Supplemental Irrigation

A Highly Efficient Water-Use Practice

Theib Oweis



International Center for Agricultural Research in the Dry Areas

About ICARDA

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is governed by an independent Board of Trustees. Based at Aleppo, Syria, it is one of the 16 centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is an international group of representatives of donor agencies, eminent agricultural scientists, and institutional administrators from developed and developing countries who guide and support its work.

The mission of the CGIAR is to promote sustainable agriculture to alleviate poverty and hunger and achieve food security in developing countries. The CGIAR conducts strategic and applied research, with its products being international public goods, and focuses its research agenda on problem-solving through interdisciplinary programs implemented by one or more of its international centers, in collaboration with a full range of partners. Such programs concentrate on increasing productivity, protecting the environment, saving biodiversity, improving policies, and contributing to strengthening agricultural research in developing countries.

In the context of the challenges posed by the physical, social and economic environments of the dry areas, ICARDA's mission is to improve the welfare of people in the dry areas of the developing world by increasing the production and nutritional quality of food, while preserving and enhancing the resource base. ICARDA meets this challenge through research, training, and dissemination of information in partnership with the national agricultural research and development systems.

ICARDA serves the entire developing world for the improvement of lentil, barley and faba bean; all dry-area developing countries for the improvement of onfarm water-use efficiency, rangeland and small-ruminant production; and the West Asia and North Africa region for the improvement of bread and durum wheats, chickpea, and farming systems. ICARDA's research provides global benefits of poverty alleviation through productivity improvements integrated with sustainable natural-resource management practices.

Much of ICARDA's research is carried out on a 948-hectare farm at its head-quarters at Tel Hadya, about 35 km southwest of Aleppo. ICARDA also manages other sites in Syria and Lebanon, where it tests material under a variety of agroecological conditions. However, the full scope of ICARDA's activities can be appreciated only when account is taken of the cooperative research carried out with many countries in West Asia and North Africa and elsewhere in the world.

The results of research are transferred through ICARDA's cooperation with national and regional research institutions, with universities and ministries of agriculture, and through the technical assistance and training that the Center provides. A range of training programs is offered extending from residential courses for groups to advanced research opportunities for individuals. These efforts are supported by seminars, publications, and specialized information services.

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By

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Water Resources Conservation and Management ICARDA's Medium-Term Plan 1998 - 2000

"ICARDA's research for the management of natural resources aims to promote their efficient, integrated and sustainable utilization for improved productivity and poverty alleviation. By definition, water is the central issue in ICARDA's dry-area mandate and is accorded highest priority; but land and the nature and utilization of its two major facets, soil and vegetation, are closely linked to water.

ICARDA will respond to the urgent need for higher productivity using less available water in the dry areas by substantially increasing its research on improved and sustainable water-use efficiency at the farm level. In rain-fed areas with continuous cropping, the Center will strengthen research on the optimal use of supplemental irrigation and the sustainability of groundwater aquifers. Expanding research to new potential areas and developing models and other generic tools will build on the current information base. In drier environments, where direct rainfall does not support agricultural production, efforts will increase to improve and promote rainfall management using appropriate techniques of water harvesting into viable and sustainable agricultural systems. Research in irrigated areas will develop management practices that ensure higher productivity and water-use efficiency in a sustainable manner, focusing on the farm level. Responding to great demands in areas of extreme water scarcity in the dry areas new attention will be given to the safe and efficient use of nonconventional water resources for agriculture including saline water and treated sewage effluent."

The Water Management Program includes activities in the following areas:

- Water harvesting including analysis of indigenous systems, catchment potential, micro- and macro-harvesting techniques, and technology transfer.
- 2. Supplemental irrigation management including scheduling, modeling, evaluation, optimization, and dissemination of technologies; and sustainable management of shallow aquifers used for supplemental irrigation.
- Management of low-quality water including brackish and treated sewage effluent for safe and improved utilization capacity.
- 4. Improving water-use efficiency in irrigated areas through improving onfarm management alternatives of water and other farm inputs.
- 5. Capacity building of national programs in water management.

