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Abbreviations and Symbols used in the Journal

a	year
A or amp	ampere
ac	acre
a.c.	alternating current
atm	atmosphere
b.h.p.	brake horse-power
bu	bushel
Btu	British Thermal Unit
cal	calorie
c.g.	centre of gravity
C.G.S.	centimetre gramme second
cm	centimetre
c/s	cycles per second
cwt	hundredweight
d	day
dB	decibel
D.B.	drawbar
d.c.	direct current
°C, °F, °R	degree Celsius, Fahrenheit, Rankine
deg	degree (temperature interval)
dia	diameter
doz	dozen
e.m.f.	electromotive force
ft	foot
ft^2	square foot (similarly for centimetre etc.)
ft lb	foot-pound
G.	gauge
g	gramme
gal	gallon
gr	grain
h	hour
ha	hectare
Hg	mercury (pressure)
hp	horse-power
h	hour
in.	inch
in^2	square inch
i.d.	inside diameter
kWh	kilowatt hour

l	litre
lb	pound
lm	lumen
m	metre
max.	maximum (adjective)
m.c.	moisture content
m.e.p.	mean effective pressure
mile/h	miles per hour
mill.	million
min	minute
min.	minimum (adjective)
o.d.	outside diameter
o.h.v.	overhead valve
oz	ounce
Ω	ohm
pt	pint
p.t.o.	power take-off
qt	quart
r	röntgen
r.h.	relative humidity
rev	revolutions
s	second
s.v.	side valve
S.W.G.	standard wire gauge
t	ton
V	volt
v.m.d.	volume mean diameter
W	watt
W.G.	water gauge
wt	weight
yd	yard
$>$	greater than
$\ngtr$	not greater than
$<$	less than
$\nless$	not less than
$\propto$	proportional to
$\sim$	of the order of
° ′ ″	degree, minute, second (of angles)

The above abbreviations and symbols are based mainly on B.S. 1991 (Part 1), 1954

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INSTITUTION NOTES

A
E S

This symbol will by now be familiar to every member throughout the world. Arrangements for the Symposium to be held at the National College of Agricultural Engineering, Silsoe, during the period 11-14 September 1967, are now far advanced and many applications have already been received. Members are warned that the number of tickets are limited and orders are being dealt with in strict rotation. Full details of this major event in the agricultural engineering calendar were circulated to all members several weeks ago; further supplies of literature, including registration forms, can be obtained from the Institution. Complete information about the AES can also be found on pages 17-21 of this *Journal*.

Annual Conference and Dinner

The Annual Conference and Dinner of the Institution were held on 11 May in London. Record attendances are reported for both events. The Conference was held in the Lecture Hall of The Institution of Mechanical Engineers, the subject-theme for the day being 'Mechanization of Cattle Feeding'. Four papers were given and these will appear, together with edited versions of the discussions, in the Autumn 1967 issue of the Journal.

It was with regret that those attending the Annual Dinner learned that the principal Guest, Maj.-Gen. C. Lloyd, Director-General of City and Guilds of London Institute, had been prevented by illness from being present. His place was most ably taken by Mr D. E. Wheatley, Director of Further Education and Training at the Institute, and he proposed the toast of 'The Institution'. Other speakers included the newly-elected President of the Institution, Mr T. Sherwen, the new President-Elect, Mr H. C. G. Henniker-Wright and Mr J. G. Jenkins, Past President of the Scottish NFU. A report of the speeches at the Dinner will feature in the next issue of the *Journal*.

30 year Anniversary Endowment Fund

An announcement of great interest was made during the course of the Annual General Meeting of the Institution in London on 11 May. The retiring President, Mr J. H. W. Wilder, informed members that a new appeal fund had been opened, to be known as the 30-year Anniversary Endowment Fund of the Institution. Timed to coincide with the thirtieth anniversary of the Institution's foundation, the fund would remain open until some time in 1968.

Drawing attention to the Institution's severe shortage of capital, Mr Wilder said that the months and years immediately ahead were likely to be crucial, entailing negotiations and discussions affecting the agricultural engineering profession as a whole. It was vital that the Institution should be clearly seen to be financially viable and self-supporting. Mr Wilder said he hoped that donations to the fund from members and the industry at large would have the effect of increasing the Institution's invested reserves by at least £5,000 and he had every confidence that this could be achieved. Members who would like to respond immediately to this appeal can do so by sending a remittance to the Institution Secretary for any amount, large or small. Cheques should be made payable to 'The Institution of Agricultural Engineers' and the envelope or covering letter marked '30-Year Fund'. All donations will be acknowledged.

Annual General Meeting

At the time of going to press, space does not permit a full report of the AGM which was held in London on 11 May. An account of its proceedings, including the appointment of new Officers and Council Members will appear in the next issue of the *Journal*.

Annual Subscriptions

Although the majority of members have now paid their 1967 subscriptions, there are still some who have not. To avoid the need for individual reminders, it is hoped that this will serve to jog the memory of those to whom it applies. It goes without saying that the Institution is wholly dependent upon its income from membership subscriptions if it is to play its full and vital part in the agricultural engineering industry and profession.

Many hundreds of members prefer to pay their subscription by means of a Bankers Order. The Institution favours this method and any member who would like to change over to this procedure can obtain the necessary form from the Institution Secretary.

Members may like to be reminded that the Institution is approved by Inland Revenue for the purpose of allowing members to claim relief of income tax in respect of their annual subscription. Thus a Member paying eight guineas per annum may find his nett payment is less than five guineas after the appropriate tax relief has been allowed. Enquiries concerning this useful benefit should be made at a local Tax Office and not through the Institution.

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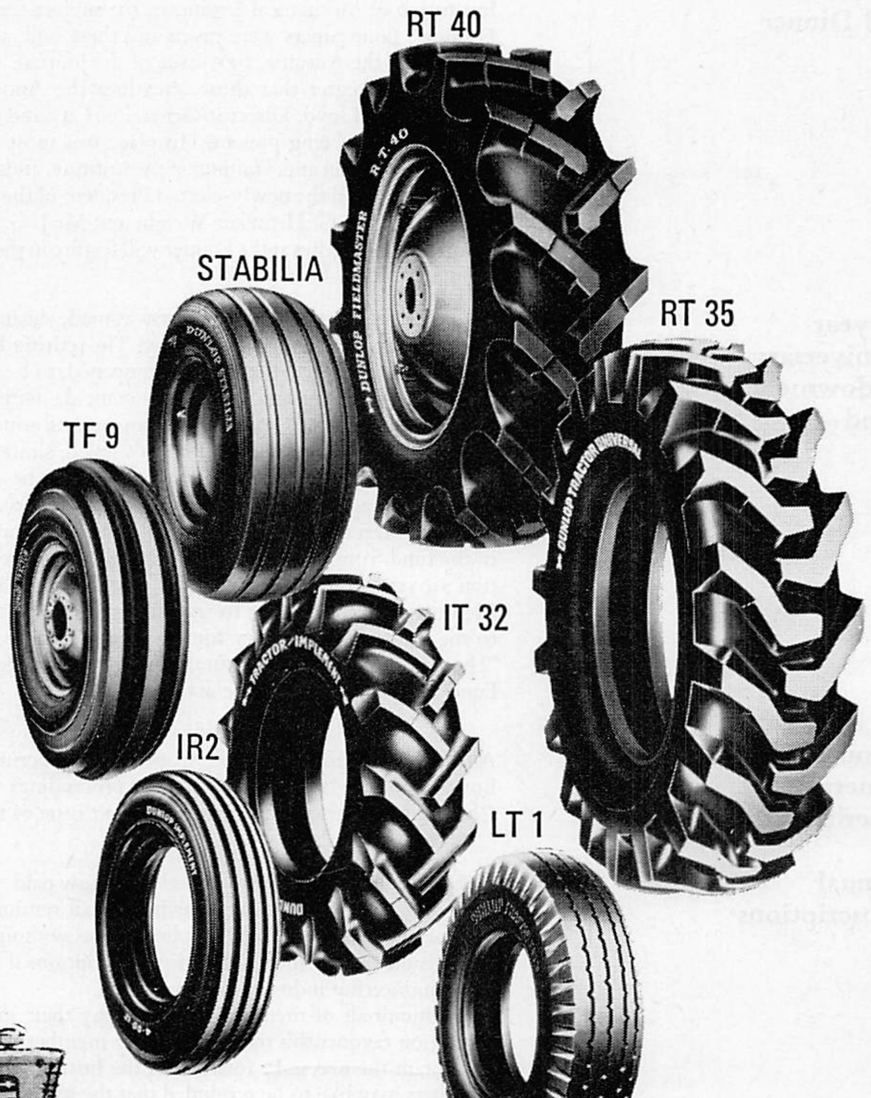

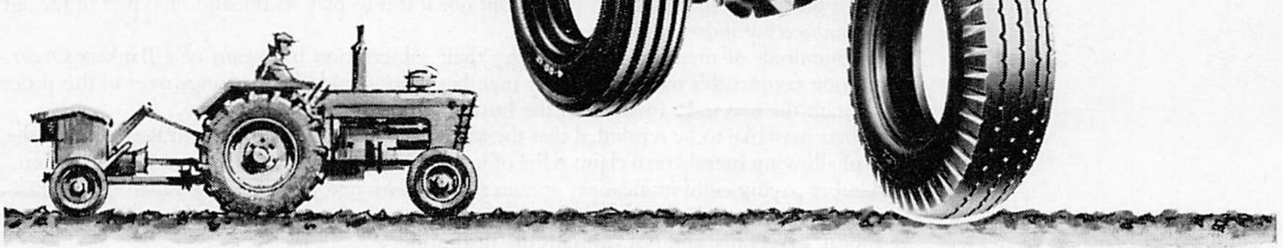

IRRIGATION INVESTIGATIONS IN RELATION TO SOIL AND CROP

by

E. J. WINTER, MC, MSC*

Presented at the Autumn National Open Meeting of the Institution on 26 *September* 1966 *at The Essex Institute of Agriculture, Writtle, Chelmsford*

INTRODUCTION

In temperate climates freely transpiring vegetation removes from the soil in summer about 2,000 gallons of water per acre per day. The energy consumed is derived mainly from solar radiation and the actual water consumption depends on meteorological, soil and plant factors.

The mainly passive nature of the transpiration and evaporation process has been exploited in numerous formulae for estimating water loss from meteorological observations (Penman[1], Thornthwaite[2], Blaney and Criddle[3]) and hence irrigation need. Various expedients have been adopted to circumvent the difficulty of lack of meteorological instruments on commercial farms. In many parts of the United Kingdom, farmers can obtain on request from the National Agricultural Advisory Service a centrally computed estimate of the current local deficit. Alternatively, tables of average transpiration amounts can be used with rainfall measurements to estimate soil moisture deficit (M.A.F.F. Bulletin 138).

In Canada, Holmes[4] has described a network of shielded ceramic evaporimeters operated by about 50 selected farmers, who telegraph weekly readings to a central laboratory whence recommendations for irrigating various crops are broadcast back to the farmers. In Israel, Stanhill[5] advises irrigation quantities according to the readings of American Class A evaporation pans installed in selected districts. The U.S.S.R. Hydrometeorological Service maintains experimental farms on which are grown test areas of crops of local importance; gravimetric soil moisture determinations at weekly intervals are used to compute irrigation requirements and incidentally also to predict likely crop yields, Rasumova [6]. In the United Kingdom, North[7] posts weekly irrigation recommendations based on weather data to a group of growers who have expressed satisfaction with the system, but they use it mainly as a check on irrigation already applied. Several countries have set up pilot schemes for irrigation advice using the neutron probe but the British farmer would probably prefer a simple inexpensive method which he himself could operate.

The N.V.R.S. deficit indicator (Winter,[8]) is in effect an imitation of a plant growing in soil. The indicator collects and stores rain in a reservoir which supplies a porous surface designed to evaporate the same amount of water as would be transpired by foliage equal in area to the rain collecting funnel. Thus the level of water below the 'full' mark in the reservoir is always related to the soil moisture deficit. The instrument is suitable for use where full irrigation is practised, but a recent modification will take account of the reduction in transpiration which occurs as soil moisture deficit increases.

Crop Water Requirements

Penman's original method for estimating crop water use from weather measurements[1] is based on the premise that there is a complete cover of green vegetation with unlimited water supply; because of the passive nature of the process, all plants would be expected to transpire at the same rate under the same conditions. Biologists however can demonstrate in xerophytic plants mechanisms for reducing transpiration rate and some crop plants also may have similar, but perhaps less obvious, mechanisms. Horticulturists recognize differing water needs in different plants.

While most growers would appreciate having unlimited water supplies for all their crops, in the United Kingdom increasing domestic and industrial needs make this ideal unattainable in the foreseeable future. Even if sufficient water could be collected in the major catchments and the projected reservoirs of the Wash and Morecambe Bay schemes, there would still remain the difficulty of bringing the water economically and in quantity to individual fields which might be a hundred miles from the main storage. The alternative, recognized in recent legislation, is to control pumping from natural water courses and aquifers and encourage individual farm storage of surplus winter drainage. Thus although some irrigation water may be obtainable for many crops, few are likely to be supplied with all they can use, and research is therefore directed towards determining how best to use quantities of water smaller than the optimum.

The Soil Reservoir

Virtually all the water transpired by plants is taken from the soil and so the study of soils in terms of the quantity of water they can supply to plants is of paramount importance.

The Russian worker Rasumova[6] regards the soil moisture content at saturation as the upper limit of 'productive' water, i.e., that part of the soil water which contributes to crop yield. Where winter precipitation stored in the soil is the sole source of the water used by crops in the following rainless summer, and where subsurface layers of the soil may impede drainage by re-

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maining frozen for an appreciable time during the spring melt, this view is justifiable. Similarly in temperate climates, in showery weather the moisture content of the surface layers of the soil may exceed field capacity for days at a time in summer, and this extra water is certainly available to plants. Nevertheless, in the Western world, field capacity, i.e. the moisture content of soil which has been saturated and then allowed to drain freely, is usually regarded as the upper limit of soil available water. Slow drainage continues even after field capacity has been reached. In sandy soils field capacity may be reached in less than a day but in finer-textured soils drainage may continue for many days. For comparative purposes many workers e.g. Salter and Williams,[9] allow all soils, irrespective of texture, to drain for 48 hours before sampling.

Because of the complexity of factors influencing drainage, and because disturbance affects the rate at which water moves through the soil, it is desirable to determine field capacity *in situ*. Conventional laboratory methods in which drainage of sieved air-dried samples is stimulated by applying a pressure of one-third of an atmosphere can underestimate field capacity, and as a result, available water capacity has been shown to be underestimated by up to 75% (Salter and Williams[9]). Nevertheless, though field capacity is best measured on soil which has acquired that state naturally in the spring, it is obviously desirable to find a method which is independent of season and weather.

The traditional lower limit of soil available water is termed the 'permanent wilting percentage' and is determined either by a biological method (the 'sunflower technique') or by applying 15 atmospheres pressure to wetted samples in a pressure membrane cell.

Recently Salter and Williams[10] have shown that the available water capacity of a soil is closely related to its fine sand and organic carbon content and negatively related to coarse sand content. They have incorporated their data in an available water slide rule intended for field use in conjunction with the 'feel' method for classifying soil by rubbing a moistened sample between the fingers (Brade-Birkes[11]).

Using Salter's data, Mackney of the Soil Survey of England and Wales has drawn a specimen soil available water map covering a district of about 200 square miles. Such maps could aid the planning of water supplies for irrigation, land utilization and the like, but at the present scale (1 inch equals one mile) they are insufficiently detailed for irrigation planning on individual farms.

