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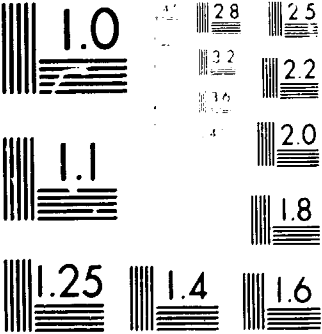
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IRRIGATION EQUIPMENT RELATED TO THE FOOD PRODUCTION SITUATION IN AFRICA*

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Abstract

To produce the required food and fibre in Africa requires that the average farmer has access to, and the skill and knowledge to use, what science and technology have produced. Irrigation (and drainage) practices have been well diagnosed as necessary engineering inputs lacking in African agricultural systems. Furthermore, appropriate equipment are required for a successful irrigation scheme. Africa is a continent of different geological, geophysical and climatic conditions; added to this is the fact that socio-economic and socio-political considerations will always dominate the degree to which technical and technological innovations are to be introduced into a country. What has been done in this study, therefore, is to view an irrigation scheme as consisting of five broad phases: collection and storage of water; land preparation; conveyance and distribution systems; drainage; and, operation and maintenance works. The various types of equipment and power units needed at the various stages have been described. As much as possible, the best conditions under which any piece of equipment should operate have also been presented.

INTRODUCTION

Irrigation and drainage practices are intended to make up deficiencies in natural moisture conditions of the soil and its inherent drainage properties. Because of this, the necessity and nature of these operations vary with the different geological, geophysical and climatic conditions in different parts of any country or continent. In Africa, it is less easy to relate the farming systems to any simple chosen statistic because of various natural and economic factors. In fact, the continent of Africa can boast of all the possible modalities and objectives of irrigation.

There are the arid areas where rainfall is scarce, and irrigation means life. Without artificial application of water there is no crop. A large proportion of the continent of Africa falls in the semi-arid climatic group. In these areas, irrigation is necessary as a regular supplement to insufficient rainfall or to make up for the maldistribution of rainfall during the crop season. In some parts of tropical Africa the rainfall is generally very high, but confined to three or four months in the year. Such areas need adequate drainage systems to get rid of the unwanted excess water which can be stored for growing a second crop in the dry season under irrigation. Even in those semi-humid areas of Africa, irrigation is needed as an insurance against the occasional failure of rain, and also as a means to increase the yield of crops requiring frequent applications of water than supplied by nature.

Irrigation is nothing new in Africa. Egypt built the world's oldest dam (more than 10 metres long and 12 metres high), about 5,000 years ago, to conserve water for both domestic and irrigation purposes. Basin irrigation, an improvement on wild-flooding, was introduced on the Nile about 3,300 BC, and has until very recently played an important role in Egyptian agriculture. Of course, in Egypt and the neighbouring African countries lying in the arid zones, irrigation has always been depended on for yearly crop production. Nevertheless, in recent years it has become evident that planned and controlled irrigation can have substantial beneficial effects on the yield and quality of a wide range of crops in areas where rainfed agriculture has always been practised. Financial advantages are not only obtained from having some produce to sell in seasons when lack of moisture has limited production and prices are high, but also it results from being able to plan ahead for marketing and processing because of better uniformity of yields and quality. With irrigation the planning of cropping areas to match factory programmes is much more easily achieved.

In most African countries where appreciable advances have been made in irrigation, the Government has always undertaken the construction and to some extent the operation of the irrigation projects. Because of the magnitude of the projects and the huge capital investment required, their realization could not be assumed as a private undertaking. Furthermore, because most African countries' water resources are public property, the governments are logically the only entity in a position to assume the responsibility for determining the most appropriate and beneficial use of waters. It is beyond the scope of this paper to describe in detail the various irrigation schemes and projects of various African countries; nevertheless, the efforts made by various governments (in terms of hectares put under irrigation) can be seen in Table 1. Many countries are still investing huge amounts of money in irrigation projects because of its potential to increase both food and fibre production.

Table 1

African Irrigation Statistics

Name of Country	Area Irrigated m. ha
Algeria	0.245
Botswana	0.002
Ethiopia	0.030
Ghana	0.007
Ivory Coast	0.009
Kenya	0.004
Libya	0.167
Malagasy	0.900
Malawi	0.002
Mali	-
Morocco	0.265
Nigeria	-
Zimbabwe	0.034
Senegal	0.120
Sierra Leone	0.0008
Somalia	0.165
South Africa	0.607
Sudan	0.790
Swaziland	0.028
Tanzania	0.004
Tunisia	0.076
Uganda	0.003
UAR	2.940
Zambia	0.600

Source: K.K. Framji and I.K. Mahajan, Irrigation and Drainage in the World, 1969, International Commission on Irrigation and Drainage, New Delhi; FAO, Production Yearbook 1968.

An area in irrigation development in which a large amount of capital expenditure is sunk is irrigation equipment, the main concern of this paper. Socio-economic and socio-political considerations will always dominate the degree to which technical and technological innovations will assist or replace manual or animal-assisted field inputs. The development of appropriate agricultural techniques in most developing countries is always greeted with two attitudes which have to be sorted out[1]. One group always fears that the mechanization of agriculture will increase the number of unemployed, whereas the other is in favour of mechanization, because it is suitable for increasing the field productivity. Unfortunately, both ways have led to a dead end in many countries when they have been strictly followed. They have either missed the target of increased agricultural productivity or they have failed to take account of the overall interests of the country by leading to excessive mechanization and over-investment. Experts now agree that only a careful selective mechanization adjusted to the existing social and economic conditions can be justified. While technical workability of machines and equipment is an important aspect of economic development, ultimately, the efficiency of an agricultural resource provides a rational basis for the emergence of an efficient indigenous modern agricultural technology, i.e., an appropriate technology. Therefore, simplistic approaches and "rules of thumb" for agricultural mechanization can be dismissed[2]. In the light of these reasons, the objective of this paper is to present and where possible to describe, as much as possible, the various types of machines and equipment used in irrigation. The appropriateness of each type of equipment for a particular type of work or size and type of land will also be given. It is hoped that the paper will serve as a guide in the selection of a particular type of equipment to suit one's own farming conditions.

