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Selection of Appropriate Irrigation Methods for Semi-Arid Regions

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INTRODUCTION

In semi-arid regions, water is a valuable commodity for irrigated agriculture. Irrigated lands in these regions are fertile and relatively abundant, but they require more water than what is available. Today semi-arid regions face more difficult problems than ever before. The deserts are encroaching upon the cultivated lands. Demand for water for various reasons is increasing and total demand has reached nearly 7 000 m^3 per person annually. Fortunately, there are many possibilities for increasing the supply of land and reducing demand for water in semi-arid regions. The greatest potential is in increased water-use efficiency. This can be done through improving existing water systems and adopting suitable irrigation methods. However, water practices developed for temperate regions may not work as well in the semi-arid regions. Irrigation methods developed in regions of relatively high rainfall and abundant water supplies are not suitable for semi-arid regions for technological, economic and cultural reasons. This study is aimed at evaluating the conditions and factors affecting the selection of irrigation methods for semi-arid regions with special reference to the countries of the Middle East and North Africa. Local cases from Syria are also discussed.

SEMI-ARID ENVIRONMENTAL CONDITIONS RELATED TO IRRIGATION

The climate of the semi-arid zone, a transitional belt between the desert and the humid zone beyond, is of the steppe type. Agriculturally, semi-arid zones are characterized by dry-farming (rainfed) agriculture, which often needs supplementary irrigation to produce good crops. The environmental factors that influence the selection of irrigation methods in the semi-arid regions of the Middle East and North Africa ("the region") are discussed below.

Water Supplies

Precipitation, ground water and water carried into the region make up the available water resources. Annual rainfall ranges from less than 25 mm in most of Saudi Arabia, Egypt, Libya and Algeria to over 1 000 mm in some mountain areas. But the comparatively high rainfall areas are of very limited importance compared to the great desert areas. For the ECWA region as a whole, annual precipitation does not average more than 100 mm, which amounts to a total of about 500 billion m^3 of water. In the areas of rainfed agriculture, this water does not permit an economic output unless management is improved. There is about 200 billion m^3 of measurable average annual water supply in rivers, streams, springs and sustained ground water yield in this region. Over 80 per cent of the region's annual supply originates outside the region and has often created political problems. Usable supplies of ground water are found in areas bordering the Mediterranean and in the northern part of the Syrian Arab Republic. Large volumes of ground water are known or are suspected under the Nubian sandstones of the Western desert in Egypt and in the vast stretches of desert in the Arabian Peninsula. But,the feasibility of sustained agricultural production in these areas has not yet been clearly established. Moreover, the ground water may not be suitable for irrigation purposes.

Soils

In general, the soils of the region are shallow. Rarely, they are more than one metre deep, most of them being less than 60 cm. These soils are too shallow to carry over moisture from one crop year to another under a dry-farming system. Also, they cannot store enough moisture during the winter to allow maturing a good crop in summer. Water has to be applied frequently when irrigating these soils. Some of the soils, especially in the Syrian Arab Republic and Iraq, have a high gypsum and calcium carbonate content. The presence of soluble gypsum and the unequal penetration of water cause uneven surface topography. Another limiting factor is the high irrigation rate of the sandy soils which have low water holding capacities. The properties of the region's soils make it necessary to use modern irrigation systems such as sprinkler and drip irrigation to achieve sustained agricultural production. Some of the soils need too frequent irrigation, which makes sprinkler irrigation uneconomical.

Labour and Machinery

Until recently, there was a surplus of farm labour in the region. Now, migration from rural areas is taking place at an accelerated pace, due to better employment opportunities provided by the non-agricultural sector. The population density on arable lands is low in Iraq and the Syrian Arab Republic and high in Egypt and Lebanon. Jordan take an intermediate position. Large-scale land reclamation projects in the region have created new employment opportunities. Labour shortage in agriculture is likely to occur in future due to the reclamation of additional lands. Countries that are primarily agricultural at this stage will be industrialized, thus creating rural labour shortage. Moreover, in the future farmer's sons will be better educated and will demand better living and working conditions, which in turn will make labour scarce and costly. Therefore, irrigation projects in future should provide for progressive farm mechanization. This may include the use of sophisticated modern irrigation equipment. But, in remote underdeveloped areas reliance on such equipment may be hazardous. A minor breakdown can stop operations. Under such conditions, the irrigation equipment should be simple and, if possible, fitted with local standardized components.

Climate

Most countries in the region are arid with certain areas having a Mediterranean-type climate. Relatively high temperatures, variable but infrequent precipitation, high levels of sunshine and hot dry winds in spring and summer characterize the region's climate. These climatic features result in high evaporation levels. High evaporation results in salt accumulation in the irrigated soils. Therefore, additional water for leaching the accumulated salts should be provided and splashing the high salt surface particles should be minimized. These conditions influence the selection of the methods of irrigation, especially sprinkler systems.

