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Farm Water Management Options to Alleviate Drought in the Dry Environments

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Abstract

The increasing scarcity of water and the occurrence of drought in the dry environments is now a serious problem threatening the social and economical development. High rate of population growth and development, require continuous diversion of agricultural water to higher priority sectors. The need to produce more food with less water poses enormous challenges to transfer existing supplies, encourage more efficient use and promote natural resources conservation. On-farm water-use efficient techniques if coupled with improved irrigation management options, better crop selection and appropriate cultural practices, genetic make-up, and timely socio-economic interventions would help achieving this objective.

In water-scarce areas, water is more limiting to production than land. Maximizing water productivity should have higher priority over maximizing yield in the strategies of water management. Conventional guidelines for determining crop irrigation requirements, which are designed to maximize yield, need to be revised for achieving maximum water productivity. In a fast changing world towards free trade and open markets, future trends in water and land use in agriculture are difficult to predict. However, under such conditions, planning water- and land-use should be based on the comparative advantages of the dry areas, but within the framework of maximizing the return from the limited available water resources.

Introduction

The dry areas of West Asia and North Africa (WANA) are characterized by low rainfall with limited renewable water resources. The share of the dry areas of the world's available fresh water is very small. Renewable water resources in WANA is about 1250 cubic meters (m^3) per capita, compared to about 7,420 m^3 for the world and 15,000, 20,000, and 23,000 m^3 per capita for Europe, North America, and Latin America, respectively (World Resources Institute 1999). In many countries of the Middle East, available water will barely satisfy basic human needs in this century (The World Bank 1994).

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The demand for water continues to grow in these areas with the fast human population growth and improved standard of living. Presently, over 75% of the available water in the dry areas is used for agriculture. However, competition for water among various sectors deprives agriculture of substantial amounts every year. In the dry areas most of the hydrological systems are already stretched to the limit, yet more food production is required every year. Such an objective may not be attained without substantially increasing the efficiency with which available water resources are used (Tribe, 1994). To maintain, even the current levels of agricultural production and environmental protection needs, greater efforts should be made to enhance the efficiency of water procurement and utilization. Increasing water productivity in dry areas becomes a vital issue were we must "produce more out of less water".

This theme poses enormous challenges to allocate existing supplies, encourage more efficient use and promote natural resources conservation. A vast array of economic, social, legal, political and other institutional factors affect both, the perception of and the response to, water management induced problems. All such factors cannot be considered in isolation. Responses require an understanding of the complex interactions that occur between social, political and physical components.

This paper discusses some of the prospects for addressing the problem of increasing water scarcity in the dry areas. It emphasizes, although not restricted to, ICARDA's experience in developing promising packages of technologies for improved on-farm water management and crops that are more water-use efficient. The paper addresses the conditions prevailing in the dry areas and particularly in West Asia and North Africa (WANA) were ICARDA has extensive experience.

Terms and Definitions

Water-use Efficiency (WUE)*: the term is used here to indicate the ratio of crop biomass production to the water consumed by the crop. Water may be consumed in evaporation, transpiration and/or quality deterioration.*

Consumed water: *The lost water is the portion of irrigation water that has left the farm and is unrecoverable at the basin level. Some of the water, which is conventionally considered as water losses at the farm, such as deep percolation and surface runoff, is completely or partially recoverable downstream and may not be considered an absolute loss.*

Absolute losses include evaporation, transpiration and the reduction in water quality, which limits its use.

Water Productivity (WP): *This term is introduced to remove the confusion arises from the misuse of the term "water use efficiency", which may indicate different meanings. In this paper it is also used to mean, "water use efficiency" as defined earlier and both terms are used in this paper interchangeably.*

Supplemental Irrigation (SI): *The application of a limited amount of water to rainfed crops that can normally grow without irrigation, to increase and stabilize production. This is different from conventional full irrigation, which is applied in areas having very low rainfall where no economical crop production can be achieved without irrigation.*

Water Harvesting (WH): *The term implies the concentration of low rainfall, which is not enough to support sustainable agricultural production, from larger area (the catchment), into a smaller area (target), where increased available moisture can support economical production. The process implies depriving part of the land from some or most of its share of rainfall for the sake of another part to be added, through runoff, to its original share of rainfall. Thus, universally water harvesting may be defined as: "the concentration of rainfall, through runoff, for beneficial use". Beneficial use can be agricultural, domestic, industrial, and/or environmental.*

