sometimes the reversion to an earlier type emphasises the difficulties the manufacturers have in seeking the best compromise to suit a wide variety of operating conditions. In addition to advances in materials, improved production techniques have enabled the manufacturer to tighten tolerances and in consequence produce a machine with a greater potential. Whether this potential is being fully realised will be developed later.

It may, perhaps, seem surprising that the fuel injection pump, which is the " heart " of a diesel engine, and indeed injection equipment generally has been relatively free from trouble. This has possibly been due to three principal causes :

(1) Good manufacturing standards and quality control in the relatively low volume production during the development years.

(2) The " mystique " it has been possible to attach to these components and the consequent reluctance of the amateur to interfere.

(3) The relatively low power rating of the diesel engines of the 1940's and 1950's.

The first factor is still under the control of the manufacturer, albeit, no doubt, more difficult for him to control. The second is fast losing its discipline, and the third, because of increasing engine ratings, is producing a harsher temperature environment in which the injector nozzle must live.

Fuel injection equipment manufacturers have made their separate contribution by producing cheaper and simpler pumps, such as a rotary distributor pump and a smaller version of the in-line pump. Their aim is to reduce the necessity for servicing and re-adjustment within the service life of the engine.

Combustion and Fuel Characteristics

Up to ten years ago, diesel engine combustion provoked many excellent Papers, chiefly because engine life between overhauls was severely limited by piston deposits and by erosion or corrosion, or both, of the cylinder liner near the top of the piston stroke. At that time two particular characteristics, Sulphur Content and Cetane Number, were frequently mentioned. The former because of the known correlation of sulphur content with cylinder liner wear, and the latter because it was the known engine performance index of fuel quality. In addition to having a corrosive influence under low temperature conditions, mixed oxides of sulphur, the combustion product of sulphur in a fuel, were found to influence the formation of lacquer or varnish like deposits on pistons and in piston ring grooves.

Fortunately, the significance of sulphur in the proportions which concern us—that is at figures below 1% in a gas oil—has been reduced by subsequent technical development. For example, by better engine design, by the use of better materials and the general adoption of and improvement to thermostats which ensures that jacket temperatures are kept above the acid dew point of combustion gases which is reached at temperatures below 130° F. Undoubtedly, however, important though these features are, the greatest contribution has come from the development of additive-type lubricating oils formerly known as detergent oils, and more recently with greater validity heavy-duty oils.

Although diesel engine builders have been spared having to deal with a fuel characteristic so significant as the Octane Number of a gasoline, a distillate fuel does have a Cetane number, and there is some danger that the importance of Cetane Number is exaggerated. Perhaps this is readily explained by the fact that two reference fuels are used and the combustion delay of the test fuel is measured in a single-cylinder laboratory diesel engine. This may seem to the layman to be analogous to Octane Number determinations, but it should be understood, however, that the correlation with practical conditions is much less precise in the Cetane Number test.

The British Standard 2,869, Class A, specification is used to prescribe quality limits for distillate fuels used in diesel engines of the type we are considering. The minimum specification figure is 45 Cetane Number.

Cetane Number has been said, historically, to be the chief factor influencing startability and roughness of running, and this is true in respect of wide differences ; for example, between 35 and 60 Cetane Number. However, it cannot really be considered apart from volatility/distillation characteristics, specific gravity, and viscosity. This may not always be fully recognised. It must be appreciated that the Cetane Number determination is carried out with controlled jacket temperatures much higher than those met with in tractor engines unless under full load. The correlation therefore only applies over a wide range of numbers, and for all practical purposes the point is merely of academic interest, because distillate fuels generally are of high enough Cetane Number to be above the threshold of sensitivity. Consequently, it does not simulate combustion in an engine under starting conditions.

The development of multi-fuel engines for military purposes in recent years has produced a better appreciation of ignition quality. Indeed, many engine builders must have been surprised at the relative insensitivity of their engines to this characteristic.

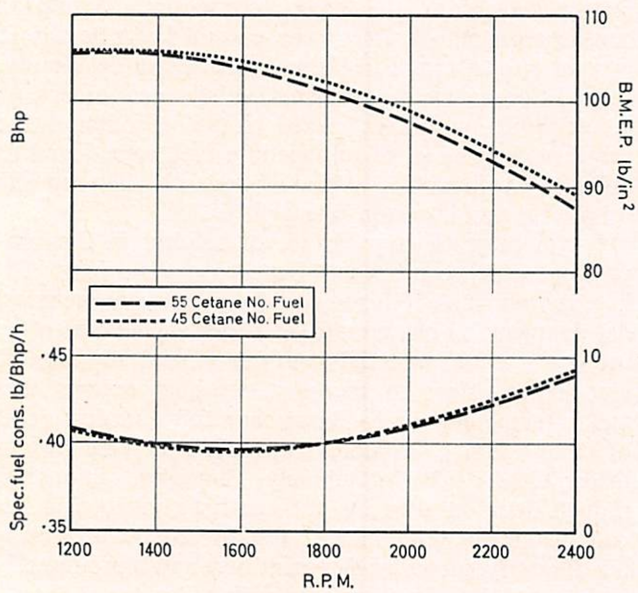


Fig.1

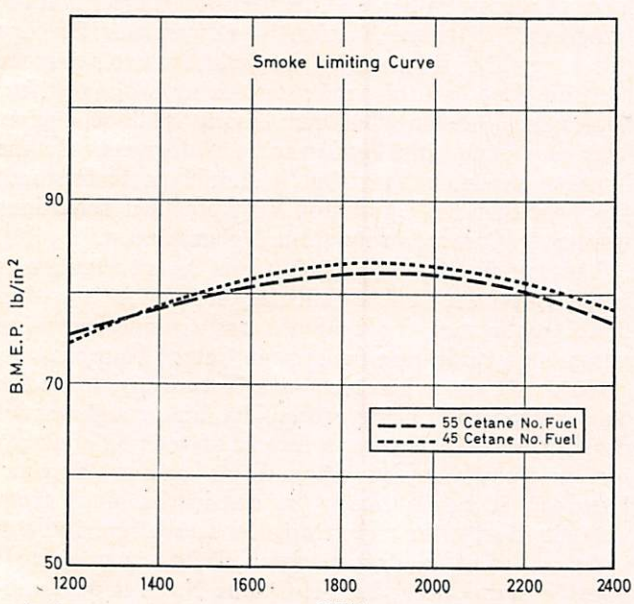


Fig.2

An example of the relative insensitivity of engines to differences in Cetane Number is illustrated in Fig. 1, which shows the relative effect on the B.M.E.P. and specific fuel consumption of two fuels with Cetane Numbers of 55 and 45 respectively, and with comparable specific gravity. Fig. 2 shows the effect of these fuels on smoke limited B.M.E.P.

Although these results were typical of engine " A," a four-cylinder direct injection engine rated at 57-b.h.p. at 2,600-r.p.m., engine " B," a small separate chamber engine, showed somewhat wider difference between these fuels.

In this case the smoke limited B.M.E.P. curves are within 2 per cent. of each other, but the peak with the higher Cetane Number fuel occurred slightly earlier than the low Cetane Number fuel. The difference between these sets of results is in practice much less than may have been met in either type of engine, when deterioration of injection equipment is considered.

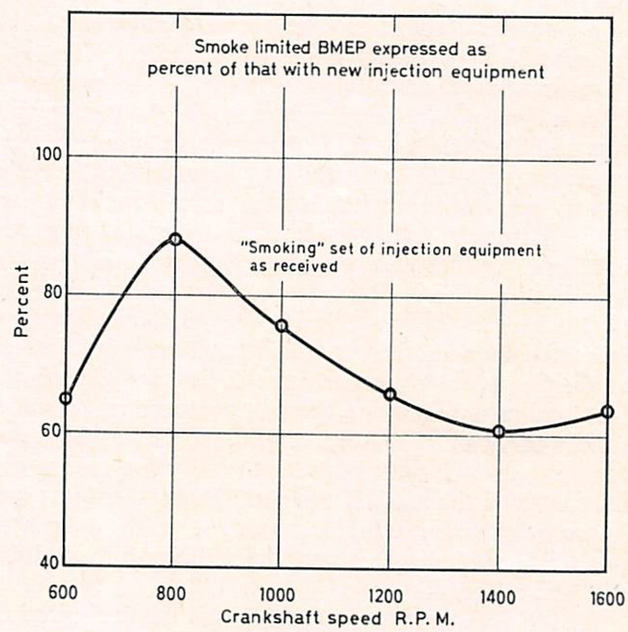


Fig.3.

The Significance of Mechanical Deterioration of Injection Equipment

Fig. 3 illustrates the significance of the deterioration of fuel injectors, and it is interesting to compare this plot with both Figs. 1 and 2. In Fig. 3 the B.M.E.P. of a direct injection engine at the just visible exhaust condition is plotted with the engine using new and deteriorated fuel injectors respectively. The B.M.E.P. is expressed as a percentage of that with new equipment, and the considerable drop in smoke limited power will be noted.

This comparison is made in order to illustrate the relative significance of nozzle deterioration characteristics and fuel quality respectively. It will be generally appreciated that over the whole range of diesel engine type and size, including engines in the automotive and industrial fields, particularly the latter where engines may reach several thousand horse-power, fuel characteristics have a greater significance than in the comparatively narrow range of size and type of engine used in agriculture.

It may be thought that dark smoke is of no undue significance in an agricultural application, which is true, of course, in terms of its nuisance value, as it is usually readily dissipated. However, in any kind of combustion it is the outward evidence of imperfect combustion which must be uneconomic. Smoke can be caused by several influences, but it is usually created through inadequate local mixing of fuel and air due to an injector condition such as blocked holes in a four-hole injector which will upset the pump discharge characteristics. It is important that needle valve seating should be adequate, otherwise black smoke will be caused by nozzle dribble.

This type of deterioration rapidly progresses, causing an increase in nozzle tip and needle valve temperatures, meanwhile increasing deposit formation until one or more holes are blocked. Fig. 4 illustrates the condition ultimately reached, and in this case also the configuration of the nozzle hole must be noted. In recent years, development of fuel system filters by injection equipment manufacturers has reduced the incidence of nozzle hole erosion.

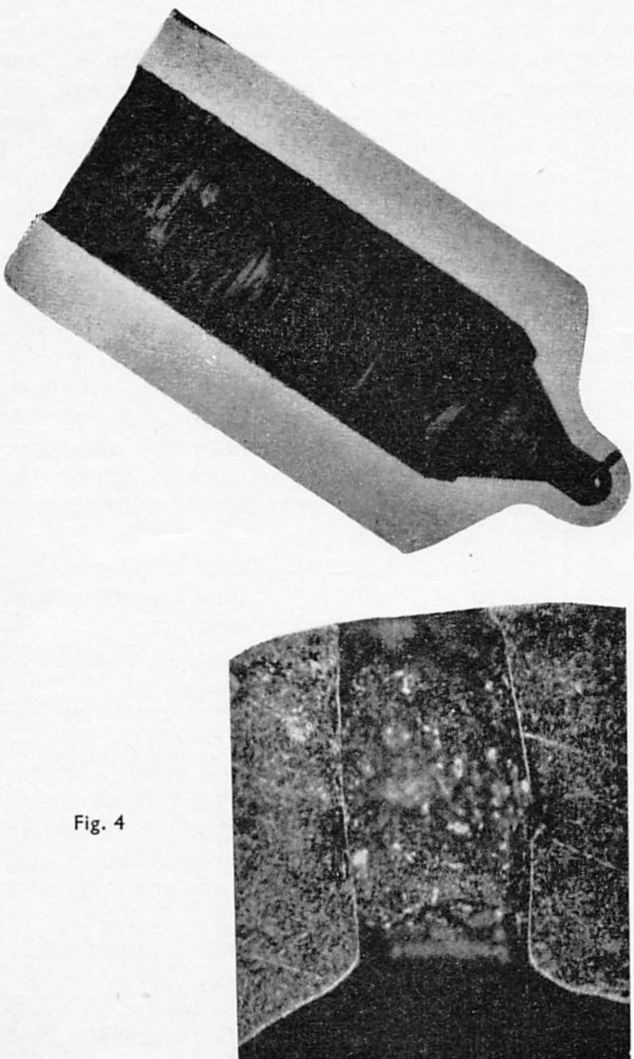


Fig. 4

Normally, injectors are more frequently disturbed than are fuel injection pumps and they are also more subject to deterioration. Where injector maintenance is known to be adequate and the fuel pump stop has not been reset, an operator may perhaps be forgiven if he believes the injection equipment is in first-class condition. Nevertheless, it will be appreciated that if the manufacturer has rated his engine to full advantage then an increased fuel flow will normally also cause increased smoke. For example, with an in-line pump, fuel output may be increased by as much as 20% at the maximum stop setting because of wear at the delivery valve unloading collar. Equally, fuel flow may similarly increase because of wear of the injector spring retaining plates and spring fatigue, or both, which will have the effect of allowing injection at a lower opening pressure.

Bailey *et al.*(1) have shown that a reduction in nozzle opening pressure in a particular engine resulted in dense smoke even at a flow rate no higher than the manufacturer's maximum pump flow condition. Even more significantly they showed that the rate of production of free carbon increased ten times. They used an opening pressure of 100 atmospheres instead of 145 atmospheres. Such a reduction may be thought to be unlikely in practice, but an examination of many sets of fuel injectors from service has shown this is by not any means impossible.