Although the numerical difference between the moisture content at field capacity and wilting point gives the total amount of water theoretically available to plants, this figure gives no indication of the ease with which the water can be abstracted by roots. Figure 1 contrasts the forces required to extract water from a sand and from a silt soil throughout the range from field capacity to wilting point. Such moisture release (or characteristic) curves vary according to the particle size spectrum of the soil. Thus a sandy soil can contain comparatively little available water, but a high proportion of this is held at low tension and therefore is *readily* available, whereas a heavier soil can

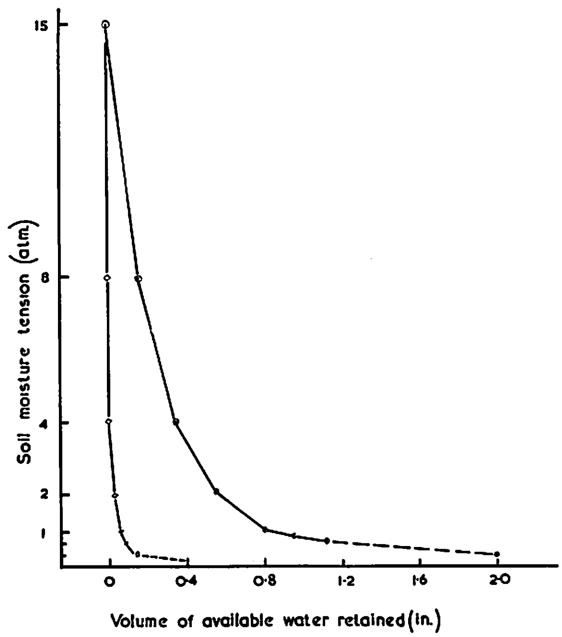

Fig. 1

Moisture release characteristics of a sand (lefthand curve) and a silt (righthand curve).

hold much more water but at a higher tension and therefore not so readily available.

The rate of water uptake by plants is also conditioned by the speed at which water can move through the soil from untapped zones towards zones already denuded of water by root action. The roots of some plants can grow faster than those of others and their efficiency in absorbing water may also vary. Salter has coined a new term 'exploitable available water' to describe the proportion of available water which can be extracted by the root system of a particular crop in soil under normal agricultural conditions. The amount of exploitable water present in a particular soil will vary depending on the rooting characteristics of different crops. Studies of exploitable water obviously form an important part of future irrigation research.

Little work has been done in the United Kingdom on irrigation in relation to ground water (water table) within reach of the roots. The Dutch have worked on this problem, but mainly in regard to light or silty soils. In the United Kingdom water tables are often associated with organic soils and there is an increasing interest in the possibility of worthwhile irrigation in the Fens and the Somerset 'moors'. Such irrigation might take the form of manipulating ground water level by adjusting the water level in the drains or of sprinkler irrigation until the roots have reached the capillary fringe above the water table.

Irrigation Experimentation

Irrigation experiments involve assessing losses from the soil water reservoir, adding the appropriate amounts of water to impose a known moisture regime and measuring the effects of this on the crop.

Although attempts are currently being made to measure transpiration by studying the vapour flux over crops most irrigation experimenters base their water loss assessments on various modifications of the Penman concept. In the Wellesbourne modification daily estimates are made which take into account season of the year, percentage of the soil surface covered by foliage and the moisture status of the soil (Winter *et al*[12]). Such *estimates* provide a basis for deciding when to irrigate and how much water to apply, but they must be supplemented by *measurements* of the actual soil moisture status under which the plants are growing. In spite of worldwide efforts to supplant it with a less laborious method the gravimetric determination of moisture content of soil samples by oven drying remains the only generally satisfactory method of directly determining soil moisture status. With reasonable care, results within about 1% of the general soil moisture content are readily obtainable with simple equipment.

The phenomenon of neutron scattering by hydrogen ions has been exploited for measuring soil moisture content. The neutron probe samples a larger volume of soil than any other normal method and once access tubes are installed, changes in moisture content of the self-same soil throughout the profile can be studied over long periods. The apparatus is, however, costly and complex and subject to faults which the ordinary user is not competent to correct. Moreover it reacts to the presence of *all* hydrogen ions in the soil, including for example those in orgainic matter. Nevertheless this instrument makes possible the study of the integrated effects of soil moisture tension throughout the root zone which would be impracticable using other techniques.

Where meteorological estimates are used in irrigation experiments a properly equipped and maintained meteorological station must be sited near the experimental area. On such a station it is useful to have a six-foot square evaporation tank sunk in the soil with no insulation between the metal sides and the soil itself (Anon[13]). Readings from such tanks have been found to agree reasonably well with estimated E_o i.e. evaporation from an open water surface. Rasumova[14] states that the U.S.S.R. standard 20 metres square tanks gave good agreement with E_o, and Winter found in Kenya that readings from a 1 metre diameter sunken tank usually agreed substantially with E_o.

Water loss from plants growing in a lysimeter in soil kept near to field capacity may be measured directly by making daily additions of water in measured excess; the difference between the amount added and the collected drainage represents the amount transpired, but because drainage is not usually complete in 24 hours, free water 'stored' in the lysimeter soil may invalidate the results. To overcome this difficulty, Green[15] computes transpiration only between dry spells when the soil can be assumed to have drained completely to field capacity.

Under United Kingdom summer conditions there is usually no drainage from field soils and so weighable lysimeters are needed for measuring crop water use. Recent modifications to the simple Wellesbourne hydraulic lysimeter are illustrated in Fig. 2 (Winter[16]). Much

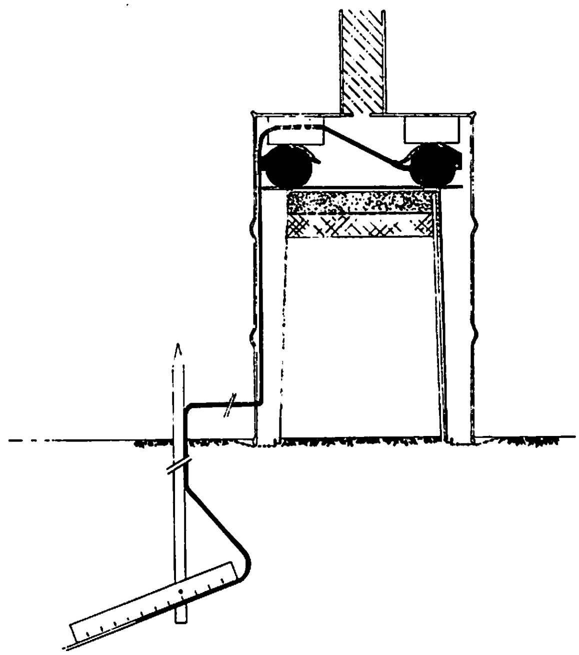

Fig. 2

Cheap field lysimeter in which the weight of the soil container is measured manometrically as change in pressure within the water-filled motor inner tube upon which it rests. The apparatus is housed in an oil drum with its rim flush with the surrounding soil surface.

larger lysimeters using this principle have been set up in Africa (Forsgate, Hosegood and McCulloch[17]), while in Australia, Rose[18] has recently built a highly-sensitive hydraulic lysimeter with continuous electrical recording. Although these instruments are more accurate than the simple Wellesbourne type their higher cost reduces the practicability of adequate replication and the simultaneous testing of many different experimental treatments.

Because of the dynamic nature of the crop/soil system it is not possible to maintain continuously a particular level of soil moisture stress in an experiment involving plants. Furthermore because, in soil, water moves downwards only from zones at or above field capacity it is not feasible in irrigation experiments to do other than water so as to bring a certain depth of soil to field capacity. Thus in field irrigation experiments soil moisture status within the root zone follows a cycle comprising comparatively slow drying resulting from transpiration, alternating with rapid wetting to a depth depending on the quantity of irrigation or rain falling on the soil surface. Watering may, be carried out when a certain soil moisture deficit has arisen or when a certain proportion of the soil available water has been used or when a definite moisture tension has been reached. The last of these is the best criterion on which to base watering treatments but direct-reading tensiometers operate only in comparatively moist soil; tensions in drier soil must be computed from measurements of soil moisture content in relation to moisture release characteristics previously determined for the particular soil.

The changeable United Kingdom weather makes it necessary to protect irrigation experiment plots from rain which would upset planned watering treatments; the Wellesbourne fibreglass shelters cover plots each 10 ft by 20 ft. Commercial irrigation equipment does not apply the water sufficiently evenly for use with such small plots and at Wellesbourne special equipment using gas jets as nozzles is used to apply water in the form of mist at the rate of about 1 inch in 15 minutes. Small plot results must be tested on a larger scale using commercial equipment, for example at the Experimental Horticulture Stations of the N.A.A.S. In such experiments wide guard areas are needed to prevent wind-blown spray reaching the wrong plots, and variability in water distribution permits only a small part of the wetted zone to be used for crop recording (Fig. 3).

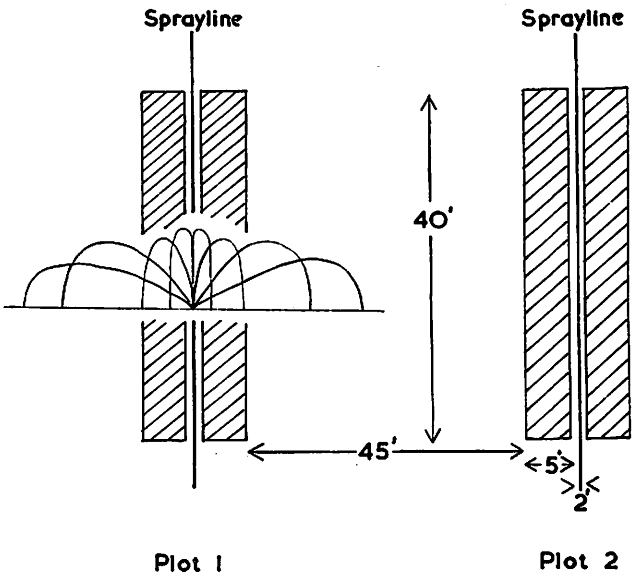

Fig. 3

Dimensions of plot and guard area for field irrigation experiments using commercial oscillated spraylines; the recorded area is shaded. Superimposed at the left is a diagram showing the trajectory of the sprayed water at different instants during the oscillation cycle. In layouts comprising fifteen such plots arranged in five randomized blocks, standard errors were frequently only 7 per cent of the general mean.

It is important to determine not only optimal watering treatments but also the effects of isolated dry spells or single waterings, and whether a plant has growth stages at which it is especially sensitive to changes in moisture supply.

Field observations have been carried out on commercial farms by persuading the farmer to omit from his normal irrigation programme, strips running across the field. Although this method yields useful indications, it cannot be regarded as a substitute for properly-controlled replicated experiments.

Crop Responses

It is generally agreed that a crop which is never short of water is likely to give maximum yield up to the limit imposed by environmental factors other than water. Copiously-watered plants tend to produce more foliage than those with limited water supply. This is obviously advantageous when the foliage itself is the marketable product, but when the desired produce consists of fruits, seeds or storage organs, the increase in marketable yield is not always as large as might have been expected from the increased foliage production. An irrigated carrot crop may have luxurious tops, but the yield of the edible roots may not be commensurate with this. Winter has shown that the ratio of root weight to shoot weight may be reduced by irrigation.[19]

Experiments on cabbage, lettuce, turnip and other vegetables have shown that a given amount of irrigation had its most beneficial effect the nearer to harvest the water was applied, and short term droughts had their most harmful effects at this time also. Certain plants were found to have well-defined moisture sensitive stages of growth; with peas, for example, these were at flowering when relief of moisture stress increased the number of peas per pod, and at the pod swelling stage when watering increased the size of individual peas. Provided the soil was moist at sowing time, watering peas at times other than when they were in the moisture sensitive growth stages had no effect on yield. Salter and Goode[20] have reviewed the world literature relating to moisture sensitive growth stages of plants and report substantial evidence that they exist in many of the major crops. Unfortunately suitable irrigation techniques have not yet been devised to take advantage of some of these phenomena, e.g. the moisture sensitive stage of wheat at antiesis.

Perhaps the most important stage, common to all crops, at which it is desirable to ensure that the soil reservoir is full, is at planting or sowing time. If the soil is near to field capacity at this time, most United Kingdom annual crops, on average soils, can achieve a reasonable yield in an average season without further irrigation. On sandy soils, where the available water capacity is low, this generalization may not hold for any but comparatively short-lived crops. Thus in most soils it seems desirable to plant or sow with the soil near to field capacity, irrigating if necessary to achieve this. If irrigation is carried out, subsequent preparation of the soil for drilling or planting should be as shallow as practicable to minimise the volume of moist soil exposed to the drying action of the atmosphere.

As has been pointed out, the volume of available water which a given volume of a soil can contain is limited; if this is shared between a large number of individual plants, obviously each will receive a smaller supply than if there were fewer plants. Thus in situations where irrigation is impracticable it may be necessary to adopt wider plant spacing to ensure adequate water supplies for individual plants. Conversely where irrigation is feasible, the plants can be spaced more closely so as to achieve a higher yield per acre; this principle has been demonstrated with, for example, cauliflower, cabbage, lettuce and pea.

Table I gives typical examples of crop responses to irrigation attained in experiments.

There can be little doubt that in the United Kingdom in most years irrigation of almost any crop would increase its yield, but irrigation is expensive in equipment,

TABLE I

Crop	*Moisture sensitive stage if any*	*Marketable yield with rain only tons/acre*	*Water applied inches*	*When irrigated*	*Marketable yield with irrigation tons/acre*	*Increased yield tons per acre/in. of water*	*Reference from which data abstracted*
Cabbage	none	16	1.0	last 3 weeks before harvest	23	7.0	Drew ([21])
Early potatoes	none	10	2.4	½ in. whenever deficit was ½ in.	12	0.83	Winter and Blackwall ([22])
Self blanching celery	none	22	2.8	1 in. whenever deficit was 1 in.	26	1.5	Winter and Blackwall ([22])
Peas	1. at flowering 2. at pod swelling	2.7 (shelled peas)	1.5	at the moisture-sensitive stages	3.8	0.77	Salter ([23])
Sugar beet	post-singling to end August (North)	2.9 (sugar)	3.6	soil restored to field capacity frequently throughout growth	3.2	0.08	Penman ([24])
Apple (Laxton's Superb in "on" years)	none	9.6	4.1	soil restored to field capacity whenever moisture tension at 1 ft depth exceeded 10 cm mercury	12.7	0.79	Goode and Hyrycz ([25])
Ryegrass	none	2.2 (dry matter)	9	½ in. whenever deficit was ½ in.	3.8	0.17	Williams, Stiles and Turner ([26])
White Clover	none	3.4 (dry matter)	9	½ in. whenever deficit was ½ in.	4.9	0.16	Williams, Stiles and Turner ([26])

labour and water and its most justifiable use is with high-value crops. Such crops include most of the vegetables, potatoes, intensively-used grass and blackcurrants. With other important crops such as sugar beet, benefits may be only marginal, and with others such as apples, indirect, in that irrigation in the current year may increase the amount of wood capable of fruiting in the subsequent year.

Even with improved conservation schemes, unlimited water supplies for irrigation are not likely within the near future and so it behoves the farmer to take account of the moisture storage characteristics of his particular soil and of the precise water needs of his particular crops in order to obtain worthwhile results with the minimum of irrigation.