IRRIGATION AS AN INPUT TO MODERN AGRICULTURE IN AFRICA

The importance of irrigation development as an input in modern agriculture is clearly evident in the development plans of different African countries. In fact, irrigation development in Africa is now taking place at a much faster rate than before. While this is a welcome development, it is all the more necessary that more attention should be paid than ever before towards the fundamental requirements for achieving and maintaining an efficient and permanent irrigated agriculture. Schultz rightly described modern agriculture in the following terms: "While waiting for the historian, one might look for a moment upon modern agriculture as a young lady of many talents and moods. She is obviously very influential politically, when courted by government her tastes are expensive, but she cannot be won by force, as is clear from experience. She is unabashed in giving her favours to the consumers of food yet heartless in her treatment of her own people - in the stresses and strains she imposes on many farm people. There are those who think of modern agriculture as fickle in her economic affairs, but they are wrong, for she is shrewdly calculating in these matters. Nor should we overlook her most important talent, that of dispelling the age-old anxiety concerning food"(3). When singled out, irrigation is one of the factors which make the tastes of modern agriculture very expensive. The engineering side of an irrigation scheme merits as much attention as its husbandry aspect, and both can be very expensive as well as rewarding (if properly managed). The proper choice and correct use of equipment have an important bearing on the profitability of the enterprise, besides ensuring that the crops benefit without detriment to the soil.

EQUIPMENT FOR IRRIGATION

In order to obtain a comprehensive knowledge of the various machinery and equipment needed for an irrigation system, it is more convenient to divide an irrigation system into the following phases:

1) Collection and Storage of Water
2) Land Preparation
3) Conveyance and Distribution Systems
4) Drainage
5) Operation and Maintenance of Irrigation and Drainage Works.

1) <u>Collection and Storage of Water</u>

Disregarding the oceans, water resources exhibits strongly differentiated regional and local patterns of availability. While the dynamics of water supply are highly dependent on the character of precipitation and evapotranspiration on the earth's surface, local and regional availability is profoundly altered by the configuration of the earth's surface, and by the differential storage capacity of the rock interstices in the earth's crusts. Where appropriate, therefore, man has always tried to develop various means of collecting water for irrigation and other needs. The main sources of water for irrigation are surface water which results mainly from runoff, and groundwater resulting from deep percolation.

Runoff water from streams and rivers is stored in reservoirs or is diverted directly through canal systems for irrigation. Runoff is also often stored in tanks or ponds and regulated for irrigation through suitable conveyance systems. Storage reservoirs vary in size, shape and according to the material used in constructing them. Farm ponds for irrigation vary from a few square metres to several hectares in surface area according the water requirements of the crops and other associated needs. Where sprinkler irrigation is applied on small farms, elevated tanks can be used to provide the needed pressure in the spray nozzles. These tanks could be made of steel or concrete depending upon the availability, cost and ease of construction of the material. Farm ponds can be lined or left unlined; they are also constructed either off-stream or onstream. Storage tanks and farm ponds are very suitable for single family farm holdings cultivating about ten to twenty hectares of land. Evaporation losses from farm reservoirs are so high in Africa that the capacities of these ponds are normally double what is needed to satisfy the consumptive use requirements. In places where the land tenure is such that a farmer is only entitled to one or two hectares of land, several farmers can either team up to construct a farm pond or the government can construct it for such a team. The construction of various types of dams to store water for irrigation, hydroelectric and domestic purposes is well known. Even though very expensive, dams are the best means of storing large amounts of water for irrigation. Dam construction has attained such a specialized level that no details of the equipment will be given in this paper. A good treatment of types of dams and their construction is given in (4). In Africa several dams have been built in various countries to cater for various needs. The Aswan High Dam, the Akosombo Dam and the Bakolori Dam are just a few dams in Africa serving irrigation among other needs.

On the whole, storage facilities are a very expensive part of any irrigation project because of the construction costs. Nevertheless, storage is very essential in those parts of Africa where heavy rains occur for three or four months resulting in excessive runoff which drains to waste. Water stored in those months of plenty and surplus will be profitably used for a second crop in the dry season, thus increasing the food and fibre production in Africa.

Groundwater is a potential source of water for irrigation in Africa. Already a lot of African countries depend upon this source of water for domestic water supply. Where adequate groundwater can be tapped on a land for irrigation purposes, the capital investment for the storage structures can be relatively cheaper compared to runoff storage. Irrigation wells are either open wells constructed in hard rock areas and unconsolidated formations or tube wells normally located in unconsolidated formations.

Open wells in unconsolidated formations are usually circular in shape, the diameter varying from 1.5 to 4.5 metres. These wells, in general, derive their water from unconfined aquifers. Their large diameters permit the storage of large quantities of water. There is, therefore, no need for constructing separate storage tanks. It is normal to line these wells with brick or stone laid in cement mortar or reinforced concrete construction. The lining is mainly to prevent cave-in of the walls of the wells. The design and construction of tube wells include a careful selection of the well diameter, well depth, the screens, gravel pack and well spacing. A well screen is a strainer, which separates the ground water from the granular material in whose pores it is contained. Careful selection of the screen is very important in tube well design and construction because it is a very expensive aspect of total cost of tube wells. Unlike open wells pumping is a necessary requirement to get the water out for use. A pumping house for the pumping equipment as well as a vertical conduit through which water flows upwards from the aquifer to the level where it enters the pumps have to be provided.

Open wells can easily be excavated using such hand tools as pick axe and shovels or power-driven shovels of various designs. After water is struck, hand excavated pits must be dewatered by pumping to enable further excavation. Dragline excavators using clamshell or orange-peel type buckets are also sometimes employed to dig open wells in semi-consolidated formations. The advantage of these excavators is that the buckets can excavate under water, unassisted as long as there is no cave-in. Depending upon the type of equipment used to sink a tube well, it may be classified as driven, jetted or drilled tube well. A thorough presentation and description of various types of equipment employed in well drilling can be obtained in (5), (6), (7).

Lifting of water in the form of pumping has already been mentioned in connection with tube wells. Where it is not necessary to construct a dam or farm pond, water can often be lifted directly from a stream or river and transported through appropriate conveyance systems to the farm. Even where water has been stored in a reservoir behind a dam, it is sometimes required to lift the required quantity of water to where it is wanted on a farm.

Until recent times, irrigation was based on simple devices for lifting water, and these devices have been in use for thousands of years in many parts of the world, of course, including Africa. Some of these are still in use today in Africa and many Asian countries. Most of these simple devices require human or animal power to operate them. They can irrigate only relatively small areas and only when the water in the river or well is sufficiently high to permit their use. Some of these devices are described below.

The Shadoof. This is one of the oldest of the simple water lifting devices. It usually consists of two upright poles joined by a cross-beam at a point about 3 metres above the ground. At right angles to the crossbeam is attached a long pole, at one end of which is hung a rope supporting a skin or bucket; and at the other end is a mass of clay or heavy weight to act as a counterbalance. The rope is pulled down manually and the bucket dipped into the stream or well. When the bucket is full of water, the rope is released, the counterbalance falls and the bucket rises. It is then pivoted round on the crossbeam and emptied into a canal or ditch from which the water runs into the field. The shadoof can irrigate an area of about 1 hectare.