In Fig. 5 the effect of increased fuel flow on smoke from a direct injection engine is illustrated, using a Hartridge Smoke Meter. Specific fuel consumption and B.M.E.P., as well as smoke level, are plotted against fuel flow. From these curves it can be seen that a 10% increase in fuel flow for this engine produced a corresponding B.M.E.P. increase of 4% with a deterioration in specific fuel consumption of approximately 6%. Thus slightly greater torque was obtained at the expense of increased specific fuel consumption and a deterioration

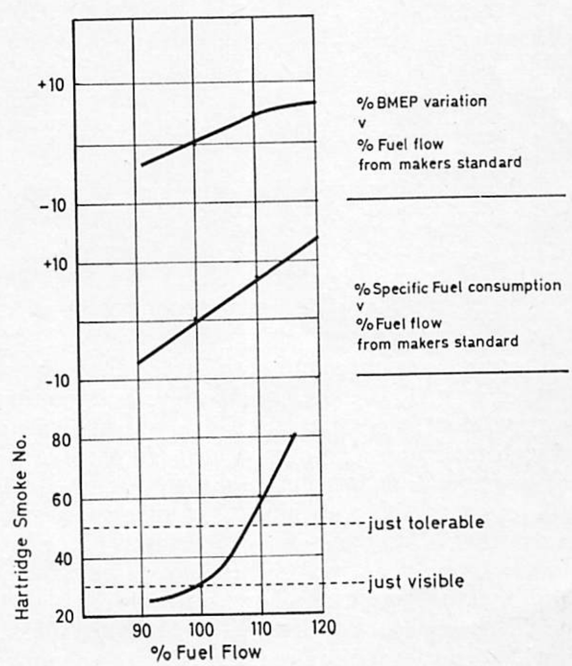


Fig. 5

in exhaust condition. This must increase the load of combustion carbon the lubricant is required to carry. If a dark smoke condition is not corrected, it must affect the optimum life of the lubricant.

Clearly, one cannot condone an unsatisfactory exhaust condition in any engine used in agriculture on the grounds that the exhaust is readily dissipated. Nor can inadequate injector maintenance be excused, particularly as some manufacturers have service exchange schemes which make it quite unnecessary for users to keep a reserve stock of these expensive items.

Startability

The problem of starting increases with decreasing ambient temperature and with deteriorating engine condition, notably the quality of valve and piston ring sealing. Fortunately, in this country we do not encounter particularly low temperatures, but there may be problems, nevertheless.

Given reasonable mechanical conditions in the engine, the first essential is battery capacity capable of producing a sufficiently high cranking speed. If the battery is properly maintained, it will produce sufficient power as planned by the manufacturer. However, cranking speeds above 100-r.p.m. are desirable to produce and retain sufficient heat in the combustion zone during the first few firing strokes.

Owing to the greater surface to volume ratio of the smaller separate chamber engine and consequent heat loss, heater plugs are usual. These markedly assist starting ; they are, however, an adjunct to starting and not a substitute for the battery. It should be remembered that the actual battery capacity drops with temperature and, depending on type, may fall by 25–40% in hard frost conditions.

The viscosity of the lubricant will affect the " unsticking " characteristics of the engine. This, however, is taken into consideration by the manufacturer in selecting and subsequently recommending appropriate grades of lubricant. It is sufficient to observe that an oil grossly contaminated with combustion carbon and having, therefore, an increased viscosity will prove less satisfactory.

Cetane number-improving additives are sometimes suggested as a palliative for poor mechanical condition. However, all Cetane Number improvers do not raise the ignition quality of fuel under low temperature starting conditions. This was mentioned at an earlier stage and has been commented upon in other Papers(2).

Starting and continuous satisfactory running may be affected in periods of severe frost by the separation of waxy material from diesel fuel. This is a normal constituent of such fuels and all will produce this phenomenon at some temperature. With those normally marketed in the U.K. some trouble with filter blockage due to wax may occur below 12 degrees of frost persisting for long periods. If water is present in the fuel, the effect will be precisely the same, and for this reason all water traps in the fuel system should be regularly drained. Some manufacturers have provided more exotic equipment to meet this contingency. Similarly, main fuel storage should be regularly drained. There is evidence that this simple precaution may be neglected on farms. This should not be so, as in our climate condensation may occur in the storage tank almost any night.

Lubricant Characteristics Influencing Engine Performance

It is interesting to recall that the modern framework of lubricating oil tests and the development of " Heavy Duty " oils started with work by the Caterpillar Tractor Company and the subsequent adoption of the Caterpillar L.1 single-cylinder engine test by U.S. and U.K. Defence Ministeries and by the Oil Industry.

Even now the single-cylinder Caterpillar engine remains one of the basic test engines still used in the U.S. and in the U.K. It is not, however, proposed to deal with the test background—an immense subject in itself—except in so far as it is necessary to explain the current position. Bates included detail which still applies in a Paper before this Institution(3).

In the early 1930's ring-stick was the characteristic chiefly influencing engine life between overhauls. Life was increasingly improved by the development and use in the late 1930's of oils containing anti-oxidants. However, as knowledge grew, it was recognised that characteristics other than ring-stick were involved and additional properties were desirable. This stems from the basic fact that an engine lubricant will be bombarded by the products of combustion passing the piston rings, as well as dust which the engine breathes. The potentially harmful of these must include carbon, water, dust, and mixed oxides of sulphur.

The successful and successive development of oils with an increasing capacity to combat these contaminants during the last 20 years, and particularly the last 10 years, has virtually made the diesel engine an economic proposition in the size we are considering, although the contribution made by engine design is recognised and we should pay tribute to it. We have, however, reached the stage when heavy-duty oils are recognised to be *essential* for modern diesel engines.

At the commencement of this Paper a fuel property, Cetane Number, and sulphur, a naturally occuring component of all petroleum products, were mentioned. Subsequently, Cetane Number was shown to be of academic interest because (*a*) current distillate diesel fuels are within the Cetane Number range where the correlation with startability varies insignificantly. (*b*) Cetane Number within the range of Oil Distillate fuels ; Cetane Number is meaningless in terms of smoke limited power and fuel consumption. As regards sulphur, modern HD lubricating oils can deal effectively with the corrosive effects of sulphur oxides and water produced during combustion of the fuel.

As the effect of sulphur in a fuel was alleged to have been overcome by the developement of modern lubricating oils, it is, perhaps, appropriate to review in their full context the significance of combustion insolubles and other contaminations in engines used agriculture.

Returning to the comments on the significance of the Caterpillar L.1 engine test, it must be recalled that this was devised to assess the combustion fouling characteristics of lubricants. At the same time, a second test, the Chevrolet L.4, was adopted in order to assess the oxidation resistance of a lubricant under high temperature conditions. This was strictly a test of the oxidation resistance of an oil determined in a gasoline engine fitted with copper lead bearings. It has therefore proved possible to measure oxidation resistance in terms of weight loss in the bearings without the application of sulphur in the fuel, which should exist if the test was undertaken in a diesel crankcase.

These or corresponding tests have been written into various specifications such as those of the U.S. and British Ministry of Defence. Unfortunately, these specification tests are frequently referred to as though they were absolute standards. A moment's reflection should serve to show that major lubricant suppliers must devise many more tests in order to develop their branded grades.

Clearly, the engine tests quoted assess particular and important characteristics which at the time of their adoption were the two most important features limiting diesel engine performance. It is important to note that neither test leads to a prediction of a reasonable oil life based on the effects of contaminants or additive reserve, nor does either test assess engine wear. Furthermore, neither test measures corrosive influences on component parts such as little end bushes.

Dyson *et al.*(4) have demonstrated the prediction of oil life in service, based on a suitable additive reserve to

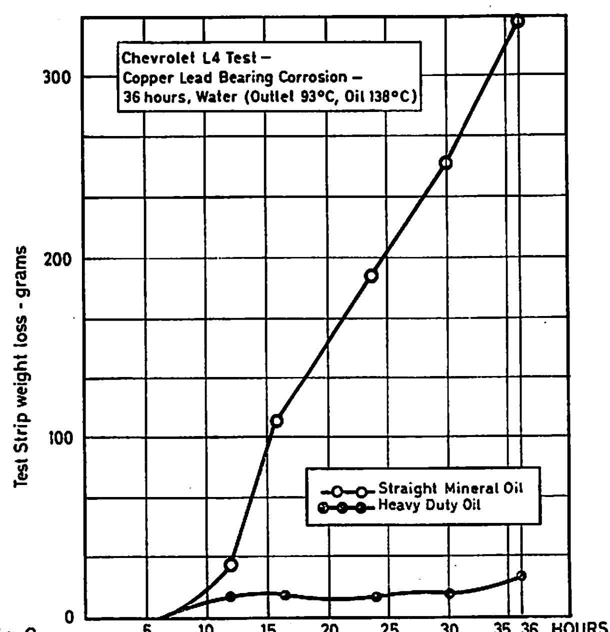


Fig.6

maintain piston cleanliness and control of corrosion using particular oils.

It must be emphasised that the greatest advances in recent years have been in combating wear. Fig. 6 shows the influence of modern heavy-duty oils in overcoming corrosion of copper lead bearings, which in this context is synonymous with wear. These were obtained in the Chevrolet L.4 test mentioned earlier.

Fig. 7 illustrates the inter-relationship of ring wear with jacket temperature, load, and oil viscosity, using straight mineral and heavy-duty oils in a single-cylinder Gardner L2/LW test and employing the radio active ring technique. Several conclusions can be drawn which are (*a*) the impressive reduction in wear made possible by the use of heavy-duty oils compared with straight mineral oils ; (*b*) with straight mineral oils the wear rate increased with the reduction of oil viscosity ; (*c*) the effect of jacket temperature ; (*d*) the slight difference in wear rate between viscosity grades when heavy-duty oils are used.

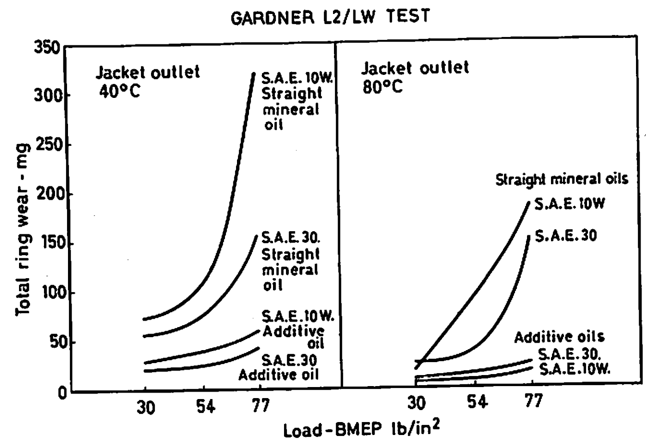


Fig.7 Influence of Load, Temperature, Oil viscosity and Oil type upon wear

To this we should add the conclusions of Dyson *et al.*(5) that a concentration of additive less than half of that normally in an oil of DEF.2101 A standard was sufficient to bring the wear rate with a 1% sulphur fuel down to that of a 0·2% sulphur fuel.

The DEF.2101 B specification, superseding the DEF.2101 A specification, would now specify a minimum performance standard for heavy-duty oils commonly used in agricultural tractor diesel engines. Some branded oils will have a significantly higher performance standard because of their development against many other types of engine test than the two tests featured in the DEF. specification. Furthermore, they also concluded that with distillate fuels engine wear is independent of fuel sulphur content, provided the additive is present above a certain critical level, and indeed that abrasive wear and corrosive wear are multiplicative rather than additive. *This is a most important conclusion.*

Engine manufacturers usually try to recommend an optimum oil life based on the requirements of the engine and the cost of oil change to the customer, taking into consideration the environment in which the engine operates. For many years before scientific methods of measuring the concentration of additives were established, oil was changed for physical reasons—for example, increase in viscosity, high percentage of diluent, the presence of water, the level of combustion insolubles, and the certainty that wear metals must be present and should be removed. Through experience of typical results and their reflection in engine conditions, the manufacturer made his selection of an appropriate oil life. Usually, recommendations are in hours.

Lubricating Oil Samples from Tractor Engines

Bearing in mind the impressive reduction in engine wear caused by developments in lubricants in the last decade and the complementary improvements of engines, it was decided to examine a range of oil samples taken from tractor engines to see how the improvements were being capitalised. Additionally, it was thought that deterioration in injection equipment on the lines previously discussed might be evident in lubricating oil conditions.

Fortunately, in recent years it has become possible to carry out spectrographic analyses of used oils in order to determine the likely source and significance of wear products. This obviously means that the significance of wear products in a used oil can be more clearly understood. To reach any conclusions which can be regarded as valid, it is of no value to examine isolated samples on demand. Inspection of a range of samples must be carried out and the test results related to knowledge of engine condition.

The results so far on the examination of used oil samples is surprising in two respects :

1. There is little evidence of deterioration of combustion characteristics, which means injection equipment is retaining its condition and its maintenance is adequate.
2. The level of wear products and silicon is higher than had been anticipated.

