18. Improving agricultural water productivity: A necessary response to water scarcity and climate change in dry areas

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Abstract

Water resources in the dry areas are limited. Most of the available water is tapped and only limited new water is expected from non-conventional sources. As more water will be needed for other priority sectors, less water will be available for agriculture. This decline comes to challenge the attempts to increase food production and to enhance food security. Climate change adds to this challenge in the dry areas as precipitation is expected to decline and drought to intensify. Agriculture as a result must cope with the increasing demand for food, feed, and fiber, but with less water. It is, therefore, essential that substantial changes be made in the way water is valued and managed to help overcome water shortages. The logical response is to produce more with less water; that is to improve water productivity (WP) which is the return for a unit of water consumed or depleted. WP in the dry areas is generally low and there is a great potential for its improvement. There are three primary ways to enhance agricultural WP: (a) Reduce non productive water depletion; (b) Improve plant, animal, etc. productivity per unit of water beneficially consumed; and (c) Allocate water to the more water productive options. Substantial and sustainable improvements in agricultural water productivity can only be achieved through integrated management at all scales. On-farm water-productive techniques include deficit irrigation, supplemental irrigation, water harvesting and precision irrigation. Improved techniques if coupled with improved irrigation management, better crop selection and appropriate cultural practices, improved genetic make-up, and timely socioeconomic interventions will help to achieve this objective. Conventional water management guidelines should be revised to ensure maximum water productivity instead of land productivity. Policy reforms and empowered new institutional setups can ensure sustainable improvement in water use in agriculture.

Introduction

The availability of freshwater is one of the great issues facing humankind today. Water shortage and needs are increasing, and the competition for water among urban, industrial, and agricultural sectors is growing more intensive. Mining groundwater is now a common practice in the dry regions risking both water reserves and quality. In many countries securing basic human water needs for domestic use is becoming an issue not to mention the needs for agriculture, industry and environment. The average annual per capita renewable supplies of water world-wide is about 7000 m^3. The threshold for water poverty level is 1000 m^3 which looks ample for countries like Jordan, where the annual per capita share has dropped to less than 200 m^3 (Margat and Vallae 1999).

With rapid industrialization, urbanization and population increase, economic realities seem certain to reallocate water increasingly away from agriculture to other sectors. Moreover, opportunities for large captures of new water are now few. Most river systems suitable for large-scale irrigation have already been developed. Unacceptable depletion of the flow to downstream users will become increasingly difficult to avoid.

The water scarcity situation in the dry areas is deteriorating every day. Over the coming years, this situation will worsen with increasing demand, given the fact that the possibility of new supplies is limited. If the world's population keeps growing at the current rate (about 90 millions each year), we are facing the challenge of feeding 8 billion people very soon – in 2025. More than 80% of these people will live in developing countries. This implies that with nearly the same water and other natural resources base we must produce food for 2 billion more people while at the same time meeting the expanding domestic and industrial water needs. The increasing pressure on this resource will, unless seriously tackled, escalate hydroplitical conflicts and seriously damage the already fragile environment in the region.

Agriculture is by far the largest user of water, accounting for about 70 percent of all withdrawals from rivers, lakes, and aquifers, and up to 95 percent in many developing countries. The water needed for crops amounts to 1,000 – 3,000 cubic meters per tonne of cereal harvested. It takes 1 – 3 tonnes of water to poduce1kg of grain. Furthermore, it is estimated that only 45% of the water used in agriculture is effectively used by crops (UN/WWAP 2003). The other 55% is partially lost by either evaporation or by losing quality while joining salt sinks, recharges aquifers, or flows downstream to be reused. Therefore, agriculture is not seen as the most efficient water user. The ever-growing competition among water-using sectors is certainly forcing agriculture to give up part of its share to higher priority uses, especially the domestic and industrial sectors. Meanwhile, agriculture must cope with the increasing demand for food, feed, and fiber, but with less water. It is, therefore, essential that substantial changes be made in the way water is valued and managed to help overcome water shortages. Under these circumstances it is crucial that the role of water in securing food supply is understood and the potential for improving overall agricultural productivity with respect to water fully realized.