The Persian Wheel. This is another old but commonly used device which can irrigate a land of between two and six hectares, depending upon the size of the wheel. It consists of a horizontal toothed wheel engaged to a smaller vertical wheel to which a series of buckets is attached. The capacity of buckets ranges from seven to fifteen litres. A beam is connected to the horizontal wheel and an ox, cow or camel is yoked to the outer end of the beam. The animal, sometimes blindfolded, walks in a circular path, thereby revolving the horizontal wheel which in turn revolves the vertical wheel. The buckets, hung over a well, dip into it and scoop up the water which they empty into a channel leading to the fields. The Persian whell lifts water up to a height of about 10 metres and can deliver around 16,000 litres of water p... hour.

The Archimedian Screw. This is another manually operated lifting device. It consists of a wooden cylinder between three to five metres long with a diameter of about half a metre. Along the whole of its length the cylinder is placed in the water and the top end rests on the bank of the stream. The crank handle is turned manually and water is cranked up the cylinder, issuing from the top into a channel leading to the fields. It can only lift water to a height of about 1 metre, but it can deliver as many as 19,000 litres of water per hour. It is more efficient than the shadoof.

Chain Pump. The chain pump consists of an endless chain with leather discs or washers attached to it at intervals of about 25cm. In some recent design leather washers reinforced by mild steel washers, are being used to make the discs. The chain passes over a notched wheel mounted on a suitable platform fixed on top of the well. On one side of the chain is a pipe of about 10cm diameter, having a flared opening at its bottom and connected to a trough at the top. The bottom of the pipe is submerged about 60 to 90cm below the surface of water. The discs have almost the same diameter as the pipe, and when the wheel is turned, each disc brings up a volume of water. Chain pumps are either animal operated or manually operated. They can give a lift of about three to six metres and can discharge water at the rate of 15,000 to 20,000 litres per hour.

Other manually or animal operated irrigation water lifting mechanisms are the Circular Two-bucket Lift which gives a lift or four to five metres and a discharge of about 13,000 litres per hour; the Rope and Bucket Lift with self-emptying Bucket which can raise water up to 6 metres and deliver water at a rate of about 12,500 litres per hour; the Counterpoise-bucket Lift with a maximum lift of four metres and a corresponding maximum discharge of 11,000 litres per hour; and the Rope-and-bucket Lift, the only simple device suitable for deep wells. It can raise water through a height of 10 to 30 metres and can give a maximum discharge of 10,000 litres per hour. These are well discussed in (5).

The natural power from wind and water have also been used, and are still in use in some countries to lift water for irrigation. The wind mill, the water-wheels (NORIA) and the hydraulic ram are examples.

Water-Wheels. These consist of great wooden wheels up to 20 metres in diameter, to which wooden buckets are fixed. Turned by the river or stream current, the wheels raise the water and discharge it into channels, which carry it to irrigate the fields. Bamboo can be used, as is done in Vietnam, to construct wheels of around 8 metres in diameter.

Hydraulic Ram. This is a mechanism used to raise a part of a large amount of water located at some height to a greater elevation. It is particularly suitable in hilly areas where there is considerable slope in rivers and streams which could be harnessed to operate the machine. In principle, it is an impulse pump. The impulse is developed at the expense of the kinetic energy of the moving column of water. In order to develop maximum impulse, the supply pipe should be as long as possible. Installation of the ram too close to the source of supply will reduce the impulse and consequently the delivery head. The main advantage of the hydraulic ram is that once installed it needs hardly any running cost. The machine can work continuously for twenty four hours and thus gives regular water supply.

Wind Mill. The wind mill uses the natural power from wind to lift water for various purposes, including irrigation. It consists of a large diameter rotor fixed on the top of a high steel or wooden tower and a reciprocating pump at its bottom. The upper end of the piston rod is fixed eccentrically to the rotor. The lower part of the suction pipe is always immersed in water in the well. When a strong wind blows, it rotates the rotor, which in turn works the pump and water is lifted up into a reservoir where it is stored to be used whenever required. The discharge rate from a windmill is not constant since it depends on wind velocity and frequency. Where winds of sufficient velocity and satisfactory frequency are assured, the operational cost of lifting water is almost eliminated. It has been found that a wind velocity of over 6.5 km per hour is necessary for the satisfactory operation of wind mills.

Moving from the above devices which are operated by human, animal water or wind power, we enter into the realm of those pumps which can be powered by human, animal or mechanical energy. These lifting devices are collectively called Reciprocating Pumps. These pumps are commonly used for lifting water from wells to be carried to the fields or stored in a reservoir. They are sometimes called piston or displacement pumps, and they function by means of a piston movement which displaces water in a cylinder. The flow is controlled by valves. The capacity of the reciprocating pump depends on the size of the cylinder chamber and the length and speed of the stroke. Reciprocating pumps are either shallow well or deep well reciprocating pumps.

Shallow well reciprocating pumps. These are used for pumping water out of shallow wells, making use of mainly atmospheric pressure to raise the water in the pump column. The piston when moved up and down by the movement of the handle displaces air from the pump column. This creates a vacuum which allows the force due to atmospheric pressure to push the water from the well into the pump column and from there to the outside. This pump can only lift water through a height of 6.5 to 7 metres. These pumps are normally operated manually even though they can be operated by animal power [8].

Deep well reciprocating pumps. These pumps can lift water to almost any height required in practice. They can be manually operated or mechanically driven by an engine or motor through a crank shaft arrangement called the working head, placed at the top of the well, to change the rotating motion of the power to that of the reciprocating motion at the piston. When manually operated, deep well pumps can only lift water up to 45 metres without any difficulty.

Variable Displacement Pumps. The commonest types of pumps encountered in irrigated agriculture all over the world are those that require either mechanical or electrical energy to operate them. These are technically known as Variable Displacement Pumps, and they vary from the pure radial flow centrifugal pump to the pure axial flow propeller pump. The unique characteristic of variable displacement pumps is the inverse relationship between the discharge rate and the pressure head. In general, they range from pumps with small discharges and high heads to large discharges with low heads. The specific speed, which expresses the relationship between speed, discharge and head, is often used as an index to the operating characteristics of these pumps. The higher the index the larger the discharge with a corresponding low lift. Similarly, the lower the index the higher the lift but with a low discharge. In the SI units, where the lift is expressed in metres, discharge in cubic meters per second, pure radial centrifugal pumps have a specific speed index of 10-42; mixed flow pumps of 40-170; and pure axial flow pumps of 150-315. Detailed discussion of these pumps can easily be found in many books on hydraulic engineering, e.g. (9) and (10).