The examination is continuing and it should ultimately be possible to draw statistically analysed conclusions.

Details on spectrographic analyses of 22 used engine oils are tabulated in Table II. Other characteristics are not included because, with the exception of samples taken from tractors which were admitted to be irregularly serviced, they were acceptable. The samples taken from tractors irregularly serviced were even more interesting because of the level of silicon and wear products they contained.

Table II

USED HEAVY-DUTY OIL SAMPLES EX FARM TRACTORS

Solid Contaminants (p.p.m.)

Sample Group	*Average Figures*			*Maximum Figures*		*Ratio, min./max.*	
	Silicon	*Aluminium*	*Iron*	*Silicon*	*Iron*	*Silicon*	*Iron*
All samples	53	32	480	300	1000+*	1 : 60	1 : 40
Samples from tractors claimed to receive regular maintenance . .	22	19	334	65	1000+*	1 : 32	1 : 20
Samples from tractors claimed to receive irregular maintenance . .	119	48	920	300	1000+*	1 : 12	1 : 2

* The averages are only a guide for comparison purposes because iron determinations of 1000+ p.p.m. have been included at 1000 p.p.m. Consequently, the comparison favours the results from irregularly maintained tractors.

In Fig. 8, iron content is plotted against silicon content. The correlation between measuring silicon content and measuring iron content will be observed. Unfortunately, it was not possible in sufficient cases to obtain details of oil life prior to sampling or of engine life at that stage.

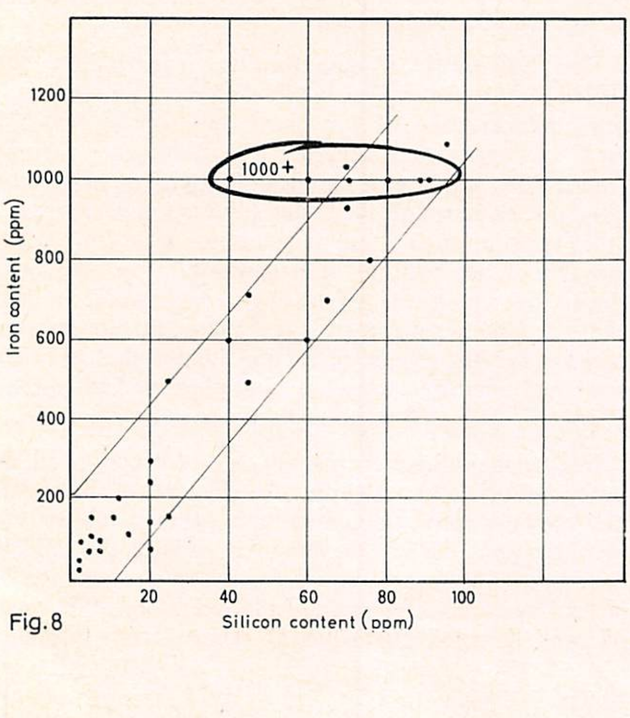


Fig.8

1. The silicon and iron contents varied between 1 : 60 and 1 : 40 respectively.
2. Oil from engines admitted by their owners to be irregularly serviced had average iron contents at least three times and silicon contents five times the average from tractors regularly serviced.
3. Oil from irregularly maintained engines had diluent contents between 6 and 14% and correspondingly low viscosities approaching on SAE.10W level.
4. The combustion insolubles contents were generally fairly reasonable, with an average figure of 2·0%.
5. Fifty per cent. of the samples taken from tractor engines claimed to receive regular maintenance had been taken at or before the manufacturers' drain period.

Interpretation of Results

It is not possible to draw precise conclusions on the significance of these results in respect of engine wear, except that iron content seems to correlate with silicon above about 20 p.p.m. silicon. However, by coincidence, two reports were received in the last three months which provide useful references. These are :

(*a*) An engine from a modern diesel tractor using a well-known branded heavy-duty multi-viscosity tractor lubricant was examined at 8,000 hrs. Crankshaft wear was described as insignificant, and engine conditions generally as " remarkably good." The engine was reassembled. Unfortunately, an oil sample was not taken.

(*b*) One engine from another modern diesel tractor using an oil of similar quality was said to be " worn out " at 1,300 hrs., and appropriate wear figures were supplied to confirm it. The iron content in the retained oil sample was above 1,000 p.p.m., and the silicon content 270 p.p.m.

It is interesting to observe that approximately 25% of the samples in Table II carried iron samples similar to (*b*) above. Thus a high concentration of abrasives must be fairly common.

The results obtained naturally inspire a question : How far do these results compare with those from similar types of engine used in other industries ? Obviously, the commercial goods vehicle engine most nearly matches the tractor engine in size and speed, although it does not have to meet the same dust hazard as the agricultural tractor when the latter is performing some field operations. It would, therefore, be unrealistic to expect a similar order of crankcase cleanliness in the tractor engine. However, Manby(6) has described considerable work on the affect of dust and has quoted efficiency figures for different types of air cleaner. This was in the context of dust hazards met in overseas operation, and it is, perhaps, surprising to see high orders of contamination in samples taken from U.K. tractors, particularly as Manby quoted high efficiency figures for oil cleaners.

In Table III corresponding iron contents are tabulated for oil samples taken from an equivalent number of engines in commercial vehicles. These were, however, all taken at 10,000 miles, corresponding to perhaps 500 hours. Most unfortunately, silicon contents were not recorded.

Table III

USED HEAVY-DUTY OIL SAMPLES EX COMMERCIAL VEHICLE ENGINES AT 10,000 MILES, APPROX. 500 HOURS

Wear Metals (p.p.m.)

	Average Figures Iron	*Maximum Figures* Iron	*Ratio, Min./Max.* Iron
All samples ..	150	350	1 : 4

If these results are compared with those from tractor engines (Table II), it will be seen that the average iron contents of all the samples from commercial vehicle engines are :

1. Less than one half, and the maximum figures less than one-third, the iron content in the best group of tractor oils.
2. Less than one-eighth, and the maximum figures less than one-third, the iron content in the worst group of tractor oils.

It must be appreciated also that the above comparisons denote the fact that the commercial vehicles were possibly run on average for twice as many hours as the tractor group.

The results on contaminants are clearly interesting when considered in the context of the Paper as a whole. It seems quite clear that we have reached the position at which :

1. Developments in engine design have made them insensitive to differences in Cetane Number likely in distillate fuels.
2. The development of heavy-duty lubricants has made possible a vastly increased engine life by minimising the ill-effect of some products of combustion, reducing piston deposits, and reducing wear.
3. There is evidence that a significant proportion of engines must be worn out prematurely through the presence of abrasive contaminants in the oil.

Returning to the introductory assumptions, it would seem that these should now be modified to read :

If engines are accorded proper maintenance, and particularly oil changes not less frequent than manufacturers' recommendations, long life is ensured because of improvements in engine design and lubricants. The natural corollary to this is :

Because of improvement in engines and in engine lubricants during the last decade, the quality of maintenance has during that period become a more important factor affecting engine life.

Acknowledgment

The author's thanks are extended to Shell-Mex and B.P. Ltd. for permission to present this Paper.

REFERENCES

(1) C. L. BAILEY, A. R. JAVES and J. K. LOCK, " Investigation into the Composition of Diesel Exhausts," Fifth World Petroleum Congress.

(2) BRUNNER and RUF, " Contribution to the Problem of Heating and Operating Diesel Vehicles at Low Temperatures."

(3) E. S. BATES, " Technical Developments in the Lubrication of Tractors," Institution of Agricultural Engineers 29th March 1955.

(4) A. DYSON, L. J. RICHARDS and K. R. WILLIAMS, " Diesel Engine Lubricants : Their Selection and Utilisation, with particular reference to Oil Alkalinity," The Institution of Mechanical Engineers, 17th May, 1957.

(5) A. DYSON, J. HUGHES, R. SMITH and K. R. WILLIAMS, " Some Aspects of Wear and its Prevention in Diesel Engines." The Institution of Mechanical Engines/A.S.M.E. Conference on Lubrication and Wear, 1st – 3rd October, 1957.

(6) T. C. D. MANBY, " The Measurement of Tractor Performance." The Institution of Mechanical Engineers' Symposium on Agricultural Tractors, November, 1961.

DISCUSSION

MR. B. W. MILLINGTON (Ricardo & Co., Ltd.) opened the Discussion by thanking Mr. Atkinson for his admirable Paper.

He was concerned with Ricardo's, and Ricardo's were concerned with engine design. Mr. Atkinson had taken a step back from tractors and had looked at the whole problem from a very detached point of view.

He asked for Mr. Atkinson's opinion as to why the divided chamber engine, the indirect injection engine, had been so successful in the tractor field, because in many ways the tractor engine, as had been pointed out in the written Paper itself, is operated under conditions where the direct injection engine would be very much preferable, even in the smaller sizes. Mr. Atkinson had given a part-answer to this question in talking about deterioration of injection equipment, particularly of nozzles. Undoubtedly, one of the advantages of the indirect injection engine was that it was very much less sensitive to the condition of the injection equipment. Another advantage was that it operated at lower cylinder pressures, and therefore verying loadings were allowed, and in general the engine ran more smoothly. A disadvantage of the indirect injection engine was that starting was more difficult, and Mr. Millington thought reliable starting of a tractor engine was extremely important. Tractors were left out in all sorts of weather, and they must start and do their job with the minimum trouble.

The direct injection engine was certainly able to start more easily, but perhaps in the smaller sizes even a direct injection engine would not start too readily at Scandinavian levels of temperature and therefore some starting aid would be necessary. If it is necessary to fit a starting aid of some sort, then it does not matter much whether a direct or an indirect injection engine is concerned.

Many indirect injection engines were of a proprietary nature, and there had been a very considerable interest by the owners of the patent in developing the engine to the utmost. He thought it was, perhaps, true to say that some of the indirect injection engines had received a greater degree of development over a longer period than the small tractor direct injection engine.

Mr. Millington thought many development engineers would be very pleased to hear Mr. Atkinson's comments on the reliability of fuel injection equipment, and particularly fuel pumps. It was his experience that the development of the correct fuel injection specification was probably the one factor which took the longest time of all. It was frequently a tedious process to obtain a really satisfactory fuel injection specification, and he thought it was to the credit of the fuel injection manufacturers that once the specification had been established it was maintained in production to a very high degree.

Another design factor Mr. Atkinson had discussed was the question of cooling—air cooling *versus* water cooling. He had said that in this country practically all tractors were water cooled, and Mr. Millington asked if Mr. Atkinson could say why that should be. One would have thought that the relatively low rating of tractor engines would provide a good case for air cooling, but Mr. Millington supposed such tractor engines were in some measure linked in manufacture to vehicle engines, which are more highly rated and where air cooling is a more difficult proposition. If one looked at the history of most tractor engines one would find that there was a vehicle engine in the family tree from which they have been developed.

Mr. Atkinson had made a very good point in saying why modern engines had improved reliability when he spoke about better manufacturing tolerances and better surface finish of running parts in manufacture. He thought we sometimes took this for granted in a western country such as our own, but those who had had any experience of some of the more backward countries attempting to manufacture their own engines would realise the extreme importance of close tolerances and good surface finish in production if the engine was going to carry the bearing loadings and so on which the more highly-rated engines required. The ability of a bearing to carry a high load was very closely associated with the ability to keep to cylindrical surfaces, close tolerances, freedom from deflection and so on in the design of tractors.

In talking about fuels and lubricants, Mr. Atkinson had indicated that the sulphur content and Cetane Number of fuels no longer mattered. It was agreed that the development of correct lubricants now meant that the sulphur in the fuel was relatively innocuous and that the Cetane Number certainly was of very little importance, provided it was above the 45 – 60 level.

It was clear that Mr. Atkinson's real interest lay in the field of lubrication, and he immediately spoke with great authority. Mr. Millington had been extremely interested in the slides showing the level of contamination in the lubricating oils of tractors operated under various conditions. The slides he had shown explained the level of iron contamination which he thought permissible and where the danger level might be.

Mr. Millington said he would like to be told how the silicon contaminating material—*i.e.*, filter contamination —got into the engine. What proportion got through the air cleaners or was introduced in the breather? How much was built into the engine in the iron castings? Engines could shed quite a lot of sand from castings during their life, although, perhaps, much of this would be of a larger particle size than was likely to trouble the engine, because it would be stopped by the filters very quickly. Nevertheless, it could be very damaging if it was released into the oil circuit down stream of the filter.

Mr. Millington really agreed with everything Mr. Atkinson had said. He thought his Paper had been a very good review from the viewpoint of a man who had stepped back to see the tractor engine in perspective today.

MR. ATKINSON thanked Mr. Millington for his kind remarks and said that his answer to the question why the divided chamber engine performed so well, compared with the direct injection engine, was that direct injection engines were made for very narrow speed ranges, loads or fairly limited operating characteristics. An engine used in a tractor must run through all the particular zones, and they tended to cancel one another out.

He agreed with Mr. Millington's remarks about the insensitivity of, for instance, pintle-type nozzles. All indirect injection engines did not have pintle-type nozzles and some of them might be at a disadvantage in consequence. Certainly the pintle-type nozzle was very resistant to interference by particles, oxidation products and so on.