It has been widely accepted that the most promising option to achieve food security and sustain acceptable standard of living in the water scarce areas is to improve the efficiency of water use or productivity. There are three primary ways to enhance agricultural water productivity: 1) to increase effective use through improved water management; 2) to increase crop yields through agricultural research; and 3) to reform policies and increase investment, particularly in rainfed areas. Improving agricultural water productivity implies getting more output or return per unit of water used. However, sustainability issues must be carefully taken into consideration. Water will be the key agent in the drive to raise and sustain agricultural production. Therefore, agriculture policies and investments will need to become much more strategic. They will have to unlock the potential of agricultural water management practices to raise productivity, spread equitable access to water and conserve the natural productivity of the water resource base.

Water efficiency and productivity concepts

Irrigation efficiencies:

The term *'efficiency'* in general reflects the ratio of output to input. It is widely used in irrigation systems design, evaluation, and management. Farm irrigation performance is based on three fundamental and interrelated efficiency terms: conveyance, application, distribution and storage efficiencies (Hansen et al.1980 ; Jensen et al. 1981; Walker and Skogerboe 1987; James 1988; and Keller and Bliesner 1990). Water Conveyance Efficiency (WCE) is the ratio of water diverted from the source to that delivered to the farm. It reflects water losses from the conveyance system mainly in seepage, evaporation and weeds consumptive use. Irrigation Application Efficiency (IAE) is the ratio of the water stored in the plant root zone to that applied to the field. It mainly reflects losses of water in deep percolation and in runoff. Irrigation Distribution Efficiency (IDE) refers to how uniformly the water is distributed in the plants root zone. It however does not indicate any water losses or how the full root zone is. Irrigation Storage Efficiency (ISE) is the ratio of water stored in plans root zone to the amount needed to fill it. It reflects how full the root zone is but does not indicate how uniform is irrigation or how much water is lost in deep percolation and/or runoff.

These irrigation related efficiencies are engineering terms necessary for sound design, monitoring, and performance evaluation of irrigation systems. The output (numerator) and input (denominator) components of these irrigation-based efficiencies use the same units and are expressed in percentage (%) with a maximum value of 100%. Values less than 100% imply *losses* during the process.

Losses of water reflected in the above irrigation efficiency terms are mostly paper not real losses. Seepage from irrigation canals and field deep percolation losses are largely recoverable through joining ground water or springs. Runoff losses can be recycled in the fields downstream. Drainage water is also recycled and used several times before becoming too saline. Despite the fact that most of these losses are recoverable, engineers strive to minimize them as reuse implies some costs to the user and probably other side implications. In addition efficiency terms do not indicate how productive irrigation water is.

Water-use efficiency:

Water Use Efficiency reflects how good water is used in agricultural production. The term has been defined in the literature in various ways by hydrologists, physiologists and agronomists depending upon the emphasis that one wishes to place on certain aspects of the problem. In general it is the ratio of the yield to the unit of water used. The most confusing aspect in this term is the evaluation of the unit of water used. Some use applied water; others use evapo-transpiration or even transpiration alone. The term is restricted to biophysical return to water ignoring other types of return such as socioeconomic or environmental. Production could be grain, biomass or any other entity. It makes it difficult to compare efficiencies at different places or under different practices unless the production and the water used are well defined and evaluated (Hansen et al. 1980; Hanks 1983; Howell et al. 1990; Gregory 1991; Joshi and Singh 1994).

Water productivity:

As mentioned before, irrigation and water use efficiencies, although useful in addressing many aspects of water management, do not reflect well the various types of return to water and the water used in the production. Water productivity defined as the return per unit of water consumed in the production can overcome those deficiencies. The return to water can be:

a) Biomass, grain, milk, meat, etc
b) Economic benefits (i.e. net income)
c) Environmental benefits (i.e. carbon sequestration)