Increasing Water Productivity

Many factors and variables influence the relation between crop production and water, some of which remain to be known. According to current knowledge, factors affecting water productivity can be broadly categorized in four groups: climate, soil, crop, and management. There are numerous interactions among factors within any group and/or among groups. High water productivity may be achieved through applying the following approaches:

Promoting water-use efficient techniques

In dry areas, moisture availability to the growing crops is the most significant single factor limiting production. It seems logical that considerations of this production factor must therefore receive high priority. Technologies for improving yield, stabilizing production and providing conditions suitable for using higher technology are important, not only for improved yields but also, for better water productivity. Yields and water productivity are substantially improved, in Mediterranean-type climate, with the application of supplemental irrigation in the rainfed areas, the adoption of water harvesting in the steppe areas and the use of improved irrigation systems in irrigated areas.

Supplemental irrigation for rainfed farming

The rainfed areas occupy an important role in the production of food in many countries of the region and the world. They cover more than 80% of the land area used for cropping throughout the world and produce some 60% of the total production (Harris *et al*. 1991). In the Mediterranean-type climate, rainfall is characterized by its variability both in space and time. In general, rainfall amounts in this zone are lower than seasonal crop water requirements; moreover its distribution is rarely in a pattern that satisfies the crop needs for water. Periods of sever moisture stress are very common and in most of the locations these coincide with the stages of growth that are most sensitive to moisture stress. Soil moisture shortages at some stages cause very low yields. Average wheat grain yields in WANA range between 0.6 and 1.5 t/ha depending on the amount and distribution of seasonal precipitation. It was found, however, that yields and water productivity are greatly enhanced by the conjunctive use of rainfall and limited irrigation water. Research results from ICARDA and others, as well as harvest from farmers, showed substantial increases in crop yield in response to the application of relatively small amounts of supplemental irrigation. This increase covers areas having low as well as high annual rainfall. Table (1) shows substantial increases in wheat grain yields under low, average, and high rainfall in northern Syria, with application of limited amounts of supplemental irrigation. Applying 212, 150, and 75mm of additional water to rainfed crop increased yields by 350, 140, and 30% over that of rainfed receiving annual rainfall of 234, 316, and 504mm respectively. In addition to yield increases, SI also stabilized wheat production from year to the other. The coefficient of variation was reduced from 100% to 20% in rainfed fields that adopted supplemental irrigation.

Table 1. Yield and water productivity for wheat grains under rainfed and supplemental irrigation in dry, average and wet seasons at Tel Hadya, North Syria (Oweis 1997)

Season/ Annual Rainfall (mm)	Rainfed yield (t/ha)	Rainfall WUE (kg /m3)	Irrigation amount (mm)	Total yield (t/ha)	Yield increase due to SI (t/ha)	SI WUE kg/m3
Dry (234mm)	0.74	0.32	212	3.38	3.10	1.46
Average (316mm)	2.30	0.73	150	5.60	3.30	2.20
Wet (504mm)	5.00	0.99	75	6.44	1.44	1.92

The impact of supplemental irrigation is not only on yield, but also more importantly on water productivity. Both the productivity of irrigation water and that of rainwater are improved when both are used conjunctively. Average rainwater productivity in the dry areas is about 0.35 kg/m^3. However, it may be increased to as high as 1.0 kg/m^3 with improved management and favorable rainfall distribution. It was found that a cubic meter of water applied at the proper time might produce more than 2.0 kg of wheat grain over that using only rainfall. The high water productivity of supplemental irrigation water is mainly attributed to alleviating moisture stress during the most sensitive stages of crop growth. Moisture stress during wheat flowering and grain filling usually cause a collapse in the crop seed filling and reduce the yields substantially. When SI water is applied before the occurrence of stresses the plant may produce its potential.

Furthermore, using irrigation water conjunctively with rain was found to produce more wheat per unit of water than if used alone in fully irrigated areas where rainfall is negligible. In fully irrigated areas wheat yield under improved management is about 6.0 t/ha using about 800 m^3/ha of irrigation water. Water productivity the will be about 0.75 kg/m^3, one third of that achieved with supplemental irrigation. This difference should encourage allocation of limited water resources to the more efficient practice (Oweis 1997).