Referring to starting performance, he agreed that direct injection engines, as well as indirect injection engines, would meet difficulties under low temperatures which were common in some parts of the world, and which reached this country occasionally.

Mr. Atkinson saw no reason why air cooling should not have been adopted. Although it is true that tractor engines had been designed by manufacturers who build automotive engines, he thought our innate conservativism was the first obstacle. The next point was that if something which was well entrenched was to be replaced, it was not sufficient just to equal it in some characteristics—it was necessary to improve significantly on those characteristics, and probably that was the difficulty which had defeated the introduction of the air-cooled engine in those applications where water-cooled engines already operated.

Referring to engine lubricant contamination sources, Mr. Atkinson said that he had obtained a considerably increased range of samples since his Paper went to Press. These showed silica and iron concentrations, and also the relationship between irregularly-maintained and regularly-maintained engines. Water and diluent affected many of the samples to a greater extent than the first batch showed. With regard to Mr. Millington's point about in-built debris, probably meaning sand, Mr. Atkinson had analysed samples from relatively new engines, one out of four having done about 70 hours' use in service and some significantly less, and there was not much evidence of in-built debris. The silicon levels—he could remember one figure, which was 70 parts per million, and another one even less—were significantly lower than those from the well-maintained tractors, so obviously much of this was coming in from the outside.

He could not say what proportion came through the air filter and what proportion through the breather. On farms where tractors were irregularly maintained, he had no doubt that some of this debris came in by means of the cans with which the engine is refilled with lubricating oil.

A Paper by Mr. Manby, of the National Institute of Agricultural Engineering, gave some very interesting information on the significance of particle size. Using this information, he had analysed two samples of oil, one from Engine B, and 70% of the particles lay between 3 and 20 microns and 30% lay between 20 and 30. An oil sample from one of the irregularly-maintained engines had shown 80% between 1 and 10 microns, and 20% between 15 and 40 microns. In other words, the size of solid particles found in these engines largely lay in the group which had been in the size group which was allgeed to be most significant so far as piston ring wear was concerned.

MR. T. C. D. MANBY (N.I.A.E.) said that Mr. Atkinson had given the impression that as long as the sulphur content of fuel was less than 1% there was not very much to worry about, because the oil additives would cope with it. If that was the case, why did the oil companies provide the farmer with a fuel which had a much higher sulphur content than that supplied to the road vehicle user? About 18 months ago he had found that the order of sulphur content figures was about ·4% for a road vehicle user to ·7 to ·9 for the farmer.

Secondly, Mr. Manby asked, did the carbon produced by smoke, apart from depleting the oil additives, in fact increase the incidence of wear?

He went on to say that recently, in 29 degrees of frost, some of the tractors in the countryside could only be kept going by playing blowlamps on the pipe leading to the filters. The trouble was not due to water or to waxing of the filters—it seemed to be due to the actual pour-point of the diesel fuel. Could the user, when faced with these conditions, do anything to help himself? Could he mix kerosene, or lamp oil or anything of that sort, with the diesel fuel to lower its pour-point?

Mr. Manby had found the oil samples extremely interesting and asked if Mr. Atkinson could give further details of the method of sampling. In his experience of sampling from engines in a dust chamber, he had found it very difficult indeed to get consistent results. He would like to know particularly whether the samples had been taken by trained staff, from Mr. Atkinson's company perhaps, from hot engines, or were they taken from oil which had been at some time drained from the engine? Did they include the filter content or not? These things were obviously very relevant, indeed.

He had done some very quick calculations while listening to the Paper and had tried to remember the figures which he quoted in the Paper to which Mr. Atkinson had referred. In 1957 what he had experienced with a normal open-type crankcase breathing system, under very dusty conditions, was that one might expect to have ·05 gram per 10 hours entering into an engine of about two litres capacity. This worked out at 80 parts per million per 100 hours, and indicated the performance he would expect from a good breathing system under intense dust conditions. In the same Paper he had quoted the level that would be fatal to engines, and that worked out at 2,000 parts per million per 100 hours.

Mr. Atkinson quoted a somewhat alarming figure of 1,000 hours as the life of an engine. Mr. Manby asked for some relevant details. Was it a British engine, had it got an open type of breathing system, had it got an oil bath air cleaner or a paper element air cleaner?

Mr. Atkinson had mentioned some points on particle size distribution, and Mr. Manby's main comment was that with particle sizes of less than 10 microns, but more than 2 or 3 microns, one would still get a very appreciable rate of engine wear—in fact, the same sort of rate obtained with particles of less than 50 microns. A particle of 2 to 3 microns would remain in suspension in the air for a very appreciable period during engine cooling, and it was this sort of particle range that even the efficient oil bath filter was allowing to pass fairly freely.

Another question he would like to ask was not actually mentioned in the Paper. Could Mr. Atkinson say if there was any evidence that aerosol ether starting aids were at all damaging to engines if used frequently? It was a very, very convenient way of facilitating starting. The other aid systems were never too reliable, and ether aerosol was his own recommendation; but perhaps in recommending it he was inviting other troubles?

Regarding the access of dust, and methods of entry, Mr. Manby said that, given a good breathing system with a crankcase which was not under depression, the tendency to draw dust in through the seals and the dipstick hole was increased. With a crankcase at more or less normal pressures, the ratio of dust going into the crankcase through the breather system and other leakage points would be about 15 to 20% of the total, while 80% had access through the standard oilbath cleaner. If the dipstick hole was particularly big, or if there was direct leakage at any point, the figures would be quite different.

MR. ATKINSON, in reply, referred to the sulphur content of diesel fuels. Oil companies supplied fuels of a different sulphur level to the agricultural world than those for the automotive, and to the industrial world they supplied fuels of very much higher sulphur content still. It varied in different parts of the world—in Australia, where fuel had a content of ·2% sulphur and where H.D. oils are still used because they were required for other reasons, users were still anxious to get the sulphur content down to zero. To remove sulphur from vast tonnages of fuel was quite a problem, and even the disposal of vast tonnages of sulphur would be a problem. Recent figures for the sulphur content of one company's fuel varied between about ·55 and ·8%. Since it was awkward to remove sulphur from fuel, why was it done for road vehicles? The answer was that the road vehicle diesel engine came into use in the days before heavy-duty oils had been developed to present standards, and the practice had become established.

Did carbon produced from smoke cause an increase in the rate of wear? Mr. Atkinson did not know the answer to these questions, and could only say that carbon smoke was sub-micronic. If oils with inferior dispersal characteristics were used, the carbon might agglomerate to larger particles.

Referring to Mr. Manby's question on pour point characteristics of diesel fuel, Mr. Atkinson mentioned the taxation implications of dilution with kerosene.

On oil sampling, Mr. Atkinson said the staff were certainly given strict instructions as to how to take samples. It was stressed that the oil must be hot and taken immediately the engine was shut down. It must not be taken from the filter; it must be taken with a syringe, if possible, through the disptick hole. Failing this, it could be taken from the sump, but not from the first immediate outflowings from the sump. All Mr. Atkinson's samples had been taken from British engines made by the well-known large manufacturers, with the exception of the engine for which he had quoted an alarming rate of wear, which not not of British manufacture.

With regard to the aerosol ether starting aids, all Mr. Atkinson would say from his own experience was that some engines had had very large doses of ether in low-temperature tests and so on, and they did not seem to suffer overmuch.

MR. THOMPSON (Perkins Engines Ltd) said that he was very much in agreement with Mr. Atkinson's remarks, but that there are one or two things he would like to comment on. The first was on the improvement of engine design. A small item not often regarded as a major part of the engine was the thermostat which Mr. Atkinson had referred to, and Mr. Thompson wished to endorse the advantages it had been shown to give in terms of overall engine life. When his company had first gone into the tractor market some years ago they were, in fact, dealing with what was basically a vehicle engine, and they found that the absence of a thermostat was something which could not be tolerated; to put it the other way round, the addition of a thermotsat extended engine life very considerably.

His company had carried it a stage further now because they felt that not only was the jacket temperature level important, but that something could be gained by going for even higher temperatures than had previously been adopted. In other words, while 80° C. was a normal setting today, though not five years ago, there was now the possibility of using sealed cooling systems at appreciably higher thermostat settings.

Mr. Atkinson had been quite justified in his dismissal of the two features of Cetane Number and sulphur as unimportant in the context of available supplies of fuels. One per cent. sulphur content was not very often encountered, in his experience, but up to that value his company had not found that wear rates or engine troubles were increased. This, of course, presupposed the use of additive oils and high jacket temperatures to offset the effect of high sulphur contents.

On the question of starting, Mr. Thompson said that it was normal practice in his organisation to establish starting specifications for an engine on the basis of a known deterioratoin of the battery equipment. That was to say, starting must be satisfactory on the basis of batteries in the state of 70% charge only. Reference had been made to 100-r.p.m. as being the lower limit of required cranking speed, and in fact, particularly in the case of the smaller indirect injection engines, speeds very much higher than this were needed—175-r.p.m. might be regarded as normal.

Returning to the question of Cetane Number, Mr. Thompson said that Mr. Millington had quoted a figure of something like 50 as being quite an acceptable lower limit for the fuel requirement in most cases. He asked Mr. Atkinson if quite a small increase in Cetane Number could reduce noise and vibration. Two or three Cetane Numbers improvement might be found to give an improvement in smoothness or reduced noise. He suggested that the effect could be shown in a dynamometer test, but he would like to know if it had been studied in terms of noise. He would also be interested to know what percentage operating efficiency was claimed for the engines in the regularly-maintained and not-regularly-maintained categories in the tests Mr. Atkinson had mentioned.

MR. ATKINSON thanked Mr. Thompson for his comments, and said that there was clear evidence of the importance of thermostats in terms of their function minimising the condensate water content of the lubricating oil in the sump, as well as the other features which had been mentioned. So far as diesel engine noise was concerned, only one manufacturer had claimed that Cetane Number differences of 2 or 3 could be detected in terms of noise. In any case, Cetane Number todays were generally above 50. A discussion of this particular point would very soon move into the realms of combustion phenomena. Mr. Atkinson's view was that noise levels were more likely to be a function of detail engine design than of fuel specifications.

FOUR-WHEEL DRIVES

by RUDOLF FRANKE*, Dr. Ing.

A Paper presented at an Open Meeting on 15th January, 1963.

1. Introduction

THE development of tractors for off-the-road use began 50 years ago and, even at that time, the value of having all wheels driven was recognised. Not surprisingly, this aspect of tractor development was initiated for military purposes, for cross-country transport and artillery haulage.

At that time an artillery truck was built by Porsche for the Austrian Army, which carried a petrol engine driven generator, and all its wheels and those of its trailers were driven by single electric motors.

Forty years ago an agricultural tractor with four-wheel drive, the first model of the LANZ-Bulldog, was built. This tractor was frame steered ; that is, the two rigid axles were connected by a vertical pivot. It had only one speed, without any gearbox and no reverse gear as such, but was able to travel backwards by causing its semi-diesel two-stroke engine to run in the opposite direction to normal.

2. Tractive Effort, Slip and Balance of Power

It is a well-known fact that the greater tractive power of a four-wheel drive tractor is developed because its entire weight is carried on, and provides adhesion for, driven wheels. The relationships between adhesion weight, wheel load, wheel slip and tractive power will, therefore, be briefly discussed here.

The drawbar pull of a tractor is plotted against its wheel slip, and the curves show the performance characteristic for the particular combination of type of surface, tyres, etc. Fig. 1 shows the slip/pull curves for conventional agricultural tractors having large rear wheels carrying about 60% of the weight and small front wheels carrying 40%. The upper curve, however, is for a tractor with four-wheel drive, while the lower one is for a tractor with rear-wheel drive only. The increased pull with four-wheel drive is obvious. The corresponding curve for a track-laying tractor would, of course, be much steeper.

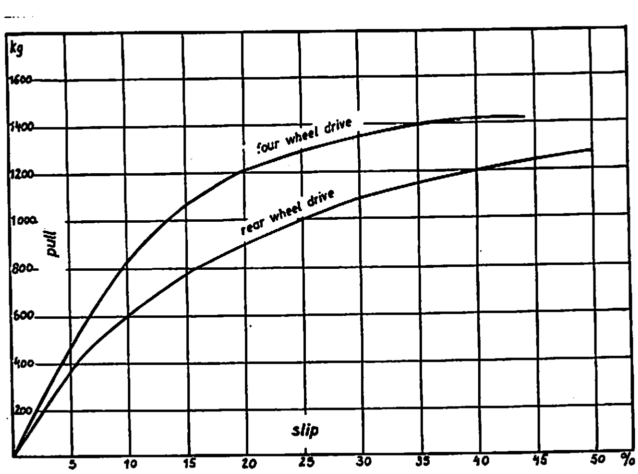


Fig. 1 Pull/slip curves for rear wheel drive and four wheel drive on medium soil.