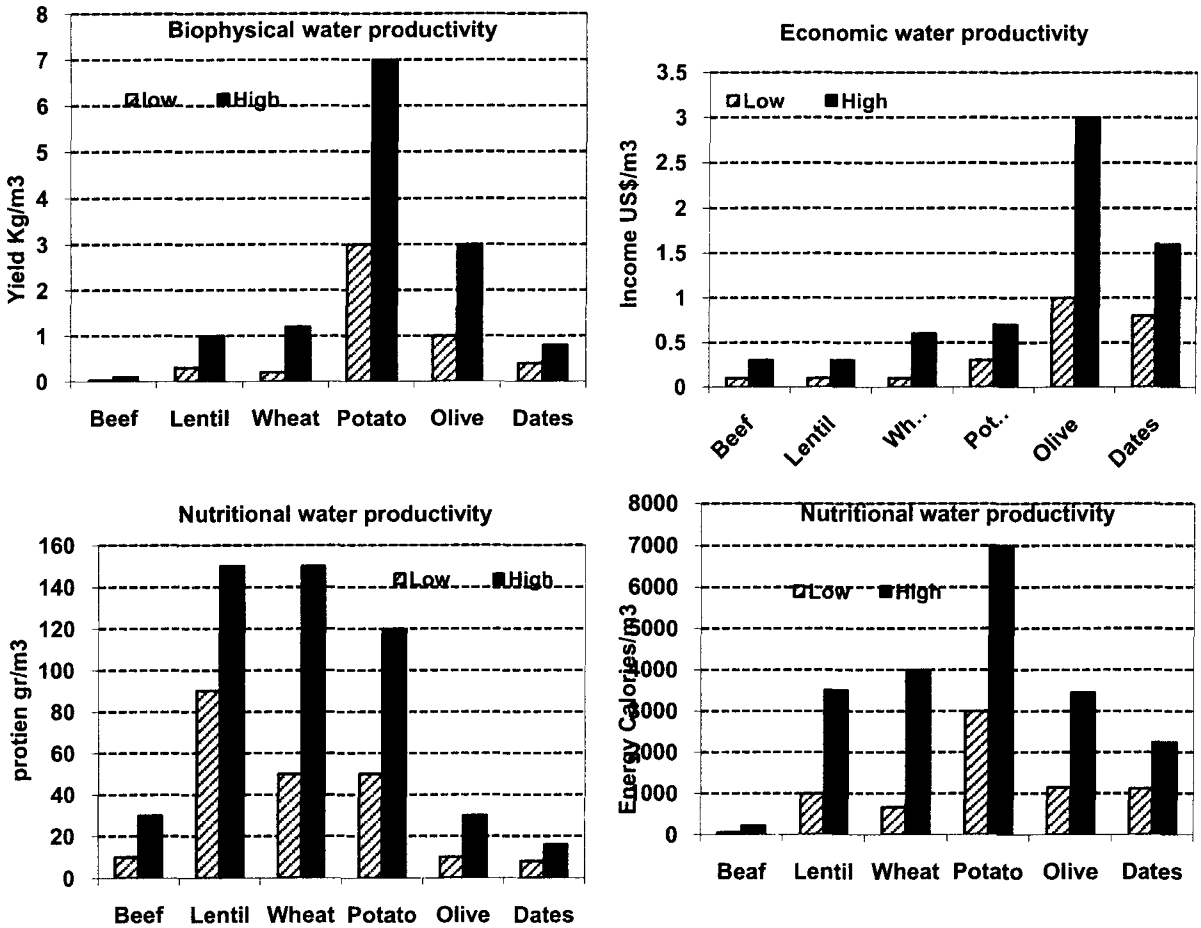

Figure 1. Estimates of a range of water productivity values (from low to high) of some agricultural products; (a) biophysical WP, (b) economic WP, (c) nutritional WP (protein) and (d) energy WP. (Molden and Oweis 2008)

d) Social benefits (i.e. employment)
e) Energy (i.e. calories)
f) Nutrition (i.e. protein)

The water consumed is meant to be the water depleted from the production system giving the return. Water depletion is the use or removal of water (from a domain, particularly a basin) that renders it unavailable for further use. Water may be depleted by evaporation, flows to sinks (such as sea or saline groundwater), or incorporation into products (such as bottled water). Therefore, it is important to distinguish between water depleted and water diverted or applied, because not all water diverted (or supplied) to irrigation is depleted. Recoverable losses (such as surface runoff, deep percolation, etc.) from any domain's boundaries can be reused within the same domain or higher levels. More specifically, depleted water includes: evaporation, transpiration, water quality deterioration, and water incorporated in the product or plant tissues. Water recycled in the farming system may not be totally lost as implied by evaluating irrigation efficiencies. Water quality is important as water with various qualities has different productivity. It is now well understood that the issue of water productivity is a multidisciplinary and scale or level-dependent (Molden and Oweis 2008; Molden 2003; Molden 1997).