Acknowledgements

I wish gratefully to acknowledge the generosity of my colleagues Dr Salter, Dr Stanhill, Dr Sale and Dr Drew for allowing me to quote their data; it is a pleasure to record my indebtedness to the officers of the Experimental Horticulture Stations of the National Agricultural Advisory Service, for their ready co-operation in carrying out irrigation experiments at those stations and to Mr J. North (N.A.A.S.) and Mr J. Goode (East Malling Research Station) for data used in Table I.

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WATER SUPPLY AND STORAGE

by

K. H. LAMBERT, BSC, MICE, AMIWE*

Presented at the Autumn National Open Meeting of the Institution on 26 September 1966 at the Essex Institute of Agriculture, Writtle, Chelmsford

INTRODUCTION

An enquiry made in 1963 showed that there was sufficient irrigation equipment in England and Wales to irrigate 210,000 acres of crops in a dry season and that this use had been increasing at about 15,000 acres per year. If irrigation continues to expand at that same rate there may be more than one half million acres irrigated by 1980. The maximum potential area which could benefit from irrigation has been estimated at one and a half million acres.

A more recent enquiry made in October 1965 has indicated a greater total development but a reduced rate of increase. There is, therefore, some doubt as to the exact picture but this may be clarified when information becomes available about the licences issued by the River Authorities under the Water Resources Act of 1963.

In the early days of irrigation in this country, it was possible in many cases to obtain all the water required throughout the irrigation season by direct abstraction from river or stream. For anyone contemplating irrigation today the likelihood of getting such a supply is reduced. In the future there may be, of course, schemes where water will be stored on a very large scale either in surface reservoirs or underground and fed back into the rivers for abstraction as required but, obviously, even where conditions permit such schemes to be carried out, financial consideration must loom large, both from the point of view of the River Authorities who would have the task of constructing and operating such works and of the farmer who must consider very carefully the cost of such water and his return from its use.

To riparian owners where the river channel is used as a distribution feeder, the costs of distribution will probably not be prohibitively large but, for those far removed from such rivers, sources of water nearer at hand or winter storage may be an economic necessity.

There is little doubt that irrigation will continue to spread and it therefore seems likely that water storage to serve individual farms or groups of farms will continue to form a substantial part of irrigation development.

Water Measurement

There will obviously be more water available for abstraction during the winter months when the flows are at their highest but, at whatever time abstraction is made, the amount will have to be measured in order to meet with requirements of the Charging Schemes. Where fed by gravity to a reservoir by means of a channel it may be possible to use a measuring weir, for example a V notch, a rectangular notch, a circular orifice or a flume. All such devices require the head of water to be measured in order that the flow may be calculated, and an automatic level recorder may enable this to be done but this may not be practical on a farm scale. In most cases, however, the water will have to be pumped and a meter will have to be used. The Water Resources Board are at present carrying out trials with meters and will compare the results obtained with other methods of calculating the water used. If it is decided to adopt metering on a widespread basis no doubt it will be possible to obtain foolproof meters but it is preferable that such instruments should remain the responsibility of the River Authority as no doubt this will provide the most efficient and most economic service in the widest sense.

The alternative methods of measurement are all approximate as they depend upon the keeping of accurate records and upon judgement. They are as follows:

(*a*) A calculation involving the number of hours pumped and the average discharge of the pump. The latter varies according to the load.

(*b*) A calculation involving the hours pumped, the number of sprinklers used and the average output of the sprinklers.

(*c*) A calculation involving the acreages irrigated and the number of inches applied to each crop.

(*d*) A retrospective assessment of the actual irrigation need for the season, by the 'Penman' method.

Where all abstraction is to take place in the winter, however, measurement of the quantities stored in the reservoir before and after the abstraction period may be sufficient without the necessity for metering, or the other alternatives.

Charging Schemes

The Water Resources Act of 1963 has placed upon the River Authorities the responsibility of preparing charging schemes, which will come into operation in 1969. Until that date, water which is abstracted other than by a Licence of Right may be subject to interim charges. Little information about such charges is available yet but it is known that one River Authority is considering a scheme which takes into account four factors, i.e., the source of the water, the season of abstraction, the purpose, and the method of disposal of the water. As regards the last factor the water will all be lost in the case of irrigation and there is, therefore, no reduction due to this factor. It seems that under this scheme irrigation water abstracted to storage

* Senior Engineer, Drainage Division, Ministry of Agriculture Fisheries and Food.

in the winter months would cost about 1s. per acre inch, that is 22,600 gallons, and in the summer this would cost about 14s. When the cost of storage is taken into account, it might appear that summer abstraction is more economic but it has to be remembered that seldom will all the required water be available at this time and that if capital works have to be undertaken by the River Authority to supply it the cost is likely to rise considerably. A second Authority has talked of ½d. per 1,000 gallons in the winter and 3d. in the summer. Charges proposed by other River Authorities are not known but they are bound to vary considerably according to circumstances.

Small Catchments

There will still be a number of schemes which will depend upon the exploitation of small catchments with the water stored by means of an impounding dam or by the exploitation of under-drainage systems fed by gravity or pumped to an off-stream reservoir. In such cases the yield of the catchment has to be carefully examined, preferably by means of gauging over a considerable period. It has to be remembered that although in a wet winter there may be an abundant flow of water, a dry winter will result in a very much smaller flow. In the absence of full gauging records it is possible to estimate the dry winter run-off by gauging for one winter only and by adjusting this gauged run-off by taking into account the actual and average rainfall.

In the case of under-drainage systems the most satisfactory method of assessing yield is also by measuring the flow in the out-fall stream. The Ministry's Field Drainage Experimental Unit has a number of experimental sites where flow meters have been installed on under-drain outfalls and it may be possible at some future time to give guidance as to what discharges may be expected, for installations in various soil types and in different areas.

The exploitation of a small catchment obviously has great attractions as the water is 'harvested' as near as possible to its source, and under favourable circumstances costs are likely to be comparatively low. There are, of course, many varying circumstances and there are areas where such schemes might best be carried out on a district basis. The time may, in fact, come when it would be sensible to set up 'Internal Irrigation Districts' similar to 'Internal Drainage Districts'. Such districts could exploit their own water resources or distribute water supplied by River Authorities. This is, however, something for the future.

Ground Water and Public Supplies

Water from wells or boreholes may be used, if suitable in quantity and quality and if licensed by the River Authority. The prospect of obtaining ground water depends upon the geology of the area and advice may be obtained from the appropriate branch of the Water Resources Board. The yield of the borehole will have to be proved by pumping test.

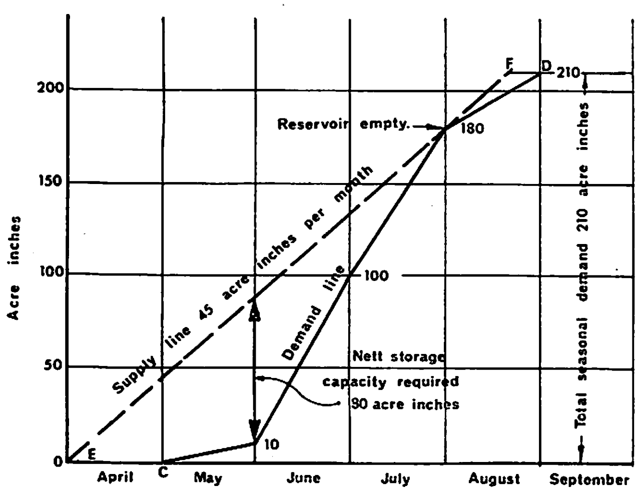
Public supply may be available for small installations and the high cost may be justified in the case of high value crops. In most cases it will be necessary to provide overnight storage in order to reduce the effect on other users during the day.

Amount of Storage Required

When the intending irrigator has decided what crops he wishes to irrigate an estimate can then be made of the irrigation demand in accordance with the methods recommended in the Ministry's Bulletins Numbers 4 and 138. It will also be necessary to consider whether provision should be made for full irrigation in all years, taking into account the fact that the driest year in ten may require 50% more water than the third driest. Consideration must be given as to whether, in the former case, the extra capital cost of storage will be balanced by extra return. This is only likely in the case of high value crops such as early potatoes.

When this has been done, it is then necessary to investigate how the water can be obtained. If all the water is to be abstracted from the river or 'harvested' in the winter months then it is not difficult to calculate the amount of storage required but, to the net figure of the water requirement, an allowance has to be added for seepage and evaporation losses, together with dead water. For seepage in a satisfactory soil it is reasonable to allow 12 in. and for evaporation another 12 in. which will take into account some make-up by rainfall.

When some water is available during the irrigation season either from the catchment which is being exploited or by abstraction from the river, it is possible to reduce the amount of storage. In order to arrive at this it is necessary to compare the irrigation demand throughout the season and the water available. Let us assume that we have from consideration of the irrigation need, arrived at the following monthly demand:



Nett summer storage capacity.

Fig 1

May	10 acre inches
June	90 acre inches
July	80 acre inches
August	30 acre inches

The total seasonal requirement is thus 210 acre inches, i.e. approximately $4\frac{3}{4}$ million gallons and this would be the net storage required if water is available only during the winter.

The reduced storage capacity with some water available in summer may be estimated by plotting graphs as shown in figure 1 above. Line CD represents the demand line on an accumulative basis and EF the supply line, assumed in this case to be 45 acre inches per month. The maximum vertical intercept between these two lines represents the net storage required and it will be seen that it is 80 acre inches, i.e. approximately 2 million gallons. The filling of the reservoir during the winter will not affect the net amount required but will simply permit the summer abstraction to be begun at a later date. Allowance for losses will, of course, have to be added to the net amount, as in the case of full winter storage.

Types of Storage

Impounding reservoirs which are formed by constructing a dam across a stream are not likely to have much future in farm irrigation in this country except in a few special cases where circumstances are particularly favourable. They have many disadvantages the principal one being the necessity to provide overflow and spillway capacity for the maximum flood which is likely to occur. The cost of such provision will be expensive and together with other difficulties inherent in an impounding project will often rule out a proposal which has appeared at first sight to be attractive. Such reservoirs are not dealt with in the remainder of this paper but points made about embankments refer equally.

Off-stream reservoirs constructed off the line of the stream generally provide the most economic solution due to the greater flexibility in their planning. They can be adapted to take advantage of the most convenient and most suitable site available on the farm. The overflow problem is a small one as the water will either be pumped in or, if fed by gravity, the entrance weir can be so designed as to divert the flow once the reservoir is full. Pumping if required will generally be moderate in cost unless abstraction from the river is only permitted for a very limited period when it may be necessary to install a large pump which will have to work at a large output for a short period.

In some areas where geological conditions are suitable, seepage reservoirs are a practical proposition. As in the case of boreholes and wells, the yield will require to be proved by test pumping.

Reservoir Design

The Reservoir (Safety Provisions) Act of 1930 requires that a reservoir designed to hold or capable of holding more than 5 million gallons of water above the natural level of any part of the land adjoining the reservoir must be designed, constructed under the supervision of and inspected from time to time by a qualified civil engineer on one of the panels constituted under the Act.

Although many farm reservoirs will have capacities of less than 5 million gallons and therefore be outside the scope of this Act, local conditions vary to such an extent that a reservoir project of any significance is essentially a matter which requires the services of a qualified civil engineer who is experienced in this field. The Civil Engineering profession, however, with a few exceptions, has not shown particular readiness to undertake the design of small reservoirs on a farm scale. Farmers, on the other hand, have not been particularly keen to employ them particularly as the amount of engineering supervision may be high in relation to the cost of the works and in any case are unfamiliar with the profession which deals with few other aspects of farming.

Although no two reservoir jobs are alike and although it is not possible to design a standard reservoir, nevertheless it is obvious that costs should be reduced where possible and where little risk is involved. With this in view, the Ministry is shortly to publish a bulletin No. 202 entitled 'Water for Irrigation', which sets out standards which give guidance for the generality of cases. It is emphasized, however, that cases will arise where more refined design techniques will be necessitated by site conditions. Many of the points which follow are dealt with in much greater detail in the Bulletin and the information in this paper is not intended to be comprehensive but merely to cover some of the more important matters.

Embankments

The design and construction of an earthen embankment can be a complicated task involving detailed site investigation of the underlying soil, the testing of soil samples as to mechanical strength, investigation of the stability of the proposed profile, etc. Nevertheless, as far as farm reservoirs of moderate size are concerned, it will be possible in many cases to reduce the work to a minimum by rejecting sites which are clearly unsuitable, by selecting sites where the required type of soil is available and by adopting dimensions and profiles as recommended in this paper which are suitable for the generality of work on this scale.

Any water-retaining earth embankment must be structurally stable and reasonably waterproof. On a farm scale it is best to limit the height to 15 ft as above this problems of stability and watertightness may raise design and construction costs above the economic limits of the project.

The stability of an embankment depends upon the type of soil occurring in its underlying foundation, the type of soil in the embankment itself, the profile and the dimensions adopted. If, however, the face of the embankment is allowed to erode or if the construction is not carried out in such a way as to give adequate consolidation, the full potential of the materials and the design will not be realized.

A thorough site investigation is necessary to determine whether the proposed site is suitable and whether the soil available can be utilized. Several trial holes should be dug to provide samples which will indicate the suitability of the soil. The holes will also show the variation in the strata and the depth of the various layers. The degree of soil permeability will be shown by the levels and influx rate of ground water. The presence of field drains on the site may present a possible source of seepage loss and to avoid this they should be plugged or preferably entirely removed. The cost of site investigation should not be excessive as, for about £20, it is possible with a light excavator to dig about ten holes per day to a depth of, say, 14 feet which will be well below the reservoir floor level in most cases.

The foundations of the embankment must be capable of carrying the embankment without excessive settlement. Low embankments with a maximum height of 15 ft as mentioned above should present little difficulty in this respect except on organic soils. Top soil should be stripped for re-use on the embankment slope and the foundation levelled to reduce the risk of the embankment sliding on its foundation.

Seepage cannot be completely overcome and the design must take into account the embankment material and the foundation so that this will be reduced to a minimum. The design of the embankment will have to be varied according to the permeability of the soil, as described below, while the foundation itself, if permeable, will require the construction of a cut-off trench down to an impermeable layer in order to bridge the gap between this and the embankment. This trench will have to be filled with soil having a suitable clay content, or with some other material such as 'Bentonite' mixed with sand and gravel.

Depending upon the soil available the embankment itself may be of homogeneous, core or blanket construction. Homogeneous construction may be adopted when the soil is a well-graded one with a clay content of not less than 20% and not more than 30%. This is the simplest and cheapest form of construction and remains stable even when the moisture content is altered. If relatively little impermeable soil is available it may be necessary to adopt the 'core' type with permeable soil surrounding a core formed of the impermeable material. If there is little or no impermeable soil available the only possible form of construction will be of the 'blanket' type where a blanket of waterproofing material is used on the wet slope of the embankment which will be constructed of the permeable material. The blanket may be a good quality dense clay or some artificial waterproofing membrane, such as Butyl rubber, PVC, polythene, etc. If PVC or polythene is used then the material must be covered with one to two feet of soil to protect it. Waterproofing materials are dealt with at greater length later in this Paper. Figure 2 illustrates the different types of construction.