If the values of pull from the last slide are used to plot curves of drawbar horse-power against theoretical speed without slip, Fig. 2, it is seen that the maximum

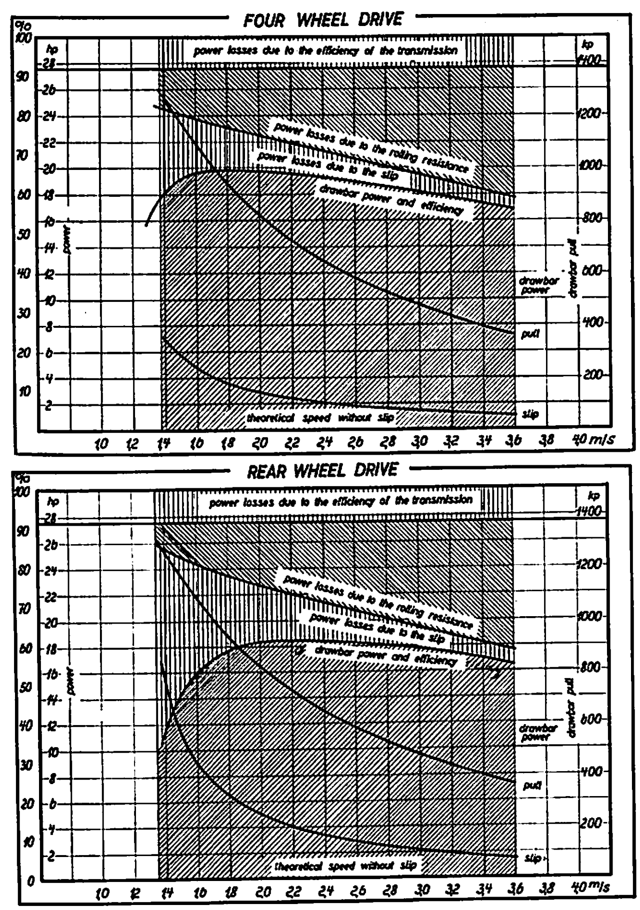


Fig. 2 Balance of power

drawbar horse-power is reached at a lower speed with four-wheel drive. Below this speed, drawbar pull increases rapidly in the lower gears, but slip increases more rapidly and lowers, consequently, drawbar horse-power. The advantage, then, of a four-wheel drive tractor is clearly seen ; it is that it can develop a higher drawbar horse-power at a lower speed than an equivalent two-wheel drive machine. Above the speed at which

* Director, Schlepper-Pruffeld des H.T.L., Darmstadt-Kramchstein, Western Germany.

maximum drawbar horse-power is developed, engine power is the factor limiting any further increase.

However, this apparent increase in drawbar pull and horse-power is not of such practical importance as is usually thought. At high values of pull, weight transference increases the load on the rear wheels of a conventional tractor to up to something like 80% of its total weight. An implement on a linkage that is able to affect weight transference can, under certain circumstances, increase this figure, so that the tractor approaches very nearly the conditions that give a four-wheel drive machine its advantage—that is, that all its weight is carried on the driven wheels. In view of this gain of 15% to 30% in drawbar pull, is the expense of an additional drive to the front wheels justified? This can only be so when it is desired to retain good directional control when working at high values of pull because, as weight on the steered wheels becomes less, the steering becomes less effective, especially on soft ground, and the driving front wheels are pulling the tractor into the desired line.

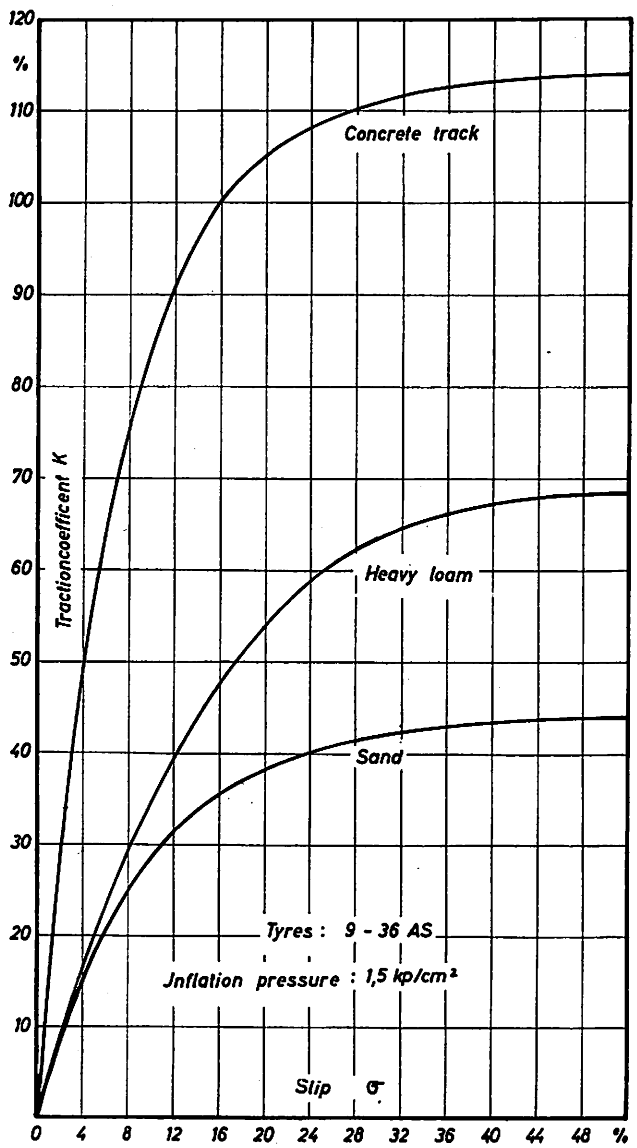


Fig. 3 Traction coefficient/slip curves on different surfaces.

3. Torsional Stress in the Driving Axles

When travelling on surfaces with good adhesion, " wind-up " is caused in the axles and driving shafts of a four-wheel drive vehicle by inequalities in the sizes of the wheels and in the distances travelled by the two axles. The stresses arising from this condition are often manifestly under-estimated.

As is well known, it is possible to compare pull/slip characteristics for tractor wheels under different vertical loads by plotting coefficient of traction (*i.e.*, pull/vertical load) instead of drawbar pull. In Fig. 3, the coefficient of traction is plotted for a particular size of tyre on different surfaces. It will be seen how rapidly the pull —that is to say, the coefficient of traction—increases with slip on a surface with good adhesion, such as concrete (Table I).

Table I

Slip % (approx.)	*Coefficient of Traction % (approx.)*
2	·30
2·5	·34
3	·40

As an example, let us consider a four-wheel drive tractor with the front and rear axle loads nominally equal, but with the diameter of the rear wheels 5% less than that of the front, Fig. 4. This difference is, in practice, small, as tyres cannot be manufactured to really close limits, and differences in tyre wear, pressure and in the actual axle loads all have their effect.

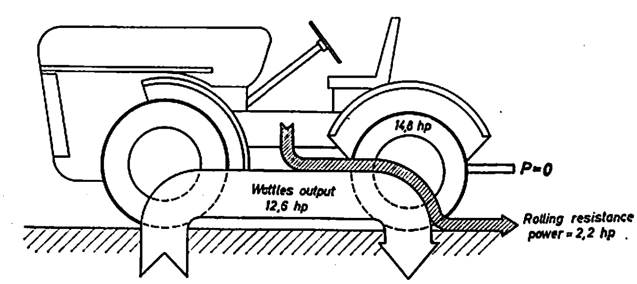


Fig. 4 Wattless output with four wheel drive on a concrete track.

Let us assume that the slip arising from the different diameters is equally divided between the two axles, so that the front wheels would run 2·5% slower than their theoretical no-slip speed, and so act as brakes, and the rear wheels would run 2·5% faster, so that they alone would propel the tractor. Let the tractor travel at about 6 mile/hour along a level concrete surface without a load, and with a rolling resistance of 3% of its own weight, which is 2 tons. The power developed by the engine is 30-h.p.

The rolling resistance amounts to approximately 130 lb. and is overcome by a force of equal amount at the periphery of the smaller, rear wheels. The braking force at the periphery of the front wheels can be calculated by dividing the axle load (1 ton) by the coefficient of traction, which, from Table I, is ·34% for a slip value of 2·5%. This braking force, 750 lb., must be overcome by a force of equal amount at the periphery of the rear wheels, making a total of 130 and 750 = 880 lb., and the torsion due to wind-up 750 times the rolling radius of the front wheels and 5·8 times as great as the driving torque required to overcome the rolling resistance. Rapid tyre wear occurs under these conditions, and large loads are caused in the steering linkage as the steered wheels tend to pivot on their steering joints, these loads being dangerously high under braking, especially if the axles are unequally loaded.

Brakes are fitted usually to the rear wheels only, although their effect is carried by the transmission to the front wheels as well. A braking force of 1,500 lb. would be required to give a tractor of this weight (2 tons) a deceleration of 11·16 ft./s^2, and this force would be equally divided between all four wheels, if we disregard the effect of weight transference. If this force is superimposed on those already acting at the wheel peripheries due to torsional wind-up—*viz.*, a driving force of 750 lb. at the rear and a braking force of 750 lb. at the front—it will be seen that the driving and braking forces on the rear wheels will cancel each other and that a braking force of 1,500 lb. will be acting at the front wheels alone. This large force has to be resisted by the transmission, and correspondingly large loads will be imposed on the steering linkage. Under these conditions, the use of a safety clutch in the drive between the axles is most necessary.

Returning to the free-running condition, we see that at 6 mile/hour the engine only has to provide 2·2-h.p. to overcome rolling resistance (Fig. 4), but the braking force at the front wheels is equivalent to about 11·1-h.p., which, as " wattless output," flows through the transmission to the rear wheels and must be, in addition to the power required to overcome rolling resistance, transferred to the road surface. This " wattless output " is not a loss of power ; the loss by the efficiency of its transmission may be estimated at 10% of the " wattless output." Torsional wind-up could, of course, be eliminated by the use of a differential between the two axles, but this would, to a large extent, nullify the effect of four-wheel drive because, in slippery conditions, the wheel or wheels able to develop least traction would spin.

The simplest way to overcome this problem is to use a dog clutch so that the drive to the front axle may be disengaged at will. When the four-wheel drive tractor is being used with a high drawbar pull on a surface with a low coefficient of traction—under conditions, that is, in which a large amount of slip will occur in the same direction in the wheels of both axles—torsional wind-up is not present nor will tyre wear be higher than with a two-wheel drive tractor.

The causes of wind-up must be eliminated during the design of the tractor, otherwise it will probably become just a tyre-wearing machine—of great interest to tyre manufacturers, but most unprofitable to its owner.

Tandem tractors, which will be discussed later, have a separate power unit for each axle with no mechanical interconnection and so do not suffer from wind-up.

4. Types of Design

Let us now look at some of the different types of four-wheel drive tractors.

The first is essentially a conventional tractor having large rear and small front tyres and with a weight distribution of two-thirds and one-third on the rear and front axles respectively. The front axle is pivotted as a normal undriven axle ; it has a differential and is driven by a shaft usually from the underside of the gearbox. Another method is to drive each front wheel by a shaft from the half-shaft of its corresponding gear wheel, which eliminates the front axle's differential, but requires an additional drive shaft and two more pairs of bevel gears. This arrangement is, of course, also subject to torsional wind-up. The weight distribution permits the retention of small tyres at the front ; ample steering lock is available and the torque transmitted by the front axle universal joints is relatively small. Tractors of this type are widely used in agriculture and forestry.

However, with a static weight distribution of two-thirds and one-third on the front and rear axles respectively, when a large drawbar pull is being exerted the axles are likely to become equally loaded—a condition which is desirable for developing maximum pull. With such a weight distribution, tyres of the same size are required on both axles, and if the usual agricultural rear tyres are used, steering lock becomes rather limited, so that it is normal for such tractors to have smaller tyres, and they are more often used for industrial purposes. The front axle is driven by one of the methods already described.

A tractor which is designed for higher speeds than are normally used in agriculture is fitted with equal size wheels. Both axles are sprung and each is driven by a propeller shaft from the gearbox. The smaller, less effective tyres have to be used in this application because large tractor tyres are liable to over-heating at speeds greater than 18 mile/hour. The static weight distribution is two-thirds front and one-third rear, enabling the ideal equal loading of the axles with a large drawbar pull. Tractors of this sort usually have a forward-control position, a platform for load carrying, and provision for the attachment of implements and ballast weights.

A frame-steered tractor must have, in addition to its vertical steering pivot, means for allowing relative vertical movement between the wheels on each side to allow for uneven ground. This may be done by mounting one axle on a horizontal pivot or by using a ball joint, such as that used in tandem tractors, in place of the vertical pivot. Frame-steered tractors are liable to jack-knifing when hauling loaded trailers down steep slopes, and for this reason are only built in small sizes for use in viticulture, orchards and market gardening where their relatively large drawbar pull with compact size and ability to maintain high pulls when turning are advantageous.

A variation of the first type mentioned is a tractor without a horizontal pivot for the front axle, but in which one half of the body is able to swivel about a longitudinal, horizontal axis relative to the other.

Some four-wheel drive tractors have unsteerable axles and are steered by differential speed between the wheels on each side in a similar way to track-laying tractors. Front-wheel drive on these tractors may be provided simply by chain from the rear wheels, but the method of steering gives rise to heavy tyre wear on hard surfaces, so their use is confined mainly to off-the-road use. It is possible, additionally, to make one or both axles steerable to improve the road performance, and in this form these tractors are increasingly being used for industrial purposes, but the large tyres used limit the amount of steering lock available.