METHODS OF IRRIGATION PRACTICED IN SEMI-ARID REGIONS

Methods of irrigation vary with differences in water supply, soil, climate and culture. They also differ with farms, even within the same community, because of differences in local conditions such as crops grown, topography and water quality. As a result of generations of improvements and modifications, irrigation methods now range from primitive wild flooding to the sophisticated sprinklers and drips. Irrigation methods can be grouped into four categories: (a) surface, (b) subsurface, (c) sprinkling and (d) trickle or drip. Different irrigation methods along with their common modifications are outlined in Table 1.

Almost all of the methods in Table 1 are used in semi-arid regions of the world. However, many of these methods are not suited to semi-arid conditions and are now passing through a series of modifications. Furrow methods are modified by introducing gated pipes, siphons and tailwater reuse systems. These modifications can increase the water application efficiency of the furrow methods by 50 per cent in many places. Several types of sprinkler systems adapted to local conditions can increase efficiency up to 70 or 75 per cent and reduce labour required for the operation. When water is expensive or limited, as is the case in most of the semi-arid areas, trickle irrigation is a good alternative. Water application efficiency of this method can reach up to 90 per cent. Some irrigation methods that are commonly practiced in the semi-arid region of the western United States and which have been modified to suit local conditions of the Arab countries are discussed below.

Border Ditch Using Water Buggies

Water is brought to the field in permanent supply ditches and distributed from ditches across the field. This method is well suited to the lands that have irregular surfaces. Water buggies are introduced to reduce high labour costs. The water buggy is an automated moving tractor which pulls a plastic rug behind. This plastic rug causes water to rise at the end of the ditch to a higher level than the adjusted field. Figure 1 illustrates how the water flows to the field while the tractor is moving.

Concrete-lined Ditches Using Siphons

Siphons are used to reduce labour requirements of the conventional furrow irrigation method. Siphons are a series of outlets, having the same hydraulic characteristics and operated with the same head of water. They deliver the same flow. Figure 2

TABLE 1 Classification of Different Methods of Irrigation

Surface		Subsurface
A. Flooding "uncontrolled" 1. Ponding or basin a) contour b) rectangular 2. Flowing water a) free flooding b) border or strip check	B. Furrow "controlled" 1. Conventional 2. Modified a) corrugation b) zig-zag c) check-back d) cluster e) basin f) broad	A. Ditch system 1. Field 2. Spud B. Ditch and mole C. Underground conduit D. Uncontrolled

Sprinkler		Trickle
A. Stationary 1. Hand moved 2. Mechanical a) side-roll b) end-tow i-drag type ii-pull type c) side-move d) boom e) solid-set	B. Continuously moving 1. Circular centre-pivot 2. Straight moving lateral 3. Travelers	A. Hand operated B. Automatic 1. Partial automation 2. Sequential operation 3. Fully automatic operation

shows small diameter siphons used for delivering water from a concrete-lined ditch to irrigated corn plants. Lining the ditch reduces the loss of water and helps easy installation and removal of the siphons. In areas where water is in short supply, farmers irrigate row-crops by placing siphons in alternate furrows. By using this practice, corn and cotton farmers can save considerable amounts of water without noticeable reduction in yields.

Furrow Irrigation with Gate Pipe

Figure 3 shows gated pipe delivering water in adjustable quantities to the alfalfa crop grown on corrugated fields. These pipelines replace field ditches and convey water across uneven terrain. They also eliminate ditch losses of water.

Subirrigation Ditch System

There are a few areas of the semi-arid region where subirrigation methods are practiced. In general, they are used in areas where natural physiographic conditions favour this method. Figure 4 shows the water table formed by subirrigation ditch system irrigating a potato field in San Luis, Colorado. Here, slopes are flat and the topsoil is permeable underlain by an impervious layer. The water table is fed by open ditches. Since the texture of the topsoil is light, the capillary movement upward is low and, therefore, less salts accumulate on the surface. It is much easier to adjust the water table in sandy soils because of their high permeability.

Side-roll Wheel System

Figure 5 shows a side-roll wheel sprinkler in operation in summer wheat in the Navajo reclamation project in northern New Mexico. This design was the first mechanized sprinkler laterals to be placed on the market. To reduce labour requirements several power-driven units can be used to move the laterals. One gasoline motor can be used for moving several laterals of this type. This system is suitable for irrigation of short to moderate height crops.

Traveler System

For larger volumes of irrigation water, the traveler sprinkler is a better system. It can be used on level, rolling and irregular topography. It has an advantage over the side-roll system in fields having obstacles such as trees, buildings and poles. Figure 5 shows a traveler sprinkler moved by an auxiliary engine stationed at the end of the field.