Dimensions of Embankments

For embankments, within the limitations suggested above, it is wise to adopt for the wet face a slope of not less than 2½ horizontal to 1 vertical and for the dry face a slope of 2 to 1. Such slopes will be stable and are convenient both to construct and maintain. If, however, surplus spoil is available it pays to flatten the back slope so that it can be put to an agricultural use. It is sometimes suggested that such slopes are over-generous and wasteful of land. This is not so as steeper slopes are more difficult to maintain and the area saved by trying to use a steeper slope is small. For instance, the total area occupied by a 5 million gallon reservoir of the dimensions given later on in this paper is approximately 3.1 acres. If the slopes are increased to 2 and 1, and 1½ to 1 on the wet and dry faces respectively the area which is saved at the expense of bank stability and ease of maintanance is only 0.5 acres. With larger reservoirs the saving of land will be even smaller in proportion. If we consider the area of land irrigated, in this case probably at least 50 acres, the cost of the odd half acre is well justified.

Excavation below ground level should not be steeper that 2½ horizontal to 1 vertical. Where an embankment of any significant height has to be constructed near an excavated slope, the toe of the embankment should be set back 10 ft from the edge of the excavation to increase stability and to permit easier construction.

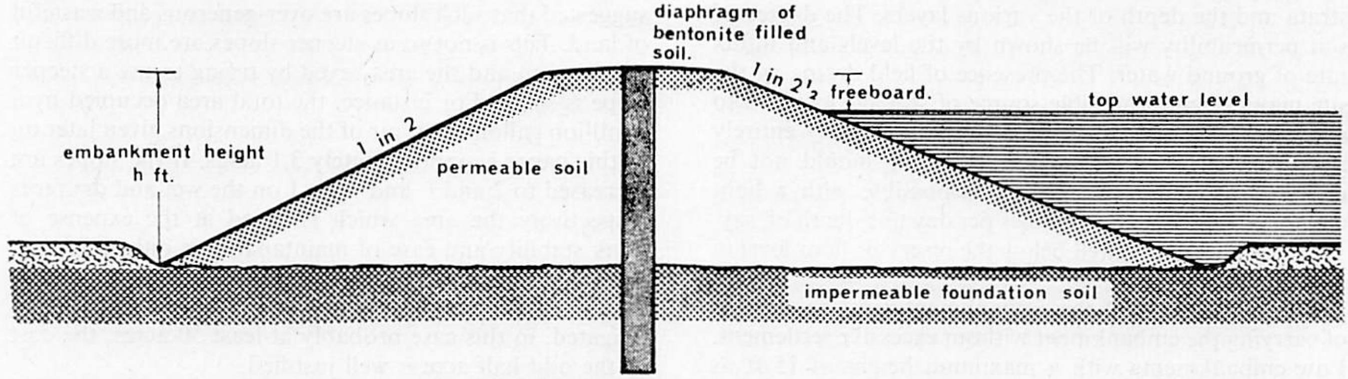
It is also false economy to try to cut down the top width of embankment and the following minimum dimensions are recommended.

Height of Embankment	*Minimum top width*
6 ft	8 ft
9 ft	9 ft
12 ft	10 ft
15 ft	11 ft

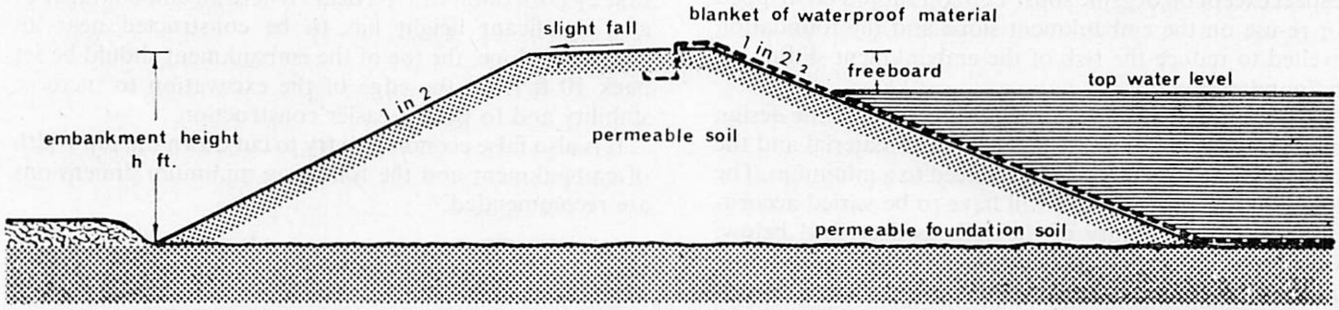
Some allowance must be made for settlement, which will occur both in the foundation and in the embankment material itself. The former may be particularly significant in the case of a reservoir constructed in a marsh area and may eventually amount to as much as 18 inches. Shrinkage of the embankment material will depend upon the nature of the material itself, the moisture content at the time of construction and the method of building. This settlement may be kept to a minimum, probably about 10% of the embankment height, by the use of the soils mentioned above and by constructing the embankment in layers, each 6 inches thick, at a time of year when the soil contains just enough water to remain intact when squeezed in the hand. The soil may have to be watered if excessively dry. Bank building and consolidation by a scraper is more satisfactory than the use of the dragline excavator and bulldozer, although the latter may be used for final shaping when the top of the embankment should be slightly cambered in order that rainfall may not cause ponding. The top soil which was stripped off the site should be respread over the exposed surfaces.

The top and back slopes of the embankment require protection from weathering and from rainfall and this is best provided by a grass covering. As the removal of an excessive amount of moisture from the embankment will result in the formation of shrinkage cracks, it is best to adopt a short well-clipped grass.

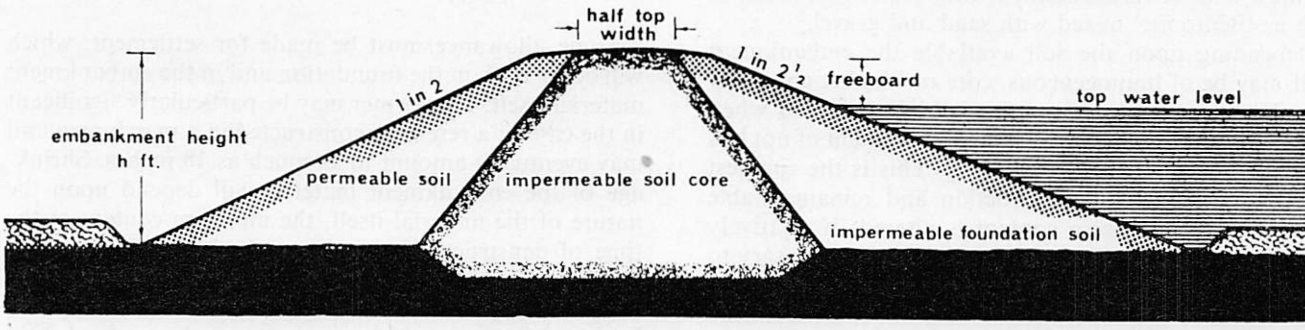
The wet slopes will require special attention, especially where exposed to wave action which may be considerable



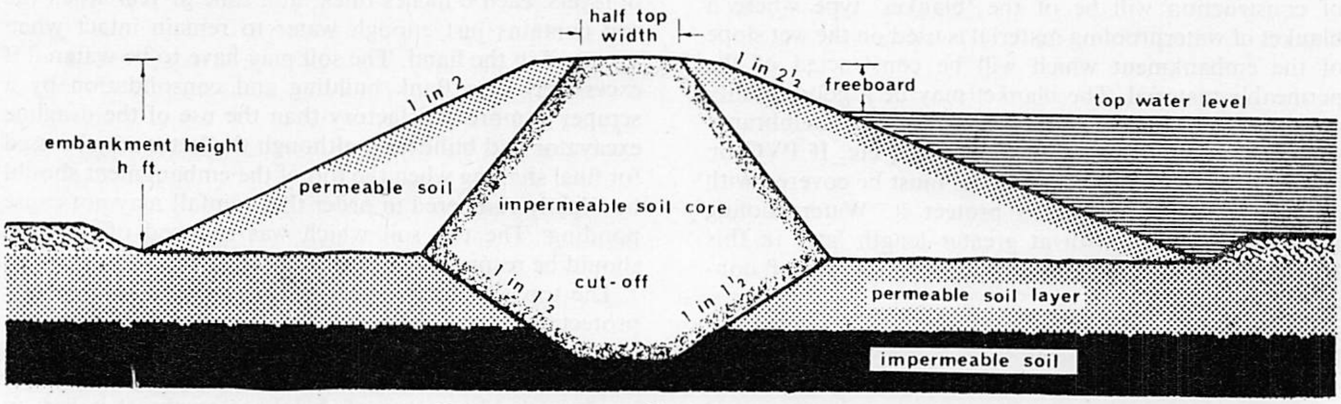
Diaphragm construction.



Blanket construction.



On impermeable soil.



On permeable soil with cut-off.

when the distance along the reservoir on which the prevailing wind may blow is sufficient to permit sizeable waves to be generated. Such parts of the reservoir may require to be protected by stone, concrete, wattle hurdles, reinforced bituminous sheets or other materials. A floating boom, anchored between vertical posts, rising and falling with the water level may also prevent damage to the banks. In the case of the less exposed banks, suitable grasses such as Creeping Bent and Rough Stalk Meadow Grass may suffice. Reeds and rushes are also useful but care must be taken that they do not spread to an excessive degree.

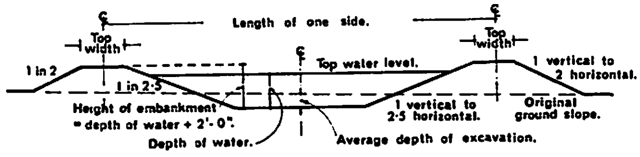
It follows from what has been said in the preceding paragraphs that earthwork should be kept to a minimum and therefore the most economic dimensions for a reservoir of any given capacity will be such that the amount of earth required to be excavated for storage is just the amount required to build the embankments.

The table below gives the dimensions for such reservoirs with capacities of one-half to 5 million gallons. It is assumed that these are constructed on evenly sloping ground, are square in plan and have water depths of from 6 to 12 ft. The table is a guide only as such uniform conditions will rarely be met in practice and in some cases embankments will not be required on all four sides. The table also gives the approximate amount of soil to be moved and it will be seen that the ratio of water stored to earth moved is larger as the capacities increase. On favourable sites, the water-to-earth ratio for an impounding reservoir will be greater but such sites are seldom available and the other disadvantages of such reservoirs which have been described earlier offset this apparent attraction.

Waterproofing

In an earlier part of this paper reference was made to different types of soil and the methods of embankment construction appropriate to each type. During the past few years various types of waterproofing materials have been marketed which permit reservoir construction to be undertaken in permeable soils. Such materials will, of course, increase the cost of the project and a site requiring waterproofing should only be used where no suitable alternative is available or where the site has some particular advantages. For example, the use of an existing chalk pit, gravel pit or some other similar site where excavation has already been carried out for some other purpose may, even with waterproofing, involve less cost than the complete excavation of a new reservoir. Such reservoirs may involve embankment along only some part of the perimeter. It should be remembered too that, if water is available free or at a very low cost, extra storage capacity to allow for seepage loss may be more economic than waterproofing but each case must be carefully considered in the light of the particular circumstances.

Sheet lining methods have been used in a number of cases in the past few years. Such linings have virtually no structural strength in themselves and are dependent upon earth backing without which they may tear, permitting leakage. This means that the earthwork must be carried out to an even higher standard than is necessary for unlined reservoirs. The lining should be laid on soil which is free from sharp stones. The upper areas where weed growth is likely must be sterilized to prevent weeds puncturing the lining which should be anchored in a trench excavated in the top of the embankment. One complication which may arise is the effect on the lining if it is possible for the water table in the ground to rise above the bottom of the reservoir when it is empty.



Section through typical offstream reservoir.

Fig 3

TABLE I

Typical Sizes of Offstream Reservoirs (Assumed square)

Reservoir Capacity million gallons	*Depth of Water feet*	*Length of One Side feet*	*Depth of Excavation feet*	*Top Width feet*	*Soil to be moved yards³*	*Total ground area acres*
½	6	150	3¾	9	2,000	0.7
1	8	185	4½	10	3,000	1.1
2	10	225	5¼	10	6,000	1.6
3	10	270	4½	10	8,000	2.2
4	12	295	5¾	11	10,000	2.6
5	12	320	5¼	11	12,000	3.1

Damage may be caused to some types of lining and a drainage system will be necessary in order to prevent this.

Flexible sheet linings are of three types: PVC, polythene and Butyl rubber, while reinforced bituminous sheet lining is somewhat different in character.

PVC (Polyvinyl Chloride) sheeting varies in chemical composition and it is best to choose a supplier who has previous experience of this type of installation. The thickness should not be less than 0.014 inches. The size of sheet available varies according to the manufacturer chosen but high frequency site welding permits any size of site to be lined. As the material tends to harden when it is exposed to sunlight the side slopes of the reservoir must be covered with soil at least 12 inches thick. These slopes should not be steeper than 1 in 4 or even flatter where wave action is expected. It is not essential to cover the bottom of the reservoir floor if it is possible to leave 1 ft of water over the lining. Plenty of material should be left slack so that if settlement occurs the material is not stretched and strained. For the same reason the vertical dimension of the lining should be kept as small as possible. Where large areas are involved, the installation of the lining is a difficult operation requiring great care to avoid damage. The ultimate life of such a lining is not known but careful maintenance is essential. Repair, particularly of damage below water, is not easy.

Polythene linings have not been used to any great extent in this country as some trouble was experienced due to the use of a very thin membrane. Recently, however, a tougher material has been marketed using a polythene of higher molecular weight and of greater thickness, i.e. 0.010 and 0.015 inches instead of 0.005 inches. This material is supplied in 24 ft widths and may be jointed by pressure-sensitive adhesive tapes with a mastic bead seal. As in the case of PVC it must be protected by soil cover.

During the past year or so, Butyl Rubber has been used for a variety of agricultural purposes including reservoir lining. It is more costly than PVC or polythene but an earth covering is not essential as it has a much better resistance to ageing and a higher mechanical strength. The thickness should be not less than 0.030 inches and the sheets may be jointed by cold solution or by welding. The slope adopted for a reservoir lined with this material should be no steeper than that for an unlined reservoir in the same soil. As in the case of PVC and polythene, the vertical dimension should be kept as small as possible to avoid excessive strain in the upper areas of the lining.

Reinforced bituminous linings of bitumen ½ inch thick reinforced by wire netting and glass fibre have been used on a number of small reservoirs. It is especially suitable for soils which can stand on a steep slope, for example, chalk. The lining is generally supplied in sheets which are 3 feet × 12 feet joined together on the site by heat and hot-run bitumen.

The cost of waterproofing will depend upon the quantity of material involved but the rates are likely to be less for larger reservoirs.

Material	*Cost of material and laying per square yard*
Reinforced bitumen ½ inch thick	18s.—20s.
Butyl Rubber 0.030 inches thick	10s.—13s.
PVC 0.014 inches thick (including soil cover)	4s.— 8s.
Polythene 0.015 inches thick (including soil cover)	3s.— 7s.

Future Trends

Where large scale storage is economically possible and where distribution costs are not excessive, there will be scope for irrigation on a large areal scale but, if either of these factors is too costly, development on an areal basis may not proceed. The seasonal uncertainty of demand and the individual considerations of a large number of farms also make it difficult to plan and to operate comprehensively. With drainage there has been in some areas a conflict of requirements between those who wish low water tables for arable crops and those who prefer high water levels for stock watering and for wet fences. Similar differences of practice and opinion may hinder co-operative arrangements for irrigation but no doubt this could be overcome in time.