Agricultural water productivity (WP)

Figures 1-4 show a range of water productivities for some agricultural products based on biophysical, economic, nutrient and energy returns (Molden and Oweis 2008). The wide range of values, from low to high, reflects the great potential for improvement. The figures show that depending on the production purpose and local conditions the selection of the product can make great deference in the return for the water. One can also notice the low water productivity in producing beef compared to crops.

It is important to note that WP is not only scale and user specific, but also site and management specific. A cubic meter of water is expected to produce more biomass in a cool than in a hot dry environment. Soil type, water quality, crop variety, production input, water and crop management are among the factors impacting WP. Market prices effect economic WP. For meaningful comparison of WP at different locations and/or environments, there is need to normalize the values of WP (Oweis and Hachum 2003).

Scales and drivers

WP is addressed at different scales (plant, farm, project, and basin levels) and a conceptual framework for better understanding of WP and water accounting across scales is introduced. It has been pointed out that highest WP at one scale does not necessarily result in highest WP at another scale. Economic productivity and opportunity cost of water make the undertaking far more complex. Nevertheless, the major drivers at each scale are:

a) At the basin level: competition among uses (agricultural, domestic, environmental, etc.), conflicts between countries, equity issues (upstream – downstream users)
b) At the national level: food security, hard currency, socio-politics
c) At the farm level: maximizing economic return (crop and allocation selection)
d) At the field level: maximizing biological output (maximizing resources productivity)
e) At the plant level: maximizing nutrient content and quality of harvest.

Potential WP improvements

Figure 2a shows worldwide ratio of biomass and yield of common small grain crops to transpiration (T) along with yield/ET ratio for two selected regions. The slope of the second line from top is greater than the slope of the top line that indicates potential improvement in harvest index. The two lower lines in the Figure indicate that improvements in water productivity are possible through improved management that increases the ratio of yield to evapotranspiration (slope of line). But in many of the most productive areas of the world, such as the lower Yellow River Basin, large improvements have already been made and the remaining scope is small. The implication is that for these areas achieving higher yields will require more evapotranspiration. The areas with the highest potential gains are those with very low yields, such as Sub-Saharan Africa and South Asia. These are also areas of extreme poverty, with the largest concentration of poor people and high dependence of the poor on agriculture (Molden and Oweis 2008; Rockstrom et al. 2007).

Crop breeding, targeting early growth vigor to reduce evaporation, and increasing resistance to drought, disease, or salinity could all improve water productivity per unit of evapotranspiration. But there are several indirect means to improve water productivity in which biotechnology can play a role: (a) Targeting rapid early growth to shade the soil and reduce evaporation; (b) Breeding for resistance to disease, pests, and salinity; (c) Boosting the harvest index for crops such as millet and sorghum that have not received as much attention as the

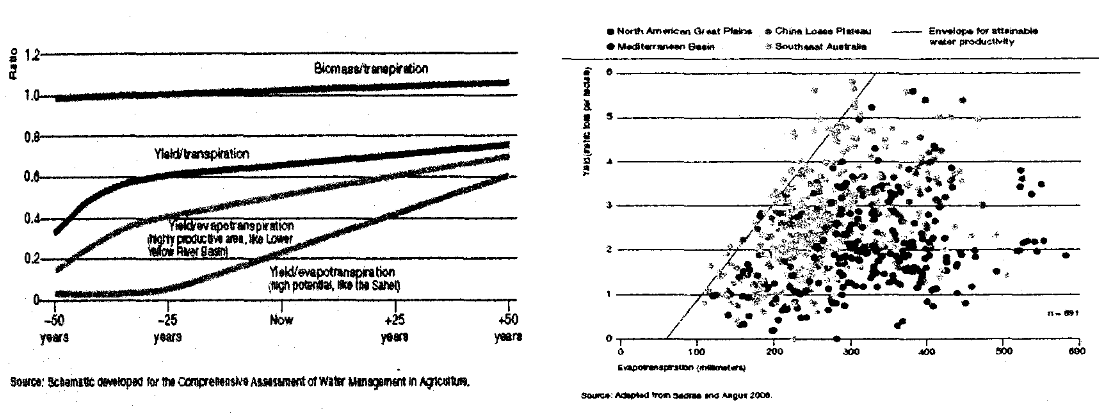

Figure 2. Potential improvements in water productivity. (a) Projected potential improvements of WP with various means and regions, (b) water yield relations of wheat grains in major regions of the world (Molden and Oweis 2008).

green revolution cereals; (d) More value per unit of evapotranspiration can be achieved by improving the nutritional quality of crops and by reducing agrochemical inputs by planting disease- and pest-resistant crops.