Introduction

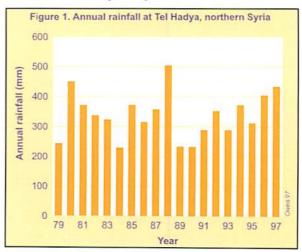
In the dry areas, water resources are limited and the share available to agriculture is decreasing at a time when more food is needed. Rainfall is a major source of water for food production in these areas and the International Center for Agricultural Research in the Dry Areas (ICARDA) works to make the best use of this resource. This is done through developing technologies for efficient use of rainfall and other available water resources. This document highlights the conjunctive use of rain and other water resources in supplemental irrigation that can help in achieving this objective. Although explanatory examples are mostly selected from Syria where ICARDA's headquarters and main research station (Tel Hadya) is located, the conclusions stated apply to most of the dry areas of West Asia and North Africa (WANA) having a Mediterranean-type climate.

Rainfall and Crop Water Needs

Precipitation in the dry rain-fed areas, especially where there is a Mediterranean-

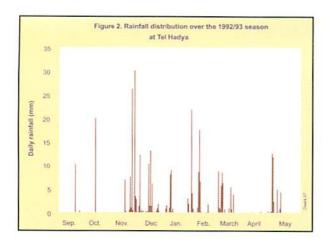
type climate, is characterized by low annual amount, unfavorable distribution over the growing season, and great year-to-year fluctuations. Except at some sites in exceptional years, rainfall amount in the dry areas is much lower than crop water requirements for economic production. Large variations in the distribution of rainfall within a season coupled with great year-to-year variations make predictions very difficult (Fig. 1,2).

As a result of unfavorable rainfall pattern, soil moisture in the root zone often does not satisfy crop needs over the





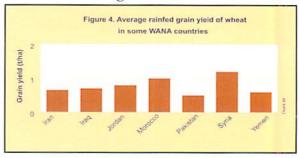
ICARDA's main research station at Tel Hadya, near Aleppo, Syria.



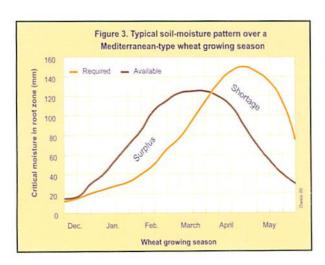
whole season. In the wet months (December to February) stored rain is ample, plants of crops sown at the beginning of the season are in early growth stages, and water extraction rate from root zone is low. Usually little or no moisture stress occurs during this period (Fig. 3). However, in early spring, plants grow faster with high rates of evapotranspiration and rapid soil moisture depletion. At this time, the chances of rain to occur become less, while soil moisture drops below critical levels. Thus, a stage of increasing moisture stress starts and continues until the end of the season. Such moisture stress is common in all Mediterranean-type rain-fed areas without exception, but varies in its starting time and severity.

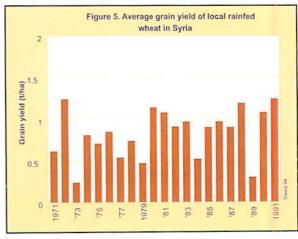
Rain-fed Crop Production

The shortage of soil moisture in rain-fed areas usually occurs during the most sensitive stages of crop growth. In the Mediterranean-type climate, this shortage is usually in the spring but sometimes at other stages. As a result of stress, rain-fed crops make poor growth and yields are consequently low (Fig. 4). The average grain yield of rain-fed wheat in WANA is about one tonne per hectare, but ranges from 0.5 to over 2.0



tonne/ha depending on the amount and distribution of rainfall, and on agronomic factors such as soil fertility and crop varieties. These levels are far below the yield potential of wheat of over 5 or 6 tonne/ha. Yields are not only low but also vary greatly from year to year as rainfall amounts and distribution vary (Fig. 5). This variation leads to instability in farmers' income.





Supplemental Irrigation

What is Supplemental Irrigation?

Supplemental irrigation (SI) can be defined as the addition to essentially rain-fed crops of small amounts of water during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields. Accordingly, the concept of SI in areas with limited water resources is based on the following three aspects.

First, water is applied to a rain-fed crop, that would normally produce some yield without irrigation.

Second, since precipitation is the principal source of moisture for rain-fed crops, SI is only applied when precipitation fails to provide essential moisture for improved and stabilized production.

Third, the amount and timing of SI are scheduled not to provide moisture-



In many areas, groundwater is being over-exploited and sustainability threatened.



Water-harvesting is a sustainable source of supplemental irrigation.



Surface water sources are the cheapest supply for supplemental irrigation.