Water harvesting for drier environment

The drier environments of WANA or as they are so-called badia or steppe cover most of this region. The steppe receives inadequate annual rainfall for economical dry farming production. The distribution and intensity are also sub-optimal. The limited rainfall comes in unpredictable sporadic storms often with high intensity. When often it falls on crusted soils with low infiltration rate, runoff occurs and water flows to other areas depriving the land of its share of rainfall. Therefore, rainfall in this zone is largely lost back to the atmosphere as evaporation. Research has shown that in the eastern Mediterranean dry region, only less than 5% of the rainfall is used by already poor range and even lesser percentage joins the ground water (Oweis and Taimeh 1996). Frequent dry periods occur during the growing season causing severe moisture stress and plant failure in most of the years. Unfavorable rainfall characteristics, poor vegetative cover, soil surface conditions, and the absence of proper management are the major causes for the loss of rainwater. Consequently, desertification occurs in this environment at an alarming rate and migration of people to the urban areas is one of the characteristics of these areas, (Oweis *et al* 1999).

Through history, water harvesting has shown good potential in increasing the efficiency of rainwater by concentrating it through runoff to ensure enough moisture in the root zone of the plants. Indigenous systems such as jessour and miskat in Tunisia, tabia in Libya, cisterns in north Egypt, hafaer in Jordan, Syria and Sudan and many other techniques are still in use (Prinz, 1994). Unfavorable socio-economic conditions over the last decades has caused decline in the use of these systems, but recently the increased water scarcity dry areas is favoring the revival of these systems.

Small basin micro catchments in the Muaqqar area of Jordan have supported almond trees now for over 15 years without irrigation in an area with 125 mm annual rainfall. In the same area where annual rainfall may drop to less than 80 mm small farm reservoirs were able to collect water every year with amounts enough to justify economical agricultural development (Oweis and Taimeh 1996). In ICARDA's on-farm water husbandry in WANA project, significant results have already been reported. In Mehasseh in Syria (120 mm annual rainfall) the shrubs having less than 10% survival rate grew under micro-catchments with over 90% survival rate. In North-west Egypt (130 mm annual rainfall) the same project has shown that small water harvesting basins with 200 m^2 catchment can support olive trees and that harvesting rainwater from greenhouses can provide about 50% of the water required by vegetables grown within it (Oweis *et al* 2001).

These experiences and many others show that the productivity of rain in the drier environments can be substantially increased when a proper water harvesting technique is implemented. This is especially true because at the present time very little of this rain is productive. At the large scale, ICARDA has developed methodology for using remotely sensed data and ground information in a GIS framework to identify suitable areas for water harvesting and appropriate methods for the prevailing conditions (Oweis *et al*, 1998). It was estimated that 30-50% of the rain in this environment might be utilized if water harvesting is practiced. This development will increase the current rainwater efficiency several times.

Efficient irrigation systems

Three main irrigation methods are used in practice; surface irrigation methods including basins, furrows and boarder strips, sprinkler irrigation methods including set systems, travelling guns and continuous move systems and trickle irrigation methods with drip, micro-sprinklers and subsurface systems. These systems greatly vary in their application, distribution and storage efficiencies. However, most of the losses associated with these efficiencies are totally or partially recoverable either at the farm level or at the basin level. For example, deep percolation losses in furrow irrigation may join ground water or are recovered in the drainage system. Also runoff losses may be recycled in the same farm or be used by downstream farmers. The absolute losses due to irrigation systems are those that may not be recovered, such as evaporation and deterioration in quality. For example; greater evaporation losses are common in surface irrigation over that in trickle irrigation.

The contribution of irrigation systems to improved water productivity is not limited to minimizing unrecoverable losses. The role of the system in making water more available in amount and timing for plant growth has great effect on water productivity (Pereira, 1999). For example; drip irrigation allows more frequent irrigation ensuring no crop water stress between irrigation applications as the case with surface irrigation, since it is not economical to irrigate more frequently with the later. The flexibility in the system to apply chemicals uniformly during irrigation and the role in controlling, or encouraging, diseases and pests can affect water productivity. Sprinkler irrigation creates favorable humid microclimate in wheat fields encouraging rusts, which can in turn reduces water productivity.