Figure 2b illustrates significant variability in yield due to differences in biophysical conditions (particularly evaporation and other climatic conditions) among sites in addition to differences in management of natural resources. Variability due to management practices gives hope for potential improvement in water productivity especially at low yield domain. It shows that the potential to improve WP is substantial in many areas and mainly management can achieve this improvement.

Tradeoffs between water and land productivities:

In conventional irrigation, water is applied to maximize crop yield per unit of land. This is the case when land availability is limiting. In the most of the dry areas, land is not any more the most limiting factor to agricultural production. Rather, water is increasingly becoming the most limiting factor. The objective, therefore, should be maximizing the return per unit of water instead 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 WP does not come without high land productivity (LP). Fortunately, both water and land productivities increase as the on-farm management is improved. However, this does not continue all the way. At high yield level achieving incremental increase requires higher amounts of water to be used. This means that water productivity drops as yield increases near its potential. Figure 3 shows the relationship between LP and WP for wheat in the Mediterranean region. When this relation is curvilinear, maximum WP occurs at less than maximum LP which is not the case for all crops and conditions (Oweis et al. 1998).

Attaining higher yields with improved WP should ensure that increased gains in crop yield are not offset by increased costs of inputs and running costs. The curvilinear WP–yield relationship emphasizes the importance of attaining relatively 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 (Allen et al. 1998) may need to be revised when applied in areas with limited water resources.

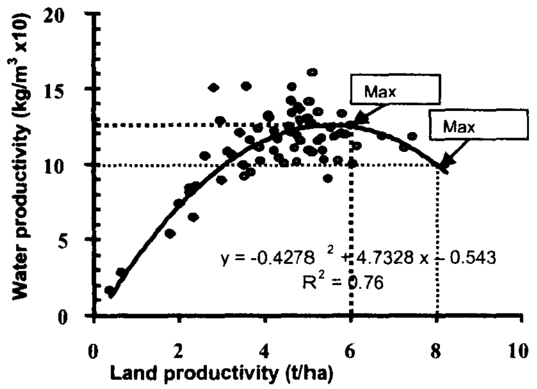

Figure 3. Relationship between water productivity (WP) and land productivity (LP) for durum wheat in Mediterranean environment (Oweis et al. 1998).

When water is short of providing full supplemental irrigation (SI) to the whole farm, the farmer has two options: a) to irrigate part of the farm with full SI leaving the other part rainfed or b) to apply deficit irrigation to the whole farm. In northern Syria, water-short farmers are advised to apply 50% deficit SI to their wheat fields. By so doing, the area under SI is doubled using the same amount of water, and total farm production is higher. A farmer having a 4-hectare farm would on average produce 33% more grain from his farm if he adopted deficit irrigation for the whole area, than if full irrigation was applied to half of the area (table 1).

Approaches for improving water productivity

Following are major approaches for improving agricultural water productivity (Viets 1962; Stanhill 1986; Monteith 1986; Oweis et al. 1998).

Increasing the productivity per unit of water consumed:

- *Improved crop varieties;* to grow new crop varieties that can provide increased yields for each unit of water consumed, or the same yields with fewer units of water consumed.
- *Alternative crops;* by switching from high- to less-water-consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.
- *Deficit, supplemental, or precision irrigation;* with sufficient water control, higher productivity can be achieved using irrigation strategies that increase the returns per unit of water consumed.
- *Improved water management;* to provide better timing of supplies to reduce stress at critical crop growth stages leading to increased yields or by increasing water supply reliability so that farmers invest more in other agricultural inputs leading to higher output per unit of water.
- *Optimizing non-water inputs;* in association with irrigation strategies that increase the yield per unit of water consumed, agronomic practices such as land preparation and fertilization can increase the return per unit of water.
- *Policy reform and public awareness;* policies related to water use and valuation should be geared towards controlling water use, reducing water demand, safe use and disposal of water, and encouraging the collective approach in using and managing water.