Individual farm reservoirs will continue to be required either to store water available in winter or to supplement arrangements for summer supply from large scale schemes. There is scope for further consulting engineers in the field to investigate sites and to prepare suitable schemes and there is scope for contractors who are willing to carry out the construction work, preferably with sufficient variety of other work which would enable them to carry out the construction of storage reservoirs at the most suitable seasons.

The further development of waterproofing linings will permit reservoirs to be constructed on sites which would otherwise be unsuitable and will permit irrigation to be carried out where it would otherwise be impossible.

Acknowledgements

Acknowledgements are due to the Ministry of Agriculture, Fisheries and Food and to Mr E. A. G. Johnson, Chief Engineer, for permission to publish this paper.

Thanks are due to the author's colleagues Mr C. N. Prickett and Mr A. B. Hughes.

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1. Prickett, C. N. 'Use of Water in Agriculture'. Proceedings of Symposium on 'Conversation of Water'. *Institution of Civil Engineers*, 1962.
2. M.A.F.F. Bulletin No. 202 'Water Supply and Storage for Irrigation', to be published in 1967.

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programme

overleaf

programm

**A
ES**

DIVISION I	DIVISION II	DIVISION III
Mechanical Handling and Farm Buildings CONVENOR: J. A. C. Gibb, MA, MSc, Mem ASAE, MI Agr E (*University of Reading*),	**Research and Design** CONVENOR: H. J. Hamblin, OBE, BA, MI Agr E (*National Institute of Agricultural Engineering*)	**Machine Performance** CONVENOR: T. C. D. Manby, BSc, MSc, C AMI Mech E, MI Agr E, *Institute of Agricultural Engi*

TUESDAY

09.30-09.55 OPENING SESSION (Chairm

10.00-11.00

Ergonomics
Progress in the application of ergonomics in agriculture *by J. Matthews*
Tractor operating comfort *by T. L. Siemens*
Chairman: *T. Sherwen*

11.00-11.30 COFFEE INTERVAL

11.30-12.45

Division I — **Materials Handling**
- An industrial view of materials handling in agriculture *by C. Hardie*
- Pallet and container design and handling in agriculture *by J. B. Holt*
- The handling of chopped grass and hay before and after storage *by G. Shepperson and W. J. Corrie*

Ergonomics
- Operators' workplace design *by W. F. Floyd and A. A. Knight*
- Report on a survey of farm workers' hearing *by Mrs E. J. Stone*

Chairman: *T. Sherwen*

13.00-14.00 LUNCH INTERVAL

14.00-16.00 OPEN AFTERNOON AT THE NATIONAL INSTITUTE OF AG

16.00-16.30 TEA INTERVAL

16.30-17.45

Division I — **Crop Drying**
- Grain drying in thin layers *by S. Pabis*
- Moisture-temperature relationships during drying *by D. J. Greig and D. S. Boyce*
- Drying chopped hay *by G. Shepperson*

17.45-19.00

Division I — **Grain Storage and Handling**
- The design of steel buildings for grain storage (*author not yet known*)
- Moist grain storage *by J. Messer*

Tillage (convened jointly by
- The mechanics of soil cultiva
- Recent approaches to tillage Laboratory *by L. A. Liljedahl*
- Some problems of increasing
- Implications of chemical we

Chairman: *J. H. W. Wilder*

WEDNESDAY

09.00-10.30

Automatic Control
Application of automatic control in agriculture and horticulture *by S. W. R. Cox*
Leader-cable tractor guidance *by P. G. Finn-Kelcey and V. M. Owen*
Automatic guidance without leader cables *by M. G. R. Warner*
Automatic control of drainage machinery *by W. R. F. Gosling*
Chairman: *K. E. Morgan*

10.30-11.00 COFFEE INTERVAL

11.00-12.30

Division I — **Control of Temperature and Humidity by Ventilation and Heating**
- For animal production *by V. M. Owen*
- For crop production *by L. G. Morris and K. W. Winspear*

Division II — **Computing and Strain Measurement**
- Collecting and computing results of testing and research *by P. E. Berry and J. Matthews*
- Methods of measuring strain *by D. E. Filby*
- A combined torque and thrust dynamometer *by J. Kilgour*
- Understanding structures with brittle lacquer *by T. R. Tyrer*

Division III — **Tractor Performance (conve**
- Trends in hydraulic systems f
- A concept for calculating tra
- Vehicle design and tractive p

Chairman: *T. C. D. Manby*

13.00-14.00 LUNCH INTERVAL

14.00- TECHNICAL VISITS

THURSDAY

09.00.-10.30

Division I — **Synthetic Materials in Agricultural Building Construction**
- Plastics materials in agricultural buildings *by J. G. Sleddon*
- Bubble houses — materials and design factors *by A. E. Canham*

Division II — **Materials Engineering**
- A pilot survey of the durability of farm machinery *by R. C. D. Richardson and M. P. Jones*
- Materials application in agricultural engineering *by D. G. Attwood*

Division III — **Variation in Machine Perfo**
- Factors affecting field perfor
  - (a) Cultivation and other m *R. Q. Hepherd*
  - (b) Harvesting machinery *Patterson*
- New approaches to placem lizers *by B. Holliday*

10.30-11.00 COFFEE INTERVAL

11.00-12.30 FINAL SESSION (Chairm

Opportunity for Discussion will be provided before the end

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ULTURAL ENGINEERING

III and IV)
R. P. Hettiaratchi
t the National Tillage

hing speed by I.Lehoczky
by J. G. Elliott

ly by Division III and IV)
merican tractors by L. E. Elfes
mance from test data by F. Kliefoth
by A. R. Reece

by

E.

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Sherwen)
ch Session.

DIVISION IV
Soil Mechanics

CONVENOR:
A. R. Reece, BSc, MSc PhD, AMI Agr E (*University of Newcastle*)

Soil Mechanics and Plant Growth
- Tillage and the root environment *by J. C. Hawkins*
- Mechanical impedance and root growth *by B. W. Eavis*

DIVISION V
Water Control

CONVENOR:
A. N. Ede, MA, MSc, PhD (*Consultant*)

Land and water management
- Soil and water conservation *by D. S. Ferguson*

Engineering Schemes to Agricultural Needs
- Irrigation and drainage in tropical countries *by P. H. Stern*
- Design of drainage systems in organic soils *by T. M. Prus-Chacinski*

Research on Techniques or Products
- The operation of trenchless pipelayers *by A. N. Ede*
- Probes for checking tube installations in situ *by D. E. Filby*
- Problems of water entry to plastic and other tubes *by J. C. Cavelaars*

Irrigation and Water Control Related to Soils
- Soil moisture storage characteristics *by P. J. Salter*
- Management of tropical soils in relation to moisture control *by L. Campbell*
- Spray irrigation developments (*author not yet known*)

The A E S is organised by a Working Party appointed by the Council of The Institution of Agricultural Engineers.

THE WORKING PARTY

CHAIRMAN:
K. E. Morgan, BSc ND AgrE, Mem A S A E, AMI Agr E (University of Reading)

DIVISIONAL CONVENORS:
See Programme.

MEMBERS:
- J. K. Bennett, FRSA, FCCS, MIOM, (Secretary I Agr E)
- D. R. Bomford, Hon MI Agr E (Past President, I Agr E)
- C. V. Brutey, AI Agr E, (Chairman, Papers Committee, 1966-67, I Agr E)
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- C. J. Moss, B Sc, C Eng, MI Mech E, MI Agr E (Director, National Institute of Agricultural Engineering)
- P. C. J. Payne, Ph D, B Sc, M Sc, Mem A S A E, MI Agr E (Principal, National College of Agricultural Engineering)
- B. C. R. Smith, (Assistant Secretary, Agricultural Engineers Association)
- T. Sherwen, C Eng, M I Mech E, MSAE MI Agr E (President-Elect, 1966-67, I Agr E)
- J. H. W. Wilder, BA, MI Agr E (President, 1966-67, I Agr E)

ORGANISING SECTION:
- E. Atkinson, C Eng, AMI Mech E, AMI Agr E (Honorary Treasurer)
- J. Kilgour, B Sc, M Sc, Gr I Agr E (Domestic Organiser)
- J. K. W. Slater, MA, M Sc, MI Agr E (Honorary Secretary)

CHOICE OF TECHNICAL VISITS

(1) *Texas Instruments Ltd.*
(2) *Rothamsted Experimental Station*
(3) *College of Technology, Cranfield*

These three visits are planned to take place concurrently on the Wednesday afternoon when no other AES activity will be in Session. Full details of the visits will appear in the AES final programme.

For more details of AES Speakers see index on next page

index of speakers

DIVISION I
Mechanical Handling and Farm Buildings

CONVENOR:

J. A. C. Gibb, MA, MSc, Mem ASAE, MI Agr E (*University of Reading*),

SPEAKERS:

D. S. Boyce, BSc, MSc, Mem ASAE, AMI Agr E (*University of Newcastle*)
A. E. Canham, MSc, CEng, AMIEE (*University of Reading*)
W. J. Corrie, NDA, ND Agr E, Grl Agr E (*National Institute of Agricultural Engineering*)
D. J. Greig, BSc, MSc, AMI Agr E (*University of Newcastle*)
C. Hardie, FMIMH, (*Transport and Handling Technical Services Ltd*)
J. B. Holt, MSc, BSc, CEng, AMI Mech E, MIMH, AMI Agr E (*National Institute of Agricultural Engineering*)
J. Messer, BSc (*National Institute of Agricultural Engineering*)
L. G. Morris, BSc, Assoc IHVE (*National Institute of Agricultural Engineering*)
V. M. Owen, BSc, CEng, AMIEE (*University of Reading*)
S. Pabis, PhD, (*Instijut Mechizacji Electryfikacji Rolniciva, Warsaw*)
G. J. Sleddon, MA, (*ICI Ltd, Plastics Division*)
G. Shepperson, BSc, MI Agr E (*National Institute of Agricultural Engineering*)
K. W. Winspear, AMI Agr E (*National Institute of Agricultural Engineering*)

DIVISION II
Research and Design

CONVENOR:

H. J. Hamblin, OBE, BA, MI Agr E (*National Institute of Agricultural Engineering*)

SPEAKERS:

D. G. Attwood, BSc, ACT(Birm) (*National Institute of Agricultural Engineering*)
P. E. Berry, MSc, ACGI, CEng, AMI Mech E, AFR Ae S, Assoc Mem ASAE, (*National Institute of Agricultural Engineering*)
S. W. R. Cox, BSc, A Inst P (*National Institute of Agricultural Engineering*)
D. E. Filby, BSc (*National Institute of Agricultural Engineering*)
P. G. Finn-Kelcey, AMIEE, DFH, MI Agr E (*Consultant*)
W. F. Floyd, BSc, PhD, F Inst P, CEng, AMIEE (*University of Loughborough*)
W. R. F. Gosling, BSc (*British Aircraft Corporation*)
M. P. Jones, BSc (*National Institute of Agricultural Engineering*)
J. Kilgour, BSc, MSc, Grl Agr E (*National College of Agricultural Engineering*)
J. Matthews, BSc, A Inst P (*National Institute of Agricultural Engineering*)
V. M. Owen, BSc, CEng, AMIEE (*University of Reading*)
R. C. D. Richardson, BSc, CEng, AMI Mech E (*National Institute of Agricultural Engineering*)
T. L. Siemens, BSME, Assoc Mem ASAE (*John Deere & Co. Limited*)
E. J. Stone (Mrs) (*University of Loughborough*)
T. R. Tyrer (*Tractor Research Limited*)
M. G. R. Warner, MA, C.Eng, AMIEE (*National Institute of Agricultural Engineering*)

DIVISION III
Machine Performance

CONVENOR:

T. C. D. Manby, BSc, MSc, C.Eng, AMI Mech E, MI Agr E, (*National Institute of Agricultural Engineering*)

SPEAKERS:

L. E. Elfes, (*Vice-President Engineering, Massey-Ferguson, Toronto*)
J. G. Elliott, MA, (*Arc Weld Research Organisation*)
R. Q. Hepherd, BSc, AMI Agr E (*National Institute of Agricultural Engineering.*)
B. Holliday, BSc (*University of Leeds*)
F. Kliefoth, (*Deutsche Landwirtschafts-Gesellschaft e.V.*)
L Lehoczky, (*Agricultural Engineering Institute, Budapest, Hungary*)
D. E. Patterson, MSc, BSc, Grl Agr E, (*Nafional Institute of Agricultural Engineerıng*)
A.R. Reece, BSc,MSc, PhD, A M I Agr E (*Unversity of Newcastle*)

DIVISION IV
Soil Mechanics

CONVENOR:

A. R. Reece, BSc, MSc PhD, AMI Agr E (*University of Newcastle*)

SPEAKERS:

B. W. Eavis, BSc, PhD (*Ministry of Agriculture, Barbados*)
L. E. Elfes (*Vice-President Engineering, Massey-Ferguson, Toronto*)
J. G. Elliott, MA (*ARC Weed Research Organisation*)
J. C. Hawkins, BSc, NDA, MI Agr E (*National Institute of Agricultural Engineering*)
D. R. P. Hettiaratchi, BSc, MSc (*University of Newcastle*)
L. A. Liljedahl, (*Crop Production Engineering Research Branch USDA*)
F. Kliefoth, (*Deutsche Landwirtschafts–Gesellschaft e.V.*)
A. R. Reece, BSc, MSc, PhD, AMI Agr E (*University of Newcastle*)

DIVISION V
Water Control

CONVENOR:

A. N. Ede, MA, MSc, PhD (*Consultant*)

SPEAKERS:

L. Campbell, BSc, DICTA, AMI Agr E (*University of West Indies, Trinidad*)
J. C. Cavelaars, MSc (*Koninklijke Nederlandsche Heidemaatschappij, Holland*)
A. N. Ede, MA, MSc, PhD (*Consultant*)
D. S. Ferguson, BSc, MICE, MIWE, M Assoc Cons Eng (*Ministry of Overseas Development*)
D. E. Filby, BSc, (*National Institute of Agricultural Engineering*)
T. M. Prus-Chacinski, PhD, DIC, MICE (*C. H. Dobbie & Partners*)
P. J. Salter, MSc, PhD (*National Vegetable Research Station*)
P. H. Stern, MA, MICE, AMIWE (*Sir William Halcrow & Partners*)

Registration forms and other details are available on request from:-

J. K. W. SLATER, MA, MSc, MI Agr E,
AES HONORARY SECRETARY
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ENGLAND.

A
E S

AES CHARGES

FULL ATTENDANCE (Inclusive Tariff)			
REGISTRATION includes pre-prints of all Papers, admission to all Sessions and subsequent bound Proceedings	I Agr E members (incl. nominated representatives of Affiliated Organizations)		Non-Members
	Graduates and Students	Others	
REGISTRATION	£ 10 - 0 - 0	£ 14 - 0 - 0	£ 16 - 0 - 0
ACCOMMODATION (including all meals and refreshments for complete period)	£ 11 - 0 - 0	£ 11 - 0 - 0	£ 11 - 0 - 0
TECHNICAL VISIT Wednesday Afternoon	5 - 0	5 - 0	5 - 0