Adopting efficient on-farm water management

Deficit irrigation

Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (English *et al*. 1990). The adoption of deficit irrigation implies appropriate knowledge of crop water use and responses to water deficits, including the identification of critical crop growth periods, and of the economic impacts of yield reduction strategies. Research results show significant improvement in SI water productivity at lower application rates than at full irrigation. Highest water productivity of applied water was obtained at rates between 1/3 and 2/3 of full SI requirements, in addition to rainfall. Application of nitrogen improved water productivity, but at deficit SI lower nitrogen levels were needed. This shows that under deficit irrigation practice other cultural practices may need to be adjusted. Planting dates, for example, interact significantly with the level of irrigation applied. Optimum levels of irrigation to maximize water productivity need to consider all these factors. (Oweis *et al* 1998)

The water productivity indicator defined above is useful to identify the best irrigation scheduling strategies for deficit SI of cereals (Zhang and Oweis, 1999), to analyse the water saving performance of irrigation systems and respective management (Ayars *et al.*, 1999), and to compare different irrigation systems, including for deficit irrigation. Eexperience from Syria showed that applying only 50% of the rainfed wheat SI requirements reduces yield by only less than 15%.

Strategies for optimal deficit SI in rainfed areas involves rainfall amounts and distribution in addition to the sensitivity of crop various growth stages to moisture stress. Zhang and Oweis (1998), have developed and used a quadratic wheat production functions to determine the levels of irrigation water for maximizing yield, net profit, and the levels to which the crop be under-irrigated without reducing income below that which would be earned for full irrigation under limited water resources (Table 2). The analysis suggests that irrigation strategies to maximize crop yield and/or net profit under limited land resources should not be recommended. On the other hand, the analysis shows that for sustainable utilization of limited water resources and higher water productivity a sound strategy would involve maximizing profit.

Table 2. Estimated amount (mm) and timing of supplemental irrigation for maximizing yield, maximizing the net profit and a targeted yield under different rainfall conditions

Rainfall	W_m[a]	W_l[b]	W_w[c]	W_{cw}[d]	W_t[e]	Time of irrigation
Bread wheat						
250	430	336	260	161	158-254	Stem elongation, booting, and grain filling
300	380	286	210	111	108-204	Stem elongation, flowering and/or grain filling
350	330	236	160	61	58-155	Flowering and/or grain filling
400	280	186	110	11	0-144	Grain filling
450	230	136	60	0	0-55	Grain filling
Durum wheat						
250	510	454	314	180	144-207	Stem elongation, booting, and grain filling
300	460	404	294	130	94-157	Stem elongation, flowering and/or grain filling
350	410	354	244	80	44-107	Flowering and/or grain filling
400	360	304	194	30	0-57	Grain filling
450	310	254	144	0	0	

[a] Amount of water required for maximizing grain yield.

[b] Amount of water required for maximizing the net profit under limited land resources.

[c] Amount of water required for maximizing the net profit under limited land resources.

[d] Amount of water required for deficit irrigation at which the net profit equals that at full irrigation under limited water resources.

[e] Amount of water required for targeted yield of 4-5 t ha^{-1} .

The decision on optimal strategies under varying conditions is a complex one, especially in rainfed areas where rainfall is varying in amount and distribution. For example, it was found that spreading out dated of sowing of rainfed wheat over the three months of November to January substantially reduces the peak water demand during the SI period in the spring (Oweis and Hachum, 2001). This reduction is improved when deficit irrigation is applied. Analysis was conducted using simplified optimization model solved by linear programming and used 4-year data (1992-1996) from field experimental research conducted on wheat in northern Syria. The results of the analysis showed that a multi-sowing date strategy has reduced the peak farm water demand rate by more than 20%, thus potentially reducing irrigation system capacity and/or size. Also, the water demand rate of a larger area can be met with the same water supply. However, optimal sowing dates that minimize farm water demand rate do not always maximize total farm production and/or water productivity. The outcome depends on crop water requirements and yield for each sowing date. Furthermore, this selection is greatly influenced by the level of water scarcity.

Selecting proper cropping pattern and cultural practices

Research has shown that good soil and crop management practices can considerably increase the efficiency with which water available from precipitation and irrigation be used. Improved water productivity can be gained if crops are well established and adequately fertilized, weeds are controlled, and appropriate crop rotations are used (Pala and Studer 1999). These activities should also be considered together with the proper management of the soil if productivity is to be sustained and resources to be conserved in the long term. Soils of the region are predominantly calcareous, frequently phosphate deficient with variable depth and texture determining the maximum amount of water that can be stored and hence the effective length of the growing season. Production improvements are optimized by new technologies that integrate improvements to crop uptake of water and nutrients. Within this context, innovations in soil and crop management are sought by agricultural scientists to make maximum use of water available for crop growth. This is mainly through increasing water supply to crops, increasing the transpiration by crops and decreasing evaporation from soil surface (Gregory, 1991). The suggested technology packages vary with agro-ecological conditions and farmer's objectives.