Table 1. Wheat grain production scenarios for 4-hectare farms with various strategies of supplemental irrigation in Syria (Oweis and Hachum 2003)

Management strategy	Rainfed	Farmer'	Full SI	Deficit SI
Total water applied (m^3)	342 mm	2980	2220	1110
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	16.6
Total 4-ha farm production (ton) under limited water available (50% of full requirements)	7.2	10.8	12.5	16.6

Reducing non-beneficial water depletion:

- ***Reducing evaporation from water applied*** to irrigated fields through specific irrigation technologies such as drip irrigation, or agronomic practices such as mulching, or changing crop planting dates to match periods of less-evaporative demand.
- ***Reducing evaporation from fallow land***, decreasing the area of free water surfaces, decreasing non- or less-beneficial vegetation and controlling weeds.
- ***Reducing water flows to sinks*** by interventions that reduce irrecoverable deep percolation and surface runoff.
- ***Minimizing salinization of return flows***—by minimizing flows through saline soils or through saline groundwater to reduce pollution caused by the movement of salts into recoverable irrigation return flows.
- ***Shunting polluted water to sinks*** to avoid the need to dilute with freshwater, saline or otherwise polluted water should be shunted directly to sinks.
- ***Reusing return flow*** through gravity and pump diversions to increase irrigated area.

Reallocating water among uses:

- ***Reallocating water from lower- to higher-value uses.*** It will generally not result in any direct water savings, but it can dramatically increase the economic productivity of water. Because downstream commitments may change, reallocation of water can have serious legal, equity and other social considerations that must be addressed.
- ***Tapping uncommitted outflows*** to be used for productive purposes.
- ***Improving management of existing facilities*** to obtain more beneficial use from existing water supplies.
- ***Policy, design, management and institutional interventions*** may allow for an expansion of irrigated area, increased cropping intensity or increased yields within the service areas.
- ***Reducing delivery requirements*** by improved application efficiency, water pricing, and improved allocation and distribution practices.
- ***Adding storage facilities infrastructures*** to store and regulate the use of uncommitted outflows (as is the case during wet years) so that more water is available for release during drier periods.

Highly water-productive technologies

Deficit irrigation:

When water is limiting the production, the rules of scheduling should be modified for improved water productivity. In intensive irrigation development, all efforts including research and advancement in technology development are geared towards achieving yield maximization per unit of land. However, in water scarce areas, water, not land, is the most limiting factor to improved agricultural production. Irrigating for less than maximum yield per unit land (deficit irrigation) could save substantial amounts of water for irrigating new lands and hence producing more food from the available water. Deficit irrigation is not the only practice that has shown good potential, but other ways are available to modify water management principles to achieve more water-efficient practices. New guidelines for crop water requirements and irrigation scheduling to maximize water productivity are yet to be developed for the important crops in the dry areas.

Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction in order to maximize the productivity per unit of water used. One important merit of deficit supplemental irrigation is the greater potential for benefiting from unexpected rainfall during the growing season due to the higher availability of storage space in the crop root zone. Results on wheat, obtained from farmers' fields trials conducted in a Mediterranean climate in northern Syria showed significant improvement in SI water productivity at lower application

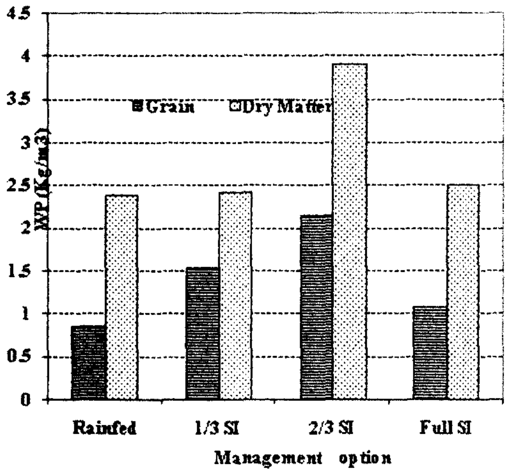

Figure 4. Water productivity (WP) of wheat grains under rainfed, full and deficit irrigation (SI) in northern Syria (Oweis et al. 2003).

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.