PART ATTENDANCE (Daily Tariff)			
REGISTRATION includes pre-prints of Papers only for the day stated, and admission on that day. It does not include the bound Proceedings	I Agr E members (incl. nominated representatives of Affiliated Organizations)		Non-Members
	Graduates and Students	Others	
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MONDAY/TUESDAY Bed & Breakfast	£ 1 -15 - 0	£ 1 -15 - 0	£ 1 -15 - 0
TUESDAY Registration	£ 5 - 0 - 0	£ 6 - 0 - 0	£ 7 - 0 - 0
Luncheon, coffee, tea and dinner	£ 2 - 5 - 0	£ 2 - 5 - 0	£ 2 - 5 - 0
TUESDAY/WEDNESDAY Bed & Breakfast	£ 1 -15 - 0	£ 1 -15 - 0	£ 1 -15 - 0
WEDNESDAY Registration	£ 5 - 0 - 0	£ 6 - 0 - 0	£ 7 - 0 - 0
Luncheon, coffee, tea and dinner	£ 2 - 5 - 0	£ 2 - 5 - 0	£ 2 - 5 - 0
WEDNESDAY/THURSDAY Bed & Breakfast	£ 1 -15 - 0	£ 1 -15 - 0	£ 1 -15 - 0
THURSDAY Registration	£ 2 - 0 - 0	£ 3 - 0 - 0	£ 3 - 0 - 0
Coffee and luncheon	£ 1 - 5 - 0	£ 1 - 5 - 0	£ 1 - 5 - 0
TECHNICAL VISIT Wednesday Afternoon	5 - 0	5 - 0	5 - 0

FACTORS AFFECTING THE FUTURE OF WATER APPLICATION

by

J. J. NORTH, BSC, MS, DIP AGR*

Presented at the Autumn National Open Meeting of the Institution on 26 September 1966 at the Essex Institute of Agriculture, Writtle, Chelmsford

INTRODUCTION

Profitable crop production in many countries of the world is almost entirely based on irrigation, as without it there would be virtually no satisfactory crop plant growth. In the United Kingdom, in common with many of the so-called humid areas, a reasonably satisfactory level of production can be achieved from natural rainfall alone. The recognised detrimental effect of even quite short periods of dry weather during the growing season have however stimulated increasing interest in the use of supplemental irrigation throughout the humid areas of the world. Post war developments provided improved portable irrigation equipment and pumping plant; whilst the development of light-weight pipe and 'quick coupling' devices provided the tools to permit widespread adoption on a field scale. The utilization of technicological developments in the field of crop production such as the growing of modern high yielding varieties and higher levels of fertilizer application, have also increased the awareness that shortage of water is often the limiting factor to further increases in production. More recently higher planting rates and closer spacings have been developed for some field crops to meet the demands of the modern market; these systems increase the inter-plant competition for water and consequently the need for irrigation.

Economic change has also an important role to play in the future development of irrigation. Higher standards of living increase the demand for processed or semi-processed vegetables. This frequently requires the matching of field production to meet the industrial demands of processing, in terms of quantity, time and quality. Elimination of the drought hazard in the production field, has encouraged processors only to place contracts with farms having irrigation facilities. At the same time there are concurrent trends of intensification of production on farms, as a means of increasing productivity. Irrigation provides one means of greater intensification for a wide range of crops and at the same time may improve productivity by a reduction in the unit costs of production. Costs of crop production are also rising; under a high cost system crop failure is far more serious than under a low cost structure and the adoption of irrigation under appropriate conditions will considerably reduce this hazard.

There seems little doubt that the trends outlined above are ones which are likely to continue, unless of course there are dramatic changes in the pattern of farming or in consumer preferences. If this is accepted, then there appears to be scope for the expansion and development of supplemental irrigation, provided of course other technicological advances donot render it unnecessary.

Irrigation Potential in England and Wales

Accepting that the irrigation of certain crops in parts of Britain can increase productivity, the agronomic potential for irrigation was estimated in 1962[1]; experience and research findings since then have not materially altered the situation. It would seem reasonable at the present time to continue to use this as a guide for forecasting the ultimate practical development of irrigation.

TABLE I

Crop	*Acreage of Irrigable area '000 acres*		
	S.E.	*N.W.*	*Whole*
Early Potatoes	48	28	76
Maincrop Potatoes	140	92	230
Sugar Beet	160	29	190
Grassland	380	370	750
Vegetables	110	42	150
Tree Fruit	36	12	48
Small Fruit	12	1.2	13
Total	890	570	1500

However, since certain economic factors were ignored many of the above figures would be substantially reduced if high charges were made for water used for irrigation purposes. Two recent enquiries[2] into irrigation practice produced results which give an indication of the stage of development which has now been reached.

TABLE II

Acreage of Crops usually irrigated in a dry season	1963 *acres*	1965 *acres*	1965 as % *of Potential*
First early potatoes	16,963	20,443	27%
Second early and maincrop potatoes	29,658	40,347	18%
Sugar beet	24,520	36,936	19%
Hops	2,697	2,671	—
Orchard fruit	6,644	9,898	21%
Small fruit (not under trees)	4,397	5,536	43%
Vegetables	37,399	40,453	27%
Grass	67,402	84,404	11%
Cereals	N.C.	N.C.	—
Other crops	20,968	15,626	—
Total area irrigated	210,648	266,360	18%

* Crop Husbandry Advisory Officer, National Agricultural Advisory Service

Grassland still provides the biggest potential for development, if cheap water can be made available, though there is still considerable scope for increasing the acreage of the potato crop under irrigation.

Economics will figure very largely in determining whether or not the agronomic potential is reached, and also in controlling the speed of development. Three other factors will also exert considerable influence; the availability of water at a reasonable price, the overcoming of labour problems associated with irrigation and the farmer's ability to put into practice the techniques which are necessary to obtain the economic benefits from using irrigation.

ECONOMICS

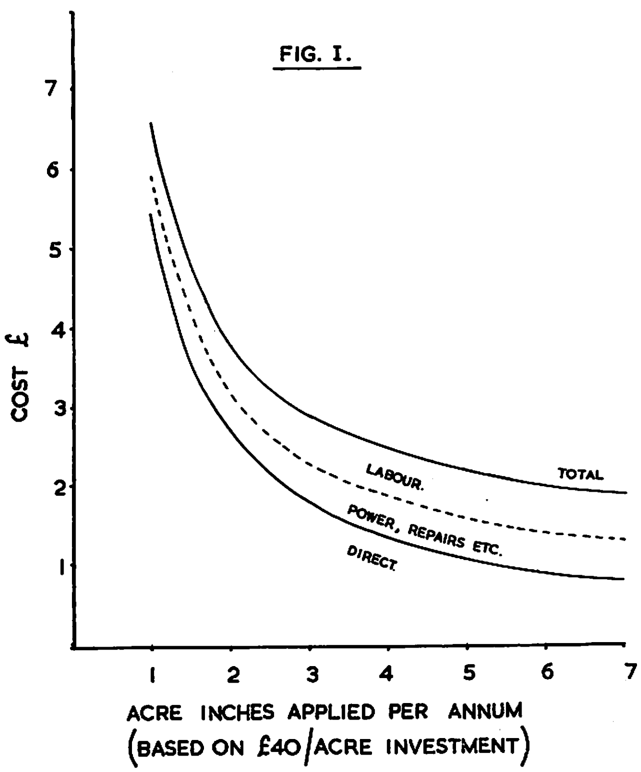
Costs

The price of conventional irrigation equipment has remained fairly static during recent years. Many farms have installed systems with costs of £30 to £50 per acre of equipment capacity i.e. costs spread over the acerage which could be irrigated at the rate of 1 inch every 10 days. Horticultural holdings usually incur higher costs sometimes rising to £100 per acre or more. Where there are no costs attributable to the provision of water, the major direct cost has been the depreciation and interest charges on the capital invested. For ease of comparison it is best to relate all costs and returns to a basis of cost or return per acre inch.

The direct cost per inch is considerably influenced by the use made of the equipment which is mainly determined be irrigation opportunity as influenced by rainfall, soil type and cropping.

By careful planning it is often possible to provide a sequence of irrigable crops, so as to increase the acreage over which a parcel of irrigation equipment can be used. For example, in most areas the average annual requirement for potatoes would be between two and three inches, for sugar beet about two inches; where both maincrop potatoes and sugar beet are grown the requirement could increase to 5 inches if equal acreages were involved. This immediately reduces the equipment cost from £2 to £4 per acre inch to about £1. Similar opportunities do not always arise; equipment used for irrigating grass will be fully utilized for that crop, but in this instance the direct costs will still be low as on average more than 5 inches will be applied. To these capital charges must be added the costs of pumping, transport and repairs which will total about 10s. per acre inch. Labour costs of about 12s. 6d. would also have to be included if the costing were on an enterprise basis. Thus the total cost per acre inch for well designed systems will be about £2. 5s., excluding water charges. In the future water charges will have to be met either as a charge levied by the River Authority or the cost of storage or a combination.

FIG. I.



Returns

These can vary considerably from farm to farm due to a multitude of factors, though a general guide to likely responses can be given assuming a good standard of management and reasonable conditions.

TABLE III

Likely Responses to Irrigation

Crop	*Increased Margin per effective inch of irrigation*
	£
Potatoes — earlies	25
— maincrop	12
Sugar Beet	6
Grassland	6
Fruit	25
Vegetables	30

The returns given are based on average prices, no account has been taken of the enhanced quality which is frequently associated with irrigated crops, or the increased returns which may accrue from the use of irrigation combined with modern crop production systems. Irrigation can also be used for frost protection. It frequently permits planting of crops which would not be possible under dry farming and can also be used to facilitate the harvesting of root crops. Some or all of these are benefits which may accrue on particular holdings, but a general value cannot be determined.

The margin between costs and returns must be sufficient to pay any water costs and also to provide the incentive for the farmer to invest money in an irrigation project.

LABOUR REQUIREMENTS

Conventional irrigation systems must receive regular attendance during irrigation; to move the sprinkling equipment within the field, to attend to the pump and where portable mains are used to move these periodically. The average labour usage[3 4 5] from survey data averages about 2.5 man hours per acre inch. On an enterprise costing basis this would represent about 25-30% of the total annual irrigation costs. In practice the introduction of irrigation seldom involves an increase in the labour force, so the real labour costs of irrigating will be less than suggested, provided the overtime costs are not unduly increased.

There seems to be little scope for substantially reducing labour requirements with conventional systems under general conditions; any major development here would be by change in equipment or system design. At first sight, the financial incentive to introduce labour economies appears only slight, even when considered on the basis of direct accounting.

2.5 man hours at 5/- = 12s 6d. per acre inch
Average annual application = 4 inches per acre
Labour costs per acre = £2 10s. 0d.

If these costs are capitalized over a 10 year period at usual rates of interest, this would permit only an extra investment of £18 8s. 0d. per acre of equipment capacity, assuming that all labour costs are eliminated, which would not be the case. Other factors must also be considered. Farm workers dislike moving irrigation equipment as it is at present; bonuses and incentives are frequently paid to get the job done at all. At the same time labour is becoming a scarce resource and on many farms this may well prevent the introduction of irrigation. Removing the chore element from this work may encourage the farmer to make fuller use of his irrigation, which in many instances would give substantially enhanced returns. These extra returns would justify a larger investment in equipment, especially on farms where irrigation is under utilized and used only as an insurance against severe drought. Finally, operation of the equipment is largely restricted to the hours of daylight or a little longer. Eliminating moving the equipment may permit 24 hour operation introducing investment economies.

Approximately 70% of the labour involved is used in moving the equipment within fields; only 30% is used in attending to the pump or moving the equipment from field to field. It is in the 'within field' moves that attention must be concentrated, especially as these moves normally have to be made under wet conditions which are extremely unpleasant for the operator. Tall growing crops especially when close planted e.g. maize, virtually makes movement of normal equipment impossible.

Reduction in labour requirements and improved effectiveness of the equipment can be achieved by either purchasing more equipment or by mechanization of some of the components of the system.

Portable Systems

Labour requirements can theoretically be reduced by decreasing the amount of equipment to be moved by increasing the area covered by each water outlet. This can be most easily achieved by increasing nozzle sizes and to a limited extent by increasing pressure.

TABLE IV

Pressure lb/in.	*Nozzle Size* $\frac{3}{4} \times \frac{7}{16} \times \frac{1}{8}$ in.		$1 \times \frac{7}{16} \times \frac{5}{32}$ in.		$1\frac{1}{4} \times \frac{9}{16} \times \frac{1}{4}$ in.	
	Wetted Diam. ft	*Discharge gal/min*	*Wetted Diam. ft*	*Discharge gal/min*	*Wetted Diam. ft*	*Discharge gal/min*
80	270	174	340	274	380	442
100	290	192	360	309	400	494
120	310	208	380	327	420	539

Source—Irrigation by Sprinkling FAO 1960

Larger nozzles mean larger water droplet sizes, higher application rates, and also higher power requirements. All these features are undesirable under most conditions mainly for agronomic reasons. In practice, the use of a large nozzled raingun only achieves a small saving in labour; in one survey only 10%[3]. High application rates involve frequent attendance which may disrupt other farm operations. However, there still appears to be scope for improvement in the design of existing sprinkling heads; any improvement in distance of throw without increasing effective droplet size or reducing uniformity of application is worthwhile.

The other alternative is to decrease the number of pipe moves by moving only the sprinklers. Instead of mounting the sprinkler directly on the lateral, the sprinkler can be mounted on skids and attached to the lateral by a length of small diameter flexible pipe. The sprinkler is then moved by pulling on the flexible pipe. allowing 4 or 5 settings of the sprinkler for each movement of the lateral line. Compared to a conventional system, this type of system saved about 30% of the labour required to irrigate a crop of potatoes. It was liked immensely by the operators who seldom had to enter a wet crop.

Semi-portable Systems

At present in the U.K. only permanently installed mains are generally used, delivering water to a wholly portable and frequently moved sprinkling system. As will have been noted earlier, this will only slightly reduce labour requirements.

Stationary Systems

This would be the ultimate system if the only criterion was one of labour saving. In these systems all the pipes, including the sprinkler laterals remain in the same position for the whole of the irrigation season. At the present time use of this type of system is restricted partly due to high capital cost, which must be offset by savings in labour costs and in part due to interferences in the field operations required in growing the crop. Costs may exceed £200 per acre where the pipes are buried, but something less than £100 per acre where above ground equipment is used. Unless special precautions are taken during the planning stage the equipment may interfere with cultivations. Recent agronomic developments may eliminate the need for post-planting cultivations and the cheaper above ground system may be suitable for use in a much wider range of crops than originally supposed. In designing these systems a compromise can also be reached between the investment in equipment and a minimal use of labour. This would involve the use of portable sprinklers which would be moved to different positions on stationary pipe. Stationary systems have tremendous advantages in tall crops, e.g. maize, fruit plantations, where the crop obstructs pipe moving, as well as being the only type suitable for frost protection purposes in tall growing crops. Those incorporating stationary sprinklers also extend the possibilities of applying fertilizers and pesticides through irrigation water. Provided costs can be kept reasonably low there would appear to be considerable scope for developments along these lines.

Mechanical Aids

Abroad manufacturers have developed equipment designed to facilitate the moving of sprinkler laterals mechanically. Both the major types have been manufactured and tried in this country, but for various reasons have not become generally accepted. Tractor towed lines are generally only suitable for grass, particularly where large areas are involved; they are not so suitable for arable crops or where the area is restricted as they require reasonable areas for manoeuvring. It is possible to visualise improvements which could be effected to provide greater flexibility for moving, but even if successful their use would still be restricted mainly to grassland.