Improved fertility improves water use efficiency (Cooper, 1991) and can, therefore, improve and stabilize production in rainfed areas and enable crops to exploit favorable rainfall in good years. Given the inherent low fertility of many dry-area soils, judicious use of fertilizer is particularly important. Extensive work in Syria (Pala *et al.*, 1996), demonstrated the benefits of appropriate fertilization on water-use efficiency and therefore on production and yield stability especially of wheat and barley, in WANA. In deficient soils, seedbed phosphate (usually together with a small dose of nitrogen) enhances the rate of leaf expansion, tillering, root growth, and phenological development, ensuring more rapid ground cover and canopy closure, and earlier completion of the growth cycle before rising temperatures increase the atmospheric demand (Gregory, 1991).

With availability of irrigation water, the role of fertilizers, particularly nitrogen, in improving water productivity is very obvious in areas where nitrogen is very deficient. Extensive work on SI at ICARDA has shown that using additional 50 kg of nitrogen per hectare may double water productivity. However, the optimum levels of nitrogen vary with soil nutrient level and the amount of irrigation given and need to be determined at the site.

Developing more efficient crop varieties

Exploitation of the interaction of genotype and management

The identification of appropriate crops and cultivars with optimum physiology, morphology, and phenology to match local environmental conditions and, especially, the pattern of water availability is one of the important areas of research within the cropping systems management for improved water use efficiency. Breeding and selection for improved water use efficiency, and the use of genotypes best adapted to specific conditions can improve soil water use and increase water productivity (Studer and Erskine 1999).

An important approach to increase the efficiency of water use is to change both management practices and cultivar concurrently. This allows a quantum jump in crop and water productivity. Seasonal shifting, i.e. the development of crop varieties that can be grown in winter under lower evaporative demand, represents an additional challenge for breeders aiming at using scarce water more efficiently, since traits such as winter hardiness and disease resistance of the cultivars have to be improved. The development of crop varieties for early growth vigor has been a major concern of winter cereal breeders in WANA for many years (Ceccarelli *et al.*, 1991). Early and complete canopy establishment to shade the soil and reduce evaporative loss from the soil surface can significantly improve water productivity of rainfed crops in Mediterranean conditions and also, apparently, of summer-rainfall crops over much of the semi-arid tropics. The following two case histories illustrate this simultaneous change in both genotype and management with the first involving early sowing in the food legume chickpea and the second covering the use of supplemental irrigation on wheat.

1. Early sowing of chickpea

In the Mediterranean region rain falls predominantly in the cool winter months of November through March. Traditionally chickpea sowing is done in late February and early March. As a consequence the crop experiences increasingly strong radiation and a rapid rise in temperature from March onwards which causes the rate of leaf area development to increase with consequent high evapotranspiration. This period of high evaporative demand occurs at the end of the rainfall when the residual soil moisture is inadequate to meet the evaporative demand. The crop, therefore, experiences drought stress during late vegetative growth and reproductive growth and produces a low yield. The replacement of traditional spring sowing with winter is possible but only with cultivars possessing cold tolerance and resistance to a key fungal diseases (Studer and Erskine 1999).

The average gains in seed yield from early sowing chickpea over three sites and ten seasons is 70% or 690 kg/ha, which translates into an increase in water use efficiency of 70% (ure 3) (Erskine and Malhotra 1997). In 30 on-farm trials comparing winter with spring chickpea in northern Syria, the mean advantage of winter sowing in seed yield and water use efficiency was 31% (Pala and Mazid 1982). Currently an estimated 150,000 ha of chickpea is winter-sown in the West Asia and North Africa region.

2. Improved cultivars under supplemental irrigation

The use of supplemental irrigation is another example of a concurrent change in both management practice and water-responsive cultivars to increase water productivity. The example demonstrates the need to combine changes in management with the use of adapted varieties in SI of wheat. This practice requires varieties that are adapted or suitable to be used with varying amount of water application. The proper varieties need first to manifest a strong response to limited water applications, which means that they should have a relatively high yield potential. At the same time, they should maintain some degree of drought resistance, and hence express a good plasticity. In addition, the varieties should respond to higher fertilization rates that are generally required under SI (Oweis, 1997), and resist lodging, which can occur in traditional varieties under irrigation and fertilization.