Up to this point, we have considered chiefly front-axle steering, but for some applications rear-axle steering is preferable. One instance is the use of a fore loader with a shovel or similar attachment when sideways movement of the shovel as the tractor turns requires to be kept to a minimum. Frame-steered tractors are at a disadvantage in these circumstances and so are not used in industrial applications.

Recently, tandem tractors have begun to come into use. A tandem tractor is a pair of conventional tractors, with their front axles removed, and connected by a joint permitting movement about a vertical axis and more limited movement about a longitudinal, horizontal axis. Steering is effected by altering the angle between the longitudinal axis of the two tractors by means of hydraulic rams controlled by the steering wheel. The driver sits on the rear tractor, the controls of which operate normally, but are connected either mechaniaclly or hydraulically with those of the front tractor. As a four-wheel drive tractor, the tandem tractor has many advantages, including : equally-sized wheels fitted with large, agricultural tyres ; more weight on the front axle in the static condition, giving equal axle loading with high drawbar pulls ; good steering lock, in spite of the large wheels, and complete absence of torsional wind-up. Furthermore, from two medium-sized, mass-produced tractors is constructed a powerful, four-wheel drive tractor which, in spite of the use of two engines and transmissions, is cheaper than the normal, limited-production, four-wheel drive machine. This is true for tandem tractors of over 100-h.p., but would not be true of, say, two 30-h.p. tractors joined to make a tandem tractor of 60-h.p.

Tandem tractors are not used for industrial purposes because their method of steering leads to large sideways movements of front-mounted tools when turning.

5. Transmissions

It should be possible to vary the forward travel speed of four-wheel drive tractors when under load, which means that a method of gear changing which can be effected without the need for declutching or a steplessly variable-speed transmission would be desirable. Hydrostatic transmission may come into general use in the future, but its cost is likely to decide the extent of this, more so in agricultural than industrial applications.

However, we cannot continue with this interesting conjecture here, apart from pointing out that one of the disadvantages of the conventional clutch is that, unless it is used with great care, its engagement can cause a jerk in the driving wheels which, on soils of low shear strength, is likely to destroy the adhesion between tyre and soil.

6. Conclusions

The track-laying tractor is superior to the four-wheel drive tractor in soft, plastic soils, but the greater initial and maintenance costs of the former and the ability of the latter to travel on hard roads when desired have led to the increasing use of the four-wheel drive machine. Its development, incidentally, would not have been so rapid without the good tractive and load-carrying capabilities of modern, pneumatic tyres.

The four-wheel drive tractor will probably supplant the track-laying tractor in agriculture ; in forestry, civil engineering and earth-moving, the two types will probably be used in conjunction.

It is not thought that the four-wheel drive tractor will replace the conventional agricultural tractor with its wide range of mounted equipment, but as the prime mover of large cultivating tools it will become increasingly important.

REFERENCE

SONNEN, F. J., " Zur Frage des Allradantriebes von Ackerschleppern," *Landtechnische Forschung*, 12, 1962, Heft 1, S. 1 – 6.

DISCUSSION

MR. T. C. D. MANBY (Head, Tractor Test Department, National Institute of Agricultural Engineering) said it was a great pleasure to be the first member to express his appreciation to Dr. Franke for so ably presenting his Paper on the many aspects of four-wheel drive tractor performance.

It was a subject of very great common interest and one on which almost everyone had had some personal experience. Starting from the early war-time period, almost everyone had been, on occasions, profoundly thankful when making a particularly difficult journey for the improved vehicle performance made available by engaging four-wheel drive. To the professional tractor testing engineer it was most difficult accurately to evaluate the advantages of four-wheel drive. It might be relatively easy to make comparative measurements of drawbar horse-power and slip/pull characteristics of two and four-wheel drive machines. It was extremely difficult to interpret the differences between such measurements in terms of practical performance so that the case for the higher cost of four-wheel drive could be factually argued.

In one of the N.I.A.E. tests a 60% increase in pull was measured after engaging four-wheel drive on wet, loosely cultivated clay soil—as seen from the curves published in N.I.A.E. Report Number 134. An observer might point out that the tractor should not have been on the land trying to do a serious job of work under these conditions. Under normal autumn ploughing conditions—*i.e.*, in wet but relatively firm soil conditions—increased rates of work had been obtained on a number of occasions when using the same plough, doing exactly the same job. The slip losses were reduced by 15–20% —identical results to those mentioned by Dr. Franke. However, so far as ploughing was concerned, this gain was not necessarily as valuable as it seemed at first sight. Instead of pulling, for example, a four-furrow plough in second gear with a four-wheel diive tractor model, it might under some conditions have been possible with a two-wheel drive tractor to travel at a faster speed, pulling one furrow less. Under these circumstances, the rates of work would usually be only marginally different. However, with another tractor the relationship between load and gear spacing might be such that it was impossible to change to a higher gear even with the reduced load. Then the initial 20% improvement would be a valid gain.

Thus the crux of the comparison in practice, as so often happened in agriculture, was that the possible gain depended on the circumstance. However, a measured 20% increase in pull during drawbar tests could obviously—and often did—mean the difference between " go " and " no go." The " go " instead of " no go " condition was much more likely to arise in connection with implements of irreducible minimum draught value ; for example, a heavily-laden trailer or disc plough or a large combine drill.

For these reasons, Mr. Manby and his colleagues thought that useful evidence as to the practical value of four-wheel drive tractors could be obtained by making a series of comparisons with crawler tractors engaged on practical jobs. The trials were made to determine the conditions under which a four-wheel drive tractor could satisfactorily replace a crawler.

This comparison was still in progress, but to date it had been found that for tractors of the same engine size, under conditions considered suitable for seed bed preparation in the Spring or for Spring ploughing, the rates of work were remarkably comparable. The exchange from tracks to wheels was not acceptable on slopes of gradients up to 1 in 3 with rather loose soil conditions, because wheel-spin occurred. On similar conditions, but with slopes of maximum gradients of 1 in 6, although the work could proceed, the wheel markings which remained were unacceptable to the farmer. Mr. Manby agreed with Dr. Franke that good directional stability could be obtained. Autumn and winter ploughing of the heavier soils, which it was desirable to set up for frost action, could not be carried out by the pneumatic-tyred four-wheel drive tractor at rates of work equal to those with the crawler. For seed bed cultivations, perhaps, cage extensions on all wheels would have been valuable, and strikes on steel wheels should next be compared with the crawler on the very heavy, wet soils. Mr. Manby asked if Dr. Franke had made similar comparisons.

Mr. Manby then showed some slides of British counterparts to some of the types of tractor and construction described by Dr. Franke.

Finally, Mr. Manby asked Dr. Franke for his views on some of the results of the German investigations on four-wheel drive, published by the Tractor Research Centre, Volkenrode. In a recent Paper in *Landtechnische Forschung* they have published curves proving that on the second and third pass of the wheel over the same ground there is an improvement in performance. This conclusion would seem to apply to soils of all types and conditions and to be supported by evidence from America. Mr. Manby's impression was that there might be a number of conditions in which this would not be likely to apply. Did Dr. Franke believe that coefficient of traction of the rear wheels of four-wheel drive tractors was at least as good as the coefficient of traction of front wheels, under early Spring ploughing conditions on clay soils—when the surface is being dried out by wind. This was often a very important condition for users in this country.

MR. R. A. JOSSAUME (Saffron Walden) said that Mr. Manby had referred to the use of an offset plough being used with the four-wheel drive tractors. He felt that if the four-wheel drive tractor was to be used effectively, an offset plough was essential. He thought that in the eastern counties the four-wheel drive tractor could, under all conditions, out-pull and out-perform the crawler tractor.

An additional disadvantage of the crawler tractor was the cost of upkeep, which was far in excess of that of a four-wheel drive tractor, and it was much more difficult to use for transport on roads moving things from one place to another.

MR. T. SHERWEN said that he was a little puzzled by the first curve that Dr. Franke showed on the performance of the four-wheel drive and the two-wheel drive plotted against a slip basis ; the two curves tended to come together towards the top end. At the top end, where a high percentage of slip was being experienced, the percentage of weight transfer from the front to the back would decrease and therefore the difference between four-wheel drive and two-wheel drive would be greater. He asked Dr. Franke to comment on this point.

On a two-wheel drive tractor there were still four wheels on the ground, and two dead wheels had to be pushed through the soil. This must add to the basic difference between four-wheel drive and two-wheel drive. In comparing four-wheel drive tractors with crawlers, it should be borne in mind that four-wheel drive tractors were normally fitted with pneumatic tyres. To make a fair comparison with tracked machines, steel wheels would have to be fitted.

In reply, DR. FRANKE emphasised that it was very difficult to make accurate measurements of slip at high slip percentages, and said that the figures at the high end of the curves might possibly be open to doubt.

MR. MANBY suggested that because both front and rear wheels were slipping, the front wheels would also dig themselves in and therefore the tractor would have a higher rolling resistance under these conditions than the two-wheel drive type.

MR. JOSSAUME said that if all four wheels could be locked together there would be no slip at all, or all the wheels would slip at the same rate. The tandem tractor was only a stop-gap device in this respect, as the use of separate engines and transmissions could not eliminate wheel-spin in the same way as a design having four wheels all positively driven by one engine.

MR. MANBY said he could not agree with Mr. Jossaume, because he had, in fact, tried such an arrangement, and especially on Chiltern land certainly, with pneumatic tyres only, the result was an unacceptable amount of wheel marking, and on the 1 in 3 and 1 in 4 slopes too much wheel-spin. Nevertheless, he agreed that there were many intermediate operating conditions where the four-wheel drive, with either steel wheels or cage extensions, could beat the crawler in all respects and certainly on maintenance-wise. He referred to one comparison with a 100-h.p. American crawler in the same field, in which the four-wheel drive tractor on steel wheels was indisputably putting up a very much better performance. But equally he could instance some ground which was ploughed by a crawler at the end of November. The resistance of that land was 20 lb. per sq. in., and with a four-furrow plough that meant a pull of 6,000 lb. The four-wheel drive tractor simply could not pull the four-furrow plough under those conditions.

But by using a three-furrow plough and working in a higher gear, the job might have been done a day sooner. On the other hand, a higher speed of travel might well be undesirable—as, perhaps, in the case of autumn ploughing.

DR. FRANKE asked if all four wheels of the tractor in question could, in fact, be locked together, and MR. MANBY replied that all four wheels were of equal size and could all be locked. A soil resistance of 20 p.s.i. was very uncommon, but he had met such soils in Bedfordshire and in parts of Yorkshire. In the intermediate ranges of conditions, four-wheel drive would cope satisfactorily. It was important not to overstate the case either one way or the other.

MR. A. C. WILLIAMS (Editor, *Farm Mechanisation*) asked if tests had been carried out comparing four-wheel and two-wheel drives with mid-mounted equipment rather than equipment to the rear. If the mid-mounted equipment required sufficient traction to make four-wheel drive worth while, he presumed the traction characteristics of four-wheel drive would be of special advantage.

DR. FRANKE replied that no such tests had been carried out.

MR. G. E. E. TAPP (County Commercial Cars, Ltd.) referred to the development of one of the four-wheel drive tractors illustrated by Mr. Manby. The tractor had four large wheels of equal size ; the front wheels were steerable, and a single differential was incorporated in the transmission with a differential lock.

In early trials a machine of this sort, but without a differential lock, was compared with a two-wheel drive tractor of similar power with differential lock. On wet, heavy land in an almost waterlogged condition the two-wheel drive tractor was equal in performance to the four-wheel drive machine. When the four-wheel drive tractor was subsequently fitted with a differential lock, it performed better than the differential lock two-wheel drive tractor by an estimated 25–50%. The comparison of performance under agricultural conditions was extremely difficult unless the tractor being compared was tested under identical conditions on the same ground and at the same time, since, apart from the measurement of soil shear strength, there was no method of expressing soil type and condition in numerical terms.

Mr. Tapp agreed with Mr. Manby that certain conditions and types of terrain would always call for crawler tractors, including especially steep ground with a crumbly surface. In such conditions a crawler tractor would compact the soil and run over it, where a four-wheel drive machine would simply dig four holes.

Referring to Dr. Franke's remarks on torsional wind-up as a factor in tyre wear, Mr. Tapp suggested that in most agricultural conditions there was so much slip that torsional wind-up could be disregarded. On the four-wheel drive tractor in question the drive ratio to the front wheels was slightly higher than the rear wheel ratio. This was intended to compensate for the extra distance travelled by the front wheels when steering, and in practice the amount of tyre wear had been found to be no greater than on similar two-wheel drive tractors, due to reduced wheel spin.

Dr. Franke had mentioned the provision of slip clutches in the drive to the front wheels to minimise torsional wind-up, but in Mr. Tapp's opinion a more important function was to prevent full engine torque being applied to a front axle assembly which could not be designed to accept it. The very large tyres and low inflation pressure of 10 to 18 p.s.i. allowed tyre deflection to take up a considerable amount of both torsional wind-up and what would otherwise be skidding when turning. Mr. Tapp's company had produced skid-steered machines—*i.e.*, with non-steerable axles, and clutch and brake steering similar to a crawler—and had found that rate of tyre wear, under conditions of practical use in the West Indies, to be better than on comparable two-wheel drive tractors.