Side roll systems using the lateral line as the axle with wheels mounted perpendicularly at each joint and moving the line forward by rachet or motor are also available. These systems are usually expensive as large diameter wheels are required for easy rolling. In addition there is the added problem of moving the system from field to field without dismantling. They are difficult to manoeuvre on all but level fields and also where crops are grown on ridges. Both these systems are unsuitable in tall growing crops, though tractor tow systems can be used where special planned crop layouts are used.

Travelling Sprinkler Machines

In many countries travelling sprinkler machines are used which draw water direct from a ditch and discharge it either through a very large nozzled raingun mounted on the machine, or through a number of sprinklers mounted on a travelling boom. The spread of travel is usually 1 to 5 feet per minute and in order to cover the acreage high application rates are involved. In addition an adequate water supply must be available, which necessitates the provision of supply ditches at regular intervals. These remove large areas from production so this system has little application to this country.

The booms can also be rotated about a central axis and by using a combination of sprinklers and rainguns up to 2 acres may be covered from one position. This eases the difficulties in supplying water, as a piped supply can be used, but tracks must be left through tall crops to facilitate the moving of the machines. These machines are also seriously affected by wind.

Developments in self-propelled booms have much more domestic interest. One system supports the irrigation pipe and sprinklers above the crop on tall towers, each tower being moved forward by a hydraulic motor operated by water pressure. The equipment pivots around a central water supply point, the size of the sprinklers being increased towards the end of the line to compensate for the large areas covered. This type of movement demands large, square fields and their use is ruled out where the slope exceeds 5%. In the U.K. a travelling sprinkler is already available again driven by a hydraulic motor, which drives a winch winding up a wire rope moving the unit across the field. Water is fed to the unit through a polythene supply pipe which unwinds from a drum as the machine moves away from the water source. Weight of water and supply pipe restricts the area covered at each setting to 1¾ acres. This type of development is more suitable for field conditions in this country and reduces the labour requirements considerably, as the machine can be moved to its new position by a tractor. These machines are relatively expensive with a relatively low output of an acre inch in 22 hours.

Labour Economies

Very few of these systems have been studied on a comparative basis. From the information available from a variety of sources, estimates of labour usage can be made.

TABLE V

Estimated Labour Usage for Pipe Moving within Fields and Relative Equipment Costs

System	*man minutes/acre/irrigation*	*Cost*
Hand moved	30—60	1
Tractor tow	12—15	1½—2
Side roll	15—20	2—3
Sprinkler machine boom —small	20—40	3—5
,, ,, ,, —large	12—15	4—6
Self Propelled —small	10—20	6—8
,, ,, —large automatic	virtually nil	8—10
Stationary	virtually nil	2—5

FUTURE DEVELOPMENTS

Application of Water to Soils and Crops

Any satisfactory system of irrigation should be able to maintain an adequate supply of moisture in the soil for maximum economic crop growth and achieve this with a minimal use of land, water and labour. Application through a nozzle gives control over the amount and rate of water application and a reasonable control over the uniformity of application, This achieves minimal use of water; the development of conventional sprinkling systems have tended to demand high labour inputs.

Sprinkler design has tended to become rather stereotyped and there would appear to be scope for some improvements. Considerable economies as have already been mentioned, could be effected if the area covered by a sprinkler could be increased. Distribution of water through the air is limited by breakup, air resistance and gravity, yet even though improvements in nozzle design[6] and jet breakup[7] have suggested possible lines of improvement, these appear not to have been developed. The use of rotating nozzles demand a conic deposition profile to obtain uniform application by overlap of the circular patterns. Wider spacings can be achieved by the use of triangular rather than square or rectangular spacings of sprinklers. Unfortunately this type of spacing is very much more susceptible to the effects of wind and misalignment of pipes in terms of uniform application than the square spacing. Again these problems merit further investigation.

The rate of water application used has also tended to become stereotyped in the range of 0.25 to 0.5 inches per hour, 0.33 inches per hour being a commonly used design standard. These were originally intended to be figures to control the maximum rate of application and to prevent soil and crop damage. Long period operation at slow application rates will aid considerably labour economy and in stationary systems or systems employing branched laterals will reduce capital costs as there will be a reduction in pipe diameters. It should be possible to consider irrigation applications over a period of 24 hours taking full advantage of the depth of rooting of the crop and the water holding capacities of the soil; though in many situations applications over an 8 to 12 hour period may be the maximum that can be economically achieved.

When travelling sprinkling machines are used a second approach can also be considered. Low rates of application using equipment producing conventional droplet sizes is one approach. On the other hand if water can be applied as a mist very much higher rates up to 3 inches per hour can be used. This feature may be of some assistance to the design engineer, though there are obvious snags to high application rates from an engineering point of view.

Automation

As stationary systems become adopted, there will be considerable scope for the use of automation and programmes could be set up to provide irrigation, fertilizers and crop protection chemicals automatically. Many devices are already available; others will require further development.

Water Supplies

As water becomes scarcer and more expensive, uniformity of application and the more efficient use of water will become increasingly important. Three problems still require practical solutions. Evaporation losses from the surface of farm reservoirs are wasteful and a cheap system for reducing or eliminating these would be worthwhile. There is also room for the development of a cheap practical water measuring device to compete with the meter to aid control. The third and probably the most important is to encourage any development which would assist in counteracting the distortion caused by air movement during irrigation. This is of great importance where short time high application rates are used.

Application of Pesticides and Fertilizers

At the present time it is not possible to make general recommendations regarding the application of these chemicals in irrigation water. There is a limited amount of field experience available in this country and the results have been surprisingly good.

It would seem reasonable to assume that soil acting pesticides could be successfully applied through irrigation water, bearing in mind their particular mode of action. Indeed there may be distinct advantages in application in this manner, as water is usually necessary to make them active. On the other hand excessive soil moisture may move the chemicals too deeply into the soil to be effective, or with some of the chemicals reduce or eliminate their selectivity. These problems should be overcome by careful water management or by formulation.

Foliar acting pesticides present a different type of problem, as the use of clean water to flush the irrigation system following application may wash the chemical off the foliage. Generally this would represent an inefficient use of these chemicals, as with normal droplet size, little of the chemical would seem to be retained on the foliage. However, in practice some results have appeared to be satisfactory and the use of irrigation equipment for this purpose should not be entirely dismissed.

In general most fertilizers can be applied efficiently through irrigation water, but since nitrogen, phosphorus and potash differ in their behaviour on soils and plant requirements also vary for these elements, different methods of application for the various situations will have to be used. Provided the fertilizer is soluble and is not volatile there are no mechanical difficulties in applying the material with the irrigation water.

It is important, however, to remember that the uniformity of application of these chemicals can be no better than that of the water application, so systems used for chemical application must be properly designed and operated if satisfactory results are to be achieved. At the same time leaching losses must also be avoided, especially in areas of overlap between irrigation cycles as in normal portable operation. Stationary systems and sprinkling machines covering complete areas without overlap are more suitable for these operations.

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continued on page 34

JACK WRIGHT MEMORIAL LECTURE

IRRIGATION IN ARID LANDS

by

E. R. HOARE, BSC(ENG), MIEE, MIE(AUST), MI AGR E*

Presented at the Autumn National Open Meeting of the Institution, on 26 September 1966 at the Essex Institute of Agriculture, Writtle, Chelmsford

This lecture is given to honour the memory of Mr Jack Wright who as a keen young farmer, saw clearly the potentials of increased food production, using carefully applied water to crops. He was not only a good farmer, growing a wide range of horticultural and farm crops, but he possessed the enthusiasm and ability to design and engineer irrigation systems. He did this so well that he created a large industrial complex of organisations to design, manufacture, install and aid the running of irrigation systems in many countries of the world. In fact, he was on a return journey from inspecting his largest scheme in Mozambique when he and his colleagues met their untimely death in an air accident.

He lived beside a beautiful southern English river that starts in the Vale of Pewsey and flows through the Chalk hills of southern England to empty in the English Channel at Christchurch. He farmed on valley greensand which has good drainage but is often dry in low rainfall periods.

As a young man, after the 1939-45 War, a touring scholarship took him to the United States, and he was extremely impressed with the developments in California. He came back determined to utilize the water of the River Avon on his own farm and also saw clearly how much advantage could be achieved by irrigation in southern England. He was quite convinced that satisfactory irrigation systems involved careful study and design and set about creating an organization to cater for this need.

The success of his efforts can be seen in the establishment at Ringwood in Hampshire of a large factory and of further production centres in France, Spain and Africa. He had a clear view of the economy of water and he chose a team of young colleagues who have been imbued with the overall idea of economy in engineering design, long life in use and each system tailored to the needs of the farmer.

The system he was inspecting in Mozambique was irrigating sixteen thousand acres and involved a capital expenditure of £1.7 million.

He had a keen appreciation of the future role that irrigation and especially spray irrigation should play in the developing agriculture of many countries. To help this in 1956 he brought together at Bournemouth a large group of engineers, scientists and farmers to discuss the many problems. Again in 1961 in Salisbury, Rhodesia, he repeated the performance after having established his organization as a leading one in the supply of irrigation equipment for many places in the world.

I feel sure he would have appreciated the lectures and discussions here today, and I, for one, am extremely sorry that I will not be hearing again his pleasant Hampshire accent raised on today's problems.

Historical

The growing of plants by controlling the supply of water to them is not a new art. In fact, it has been practised in many countries for thousands of years. Most is known about the early systems in Iraq where the waters of the Tigris and Euphrates were used to irrigate a wide range of crops, probably as far back as 4,000 B.C. The earliest written record is contained in the Code of Hammurabi (circa 1,700 B.C.). This Code is a highly developed set of laws and there is evidence that it was rewritten from a similar code several hundred years prior to 1,700 B.C. Whilst the Code of Hammurabi relates specifically to the area enclosed by the Tigris and Euphrates, contemporary areas were developed in Pakistan and in China. The interest of this is not to prove how early man proceeded to irrigate land, but to show that civilizations came into being and were supported by irrigation farming over a period ranging from 2,000 to 3,000 years and possibly much longer. If disaster from irrigation causes did overtake the civilization of the Mesopotamian valleys, this was largely due to the great retreat of the sea at the mouth of these two rivers bringing about an increased drainage problem. This is mentioned because at times in arid areas when irrigation is considered there is a belief that when land is irrigated it must of necessity gradually go out of use.

In modern times there was a great upsurge in irrigation development particularly in India, and Egypt, brought about by Britain. Similarly there was development starting in California about 1870. Schemes were suggested at this same time in Australia, but population pressures were not sufficient to bring them at that time to fruition. This development mainly occurred in the arid areas of the world, and it will be as well if consideration is now given to these particular areas.

Arid Areas of the World

It will have been noticed that the early irrigation schemes started in relatively arid areas. At that time the human world population would have been low and there would

* CSIRO, Irrigation Research Laboratory, Griffith, New South Wales.

have been much more favourable rain supplied lands on which to grow crops. Most of these lands, however, were probably covered with large forest trees and it was easier to divert water over flat shrub covered country, than it was to cut down and clear large forest trees.

There is some suggestion that the arid areas of the world are man made and that cultivation helped create these barren wastes. In general, the arid areas of the world lie about 30°N and 30°S of the equator, and are caused by the wind systems which give a high moisture deposition in the Tropics (monsoon belt) and practically no deposition along the 30° latitude areas. Deposition again occurs in the 40° latitudes and upwards, with increasing regularity of rainfall. The systems are, however, disturbed by mountain masses and we have the rainfall patterns over the world with which we are familiar. River systems with collecting areas in the tropical monsoon areas which flow north and south pass through arid areas and hence, become most suitable as irrigation water supply system. Such a river is the Nile. Rivers which have collecting basins in the Tropics, but flow at constant latitude, do not pass through any arid areas, and have little use as irrigation supplies, and yet, they deliver to the sea vast quantities of fresh water. Such a river is the Amazon with a collecting basin of some 2 million square miles in a rainfall area ranging between 40 and 80 inches a year. In tropical areas due to cloud and high humidity, the evaporation is low and from an open water surface would not exceed 45 inches. The runoff, therefore, over this area is enormous and in the case of the Amazon, the quantity of water delivered to the sea could irrigate 400 million acres with an annual application of 5 feet of water. There are many other rivers with such characteristics, such as the Mekong and Salween in Asia, and the Congo and Niger in Africa. There are two other types of river systems, those that start in high mountain areas where snow or rainfall is high and later flow through arid areas on their way to the sea. Examples of such river systems are the Indus and Ganges of India; the Tigris and Euphrates of Iraq; the Yangtze and Yellow rivers of China; the Murray and Murrumbidgee of Australia; there are hundreds more. The other river type is that of a river which flows through a relatively flat plain in a monsoon area and where long flat dams are built to store water for the dry periods of the year. Such rivers are the Cauvery and Kistna of India; and the Ord and Burdekin of Australia.

Comparison of temperate rain areas with arid areas

In the arid areas of the world the absence of rain is associated with clear skies resulting in high sunshine hours and intensities combined with relatively cool nights. Where lands are suitable and water is applied, the climate is very suitable for growing a large range of crops which includes most plants of the temperate regions plus many of the sub-tropics.

The evaporation in such areas is high. In the near monsoon climates it is often 80 inches in one year, dropping to 50 inches at 40° latitude. The water application of various crops through the summer range from 30 to 60 inches with fruit and orchard crops having 30 inches applied, to rice having 60 inches applied. Considerable quantities of grain and pasture, however, can be grown through the winter period with not much more than 12 inches being used to produce high crop yields. This is the situation in Australia where wheat is grown on irrigated lands through the winter when 6 inches of water falls as rain, and a further 6 to 12 inches is added in the late spring to mature the crops. The land is then left without irrigation throughout the summer, and the cattle or sheep graze on the crop of dried seed and herbage which is left as hay on the ground. Any rain spoils such a hay crop. In a temperate area, such as England, the quantities of water to be added as irrigation range from an inch or so to perhaps 12 inches. The problem is to ascertain the precise period at which the limited quantity of water should be applied and the economics of the operation relate to the amount of extra crop achieved for the use of the water and equipment. In the case of the arid areas nearly all the water is supplied as irrigation water and the economics relate to the whole farming system.

If an example is chosen then hay can be produced in Britain under natural rainfall, giving 1½ tons to the acre. An extra 3 inches of water may add ½ ton of hay. In the case of an arid area, 5 feet of water may be applied to produce 10 tons of hay. It will be noticed that in terms of water the higher efficiency occurs in the case of the supplementary irrigation. The overall efficiency is very much in favour of the irrigation in the arid areas since 2 tons of hay are harvested for each foot of water used. It must be remembered, however, that no greater amount of equipment is used to disperse a few inches of water than a few feet and the overall economy is on the side of the arid areas, providing water is available.

A comparison of temperate rain grown cropping areas and arid zone areas is shown in Table I.

TABLE I

Comparison of temperate medium rainfall zone (England) with semi-arid zone (M.I.A., Australia)

	Temperate Zone	*Semi-arid Zone*
Summer rainfall	12 in.	7 in.
Evaporation (summer)	18 in.	45 in.
Deficit	—6 in.	—38 in.
Winter rainfall	11 in.	7 in.
Evaporation (winter)	5 in.	15 in.
Deficit	×6 in.	—8 in.
Monthly Peak	0.13 in./d	0.40 in./d
Weekly Peak	0.14 in./d	0.48 in./d
Daily Peak	0.18 in./d	0.69 in./d

It will be noticed how on any one day there is over a 3 to 1 ratio on water demand. The high water demand often creates a water stress in plants over and above that due to the soil moisture. This is due to the increased gradients in both soil and plant required to pass the high flow rate of water.