Water-harvesting in surface reservoirs is a good source of supplemental irrigation. This mountain lake in northern Tunisia supports wheat and vegetables downstream.

stress-free conditions throughout the growing season, but to insure that there is a minimum amount of water available during the critical stages of crop growth that would permit optimal instead of maximum yield.

The management of supplemental irrigation is seen as a reverse of that of full or conventional irrigation (FI). In the latter, the principal source of moisture is the fully controlled irrigation water, while the highly variable limited precipitation is only supplementary. Unlike FI, the management of SI is dependent on the precipitation as a basic source of water for the crop.

Water resources for supplemental irrigation are mainly surface, but shallow

groundwater aquifers are being increasingly used. Of the non-conventional water resources, such as treated sewage effluent, which have potential for the future, water harvesting is an important one.

Improving Production with Supplemental Irrigation

Research results from ICARDA and other institutions in the dry areas, as well as data from farmers' fields, show substantial increases in crop yields in response to the application of relatively small amounts of SI. This increase is possible in both low and high rainfall conditions. Average increases in wheat grain yield under low, medium and high annual rainfall at Tel Hadya were about 400%, 150% and 30% using SI amounts of about 180, 125 and 75 mm, respectively. Generally, optimal SI ranges from 75 mm in areas with annual rainfall of 500 mm, to 250 mm in areas receiving 250 mm rain. Determining the optimal amount of SI under various conditions is discussd later.

When rainfall is low, more water is needed, but the response is greater; however, increases in yield are remarkable even when rainfall is as high as 500 mm. The response is greater when rainfall distribution over the season is poor. However, in all rain-fed areas of the WANA region, some time in the spring there is usually a period of stress, which threatens yield levels. Soil-moisture stress usually starts in March, April or May if total seasonal rainfall is low, average or high, respectively.

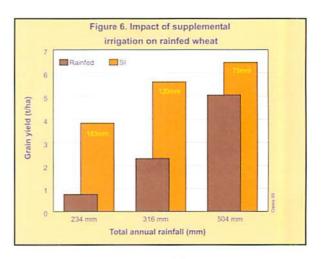
In Syria, average wheat yields under rain-fed conditions are only 1.25 t/ha and this is one of the highest in the



Yield is much higher with supplemental irrigation.

region. With SI, the average grain yield rises to 3 t/ha. In 1996, over 40% of rainfed areas were under SI and over half of the 4 million tonnes of national production was attributed to this practice.

Supplemental irrigation not only increases yield, but also stabilizes production. The coefficient of variation in production in Syria was reduced from 100% in rain-fed crop to 10% when SI was practised (Fig. 6). This stability is of great importance since it secures farmers' income.



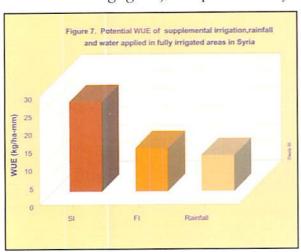
High Water-Use Efficiency

Water-Use Efficiency (WUE) is a measure of the productivity of the water consumed by the crop. In areas with limited water resources, where water is

the greatest limitation to production, WUE is the main criterion for evaluating the performance of agricultural production systems. No longer is productivity per unit area the main objective, since land is not as limiting to production as is water.

Average WUE of rain in producing wheat in the dry areas of WANA is about 0.35 kg grain/m3, although with good management and favorable rainfall (amount and distribution), this can be increased to 1 kg grain/m3. However, water used in SI can be much more efficient. Research at ICARDA showed that a cubic meter of water applied at the right time (when the crop is suffering from moisture stress), combined with good management, could produce more than 2.5 kg of grain over the rain-fed production (Fig. 7). This extremely high WUE is mainly attributed to the effectiveness of a small amount of water in alleviating severe moisture stress during the most sensitive stage of crop growth and seed-filling. When SI water is applied before such conditions occur, the plant may reach its high yield potential.

In comparison to the productivity of water in fully irrigated areas (when rainfall effect is negligible), the productivity



is higher with SI. In fully irrigated areas with good management, wheat grain yield is about 6 t/ha using 800 mm of water. Thus, the WUE is about 0.75 kg/m³, one-third of that under SI with similar management. This suggests that water resources may be better allocated to SI when other physical and economic conditions are favorable

Management of Supplemental Irrigation

The most important considerations in good SI management are when and how much water to apply. Yet many, perhaps most, farmers apply too much water if they can get it. Evidence of the over-use of irrigation water is clear in many dry-area situations, and SI is no exception. Farmers tend to overuse water in SI because of the low water and irrigation costs. The aim of any management program for SI should be to provide sufficient water to crops at the right time and also to discourage farmers from over-irrigating.