The choice of the power unit to operate these variable head pumps will depend on several factors, including the initial capital cost, the running cost, the speed and power required, whether the pump will be portable or stationary, and whether it will pump for long or short periods.

If electric power is easily accessible, electric motors are almost certainly cheaper to operate than any other power source. They are very suitable for permanent installations with long hours of pumping. They are not suitable for portable pump units, nor for pumping for short intermittent periods.

Petrol engines have a low initial cost but high running costs. They have relatively shortlife, and high maintenance requirement. They operate equally well over a wide speed range. They are therefore most suitable for portable units, and for intermittent pumping for short periods, and as a stand-by unit for use when the main pumps are being overhauled. Petrol engines are most suitable for generating power up to 20 or 30 kW (30-40 HP), beyond which diesel engines are better.

Diesel engines have a higher initial cost but lower running cost. They are usually robust in construction and built for long trouble-free service in tough conditions. Large engines are available, but above about 75 kW it is advisable to have more than one smaller engine than a single very large one. The most economical operation is at constant speed, and usually at a lower speed than petrol engines.

From the above briefly discussed lifting devices, it can be seen that the need to pump water from lower level to a higher elevation has engaged man's creative ingenuity for a long time. The man operated shadoof to the very large and automatically regulated variable head pumps offer a wide range of choice for irrigation water pumping in Africa. With the cost of oil rising each year, it will not be wise at this time to write off the simple man and animal powered mechanisms as outmoded. Probably, this is the time for serious research to be done into finding how best to improve upon the efficiencies of these age-old methods.

2. Land Preparation

A very important phase in planning a system of irrigation is the preparation of the land. More important is this task if surface irrigation - the most predominant type of water application in Africa - is envisaged. The land surface has to be cleared and levelled to permit uniform distribution of the water and provide for drainage of excess surface water. Land preparation involves clearing of new ground or the redevelopment of a new form of land already in use, and moving soil from high spots and placing it in low spots, providing a more uniform plane to the surface of the land. The details required will vary according to the size and type of the scheme. Some methods of surface irrigation, such as wild flooding, corrugation and basin irrigation, require less elaborate land preparation, whereas others such as furrows or borders, require very careful preparation.

Equipment is needed to carry out the various tasks involved in land preparation: equipment for removing grass, trees and roots from the area to be irrigated; equipment for breaking up stratified soil profile conditions which may interfere with the growth of crops; equipment for making major cuts and fills; equipment for doing the final grading work to provide a smooth, uniform surface to the field; and equipment for constructing the levees, ridges or furrows needed for irrigation. There is no doubt that man's present ability to dig and fill with the help of sophisticated machinery is something to marvel at. Despite this advancement, earth movement, land levelling, and land clearing are still carried out in a variety of ways. Land clearing is still done by human labour with pick axes, cutlasses and hoes while earth is still moved by wheelbarrows, headpans or animal-drawn drags and scrapers, each having only a few cubic metres capacity a day. On the extreme end of the scale are the present day tractors with tree-felling attachments which can clear large areas within a few days; or the modern draglines built with buckets able to handle 10 to 20 cubic metres of material at a pass, and able to move up to 20,000 cubic metres of earth a day.

Land Clearing. Grasslands or savannahs and semi-desert lands require little or no clearing, hence the cost of clearing is much less. On the other hand clearing dense forest is expensive and laborious no matter what machinery and equipment is available. Buldozers are now used more than any other machines for clearing trees on large farms. The overturning action tears out or loosens a lot of the roots, especially shallow roots.

There are several special-purpose bulldozer blades for land clearing (Figure 1). The "stumper" has a small squat blade with teeth at the bottom for digging out tree stumps. The "cutter" has a high pusher at the top and a straight blade at the bottom for cutting the roots. The "Rome" blade gets rid of the tree but leaves the stump, and to do this it has a "stringer" which splits the tree stem and a sharp horizontal blade which shears off the stem at ground level. After felling and stumping the trees the next operation is to get out the roots. This is accomplished with a toothed dozer blade, or a root rake, which is similar but has a hollow framework so that soil is spilled through the blade and only the roots retained (Figure 2).

When the land being developed is treeless savannah it may be possible to use a "prairie-buster" or "digger" moulboard plough. These are large, tough ploughs with good clearance to avoid chocking with trash, and often have a "stump-jump" device which is a spring-loaded release to prevent damage when the plough hits an obstacle. Where rocks and stumps are common a disc-plough will be more appropriate; the 'Rome' plough can also be used.

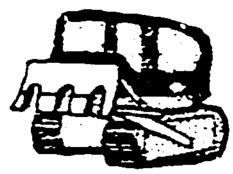

FIG. 1(a). STUMPER

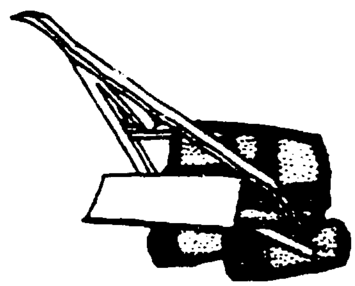

FIG. 1(b). TREE PUSHER AND CUTTER

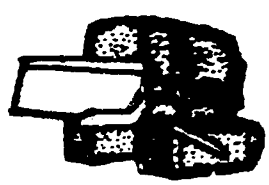

FIG. 1(c). TREE FELLER

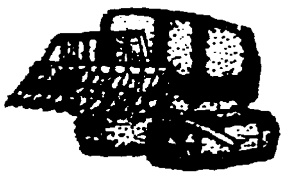

FIG. 2 ROOT RAKES

When machinery for land clearing is too expensive or not available, other methods must be used. Hand labour assisted by such devices as the petrol-engined saw, or clearing by hand but using tractors to haul off or stock pile for burning. Explosives can also be used for removing large stumps. Dynamite is the best explosive, and blasting is best done when the soil is wet. Blasting, however, calls for people properly trained in handling explosives. Chemical poisons such as arsenic poisons and hormone growth-regulators of the 2-4-D type may be appropriate in some case to get rid of unwanted growths; they must however be used with care.

Land Levelling for Irrigation

Land levelling for irrigation is different from other earth-moving operations. This is because the amount of soil to be moved is not large, but the levelling has to be more exact to achieve more uniform distribution of water on the field. There are different types of appliances, powered by different machinery, animal or human power, for land levelling and smoothing.