Water harvesting:

The drier environments, the steppe or *badia*, occupy the vast majority of the dry areas of the world. The natural resources of these areas are subject to degradation and the income of the people, who depend mainly on livestock grazing, is continuously declining. Due to harsh conditions, people are increasingly migrating from these areas to the cities, with associated high social and environmental costs. Precipitation in the drier environments is generally low compared to crop basic needs. It is unfavorably distributed over the crop-growing season and often comes with high intensity. As a result, rainfall cannot support economical dryland farming. In the Mediterranean areas, rain usually comes in sporadic, unpredictable storms and is mostly lost in evaporation and runoff, leaving frequent dry periods during the crop growing season. Part of the rain returns to the atmosphere by evaporation after it falls, and part usually flows to swamps or to "salt sinks", where it loses quality and evaporates (Oweis et al. 1999).

Water harvesting in agriculture is based on the principle of depriving part of the land of its share of rainwater and adding it to the share of another part. This brings the amount of water available to the target area closer to the crop water requirements so that economical agricultural production can be achieved. It is thus the process of concentrating precipitation through runoff and storing it for beneficial use.
Without water harvesting intervention, all rainwater and land production are lost, while with water harvesting part of the land and most of the rainwater are used in production. Thus, rainwater productivity is immensely increased. Notable wealth of indigenous knowledge on water harvesting is available and documented. Indigenous systems such as *jessour* and *meskat* in Tunisia, *tabia* in Libya, *cisterns* in north Egypt, *hafaer* in Jordan, Syria and Sudan and many other techniques are still in use (Oweis et al. 1999 and 2001). Water harvesting may be developed to provide water for human and animal consumption, domestic and environmental purposes, as well as for plant production. Water harvesting is also effective in combating land degradation and desertification.

Unfortunately, the introduction of systems which have been tested under various climatic, soil, land-tenure and socio-economic conditions are usually not accepted by the target groups. The most significant problems and constraints hindering the integration of water harvesting in the agricultural production are:
- Technology inadequacy to meet the local conditions;
- Lack of acceptance, motivation and involvement among beneficiaries;
- Lack of adequate hydrological data and information for confident planning, design and implementation of water harvesting projects;
- Insufficient attention to social and economic aspects such as land tenure, unemployment and return of water harvesting system;
- Inadequate institutional structures, beneficiary organizations and government training programs for farmers, pastoralists and extension staff;
- Absence of a long-term government policy.

Supplemental irrigation:

Shortage of soil moisture in the dry rainfed areas often occurs during the most sensitive growth stages (flowering and grain filling) of the crops. As a result, rainfed crop growth is poor and yield is consequently low. Supplemental irrigation (SI) can, using a limited amount of water, if applied during the critical crop growth stages, result in substantial improvement in yield and water productivity. Therefore, supplemental irrigation is an effective response to alleviate the adverse impact of soil moisture stress during dry spells on the yield of rainfed crops. Unlike full irrigation, the timing and amount of SI cannot be determined in advance owing to rainfall randomness. Supplemental irrigation in rainfed areas is based on three basic aspects (Oweis and Hachum 2003): Water is applied to a rainfed crop that would normally produce some yield without irrigation, irrigation is only applied when rainfall fails to provide essential moisture for improved and stable production, and the amount and timing of irrigation are scheduled to ensure a minimum amount of water available during the critical stages of crop growth.

Average WP of rain in producing wheat in the dry areas of West Asia and North Africa (WANA) ranges from about 0.35 to 1.00 kg grain/m^3. However, water used in supplemental irrigation can be much more efficient. Studies at ICARDA showed that a cubic meter of water applied at the right time (when crops suffer from moisture stress) and good management could produce more than 2.5 kg of grain over the rainfed production. 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. This stress usually causes a collapse in the crop development and seed filling and reduces the yields substantially. When SI irrigation 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 (rainfall effect is negligible) we find greater advantage with SI. In fully irrigated areas with good management, wheat grain yield is about 6 t/ha using a total amount of 800 mm of water. This makes WP about 0.75 kg/m3, one third of that under SI with similar management (Figure 5). This suggests that water resources are better allocated to SI when other physical and economic conditions are favorable

In the high lands of WANA region, frost conditions occur in the winter and put field crops into dormant condition. Usually, the first rainfall, sufficient to germinate seeds, comes late resulting in low crop stand when the frost occurs. Rainfed yields as a result are much lower than when the crop stand pre-frost is good. Ensuring a good crop stand in December can be achieved by early sowing a and applying a 50-100 mm of supplemental irrigation early in the season.