Although this irrigation system requires high working pressure (about 9 atm.), its labour requirement is very low. The main limitations of this system are (a) its high delivery rate which limits its use to heavy textured soils and (b) large water droplets that cause breaking of soil aggregates and splashing of soil particles. Therefore, it is not advisable to use this system on salty soils or soils of low permeability. Another limitation is its low resistance to wind speed more than 10 km per hour. This reduces the uniformity of water application.

Central Pivot System

The central pivot system consists of a single sprinkler lateral with one end anchored to a fixed pivot structure and the other moving in a circle about the pivot. Use of this type has grown rapidly in recent years, primarily because of low labour requirements. Figure 7 shows a centre pivot system irrigating a corn field in the Navajo Irrigation Project at Farmington in New Mexico. This type is capable of irrigating tall plants and operating for long periods of time with minimum attention. Also, it does not require land levelling and can move satisfactorily on rolling lands.

The main problems for this system are (a) that high wind speeds (above 25 km/hr.) cause distortion of the applied water and (b) a relatively high rate of water discharge is required, which is not desirable for heavy clay soils having low infiltration rate. Under these conditions, the system causes uneven irrigation and excessive soil erosion.

A modification of this sytem incorporates adjustable nozzles capable of being moved in all directions, as seen from Figure 8. The height of the nozzles can be adjusted to the height of the crop and the distance between them can be changed according to the age and density of the crop. This modification introduces better wind tolerance (up to 45 km/hr.), uniformity in water application and less evaporation losses. The modified type is not affected by ice accumulation under freezing temperatures and it does not require as much operating pressure as the ordinary type.

Trickle or Drip System

Trickle irrigation is replacing surface methods in some areas, mainly in arid and semi-arid regions. But, trained irrigation labour is not available or is very expensive. The system is more suitable for soils that are shallow or are highly permeable. It is especially used on soils having steep slopes or where winds are prevalent. Its potential benefits lie in high water use efficiencies of up to 90 per cent. It provides greater control over the placement and amount of water applied. All these features of the trickle system make it the ultimate choice for arid and semi-arid areas. The use of the system is spreading rapidly, but the total area under the system in the world is still insignificant compared with other methods. The development of inexpensive and flexible plastic pipes that are easy to perforate and connect is the main problem hindering wider use of the trickle system. Another problem is the clogging of the emitters when water containing precipitable salts is used. Furthermore, the design of the trickle system has to adjust to specific crop and soil environments. Unlike other irrigation systems, it is not capable of delivering large amounts of water quickly in case the soil becomes too dry due to some sudden change in the environment.

Plant response to trickle irrigation appears to be somewhat superior than to other irrigation methods. Figure 9 shows a citrus tree being irrigated by trickle in the Phoenix area of Arizona. Trickle irrigation can be used on many other crops. Orchards, vegetables and even some field crops can be trickle irrigated. Figure 10 shows a field experiment at Riverside, California, to study the response of alfalfa, a high water requirement crop, to trickle irrigation. This system is not, however, used for field crops because of its high cost. But in certain areas, owing to the advantages listed above, it may turn out to be the best choice.

CHOICE OF IRRIGATION METHOD

Every irrigation method has advantages and disadvantages and has a definite place in the irrigation system. The best irrigation method is the one that is suited to local conditions. The basic requirements are efficiency and adequacy. Irrigation methods should be flexible to apply varying depths of water (usually from 6 to 26 cm per irrigation) to meet the needs of different crops or of the same crop at different stages of growth. Wrong selection of an irrigation method or poor design of the system would affect water-use efficiency adversely. In order to demonstrate proper selection of irrigation systems, two areas in the Syrian Arab Republic are evaluated below.

Kameshli area

Water supply: Ground water from five wells having low discharge rates is the only source. The best well has a discharge rate of no more than 50 m^3/hr. The water quality is good.

Soils: Heavy clay, deeper than one metre, level with a slope of less than 1 per cent and very low infiltration rate (less than 1 cm/hr.).

Climate: Dry hot summer, wet and relatively cool winter, average annual rainfall 480 mm, maximum precipitation of 105 mm in January and nil in August, yearly potential evapotranspiration estimated at 1 700 mm, and average wind speeds are low to moderate.

Crops: Forage crops (mainly maize) must be planted, consumptive use of maize reaches 10 mm/day in July, another forage crop is alfalfa which has a consumptive use range from less than 1 mm/day in January to about 9 mm/day in July and August.

Labour: Available, but not trained in irrigated agriculture.

Irrigation method: The low infiltration rate of heavy clay soil prevents the use of sprinkler irrigation in this area. The nearly-level terrain and availability of labour favours the selection of long furrow method (up to 500 m long). And, in order to increase water efficiency, gated pipes and tailwater systems are suggested.