Bulldozers, consisting of crawler tractors equipped with different dozer blades, are commonly used in cutting and pushing earth to short distances. They give the cheapest cost per cubic metre for rough grading, especially for moving short distance up to 25 metres. Their efficiency decreases as the distance increases; for hauls of over 100 metres it is advisable to pick up and carry using a scraper. The longer the haul the more likely it is that wheels will be preferable to tracks.

Scrapers give more accurate levels than dozers, but still not enough accuracy for irrigation so the final smoothing needs a grader or land plane. There are a variety of scrapers in land levelling (or grading). They range in size from the terracer blade to heavy carrier-type scrapers. The carrier-type scraper is widely used for large scale land grading operations. The most accurate levelling is achieved by a land plane which is like a grader with a very long wheel base, and which planes soil off the high spots and deposits it in the low spots (Figure 3). A land plane should only be used for the final smoothing after the main movement of earth has been done by a dozer or scraper. Wheeled scrapers and leveller blades are frequently used for medium and small scale levelling jobs.

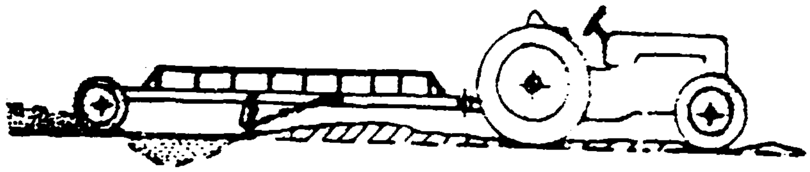

FIG. 3. LAND PLANE

For smaller fields and in places where animal power is cheap, the most efficient implement for land grading is the animal-drawn buck scraper (Figure 4). It may be used to move the soil lossened by ploughing or other tillage practices. It is most efficient when the haul distance does not exceed about 50 metres. Even though a simple device, the operator must follow certain exact procedures to make it work effectively. The wooden float (Figure 5) is used for land smoothing with bullock power. Large size floats are sometimes used with tractors. The principle of operation of the wooden float is similar to that of the carpenter's plane. It has three blades - the cutting blade in the front, the spreading blade in the centre and the covering blade at the back. As the float is pulled forward, the cutting blade cuts the high spots and pushes the soil into the low areas encountered ahead. The other two blades assist in obtaining a uniform field surface. For smoothening small fields for the basin method of irrigation, a wooden U-leveller is a handy implement (Figure 6).

Here again, it is only proper to conclude that there is a wide range or choice in the type of implements and methods to be used for land clearing, land levelling and land smoothening for irrigation. The choice of a particular method or equipment must be justified by the socio-political and socio-economic conditions of a particular location.

3. Conveyance, Distribution and Water Application System

The conveyance and distribution system of an irrigation set up consists of canals, pipelines or flumes used for conveying the water from its source to the high edge of the field where it can be released into the field either by surface irrigation or by sprinkler system. The structures needed for the control and measurement of the water are also considered to be part of the distribution system.

Open Ditches

The water can be conveyed either by a system of open ditches or by pipes. Sometimes these two systems can be combined. The open ditch system consists of the main canals which take water from the storage reservoir. Water is then diverted from the main canal into a system

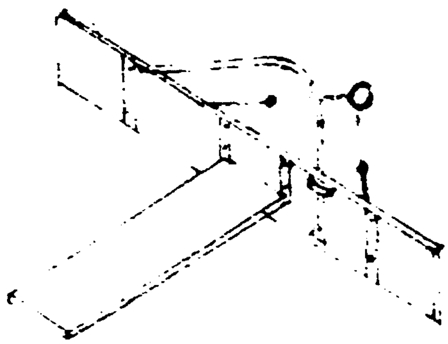

FIG. 4. ANIMAL-DRAWN BUCK SCRAPER

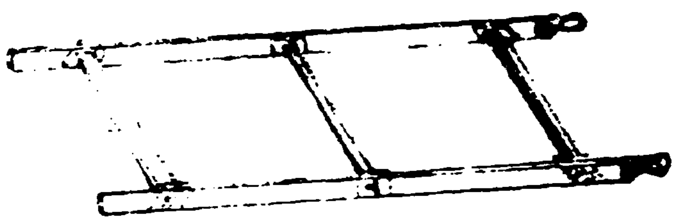

FIG. 5. WOODEN FLOAT

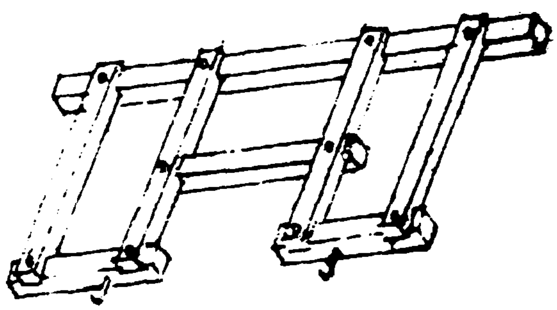

FIG. 6. WOODEN U-LEVELLER

of secondary and tertiary ditches which will distribute it throughout the farm. The most widely used of all distribution systems are the unlined earthen ditches because of their low cost and ease of construction. Unlined ditches for delivering water to basins or borders are frequently constructed with semipermanent levees so that they can be used for a number of years. Ditches serving furrows, basins or borders for irrigating annual crops are often dug at the beginning of the irrigation season and removed prior to harvest.

There are several methods by which unlined ditches can be constructed. Where farms are small and labour is plentiful, they can easily be dug by hand using hoes, shovels and pick axes. Simple animal-drawn tools (Figure 7) can be used in forming the ditches. To use the drag-type ditcher a furrow is first opened with a mouldboard plough. The ditcher is then used in the furrow to enlarge it into a channel. The operator can add weight by standing on the runner board. On large farms unlined ditches are usually constructed with tractor-drawn tools. Dragline excavators equipped with V-shaped cutter blades and tractor-mounted digger loaders are frequently employed for constructing large size irrigation and drainage canals. Though cheaper to construct, the maintenance cost for unlined ditches are high.

Sometimes it may become necessary to line the open ditches carrying and distributing irrigagion water. The reason for doing this may include: reducing seepage inorder to conserve water as well as prevent waterlogging, checking soil erosion, increasing the conveyance capacity of the channels, preventing aquatic growth and also discouraging the breeding of mosquitoes, snails and other parasites (because high water velocities are possible), and to cut down maintenance cost. The effectiveness of various types of canal linings is well discussed by Kraatz (11). Manual labour as well as machines can be used for lining. In places where prefabricated slabs or bricks, rock for forming rubble masonry lining are more suitable, manpower will be more appropriate, hence they are to be used where labour is plentiful and cheap. Machines are available for lining ditches of all sizes.