It had been stated that a frame-steered or centre-point steered design gave theoretically better steering than Ackermann designs and reduced torsional wind-up. This was true on hard ground surfaces, but in agricultural conditions with 5 to 10% wheel-slip accepted as normal the advantages of a frame-steered layout were not so apparent. The disadvantages of such a layout were two-fold. In the first place, where a differential was fitted in each axle, in certain conditions of surface irregularity the tractor could be supporyed momentarily on two diagonally-opposite wheels, with the result that the tractor came to a standstill, with the other two wheels spinning. This could be overcome by using two differential locks or only a single differential. Secondly, the rear-end movement characteristics of frame-steered tractors made them less suitable for use with mounted implements, due to the heavy side loads imposed on the linkage and implement.

MR. HEBBLETHWAITE (N.I.A.E.) referred to Mr.

Jossaume's statement that in agricultural conditions, given two tractors of equal weight, a four-wheel drive tractor of the type mentioned by Mr. Jossaume could out-pull a crawler. He asked Dr. Franke is this was possible.

DR. FRANKE said that he was sure there were some conditions in which the four-wheel drive tractor was better than the crawler tractor. For instance, on ice or maybe on snow. In reply to a further question by Mr. Manby asking if he believed that a crawler, in agriculture, could be replaced by a four-wheel drive tractor, Dr. Franke said that he did not believe, with tractors of equal weight, that four-wheel drive tractors could give an equivalent performance.

COL. W. N. BATES (KENT) agreed that, in theory, the crawler would outpull an equivalent four-wheel drive machine.

MR. M. G. PRYOR said that the important objective was to do a given amount of work in a given time. The crawler, because of its high wearing rate, did this work slowly. Four-wheel drive tractors could travel more quickly, and therefore they did not need the same amount of grip.

Replying to a further question from MR. A. C. WILLIAMS, DR. FRANKE said that he believed the four-wheel drive tractor had a greater part to play in agriculture in the future than at the present time.

COL. BATES asked Dr. Franke and Mr. Manby if any serious research had been done in connection with a four-wheel drive layout having an electric motor for each wheel and a diesel electric generator, as demonstrated by Le Toumeau some 10 years ago. Had the fuel cell an application to a four-wheel drive tractor ?

DR. FRANKE said that he had no experience to answer from, and MR. MANBY said that the problem with the La Toumeau electrical transmission system was that it required D.C. characteristics, which made for very expensive construction. He felt that there was no undue bias in the industry towards hydraulic drives rather than electrical drives, and that fuel cell and other electrical developments would be watched with keen interest.

MR. MATTHEWS (Matbro Ltd.) referred to the question of torsion in the transmission (wind-up) of the conventional type of machine. Dr. Franke had obviously referred to the Ackerman system, where one axle, when steering, followed a different path from the other. He accepted the question of wind-up and torsion as expounded by Dr. Franke, but agreed with Mr. Tapp that it was a theoretical question which was probably less important in practice. It was very necessary for every manufacturer to ensure that his machine was able to withstand these stresses. He inclined to the view that on an Ackerman-steered machine torsional wind-up when running had a much greater effect than on the straight. Did Dr. Franke consider that the wind-up and torsion in the transmission when an Ackerman-steered machine is being steered was important ?

DR. FRANKE said he felt this was a question of traction coefficients and that the steering effect was also related to the torsional wind-up.

MR. MANBY remarked that, given a coefficient of friction of unity, the torsion in the transmission of a machine that is steering in a straight line, as Dr. Franke had carefully explained, would give certain loadings, depending on the difference in diameter and rolling resistance of the two wheels. He thought that the torsional stresses set up in this way could have serious effects, but that those due to steering were even more important than the stresses due to the difference in rolling resistances of the front and rear wheels.

DR. FRANKE said that the problem was particularly acute with a single-axle p.t.o.-driven trailer, because of the steering characteristics and the difference in wheel radius.

In reply to Mr. Pryor, who asked if wind-up was more serious from the point of view of the strength of the transmission, rather than the tyre wear, Dr. Franke replied that he thought tyre wear was the more important.

MR. MANBY said that he was surprised at Dr. Franke's reference to 11-h.p. as the figure for power loss in the tractor transmission. He did not think that N.I.A.E. test results, even in good adhesion conditions—tarmac test results—tended to confirm this figure. Even on firm going, wind-up losses were probably less serious than they appeared theoretically.

DR. FRANKE replied that what he had called the " wattless " output represented the amount of power required to maintain a state of torsion in the transmission. st was not a power loss as such, and in normal circum-Itances occurred only for short periods.

INSTITUTION NOTES CONTINUED

Appointment of Assistant Secretary

In view of the growth of Institution activities, the Council has appointed Miss J. P. Housley as Assistant Secretary. Miss Housley, who joined the Institution staff in 1960, is an Honours Graduate of London University, and has had considerable educational and administrative experience, including a period in the U.S.A. on an International Exchange Scheme.

While Miss Housley will continue primarily to be engaged on examination and educational work, she will also assist the Secretary in general administration.

B.U.P.A.

Members who participate in our British United Provident Association Group will be pleased to learn that for the second year running the B.U.P.A. are increasing the benefit for accommodation in Hospital or Registered Nursing Homes under scales 6 – 11 by a further 2 guineas per week with no increase in contributions. This increase takes effect from January 1st, 1963. Members who would like further particulars are asked to write to the Group Secretary, Prama House, 267, Banbury Road, Summer-town, Oxford.

THE TESTING OF PROTOTYPE IMPLEMENTS

by P. Hebblethwaite*, M.S., B.Sc., N.D.A., A.M.I., Agr. E.

A Paper presented at a Meeting of the West Midlands Branch on October 29th, 1962

Introduction

THE Oxford English Dictionary defines a prototype as " The first or primary type of anything ; pattern, model, standard, exemplar, archetype." This Paper takes the definition literally and therefore deals only with the testing of machines embodying *new principles* which cannot as a result be compared directly with existing types in the same broad class. The word " implement " is taken to cover everything from tractor ploughs to combine harvesters and barn machinery. Previous Papers to this Institution[1] [2] have dealt with the N.I.A.E.'s broad approach to testing and the routine testing of certain machines[3] [4] ; in contrast, it is intended that the philosophy of the present Paper should not be restricted in its application, but should apply to the work of manufacturers and official stations alike. The testing of machine durability will not be covered, as this is often of secondary importance in relation to a prototype which is frequently a " one-off " job, and therefore not entirely representative† with respect to durability.

There are three aspects to the philosophy of testing prototype implements ; they cannot be put in any particular order because the work as a whole will only be of very restricted value if any one is omitted.

1. Operation under a representative range of conditions.

2. Statistical treatment of the work or, even if no actual analysis is carried out, at least submission to the statistical disciplines of randomisation, replication and avoidance of bias.

3. A fundamental approach to performance testing—to ask the question : " What is the *optimum* product or job required of the machine ? " *not* " Is the prototype doing a job similar to or slightly better than existing machines ? "

There are, of course, time and financial restrictions placed on all three of the above requirements ; these will be more obvious when examples are examined.

Over the years and over the industry as a whole, prototype testing has ranged from, at the one extreme, asking the opinion of a farmer friend when the machine in question is operated by its designer on a plot in the factory grounds, through to the comprehensive prototype and pre-production batch test programmes spreading over three or four years which have gone into the development of certain new combines and balers. The cost of such programmes may run into five figures and may involve work in half-a-dozen countries. It is fortunate, or perhaps just a logical situation, that it is usually (but not always) the more expensive and therefore profitable machines which demand such a programme, and one reason why the number of manufacturers of such units tends to diminish. Let us hope that in this we do not follow the lead of the aircraft industry ; certain aircraft are now so complex that it is argued that no European country can, single-handed, develop, test, and produce such a unit. In contrast, there is another lead from the aircraft industry that we must follow. With them the need for testing and the pursuit of improved testing methods had been accepted almost without question from the outset. In agricultural engineering this is by no means always the case, and in many spheres implement testing is still not fully accepted or its potential fully tapped.

It is illogical when the publicity budget for an organisation completely dwarfs the testing budget. This view is to be expected from a professional tester, but equally every thinking farmer would share the same view. Was it Confucius who said : " The aroma of a good broth is its best advertisements " ?

Range of Conditions

If, as is usually the case, a test has to be planned and carried out within a definite time limit, the selection of a suitable range of conditions for the work must rely to some extent on the judgment of the tester. Data from surveys or previous tests can often indicate a realistic range, but data are not always available or, for factors like the " laidness " of a crop, are not normally measurable.

If, say, a new spacing drill is under test, one aspect of " range of conditions " is its ability to sow all types of crop and, within each crop, range of seed sizes and of flow characteristics which it *can reasonably be expected to encounter in practice*. To attempt to drill the seed of some obscure ornamental plant would be time-wasting and probably misleading.

Many tests have produced misleading results because of lack of attention to range of conditions, and one has only to think of how a potato harvester might work well on silt, but fail utterly on a heavy, stony soil to realise its full importance. The absence of a range of conditions is also one of the major criticisms of a demonstration which is not repeated on a number of sites.

Statistical Approach

Let it be stated at the outset that, to the statistician or the regular user of statistical analysis, this paragraph presents nothing new, except the suggestion that further basic work is required on the treatment of data obtained from field machinery. The behaviours of biological variables such as crop yield, height, etc., are relatively

* Head of Implement Testing Department, N.I.A.E.

† Care must also be taken that the functional performance of a prototype is representative of the production version it precedes. Modifying a prototype to make it suitable for quantity production may alter its performance somewhat, and at least a limited amount of further performance testing may be called for, together with as full an assessment of durability as possible.

well known in a statistical sense, as are the distributions of the strictly engineering variables—*e.g.*, the dimensions of successive pieces produced by automatic machine tools. On the other hand, we have much to learn of the distributions which result from the interaction of biological with machine variables.

Too rarely has implement field test data been subjected to statistical analysis.[5] " You can prove anything with statistics " is a statement which has been expressed even in our field ; it has, however, no foundation in relation to the statistics referred to here. Statistical analysis never *proves* anything—it only provides an objective means of expressing the probability, or likelihood, of a particular conclusion being correct.

Table I
HYPOTHETICAL FIELD TEST DATA FOR TWO HARVESTERS

Machine	*Output—lb./min.*	*Mean*	*Standard Deviation(s)*
A	97 73 84 90 81 64 76 90	81·9	10·7
B	84 71 78 79 75 69 73 80	76·1	5·0

To the uninitiated, the temptation to conclude that Machine A in Table I is working faster than Machine B, and to act upon this finding, is considerable. A more appropriate summary of this hypothetical comparison is that, although in this condition the average output for Machine A was 5·8 lb./min. ($\sim 8\%$) greater than Machine B, this difference was *not statistically significant*. This means that the variation between succeeding samples from the individual machines was such that a similar apparent difference might have occurred by chance between two identical machines—or, in terms of probability, would be likely to occur by chance in one case in five.

The experienced eye will draw the correct conclusion merely by inspection of a set of figures such as the above. However, in practice several variables are often involved, and to distinguish the statistically significant from the insignificant, the actual analysis must be carried out.

What has been said above is elementary, and an apology is due if it is a question of preaching to the converted. However, it is surprising how often in practice (frequently because the attention of the tester is focused on quite different points of detail) this aspect of field tests is missed.

Randomisation or the allocation of plots or treatments at random is regarded by the cynical as just a statistical ritual ; it is, however, an important step towards a valid result. At least one important reservation should be made, however. Stratified sampling (randomisation only within the strata) is often necessary in field work of the type under discussion. Thus, referring to the previous heading, a purely random selection of test conditions is usually a practical impossibility. One can, however, select at random ,say, three heavy land farms, three on light land, etc. ; this is stratified sampling.

Sometimes a simple two-plot comparison has to suffice, but because of the ease with which erroneous conclusions can be drawn from such an experiment from which replication is absent, it cannot be stated too frequently : " Beware of the two-plot experiment." The chief enemies of replication are time and/or cost. Every experimenter knows the disappointment of an insignificant result which is largely attributable to lack of replication, but replication is usually costly and in large measure the balance is a matter of judgment.

A	B

The most elementary comparison—a two-plot experiment (replication absent).

Definition of Optimum Performance

Conversion and strengthening of a horse or hand-tool for tractor draughts and speeds is a development phase which has now largely passed into history in the U.K., but at the other end of the scale a major problem facing the designer and tester alike is to get back to truly first principles and to avoid the channelling of thought which results from reviewing existing ways of tackling an operation.

It is surprising how often the answer to the original question " What is the *optimum* product . . . ? " is not fully known and certainly not known in the clear-cut way in which the designer and tester would like the information. Thus the evaluation of machine performance has frequently been limited by the absence of the required agronomic research results or, more simply, the tester finds himself up against " agronomic barriers." To some extent, this is an indictment of purely agricultural research, but equally it is up to the tester to ask the questions in a precise way. The following typical questions are, in themselves, relatively simple, but the answers and the work involved in answering them may well be complex.