Jourine area (El-Ghab Irrigation Project)

Water supply: Good quality water delivered from a main irrigation canal, a few springs also flowing in the area and estimated water availability about 0.45 litre/sec./hectare.

Soils: Mostly structureless, highly calcic, black to dark grey, loam to silt (high in sand fraction), 20 to 30 cm marly layer deeper than 100 cm, non saline (E.C. 4 mmohs/cm), organic matter up to 10 per cent and very high infiltration rate (greater and 15 cm/hr.). There are some surface and subsoil drainage problems also.

Climate: The average annual rainfall about 1 000 mm, more than half of it falls in December, January and February, dry summer months, high wind speeds, especially during spring and summer, average wind speed 85 km/hr. with a maximum of 160 km/hr. reached during the irrigation season (April-July).

Crops: Forage crops (mainly alfalfa and corn) necessary for cattle at the established governmental stations, maximum water consumptive use of alfalfa about 350 mm per month during June, July and August.

Labour and machinery: Labour in this area is scarce and costly, full mechanization a necessity.

Irrigation method: The high infiltration rate of soils, the labour shortage in the area, the limited availability of irrigation water and the relative high water requirements of crops dictate the choice of a pivot sprinkler, throught to be best suited to the local conditions. The main disadvantage of this sytem is the distortion of the water distribution patterns during high wind speeds. Data on the adaptability of this system showed that excessive water was lost by wind drifting and was distributed poorly. This sytem was modified by pushing nozzles downward and making them movable. Although the modification improved the uniformity of the water application and reduced evaporation losses, it still did not meet the required improvements. The local conditions of the Jourine area are so severe that no irrigation method would be entirely satisfactory. Unique irrigation methods for this area will have to be developed through intensive research at the local level, particularly trickle irrigation methods for forage crops.

SUMMARY

The best way to increase water supply and to reduce water demand in semi-arid regions is to increase water-use efficiency. This can be done through improving existing water systems and introducing appropriate irrigation methods. Furrow methods can be modified by introducing gated pipes, siphons and tailwater reuse systems. These modifications can increase water-use efficiency by furrow methods up to 50 per cent in the semi-arid regions. Several types of sprinkler systems can be adapted to local conditions. They increase efficiency by 70 to 75 per cent and minimize labour requirements. When water is expensive and very limited, as in the case of most semi-arid areas, trickle irrigation is a good alternative. Its water application efficiency could reach as high as 90 per cent.

Each irrigation method has advantages and disadvantages and has a definite place in an irrigation system. The best irrigation method is the one that is best

suited to the local conditions. The procedure of choosing the best irrigation method for some local cases in the Syrian Arab Republic demonstrates that socio-economic features of the irrigated areas should play an important role in the selection. Improper selection or a poor design of the system may render efficient irrigation impossible.

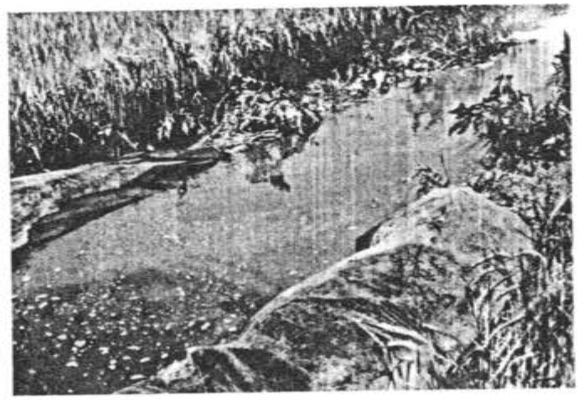

Figure 1 Border ditch using water buggy device to irrigate summer barley. The water buggy is an automatic moving tractor pulling a plastic rug which raises the water level in the ditch behind the tractor and allows the water to flow to the field while the tractor is moving, (San Luis, Colorado).

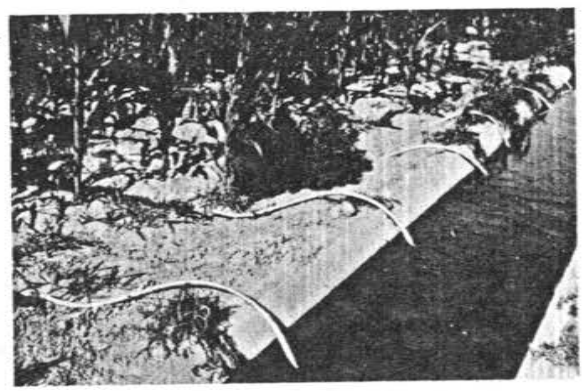

Figure 2 Small diameter aluminum siphon tubes used in furrow irrigation of corn. By irrigating alternate furrows, water is saved without considerable losses in yield, (McCook, Nebraska).