Elevated flumes or canalets made of precast concrete are also often used for delivering water from the main canal system to the fields under surface irrigation. Flumes are mostly either semicircular or elliptical, hence they have a very high water conveyance efficiency.

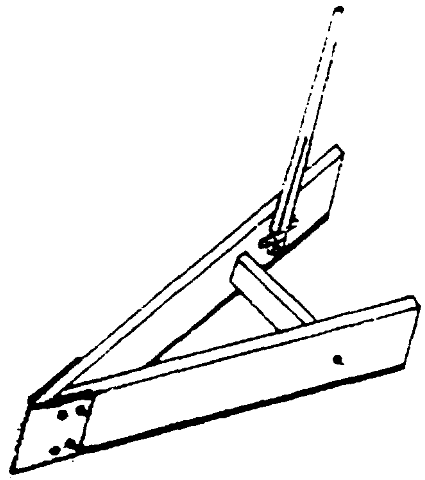

FIG. 7 (a). HOMEMADE DRAG-TYPE DITCHER

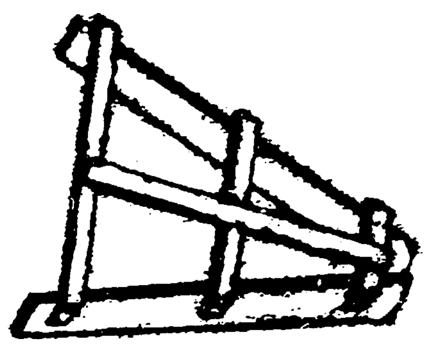

FIG. 7 (b). WOODEN A-FRAME RIDGER

The ends of the flume sections are supported on pedestals. Installation of flumes requires skilled workmen who can place the supports at the correct elevation to provide the required slope. Because they are designed to carry the required flow with a minimum allowance for freeboard, constant-level automatic gates are part of this system, so that accurate control of the water level in the flumes is maintained. Siphon outlets are normally used for taking water from the flumes to the fields. To dissipate the energy of the falling water the siphons drop into a stilling basin, which is a component of the siphon. The flume distribution system needs correct engineering design to realize its greatest potential value. The initial costs are quite high in comparison with those of other distribution systems. Where either wood or metal is available, flumes can easily be constructed with these materials. Flumes are very useful for carrying water across natural depressions, or for conveying water along very steep sidehills.

Tunnels are used as conveyance channels inorder to shorten the length of a diversion canal, to avoid difficult and expensive construction on steep, rocky hillsides, and to convey irrigation water through mountains from one catchment to another. Tunnel construction is such a specialised type of work that no further details will be given in this work on the equipment needed for their construction. Such jobs should normally be referred to consultants who have specialised in tunnel construction when they are encountered in irrigation schemes.

To ensure that irrigation water is used economically and efficiently, the irrigator must know the size of the stream he is using and the amount of water that he takes from it. Various structures have been designed for regulating and measuring flow; they help to provide control and also reduce the work involved in irrigating crops. The number and type of structures required will depend on the type of ditch, the slope, and the obstacles encountered in conveying the water to its destination. For open channel flow such structures as Canal Outlets, Overflow gates, Underflow gates, Division Boxes, checks, Drops, Siphons Outlets, and Constant Level Devices etc, are necessary for effective distribution and control of irrigation water. Measurement of irrigation water can be carried out by such devices as wiers, orfices, flumes, etc. Credit is given to Kraatz and Mahajan who have compiled and described in detail all the above structures in two volumes (12).

As a conclusion to these minor hydraulic structures, it would be proper to re-echoe the words of Kraatz and Mahajan in their introduction to (12). "Engineers have often neglected these "minor works, particularly those required at the farm level; to contractors they do not mean much profit and they are dispersed and difficult to supervise; and last but not least, authorities have sometimes appeared less willing to invest in tens of thousands of such small scattered works than in large works having greater prestige value. This results in many omissions of essential small structures, and failures or unnecessary deficiencies in some irrigation systems."

Pipeline Irrigation Distribution System. A very efficient way of conveying and distribution farm and irrigation water is by means of pipelines. This method has many advantages: it practically eliminates seepage and evaporation losses, it reduces maintenance work, makes water control relatively easier, eliminates weed problems in channels, and makes it possible for water to be carried either by gravity or under pressure. Such pipelines may be permanent installations or portable. The permanent installations are normally underground pipelines which operate under pressure. They are usually constructed with factory-made reinforced concrete pipes, vitrified clay pipes and asbestos cement pipes. Plastic or PVC pipes are also sometimes used. In case of small farms, where high pressures are not involved, they may be constructed of non-reinforced home-made or factory-made concrete pipes. The portable pipelines may be carrying above-ground main supplies, or acting as laterals to connect a permanent main to distribution points. These are usually available in aluminium alloy, thin-walled steel or plastic. Quick coupling devices are essential for joining lengths of the portable pipelines. These couplings may be self-sealing under pressure. They are made to latch and unlatch automatically, so that erecting or dismantling the equipment is quick and easy.

A great deal could be written about the laying of underground pipes, especially with reference to the equipment to do this in irrigation, but it is such a vast topic that it will suffice to make reference to books treating this problem in detail.[13] It should however be stressed that in laying of any pipelines great care must be taken because of the immense capital cost sunk in the pipelines.

Like the open ditches used to convey irrigation, specialised structures are used with underground pipeline systems to control and measure the water and protect the pipelines from damage. These include the inlet structures, water control and diversion structures, air release vents and end plugs (5). Devices for measuring irrigation water in pipes are well covered in (14).

Water Application Systems

No useful purpose is served in irrigation if the water is conveyed and distributed very efficiently but the mode of application is not the right one. It is therefore very important to choose the right type of irrigation water application method. In selecting this the various factors worth considering are the national requirements, local traditions and skills, the degree of mechanization on the field, the scale of the project, water factors, soil factors, crop factors, climatic factors, frequency or application, and last but not the least, the economic factors.