Table 3. Average 4-years rainwater and supplemental irrigation (SI) water productivity for durum and bread wheat varieties grown in northern Syria. (Oweis, unpublished data)

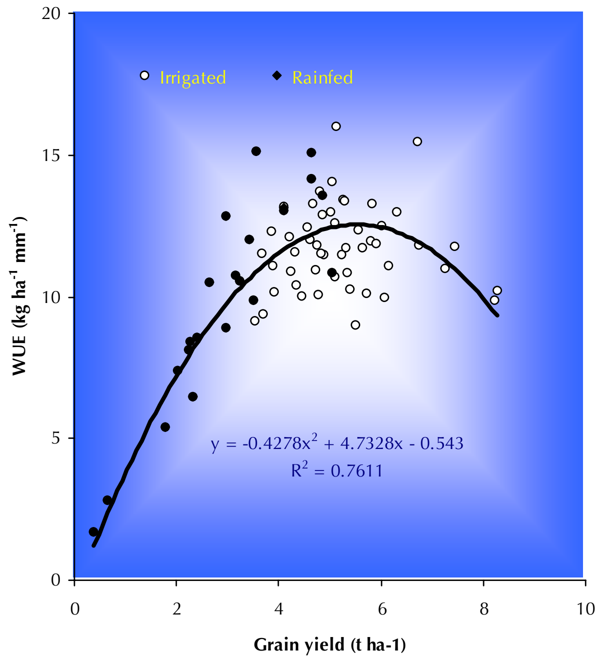
Variety*	Rainwater productivity (kg/m3)	SI water productivity (kg/m3)		
		Full SI	33% of full SI	67% of full SI
Cham 1	0.809	1.050	1.426	1.244
Cham 3	1.008	0.943	1.303	1.097
Lahn	0.880	0.889	1.733	1.328
Omrabi 5	0.903	0.794	1.310	1.370
Gomam	0.929	0.903	0.717	1.394
Mexipak	0.769	0.601	0.808	1.000
Cham 4	0.976	0.952	1.647	1.374
Cham 6	1.048	0.845	0.927	1.106

** Cham 1, Cham 3, Lahn, and Omrabi 5 are durum and Gomam, Mexipak, Cham 4 and Cham 6,are bread wheat.*

Water productivity vs. land productivity

In conventional irrigation, water is applied to maximize crop yield (maximizing production per unit of land). This is the case when water is not limiting, rather when land is limiting. In the dry areas, land is not, any more, the most limiting factor to production rather water is increasingly becoming the limiting factor. It is, therefore, logical to conclude that since water is more limiting factor, then the objective should be maximized the return per unit of water not per unit of land. This should yield higher overall production, since the saved water can be used to irrigate new land with higher production. However, high water productivity does not come without high yield. Fortunately, both water productivity and yield increase at the same time as improvement to on-farm management is introduced. This parallel increase in yields and water productivity, however, does not continue all the way. At some high level of yield (production/unit of land) incremental yield increase requires higher amounts of water to achieve. This means that water productivity drops as yield increases above certain levels. Figure 1 shows the relation between yield increase and water productivity increase for durum wheat under supplemental irrigation in Syria.

Figure 1. Relationship between crop water productivity and crop grain yield for durum wheat under supplemental irrigation in Syria (Oweis *et al* 1998).



It is clear that the amount of water required to produce the same amount of wheat at yield levels beyond 5 t/ha is very high compared to the requirements at lower levels. It would be more economical to produce only 5t/ha, then use the saved water to irrigate new land than to produce maximum yield with excessive amount of water at low water productivity. This is keeping in mind the assumption that water not land is limiting and that there is not sufficient water to irrigate the available land. Generally, maximum water productivity occurs at sub-optimal crop yield per unit area. This is provided the relation is not a straight line, which is not always the case.

The association of high WUE values with high yields has important implications for the crop management for achieving efficient use of water resources in water scarce areas (Oweis *et al* 1998). However, attaining higher yields with improved WUE should ensure that increased gains in crop yield are not offset by increased costs of inputs and running costs. The curvilinear WUE–yield relationship emphasizes the importance of attaining relative high yields for efficient use of water. A policy for maximizing yield and/or net profit should be looked at very carefully under water scarcity conditions. Guidelines for recommending irrigation schedules under normal water availability

(Alan *et al* 1998) may need to be revised when applied in areas with limited water resources.