When to Irrigate?

Unlike in full irrigation, the time of SI irrigation cannot be determined in advance. This is due to the fact that the basic source of water to rain-fed crops is rainfall, which being variable in amount and distribution, is difficult to predict. Since SI water is best given when soil moisture drops to a critical level, the time of irrigation can be best determined by measuring soil moisture on a regular basis. Unfortunately, there is no simple device that an average farmer can use for this purpose. The well-known ten-

siometers are not suitable, since SI allows lower soil-moisture potential than the tensiometer is able to read correctly; other more sophisticated methods are not appropriate either.

Instead, most farmers in the region rely on personal experience related to the amount of rainfall received and crop appearance. Generally, they tend to irrigate earlier than necessary with more frequent irrigation than needed when they have ondemand water supply.

ICARDA is now testing various plants with potential as indicators of timing SI. ICARDA is also developing a methodology,



Tensiometers are not suitable for scheduling supplemental irrigation.



potential crops, are being tested as indicators of wheat supplemental irrigation time.

through modeling, for analyzing historic rainfall records in the area together with soil and crop parameters, to determine the most probable conditions to occur after knowing the rain amounts

at any time during the season.

Research in the eastern
Mediterranean region has shown
that the amount of rain falling
before the end of March is a good
indicator of what will happen
later in most years. Usually, however, one to three supplemental
irrigation applications annually
appear sufficient for wheat,

depending on the rainfall amount and distribution. These irrigations may best be given between late March and early May.



Supplemental irrigation trials at ICARDA's research station at Tel Hadya near Aleppo in northern Syria.

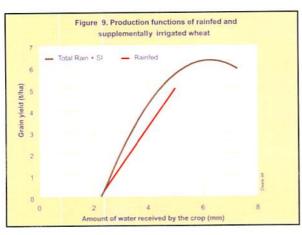
How Much Water to Apply?

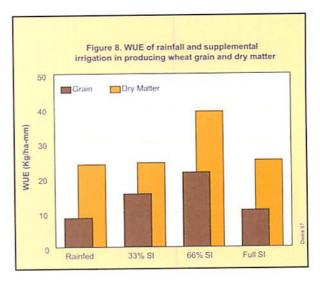
In water-scarce areas, the amount of irrigation water to apply should not be to satisfy full crop water requirement or to produce maximum yield per unit area, but rather to satisfy several criteria of which Water-Use Efficiency is the most important.

1. Water-Use Efficiency

ICARDA has found that, in Syria, supplementing only 50% of the crop irrigation requirements reduces the grain yield by only 10–20% relative to full irrigation. Using the saved 50% to irrigate an equal area gives a much greater return in the total production. In some areas, groundwater resources are being over-exploited for full irrigation and their quality is deteriorating. With such pressure on the existing water resources, sustainable use can be obtained only by producing more crops from less water, that is, improving water-use efficiency.

Water-use efficiency in SI is a function of the amount of irrigation water applied. It was found that maximum WUE is attained when one- to two-thirds of the full irrigation water is applied (Fig. 8). Given that many farmers over-irrigate, at least one-third of the full irrigation

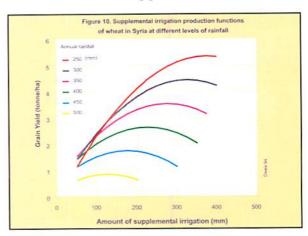




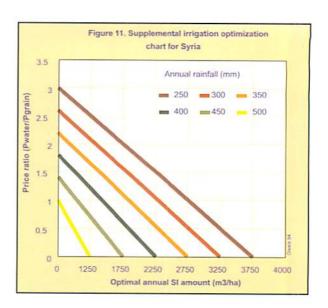
requirement can be saved without any losses in productivity.