Applying 50 mm of SI to wheat sown early increased grain yield by more than 60%, adding more than 2 t/ha to the average rainfed yield of 3.2 t/ha (Ilbeyi et al. 2006). Water productivity of wheat reached 3.7 kg grain/m3 of consumed water compared to 1 to 2 kg/m3 under traditional practices (Figure5).

Alternative cropping patterns:

Due to increased water scarcity and climate change, current land use and cropping patterns should be modified if more food is to be produced from less water.

Water is likely to be the major constraint and new land use systems that respond to external as well as internal factors must be developed based on available water. This should include adopting water efficient crops, varieties, and sound combinations of crops in the farming system.

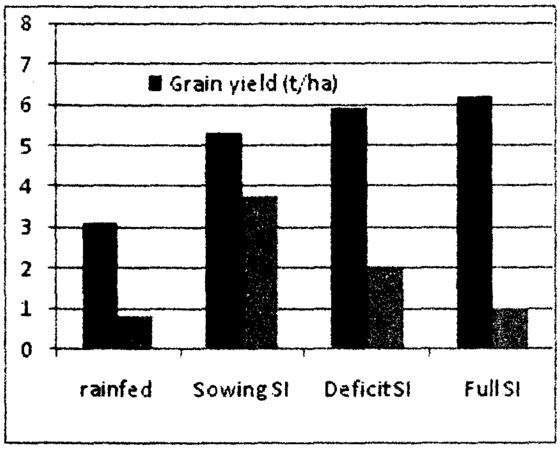

Figure 5. Water productivity and yield of wheat grains under various water management strategies; rainfed, full supplemental irrigation, deficit irrigation and sowing irrigation (Ilbeyi et al. 2006) .

In cases of extreme water scarcity the concept of importing virtual water becomes viable. We do not encourage adopting this concept as a national policy in developing countries as it affects food security. Caution should be taken when evaluating the monetory, social and environmental returns for water and the best crops should be adopted for maximum benefits. Further more, modifications of cropping patterns should be introduced gradually with appropriate policies to encourage adoption.

Precision irrigation:

Improved technologies that already exist may at least double the amount of food produced from present levels of water use. Implementing precision irrigation, such as micro- and sprinkler irrigation systems, laser leveling and others techniques contribute to substantial improvement in water application and distribution efficiency. It is true that water lost during conveyance and on-farm application is not an absolute loss from a basin perspective, but its quality may deteriorate and its recovery comes at a cost. To account for these losses, the size of the irrigation system will significantly increase and this again comes at a very high cost. Policies to implement and transfer these technologies are vital. There is a need to provide farmers with economic and more efficient alternatives to on-farm water management practices with incentives that can bring about the needed change.

Other considerations

Environmental water productivity:

It is now globally understood and accepted that *environment* is a water-using sector, which is strongly linked to the sustainability of water resources development and management. This is a complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-off among social, economic, and political considerations. Strategies to reduce poverty should not lead to further degradation of water resources and ecology. Environmental water needs and that for food production should be complementary for sustainable livelihoods.

Enabling environments:

Lack of appropriate policies and institutional setups are main obstacles for adoption of improved water management options. Valuating water is essential if productiity is to improve. Socio-political constrains do not allow water pricing, but alternatives to pricing can be developed.

Water trading through goods is an old practice. It can be used in countries with extreme water scarcity to reduce inefficient water use; but agricultural practices of rural communities should be protected. Water management institutions such as user associations and community cooperatives are weak in the region and need strengthening. They should be allowed to participate in the decision making regarding water issues. Training is essential to improve skills and participation. These vital changes are essential in order to unlock the potential of water management in agriculture.

Conclusions and recommendations

In the dry areas, water is the most limiting resource for agricultural production and is increasingly declining. As more food in needed with less water available, the only option available is to increase agricultural water productivity. Focusing on water productivity in addition to land productivity is therefore a recommended strategy. To achieve this, more efficient water management techniques must be adopted. On-farm water-productive techniques should be coupled with improved irrigation management options. Major changes needed would include: water allocation to more water-efficient crops/techniques, more water-efficient land use, water valuation to truly reflect its value, trade policy to import high water demand goods, regional cooperation for combating water scarcity and new policies to address water scarcity issues.

Substantial and sustainable improvements in water productivity can only be achieved through participatory and integrated farm resources management. More investment in rainfed agriculture, in reallocating water resources to higher water efficient options such as SI and WH and in improving WP through appropriate policies and institutional set ups is recommended.

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