Whilst this table shows figures of evaporation, these must be modified to suit the crop and its stage of growth. For instance, a cotton crop growing through a summer period may face an evaporative demand of 38 inches but due to its small size and its period of ripening, may only use 24 inches of water over the growing period.

Another difference is contained within the soil moisture profile. In the temperate region, the winter excess of water wets the subsoil and there is either a water table at depth or a continuous drainage of water through the soil. In summer dry periods the plants may have their roots within range of the fringe of this water table and a reserve of water is available for the increasing dry period. In the irrigated arid area the top of the soil is successively irrigated and the lower portions of the soil may be completely dry. Since there is no drainage water or wetness in the lower portions of the soil, there is little reserve, and the water application is critical for the well being of the plant during the peak summer period. If any salinity exists in the soil, then under these latter conditions, salts will move upwards to the soil surface unless sufficient quantities of water are added to carry them down into the lower portions of the soil. It is often necessary to irrigate in excess of actual plant requirements to carry the salt concentrations below the root levels in the soil. In order to satisfactorily meet these requirements it is often necessary to tile drain the soil at depths below 5 feet to remove excess water and to continue to leach the soil downwards.

Productivity and Population

As a result of the high level of sunshine the yield of crops in irrigated arid areas can be high or alternatively, several crops can be grown in any one year. The water demand in relation to yield is shown in Table II, and it will be seen how great are the differences in yield for various types of food.

It must be remembered that fruit, milk and vegetables contain large quantities of water and so their food value is not strictly in accord with the weight. Whilst calorific value is an indication of food level, the type of food and their advantageous effects on diet are not so readily conveyed. The quantity of food available for consumption in a western diet (England, Australia, U.S.A.) is shown in Table III.

The diet of the Japanese, or the more fortunate half of India and China, is very similar to the western diet, but with most of the meat deleted. It will be noticed that 4½ acre feet is required each year to produce enough food for one person on a western type diet whilst 1½ acre feet is sufficient for an eastern type diet. Since the present population increase represents a doubling of the population every 30 years then on the score of water availability, India and China do not readily convert to a western type diet. There is not enough water.

In some discussions it has been suggested that in arid areas near populations of great density, such as China and India, it would be possible to use atomic energy to distil sea water to produce enough water to grow food crops.

TABLE II

Unit of agricultural commodity	*Total use of water per unit of production*	*Water supplied by irrigation per unit of production*	*Cost of irrigation water at 1d. per 1,000 gallons per unit of production*	*Value of commodity on farm per unit of production*	*Crop return ratio water cost*	*Gross value of crop per acre*
1. 1 lb wool (dry)	42,000 gal	none	—	60d.	—	£2
2. 1 lb wool (irrigated) winter pasture	6,200 gal	3,500 gal	3.5d.	60d.	17	£30
3. 1 lb wool (irrigated) 3½ lb meat	18,000 gal	13,000 gal	13d.	60d. + 55d.	9	£15 + £13
4. 1 lb. beef meat	4,200 gal	3,200 gal	3.2d.	18d.	6	£24
5. 1 lb peaches	49 gal	34 gal	0.034d.	4.3d.	130	£400
6. 1 lb. rice paddy	200 gal	200 gal	0.20d.	3d.	15	£84
7. 1 lb wheat grain	230 gal	100 gal	0.10d.	2d.	20	£19
8. 1 lb grapes	81 gal	56 gal	0.056d.	3d.	50	£168
9. 1 lb lint cotton	780 gal	580 gal	0.58d.	48d.	80	£140
10. 1 lb onions	36 gal	24 gal	0.024d.	1½d. to 3d.	60-130	£140-£280
11. 1 lettuce	18 gal	12 gal	0.012d.	3d. to 6d.	250-500	£400-£800

£1 Australian = 16/- Sterling

TABLE III

Western Diet for one person per year, allowing for preparation and wastage and water used to grow the quantity of food		
Quantity of food per year		*Thousands of gallons per year*
50 lb of milk solids 32 lb of fat	×1,800 gal	90
213 eggs	× 90 gal	18
240 lb meat (carcass wgt.)	×4,200 gal	1,000
115 lb sugar	× 100 gal	12
9 lb nuts	× 200 gal	2
181 lb fruit	× 50 gal	9
244 lb vegetables	× 50 gal	12
190 lb grain	× 230 gal	93
Total		1,186 thousand gallons per Year

The average power consumption of electric energy is between 2,000 and 4,000 kWh per year in a western community, and with careful planning, the usage rate doubles about every seven years. The equivalent amount of energy based on an ideal method required to distil enough water on a western type diet would be over 50,000 kWh per year or over 16,000 kWh for an eastern type diet. Whilst this may be possible some time in the future in some limited prosperous areas of the world, this is not realistically possible for the increasing 2-3 thousand million more people expected in the next 30 years.

At present there are about 400 million acres of land under irrigation, at the moment most of it under furrow irrigation. Records for the whole world are not easily obtained, but examples from some countries indicate the extent. India has gross irrigated area of 70 million acres and with Pakistan over 100 million acres can be credited to the Indian continent. China is rapidly expanding her irrigation but the author has no precise figures. The world

TABLE IV
INDIA
Cultivable Area. Cropped Area. Net and Gross Irrigated Area in the country. 1960-61
(In '000 Acres)

Sl. No.	*Name of State*	*Total geographical area*	*Total cropped area*	*Gross irrigated area*
1	Andra Pradesh	67,873	29,199	8,580
2	Assam (including N.E.—F.A.)	54,335	6,483	1,533
3	Bihar	43,007	27,446	5,095
4	Jammu and Kashmir	55,055	2,000	762
5	Kerala	9,603	5,804	1,268
6	Madhya Pradesh	109,575	44,959	2,319
7	Madras	32,085	18,089	7,995
8	Bombay	122,219	70,650	4,827
9	Mysore	47,482	26,163	2,413
10	Orissa	38,504	14,958	2,820
11	Punjab	30,133	24,048	9,600
12	Rajasthan	84,576	34,627	4,328
13	Uttar Pradesh	72,611	53,696	13,661
14	West Bengal	21,714	15,701	3,379
15	Delhi	366	280	84
16	Himachal Pradesh	6,962	1,060	166
17	Manipur	5,522	410	168
18	Tripura	2,583	615	29
19	Andaman and Nicobar Islands	2,058	23	
20	Laccadive	7	7	
	Total	806,270	376,218	69,027

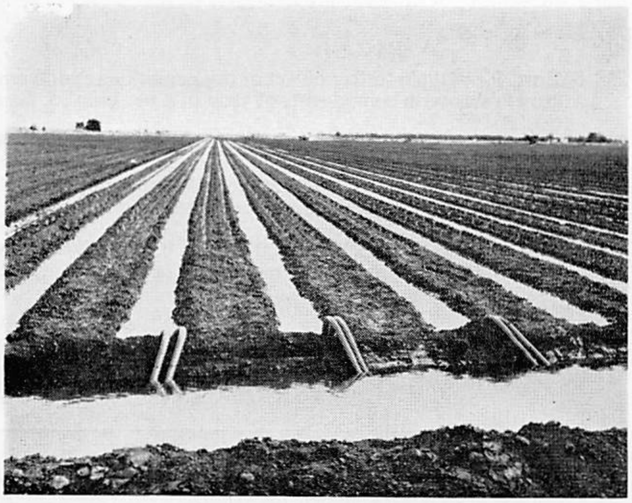

Fig 1

Fig 2

These two photographs demonstrate large scale furrow irrigation and give an indication of the resulting harvesting problems in a large horticultural holding

irrigated area supports at present about 400 million people and if fertilizers and increased technology were used then this irrigated area would support between 800 and 1,200 million people. It is thought that it would be feasible to double the existing acreage, but unfortunately, not in Pakistan, India and China, where the large populations exist. The Continent with the greatest potential is probably Africa, because the Congo and the Niger collect water at high altitudes and it would not be too difficult to take some of these waters to surrounding arid lands. There are many rivers in Africa that can be developed but the population density in Africa, a vast Continent, does not necessarily mean that it is essential to do so at present. Australia which is extremely dry, has developed 3 million acres of irrigation and has a potential of perhaps a further 7 million acres north of latitude 25°S. America has reached the full capacity of its readily available irrigated areas with some 20 million acres. Its acute water shortage can be exemplified by the consideration given by the North American Water and Power Alliance (N.A.W.A.P.A.). In this case water from Alaska and Canada is to be used in British Columbia, Saskatchewan, Ontaria, California, Arizona, New Mexico and Mexico. About 120 million acre feet are to be diverted over 1000 miles from its source at cost of $80 thousand million. This scheme at present is a talking point but its introduction appears inevitable. Its major role will probably be for city water supply which is only 1/30th of the water requirements for food.

As well as the role of irrigation in the arid areas the increase that can be brought about by supplementary irrigation in the areas where crops are grown under natural rainfall conditions is considerable as discussed by Winter and others at this Open Meeting. It is probable that increases in agricultural output can be quite as large from supplementary irrigation as the possible contribution from arid areas under irrigation. The increase of yield from supplementary irrigation will be at much less water usage and will involve sophisticated systems of the type so well exemplified by Mr Jack Wright.

He was most anxious to economize in water usage, and evolved carefully designed systems to meet this need. May his colleagues be continually inspired by his concepts.

OBITUARY

The Council records with deep regret the death of the following members:

Gill, K. R. *Member*

Longman, G. F. N. *Associate*

Purchas, F. B. *Associate*

Paper by E. J. Winter (continued from page 9)

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Paper by J. J. North (continued from page 27)

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ELECTIONS AND TRANSFERS

Approved by Council at its meeting on 12 January 1967

ADMISSIONS

Member	.. .. ..	Booth, R. F. C.	Surrey
	.. .. ..	O'Callaghan, J. R.	Newcastle-upon-Tyne
Associate Member	.. .. ..	Addison, W.	Durham
	Overseas ..	Gabriilides, S.	Greece
	Overseas ..	Hatzilacos, G. A.	Greece
	..	Parker, A.	Co. Durham
Companion	.. .. ..	Morgan, N. G.	Bristol
Associate	.. .. ..	Ackland, M. W.	Devon
	.. .. ..	Aubrey, F. J.	Cambridge
	.. .. ..	Baynham, J. G.	Gloucester
	.. .. ..	Carruthers, J...	Midlothian
	.. .. ..	Casley, H. R...	Herts
	.. .. ..	Dalton, J. W...	Suffolk
	.. .. ..	Emerton, B. J.	Middlesex
	.. .. ..	Goddard, G. W. J.	Suffolk
	.. .. ..	Hadfield, H. G.	Essex
	Overseas ..	Higgs, J. K. G.	Republic of S. Africa
	Overseas ..	Hill, P. R.	Republic of S. Africa
	.. .. ..	Hutchings, I. J.	Devon
	.. .. ..	Philip, A. W.	Aberdeenshire
	.. .. ..	Pritchard, J.	Devon
	.. .. ..	Russell, J. H...	Bristol
	Overseas ..	Sivalingham, P.	Ceylon
	.. .. ..	Smart, S. S.	Warwicks
	.. .. ..	Spencer, W. C.	Lancs
	.. .. ..	Thompson, J. T.	Warwicks
	.. .. ..	Wattis, F. J.	Warwicks
	.. .. ..	Weiss, E. A.	Notts
	.. .. ..	Young, B. T...	Lancs
Graduate	.. .. ..	Ashley-Smith, J. R.	Co. Durham
	.. .. ..	Balls, R. C.	Lincoln
	.. .. ..	Bartlett, D. I...	Cambridge
	.. .. ..	Barton, J. M.	London
	Overseas ..	Cullen, J. A.	Uganda
	Overseas ..	Graham, C. J.	Canada
	.. .. ..	Kuyembeh, N. G.	Newcastle-upon-Tyne
	.. .. ..	Reisner, J.	Essex
	.. .. ..	Shipman, J. G.	Devon
	.. .. ..	Thomas, E. P.	Radnorshire
	.. .. ..	Webb, P. A.	Herts

continued

ELECTIONS AND TRANSFERS (*continued*)

Approved by Council at its meeting on 12 *January* 1967

Student		Agar, R. S.	Oxon
		Anstee, P.	Essex
		Apeaning, J.	Newcastle-upon-Tyne
		Lee, G. D.	Co. Durham
		Mithani, K. A.	Beds
		Powell, R. M.	Beds
		Russell, P. J.	Beds
		Sanders, J. D.	Sussex
		Scott, D. G.	Beds
		Uma, I.	Beds

TRANSFERS

Member	*Overseas*	Christie, D.	West Cameroon
		Norman, R. F.	Cambridge
		Smith, G.	Derby
Associate Member		Ainsworth, N.	Derby
		Brook, R. H. F.	Cambs
		Cromarty, A. S.	Berks
		Frost, E. D.	Surrey
		Harrison, T. H. E.	Yorks
	Overseas	Hinton, D. P.	Rhodesia
	Overseas	John, I. P.	Guyana
		Low, J. P.	Cornwall
	Overseas	Sarker, K.	W. Germany
		Witney, B. D.	Newcastle-upon-Tyne
Graduate		Bebb, D. L.	Worcs
		Colwill, J.	Worcs
		Osmond, C. R.	Hants
		Quansah, S. S.	London
		Rushton, P. O.	Herts
		Sapsford, R. P.	Wilts
		Tullberg, J. N.	London

BRANCH HONORARY SECRETARIES

EAST ANGLIAN

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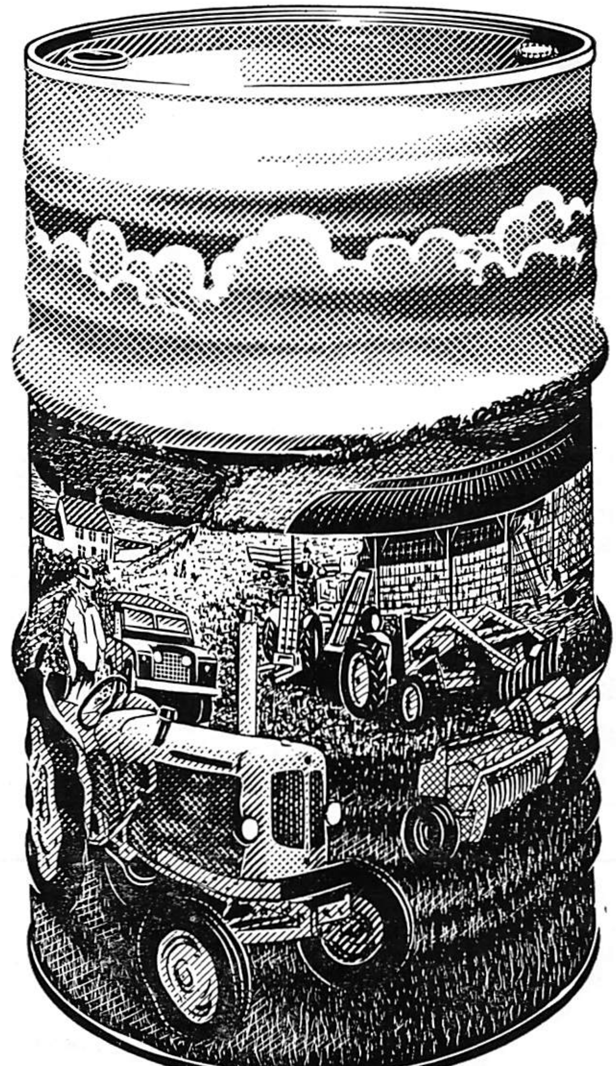

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