2. Farmers' Benefits

ICARDA has developed methodologies for helping farmers to determine the right SI management. Developing rainfed and SI production functions is the basis for optimizing water-use strategy. Supplemental irrigation production functions are developed for each rainfall zone by subtracting rainwater production function (Fig. 9, 10) from total water (SI+rain) production function. Since rainfall amount cannot be controlled, the objective here is to optimize SI water amount. This is done by determining the amount of water applied to maximize



the net benefit to the farmer. Knowing the per unit cost of irrigation water and the expected price for a unit of the product, maximum profit occurs when the marginal product for water equals the inverse price ratio of water to product. Based on this, profit maximization charts can be developed to help the farmer decide on how much water to apply (Fig. 11). However, the cost of irrigation, the price of the production, and annual rainfall should be estimated. The latter can be determined after most of the rain has fallen in March



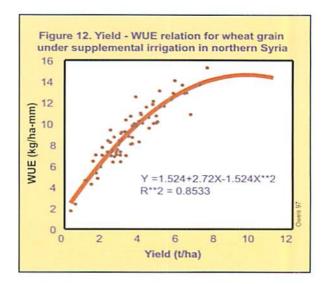
3. Yield, Water Use-Efficiency and Profit

Maximizing farmers' profit may not necessarily result in maximum WUE— just the same as maximizing WUE may not give maximum profit. When the cost of irrigation is low, farmers do not have much incentive (in terms of profit) to try to maximize WUE; they tend to apply full crop water needs to achieve near-maximum yield. However, when

the cost of water is high, or access to water is limited, maximum yield does not provide maximum profit. The relation between wheat grain yield and total WUE under SI systems shows a non-linear increase in WUE with increase in yield peaking around 8 t/ha (Fig. 12). However, the increase in WUE slows down after 50% of this yield is reached. The proper management under these circumstances should take into consideration: (a) the interests of the farmer together with the long-term sustainability of the resource, and (b) the value of water at the national and farmer levels.



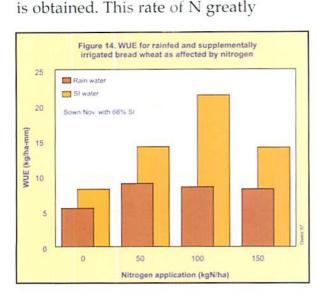
Transfer of supplemental irrigation technologies is an important objective of ICARDA.



Cultural Practices

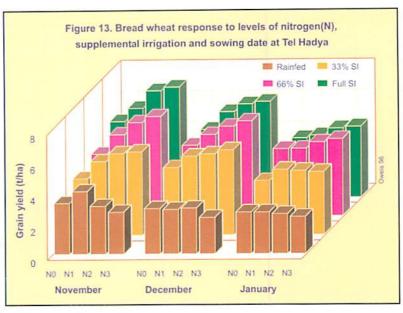
1. Soil Fertility

SI alone, although it alleviates moisture stress, cannot ensure good performance of the rain-fed agricultural system. It has to be combined with other farm management practices. Of most importance is the soil fertility, particularly in the Mediterranean region nitrogen is usually the main deficiency. Absence of nutrient deficiency greatly improves yield and water-use efficiency. Under rain-fed conditions, the rate of fertilizer nitrogen needed is not high, and with some water stress, high rates may actually be harmful. Under the Syrian rain-fed conditions, 50 kg N/ha was sufficient (Fig.13). However, with more water applied, the crop responds to nitrogen up to 100 kg N/ha, after which no benefit





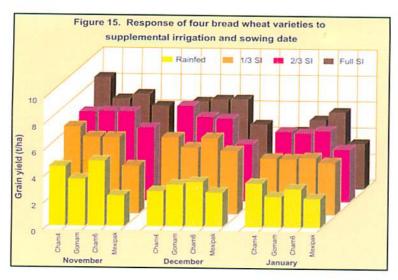
Nitrogen deficiency affects both yield and water-use efficiency.



improves WUE (Fig. 14). It is also important that there is adequate available phosphorus in the soil so that response to N and applied irrigation is not constrained. Other areas may have deficiencies in other elements. It is always important to eliminate these deficiencies to increase yield and WUE.

2. Crop Varieties

Selection of the appropriate crop variety makes a difference under both rain-fed and SI conditions. In rain-fed areas, breeding seeks to produce drought-



resistant varieties. These perform well under rain-fed conditions, but because they were not developed for SI conditions their response to more reliable water supplies may not be high (Fig. 15). A suitable variety for SI is one with good response to limited water application while maintaining some drought resistance.