It is correct to assert that over 90% of the irrigation carried out in Africa is surface irrigation, and that this trend will continue for a very long time. By surface irrigation is meant applying the water to the crop-soil system and allowing the water to flow or impound on the field, thus infiltrating into the root zone. The equipment needed for this varies from virtually nothing in wild flooding to remote and automatic controls of one kind or another. Automation in irrigation is considered as another tool for doing work move efficiently, and it consists of a complex system of electronic and hydrologic devices which become substitutes for some of the workers such as the ditchtender, the gate tender or the irrigator. Anyway, for the present everyday purpose, at least in the continent of Africa, such devices as flexible rubber tubings used as siphons, special gates etc are used to deliver water directly to the fields. Levelling of the fields and the construction of furrow and borders has been discussed earlier. For corrugations, however, such simple devices as in (Figure 8) can be used.

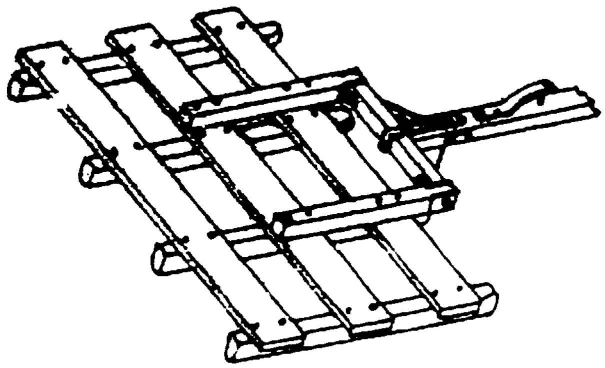

FIG. 8. WOODEN CORRUGATOR

Metal pipes are sometimes used in place of the wooden runners. These wooden corrugators can be easily drawn by animal power.

There are some situations in irrigation for which overhead or sprinkler methods of water application are the most appropriate. When this is encountered there is a choice among a variety of systems for use in water application. In all they all try to simulate rainfall.

The reaction rotation sprinkler is the kind most often used for lawns and in private gardens. The rotating head is driven round by the reaction of the jets at the end of two or four arms. The distribution is fairly even but it can only cover a small circle, hence only good for very small fields.

The fixed-head sprays are used for lawns and orchards. The advantages are that it is robust and has no moving parts. It can give fairly high intensities, but gives a poor distribution.

For the nozzle-lines, nozzles are fixed at intervals along a pipe which is oscillated through an arc of about 90-120° by a water-driven motor. The installation is often permanent. The advantage is its low application rates with small size drops, hence very suitable for nurseries. The capital cost is high, and a clean water supply is required to avoid blocking of the small nozzles.

Perforated pipes made of light weight aluminium piping with many small holes drilled in the top to form jets are often used for overhead irrigation. The water comes out at different angles on both sides and wets the surrounding area.

The slow-rotation sprinklers are by far the most commonly used and the most important class of sprinklers. Most of these sprinklers have either a single nozzle or double nozzle. The table below summarizes the types and their water application rates.

Table 2

Pressures and application rates of various types of slow-rotation sprinklers

Type	Purpose	Pressure kN/m^2	Application rate mm/h
Low pressure	When higher pressures not possible	70-200	3-25
Medium	General agricultural use	200-400	5-45
High pressure	Grass or forage crops	400-700	5-50

Based on portability, sprinkler systems are either portable semi-portable or permanent systems. The portable systems are either moved by human labour or by means of machines, some of which are automated. With the permanent systems, the labour cost is greatly reduced but because the mains, submains and laterals are usually fixed, the initial cost is very high.

Drip (or Trickle) irrigation and subsurface irrigation equipment need a brief mention. Even though these methods of water application of irrigation water are not common in Africa, they have a great potential in the near future in some parts of the continent. Drip irrigation in particular has the greatest water saving efficiency among all the other known methods of irrigation. In the arid regions where water is scarce or costly to secure, this system may become more appropriate economically when used for certain crops.

Subirrigation applies water beneath the ground rather than on the surface. The facilities needed to achieve this are lateral ditches (constructed as described in open ditch), mole drains tile drains or through porous drain pipes. Despite its several advantages this method is not common because lands suitable for this method of irrigation are rather limited and occur on very few farms, since it requires a special combination of natural conditions.

The term drip irrigation, as used today, is meant to cover all those irrigation techniques which conduct water and nutrients to the roots of the plant by means of special water outlets in, for the most part, permanent pipes. Drip irrigation is becoming increasingly popular in areas with water scarcity and salt problems. Various types of drippers with water discharge rates varying from 2-20 litres per hour have been developed to enable water to be discharged at the desired slow rates. A drip irrigation system consists essentially of a main line, submains, laterals, and emitters. The mains, submains and laterals are usually made of black PVC tubings. The emitters which distribute water for irrigation are also usually made of PVC material. PVC material is commonly used because of its resistance to saline water and chemical fertilizers. Other components of a drip irrigation equipment are a valve, pressure regulator, filters, pressure gauge, fertilizer application eqipment, etc. It also requires a pump to lift the water and produce the desired pressure and distribute the water through nozzles or emitters. Automatic devices have been incorporated into some of the recent designs for labour saving purposes.

It is most appropriate in places where labour and water are becoming increasingly expensive and in shorter supply every year and where products with a relatively high market value can be irrigated.

The history of commercial activities in developing countries shows how, on several occasions, new technologies have been unadvisedly imposed on some countries in which their application do not appear to be economically expedient. It would, therefore, be a good excercise if at this early stage of its development and application, a clear analysis is carried out to find out the economic limits for the use of drip irrigation. This will ensure that serious misdirection of capital investment in developing countries is avoided as much as possible.

4. Drainage of Irrigated Lands

The installation of a system of conveyance and distribution systems to get the water onto the land is only part of the story of a successful irrigation scheme. Of almost equal importance is the disposal of excess water from the land surface as well as within the crop root zone. Unwise application of water and inadequate planning frequently results in salinization and waterlogging. The destruction of several thousands of hectares of irrigated lands in China, the USSR, Egypt, India, the Western United States and the Euphrates due to inadequate or lack of drainage are well known. Reclaiming lands ruined through faulty or misused irrigation is almost as expensive as bringing new lands under irrigation for the first time. It is therefore necessary that adequate provision is included, during the initial stages of any irrigation scheme, to dispose of the unwanted excess water from the irrigated lands. This may be achieved in a number of ways: a grid of open ditches may be laid along the boundaries of the fields, or lines of subsurface drainage systems laid in the fields to collect the water and convey it to a collector ditch. The construction of open drain is similar to that of open conveyance and distribution systems; no further details will be given about the equipment since they are the same as already described.