Case Study From Syria

ICARDA long-term research in Syria has shown that applying only 50% of full supplemental irrigation requirements (over that of rainfall) would cause a reduction in yield of only 10-15%. This finding, in light of the increasing water scarcity in Syria, have encouraged ICARDA and the Extension Department of the Ministry of Agriculture to test a deficit supplemental irrigation strategy at farmers fields.

The objective was improved farmer return and conserve water resources by improving water productivity under limited water resources. The hypothesis was that applying 50% of supplemental irrigation requirements to the whole field will, while maximizing water productivity, bring more benefits to the farmer than applying 100% of wheat irrigation requirements to half of the field, while the other half is left rainfed. The demonstrations were conducted at farmer's fields and managed collectively by the farmer, the researchers and the extension agents.

The farmer's managed demonstration plots were established over 6 years in the rainfed areas with annual rainfall ranges from 250 to 450 mm. Rainfed wheat yields in this area is generally low (less than 2 tons/ha) and variable from one year to the other. Supplemental irrigation is practiced in the area and has shown good potential to increase and stabilize production. However, it was observed that farmers tend to over irrigate and the ground water in the region has been continuously depleted.

Farmer's land was divided into four one-hectare parts: the first was left rainfed, the second was irrigated by the farmer, as he usually does, but water amounts was measured, the third was irrigated to ensure no moisture stress and the fourth part was irrigated with 50% of the full irrigation requirements. Water requirements were determined using evaporation from Class-A pan installed in the field using appropriate pan and crop coefficients. Rain was measured also at the farm. Irrigation water was given from wells or public canal and measured by calibrating the flow rate and determining the time needed to apply the required amount. At the end of the season the crop yields were measured and other data were collected. The farmers used improved wheat cultivars and recommended inputs and cultural practices at each site.

Under unlimited water resources the farmer has no incentive to save on irrigation water. In this case full crop water requirement is applied to produce maximum yield with lower water productivity. However, when water is not enough to provide full irrigation for the whole farm, the farmer has two options: to irrigate part of the farm with full irrigation leaving the other part rainfed or to apply deficit supplemental irrigation to the whole farm. With the assumption that under limited water resource only 50% of the full irrigation required by the farm is available the option of deficit irrigation was analyzed in comparison to other options.

The results are summarized in Table 4. They show that under the rainfall conditions prevailed in Syria during the years 1994 to 2000, a farmer having 4-hectare farm would on average produce 33% more grain from his farm, if adopt deficit irrigation, than if applied a full irrigation strategy. The advantage of applying deficit irrigation increased the gain by over 50% from that of the farmer practice of over irrigation. Applying deficit supplemental irrigation strategy, when water resources are limited, will eventually double the land area under irrigation. The results of this program can well demonstrate the possibility of producing more with less water.

Table 4. Wheat grain production scenarios for 4-hectar farms with various strategies of supplemental irrigation in Syria.

Management strategy	Rainfed	Farmer's	Full SI	Deficit SI
Total water applied (m^3)	342 mm	2980m^3	2220m^3	1110m^3
Grain yield (t/ha)	1.8	4.18	4.46	4.15
Water productivity (kg/m^3)	0.53	0.70	1.06	1.85
Possible 4-ha farm production (ton) if water is not limiting	7.2	16.7	17.8	17.8
Possible 4-ha farm production (ton) under limited water (50% of full irrigation requirements is assumed available)	7.2	10.8	12.5	16.6

Conclusions

In the dry areas, where water scarcity is increasing, generally water, not land, is the most limiting resource. Under such conditions adopting irrigation strategies to maximize the return per unit of water i.e. increasing water productivity may have higher priority over that of maximizing yield per unit of land.

It is possible to substantially increase water productivity through adopting improved irrigation systems, applying sound irrigation management, growing improved crop cultivars and appropriate cropping patterns and cultural practices. It is however, important that these interventions be integrated with full participation of the farmer to develop viable strategies and efficient and sustainable production systems.

Guidelines for determining crop irrigation requirements to maximize water productivity are needed in water scarce areas. Furthermore, relations between water productivity and water used need to be developed for most of the crops in these areas.

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