3. Planting date

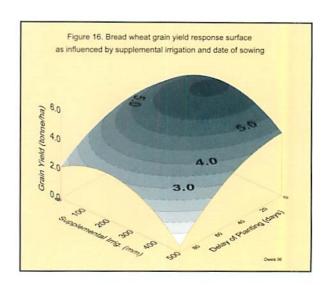
Under rain-fed farming, the earliest planting is usually in November, when enough rain for germination has fallen. Around 15 November is the optimal date for achieving highest yield under rain-fed conditions in the eastern Mediterranean region. Delaying planting after this date has negative impact on yield. Under SI, early planting (1 November) has an advantage in both yield and WUE (Fig. 16). With recommended levels of SI and N, wheat yield was decreased substantially by delaying sowing from December to January; for WUE the decrease occurred mainly with the delay from November to December with little decrease afterward. With SI, early planting is possible unlike under rain-fed conditions, where one has to

wait for enough rain.
Delaying planting, however, is not always a disadvantage for SI. Planting in mid-December and mid-January delayed flowering and grainfilling by one and two weeks, respectively, compared with the crop planted in early November. This shift delays the need for SI, and a system of phased planting may be used to spread the peak water requirements during

spring. This would reduce the need for high water supply discharge and reduce the size of the irrigation system needed. Knowing that SI cost is a major issue, this concept can help to make it more economic.



Suitable planting dates can be used to reduce pressure on water resources and irrigation systems.



Irrigation Systems

The difference between SI and full irrigation is in the management, not in the physical system. Irrigation systems that are suitable for full irrigation are also technically suitable for SI. There are also economic considerations. Systems for SI are only occasionally used. In most of the rain-fed areas only one to three irrigations may be needed each year. Using a system occasionally rarely justifies large investment. This may be why most SI systems are of the surface type, although they have lower application efficiency and uniformity. More costly systems, such as sprinklers and trickle are mainly acquired for full irrigation in summer but utilized for SI in winter. When labor and water are costly and field is not suitable for surface system, or no full irrigation systems exist, then sprinkler systems are generally used. The objective then is to minimize the cost by appropriate selection of the type and size of the system. One problem can be that the need for water occurs at the same time for all the planted area. Irrigation has to be applied to a large area in a short time. A large water supply rate and a large irrigation system are then needed. This conflicts with the objective of minimizing the cost. To overcome this problem the following strategies may be adopted.

1. The use of mobile sprinkler systems that can be moved easily within the field either mechanically or by hand when labor is cheap. Hand-moved systems are suitable when labor is not very costly. However, side-roll and gun sprinklers also give good value for money.

- 2. The problem of the requirement of large discharge rate and system size during the narrow peak period can be reduced substantially by spreading the peak water requirements over a longer period in late spring. This can be done by using different planting dates in different parts of the field, ranging from early November to late January, and selecting different crops and varieties that require water at different times. Although this may affect the yield and production a little, it will cut the cost of irrigation.
- 3. During the peak irrigation period, the amount of water required may be divided into two or more applications. A smaller amount is given, but covering the field faster avoids severe stress.
- 4. Water can be stored in the soil profile before the beginning of the irrigation time. During the early spring, crop consumption rate increases and some soil storage space is created before the critical level is reached. During this time farmers can start irrigating early and fill part of this space, which in turn will delay the time by which next irrigation will be needed. This will reduce the peak water need. In fact, some farmers who have small irrigation systems (one hand-moved system) already practise this.
- When the farm has irrigated summer crops, the system must be designed to suit both full and supplemental irrigation.

6. When the system is only for SI, size and cost may be reduced by considering the optimal water-scheduling needs, not the crop's full water requirement. Providing 50% of the

full irrigation requirements not only increases WUE and net return, it also cuts water need, irrigation system size and cost.



Hand-moved sprinkler system is low in cost but requires extensive labor.



Drip systems are still very costly for field crops.



Attempts to adapt furrow irrigation for supplemental irrigation of wheat may help in reducing irrigation cost while maintaining high efficiency.



Border irrigation is not very common in the area due to the costly land-leveling requirements.



Surface irrigation is very popular. It is labor-intensive but requires no capital investment.



In Iraq, this linear-move system is used for full irrigation in summer and supplemental irrigation in winter.

The CGIAR Centers