Before the introduction of tiles farmers successfully drained their fields by means of such simple materials as poles, stones and open wooden boxes. Ditches of suitable dimensions were dug in which were placed three poles arranged in the shape of a triangle. The ditches were then filled. Such drains were given an outlet into an open collector ditch. Large flat stones were also arranged in the form of an open box in dug out ditches to conduct water underground to collector drains. In the absence of flat stones ordinary stones could be packed into the ditch to suitable depths. Despite their temporary nature, there are some good points in these methods to make them worthy of recommendation for use where these materials are in plentiful supply and the farmers are not in a position to invest in the more expensive but far more superior tiles. The digging, laying and backfilling can be done by man power. Unlike other soils, clay soils frequently do not exhibit a regular water table. The internal drainage of clay soils can be easily improved by mole drains. A mole drain is an unlined duct formed by pulling a torpedo, at a depth below the ground surface, by means of a mole plough. These ducts collect the water for ultimate disposal.

The use of tile for subsurface drainage is now more popular because of its efficiency. They are more durable when properly installed and, on the average, last much longer than the previous methods. While clay and concrete drain tile have been the principal drainage materials for many decades, research has resulted in many more drainage conduit-materials. Examples are: The Bitumenized fiber perforated pipe, rigid plastic perforated pipe, corrugated-wall metal conduit, and flexible-type conduits, details of which can be found in (15).

Excavation and laying of the tiles can be done in two ways - by the use of hand tools and with machines.

Digging with hand tools is the more common method because it is easily learned by inexperienced labourers. Special tools are however needed to get a good job done. These include special forms of spades called drain or tile spades, the ditch cleaner or scoop, the grade stick, and the tile hook. These are used for specific jobs (16).

Digging and laying of tile drains by machines is almost an automatic operation these days in the technologically advanced countries. There are several machines on the market for tile drain installation. The trenching machines of various designs have been developed with such devices as: tube feeding and guiding devices, grooving-devices for trench bottom, blinding attachments, machine-mounted automatic backfillers, and automatic grade-control systems.

Operation and Maintenance of Irrigation and Drainage Systems

Effective with the completion of the construction of irrigation and drainage system facilities, responsibility for their care, operation and maintenance changes hands from the construction team to the operation and maintenance personnel. At the time of this change-over, equipment and supplies initially necessary to perform the function should be available. Irrigation and drainage system operation is a continuous activity, hence the requisite equipment should also be available all the time.

Canals and reservoirs may have to be dredged from time to time, and this may be done by hand or by means of dredging machines, depending upon the size of the work. Aquatic plants, a nuisance in open ditches, may have to be cleared, and the mode of control may vary from human labour to the use of special chemicals. Subsurface drain pipes will sometimes become filled with sediment or get completely blocked by chemical deposits. The pipes will have to be cleaned in situ or dug out and cleaned or replaced by new ones. Farm machines will need repairs and servicing or complete replacement after some time.

Basic equipment should include vehicles for transportation of personnel, of materials and of appliances. Tractors equipped with blades and loading devices, berming machines for maintaining the side slopes of the canals or laterals, and weed control devices including those for the application of herbicides and for burning, are important items of equipment needed for maintenance of irrigation and drainage systems. Where it can be purchased, the mobile crane with attachments such as a shovel, backhole, dragline, etc is an efficient maintenance unit. The above equipment could be acquired for the project or rented for use by the maintenance personnel. The renting is quite suitable for small farms in order to reduce capital outlays. In some cases, the maintenance could be let out on contract.

In countries where labour is in ample supply and unemployment is a problem, as much use as possible should be made of manual labour in weed control and cleaning or dredging of the channels and canals.

From past experience in many developing countries, the records of the operation and maintenance of many engineering projects such as roads, factories, etc, leave much to be desired. The ability to maintain the various equipment should therefore be a major deciding factor in selecting the type of equipment, not only for maintenance, but for the other activities already mentioned earlier.

CONCLUSIONS AND RECOMMENDATIONS

Like many technical disciplines, the principles of irrigation (and drainage) are the same everywhere; the practice may, however, differ from place to place. In dealing with irrigation equipment, the practice of irrigation is essentially what is being discussed. In a continent of diversity such as Africa, it is practically impossible to be specific about the type of equipment most suitable for a particular country. What has been done, therefore, is to present briefly an outline of the various engineering phases of irrigation system development and to discuss the various types of equipment currently used to achieve those ends. An irrigation system should properly perform the following functions, i) store water so that it is available in sufficient quantities whenever required, ii) deliver water to all parts of the cultivated area, in amounts needed, iii) provide complete control of water, iv) measure the amount of water at various parts of the irrigation system, v) dispose of unwanted excess water from the field, vi) allow even distribution of water into the soil of each field, etc. These various requirements have been examined under the five broad topics - from storage to operation and maintenance. The various types of equipment and power units needed at the various stages have been presented. As much as possible the best conditions under which any equipment should operate has also been presented.

It is clear that some of the systems and equipment call for both capital investment to cover the high cost of installation and a considerable degree of technical expertise to derive the best use out of them. On the other hand, some of the equipment are the already well known ones which have been in use for several hundreds of years, and require little capital investment.

About 90% of the food production in most African countries is carried out by the peasant farmers who form about 70-80% of the working population of Africa. This clearly shows that the development of any irrigation equipment for food production in Africa should be designed with the peasant farmer in mind. Research is recommended into simple irrigation equipment for rural farmers. Undoubtedly, the most important factor in the determination of the type of equipment is the fact that many of the farmers all over the continent are without funds to invest in most of the modern and sophisticated equipment. To such a man in this position, it is immaterial how easy or comfortable may be the use of an equipment which he cannot acquire. He has to use a method which comes within his means. In the same way, the man who has only a few acres of land to cultivate in a grass savannah region does not need to invest heavily in equipment.

There are, however, many localities where the amount of work would not justify the purchase of some type of equipment even though such equipment are needed for a particular job. Such equipment and power can be rented for a nominal sum.

Where large and difficult areas are to be developed for irrigation, the use of some of the sophisticated equipment for the various phases of construction and maintenance may be justified. The choice of the type of equipment and irrigation methods to use cannot be made on the basis of a simple criterion; it can only emerge from an economic analysis.

It is undoubtedly clear that the man who is bound by traditional agriculture cannot produce much food no matter how rich the land. To produce substantially more requires that the farmer has access to, and the skill and knowledge to use, what science knows. To modernize also requires the acceptance and adoption by farmers of any agricultural input; it cannot be too strongly and too often stressed that ill-conceived, hasty, inefficient, unnecessary and therefore costly equipment of all types would be akin in their disastrous effects to the curses of doing nothing about the present state of traditional farming.

It must be remembered that "mother Africa is a grand old lady: we may guide her, persuade her - and even seduce her, but we cannot drive her. We must learn to know more of her home life and economy, her ecology." (17)

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