(*a*) Plough : How consistent should furrow depth be when working in a given condition ?

(*b*) Fertiliser distributor : What degree of distribution unevenness can be tolerated before yield depression or other undesirable effects result ?

(*c*) Cereal drill : Is seed spacing in the row worthwhile and, if so, with what accuracy ?

(*d*) Ground crop sprayer : What evenness of distribution of, for example, herbicides is required to obtain acceptable weed kill and crop tolerance ?

(*e*) Agricultural mower : In what conditions, if any, is a scissor cut preferable to a flail cut from the crop's point of view ?

(*f*) Forage harvester : What is the optimum degree of laceration and chop length from the point of view of the silage process ?

(*g*) Hammer mill : What is the optimum fineness of grind and what particle size distribution spectrum can be tolerated by the various classes of livestock ?

Comparison Machine

An illustration of the value of including a comparison machine has been given earlier[6], largely in connection with tests of production machines. In the present context, however, it may be equally valuable, particularly as a means of defining field or crop conditions which are not definable in simpler terms using familiar instruments. In the sense in which the N.I.A.E. use the phrase, the comparison machine is usually conventional and well known, but it need not be in any way the best machine in its class for it to serve its purpose as a yardstick.

Use of a comparison machine may appear to clash with the suggestion made in the introduction (item 3) to the effect that a criterion of optimum performance to be avoided is the job done by existing machines. However, the clash does not occur if the performance of the two machines (prototype and comparison) are examined in fundamental terms and against the background of the two chains of operations (often different) into which the two machines fit. For example, if a new type of centrifugal fertiliser broadcaster is compared with a conventional plate-and-flicker machine, the numerical variation of the transverse distribution pattern of the latter may well be inferior (fertiliser collected in 3 in. trays). However, when the two patterns are examined in terms of their expected effect on crop yield, the order could well be reversed.

The Operator

The rather obvious suggestion that the inventor should not drive his prototype when it is on test has already been made. At the other extreme, it is essential to avoid the situation where the performance of the prototype (or of the comparison machine) is under-estimated due to any inability on the part of the operator to set the machine properly. Again, this is a situation which draws upon the tester's art as well as his science—no amount of statistical analysis can correct for the false impression given by an incorrectly operated machine.

REFERENCES

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

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

3 Bailey, P. H., "The Testing of Green Crop Driers," *J.Instn. Agric.Engrs.*, 1951, 8 (1), 15.

4 Hebblethwaite, P., Richardson, P., "Procedures for Sprayer Testing," *J.Instn.Agric.Engrs.*, 1961, 17 (2), 51.

5 McKibben, E. G., Berry, M. O., "The Value of Replications in Research," *Agric.Engng.*, Michigan, 1952, 33 (12), 792.

6 Jacob, W. C., "Applied Statistics in Farm Machinery Development," Paper 59–631. A.S.A.E. Winter Meeting, 1959.

DISCUSSION

MR. R. M. CHAMBERS (Massey-Ferguson Ltd) asked how in measuring plough furrow depth it was possible to use the irregular surface of the unploughed land as a datum.

MR. HEBBLETHWAITE said that in the slides he had shown the N.I.A.E. furrow depth recorder travelled on sledge runner with a base of 20 × 30 in., thus reducing, but not eliminating, variation in the datum. The area immediately against the furrow wall is avoided for measurement, as it may well have been deformed by landslide pressure.

MR. CHAMBERS added the supplementary question : Is accurate furrow depth control necessary ?

MR. HEBBLETHWAITE thought that cultivation experiments had shown most crops to be fairly tolerant—say, ± 2 in.—but there were particular conditions, such as fields where a sterile layer ran just below cultivation depth, where the reverse was true. The complete answer to the question he would like to know.

MR. G. T. MERRYWEATHER (Agricultural Technical Advisor, Goodyear Tyre & Rubber Co. (G. B.) Ltd.) wanted to know if any measurements on the "smear effect" on the furrow bottom were made in the course of plough testing.

MR. HEBBLETHWAITE said that they were not ; rather, this was a subject for research departments of the N.I.A.E.

MR. E. H. MANDER (farmer) wanted to know if any particular type of forage harvester could produce a grass stubble which would recover more rapidly than a stubble left by a cutter bar.

MR. HEBBLETHWAITE did not know of one. Very few experiments had been done, and the impression he had gained was that with stubbles of comparable length, no appreciable difference in recovery rate could be expected. Height of cut did, however, influence recovery, and, in addition, flail stubbles were visually less attractive due to the drying out of the split ends.

A questioner referred to a slide which showed the effect of ploughing speed on furrow break-up and asked whether any measurements were made in the course of plough tests to distinguish between the condition of these furrows.

MR. HEBBLETHWAITE replied that, currently, they were not doing anything more than commenting on this aspect of a machine's work until such time as research indicated what was optimum for a particular condition.

MR. J. M. CHAMBERS (New Idea Farm Equipment,) suggested that a farmer's evaluation of ploughing was—how little trouble he had in preparing what he considered to be a good seed bed ; not in terms of aeration and plant response, as the speaker had indicated.

MR. HEBBLETHWAITE agreed that if in the future some such comparisons were introduced into testing, it would be fair to compare the operations of seed bed preparation as a whole, perhaps subjecting the test and comparison ploughs to similar secondary cultivations.

MR. J. M. CHAMBERS wanted, in addition, the effect of the cultivations on weed control to be taken into consideration.

MR. R. M. CHAMBERS referred to an experiment on potato spacing which had been quoted. He said that he believed that this had been done on maincrop potatoes and had shown the crop insensitive to spacing variation. Had it been done in a crop of earlies, he suggested that the result would have been different.

MR. HEBBLETHWAITE could not confirm this view, as the experiment cited was not his own. He agreed that the shorter growing season and absence of compensation effect could result in an increase sensitivity to spacing.

MR. F. D. SWIFT (Wolseley Engineering, Ltd.) asked to what extent the season, weather conditions, etc., were taken into account when measurements were made in a crop like potatoes.

MR. HEBBLETHWAITE referred to the increased susceptibility of a crop of potatoes to damage if rapid growth had taken place late in the season. Changes in conditions were, he agreed, a major challenge to the tester and, in general terms, were taken into account at the N.I.A.E. by the itinerant nature of the test programmes and by the use of comparison machines.

MR. J. M. BOYDELL (Materials Handling Engineer) wanted details of the trays used for collecting fertiliser in test work, and of the nature of the ground surface surrounding the trays.

MR. HEBBLETHWAITE described the 3 in. × 4 ft. polythene film trays which the N.I.A.E. had used for some time. The film helped to make the particles " drop dead," and a hessian strip on the floor helped to reduce bouncing of granules off the concrete. He added, however, that as a result of investigation they were about to change to a 1 ft. × 4 ft. hardboard tray which had cardboard egg separators in them to prevent " ricochet out " of granules.

MR. BOYDELL described a method which he had seen using trays 1 in. deep containing diesel fuel. The trays were surrounded by sawdust to prevent bounce, and measurement of collected fertiliser was by volume.

MR. HEBBLETHWAITE said that he was familiar with the method, and because it was perfectly free from losses due to " ricochet out," an adaption of it had been used at the N.I.A.E. as a reference method for checking tray design. Measurement by weight had to be used however, and this made the method too lengthy for routine use.

MR. D. R. BOMFORD (Bomford Bros., Ltd.) asked if it would be possible to use deep trays to prevent errors due to ricochet.

MR. HEBBLETHWAITE said that he thought that it was, and in fact the new N.I.A.E. trays were 6 in. deep ; the height of the distributor disc above the ground would be increased ocrrespondingly.

MR. H. F. HOWELL (Massey-Ferguson Ltd) asked to what extent corelation of test results had been achieved between the various European testing stations. He understood that Europe, North America and the U.K. had agreed on tractor test procedure and that test results were comparable, but wanted to know how far this process had gone with other machinery.

MR. HEBBLETHWAITE replied that this was a broad ubject which could be subdivided into informal bilateral discussions (on test procedure) between national testing stations, and the more formal multi-lateral work of organisations such as O.E.C.D. The former had preceded the latter, and was active right up to the present. He pointed out that the O.E.C.D. tractor test code currently in use in Europe was similar to but not identical with the Nebraska code. He mentioned the different approach to implement testing field work in countries such as Sweden—the machine is in the hands of a farm operator as distinct from test station staff as in the U.K. and certain other countries. Under O.E.C.D., first steps had already been taken towards producing test codes for fertiliser distributors and combine harvesters. Inevitably, the indoor phases of a test were easier to standardise than the field work. Procedure and presentation standardisation would precede attempts at result correlation. This latter step, although feasible to a certain degree, would never be 100% due to major differences between national conditions.

MR. R. M. CHAMBERS, referring to fertiliser distributor testing, asked whether plastic materials were used to make reproducible results possible.

MR. HEBBLETHWAITE said that the N.I.A.E. did not use such a standard material, although he saw the attraction of a durable material. The cost of, say, polythene granules would be very high, and they preferred to get typical fertilisers direct from manufacturers.

MR. W. S. HOCKEY (Massey-Ferguson Ltd) referred to the original point in the Paper on optimum performance, saying that official testing stations and research workers might well look for this, but that a manufacturer's first aim was a marketable product which would, *in the opinion of the user*, be acceptable over as wide an area as possible. Other things being equal, the user would select the most regularly-spaced potato setts and the cleanest *looking* forage harvester stubble, regardless of what the agronomist said. Did the speaker believe that the agronomic optima were ever achievable ?

MR. HEBBLETHWAITE agreed with Mr. Hockey in the short term, but said that, long term, he regarded the optima as achievable. He said that several of his examples illustrated that visual appeal could initially override agronomic value. However, his first example was traditional match ploughing, and this is no longer seen in practical use. Similarly, flail harvester stubbles were being accepted, although sometimes reluctantly. Also, major changes had been made in haymaking technique ; thus education was guiding the farmer by stages towards the optima.

He said that he appreciated the pressure on the manufacturer and said that it was usually a matter for the manufacturer's conscience, in that he must push the design in the right direction as far as he econoimcally dare. In the long term, such a policy would also be economically correct, but there were several examples where if at this moment in time an " agronomically optimum machine " were produced it would be a financial failure. This always had been, and always would be, one of the major obstacles in the way of the pioneer.

ELECTIONS

Approved by Council at their Meeting on the 11th January, 1963

MEMBER	Downing, W. W. W.	Gloucestershire
ASSOCIATE MEMBERS	Cullen, M. H.	Midlothian
	Davey, R. J.	Cornwall
	Davies, R. E.	Warwickshire
	Fabian, E.	Cheshire
	Graham, R. McD.	Warwickshire
	Hart, R. J.	West Lothian
	Inns, F. M.	Essex
	O'Nions, D. R.	Warwickshire
	Seager, A.	Cambridgeshire
	Staniforth, E.	Cheshire
	Statham, V. A.	Warwickshire
Overseas	Balabanoff, W.	Kenya
ASSOCIATES	Bradley, M. J.	Hampshire
	Dickinson, E. J.	Warwickshire
	Dingle, T. B.	Norfolk
	Free, A. V.	Suffolk
	Nissim, D. L.	Kent
	Rosson, A. P.	Warwickshire
Overseas	Cochrane, J.	Uganda
	Rattray, R. R.	Sierra Leone
GRADUATES	Baird, G. J.	Perthshire
	Banks, R. J.	Berkshire
	Bowman, A. McR.	Lanarkshire
	Davies, R. W.xR.	Gloucestershire
	Evans, D. V.	Monmouthshire
	Laird, T. R.	Stirlingshire
	Lucksford, R. J. L.	Wiltshire
	Macphee, O. C. G.	Westmorland
	Rowell, M. H.	Essex
	Savage, R.	Wiltshire
	Skinns, D. A.	Lincolnshire
	Thorburn, M. E. G.	Middlesex
	Whittall, R. W.	London
Overseas	Kennedy, M. R.	New Zealand
STUDENTS	Chick, D. C.	Co. Durham
	Fyffe, A. E.	Angus
	Jamieson, T. W. W.	Midlothian
	Mead, D. A. C.	Sussex
	Warren, J. D.	Ayrshire
	Watkins, G.	Wiltshire
	Willcocks, T. J.	Kent

TRANSFERS

FROM ASSOCIATE MEMBER TO MEMBER	Reeds, M. J.	Hertfordshire
FROM ASSOCIATE TO ASSOCIATE MEMBER	Farmery, H.	Yorkshire
	Merriman, K. A.	Cambridgeshire
Overseas	Bush, G. J.	Gold Coast, Africa
FROM GRADUATE TO ASSOCIATE MEMBER	Rose, G.	Warwickshire
Overseas	Shaw, P. G.	Tanganyika
FROM STUDENT TO GRADUATE	Barton, P. S.	Lincolnshire
	Lemon, R. E.	Westmorland
	McLaren, E. A.	Worcestershire
	Webb, D. G.	Warwickshire
	Hellier, J. A.	Yorkshire

IN THIS ISSUE

Because of the rearrangement of London Open Meetings, the Journal will in future be published in February, May, August, and November each year.

PRINTED BY HEPWORTH & CO. (TUNBRIDGE WELLS) LTD.