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# Adapting Agricultural Water Management to Water Scarcity in Dry Environments

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## Abstract

The Middle East is experiencing severe and growing water scarcity. The impact of this scarcity on food security and the environment could potentially lead to sociopolitical instability and conflicts. There is limited potential to substantially increase water resources in this region because of several constraints, including climatic, political, cost, and quality issues. In fact, all global circulation models predict that precipitation, and hence water resources, in the Middle East will decline as a result of climate change in the coming decades. Agriculture, the largest user of water, receives a progressively smaller proportion of total water resources. However, food demand continues to rise as a result of rapid population growth and improved standards of living. Water availability for agriculture is one of the most critical factors for food security in many regions of the globe. It is, therefore, essential for countries across the region seeking stability and food security to produce more with less water—”more crop per drop.”

Conventional approaches seek to increase crop yields (land productivity) while investing in modern irrigation systems, but this approach has major limitations. Higher crop yields generally require more water, which is not available. Modernizing irrigation systems may not result in substantial and real water savings; they increase the field and farm irrigation efficiency, but the overall water savings at the basin or landscape levels may not be proportional.

In water-scarce areas, where water is more limiting than land, the focus must shift from land productivity (yield per unit area) to water productivity, which is the returns (biological, economic, environmental, nutritional,

and/or social) per unit of water used. Research has shown that it is possible to double water productivity in many countries of the region in two decades. This is equivalent to doubling the available water resources. However, this will require major changes in the way we use and manage agricultural water; changes in cropping patterns, irrigation approaches, crop improvement strategies, policies, and institutions; and greater investment in research and capacity development.

Water productivity can be increased by improving crop water management and technologies, such as deficit irrigation, supplemental irrigation, and water harvesting. Simultaneously, countries may cultivate highly water-productive crops while importing crops with lower water productivity. Policymakers must make painful choices to rationalize water use while ensuring access to the poorest households. Resolving the crisis will require enduring progress toward political, social, economic, and administrative systems that shape the use, development, and management of water resources and water delivery in a more effective, strategic, sustainable, and equitable directions.

## Background

Food security at the national level is the assurance that food is available and accessible to meet the current and future minimum requirements of all the people in a country. This, of course, may be achieved not only by producing food internally, but also by securing the resources and ability to import sufficient to cover the food deficit. Food insecurity is a major concern of all countries in the Middle East. Arab countries imported over 70 million tons of grains in 2011, more than half of their needs, and the gap between national needs and production is widening. A major concern arose during the 2007–2008 world food crisis, when wealthy countries in the Gulf were unable to buy wheat because of market shortages. Many countries started allocating resources to enhance food self-sufficiency, although at much higher costs and water consumption. Constraints are mainly associated with water scarcity but also unfavorable climate and/or degraded land resources and investment (Solh 2011).

The amount of water available for agriculture is one of the most critical factors for food security in many regions of the world. Strong relationships among water scarcity, food production, and food security were established and will be clearer in the coming decades (Rosegrant and Cai 2001). Water scarcity and quality are potentially serious threats to food security and health in dry areas. There is a direct relationship between access to water and access to food and feed security. The proportion of the population without access to reliable, uncontaminated water is as high as 78% (ICARDA 2007). It may be noted that the food needs of a person with an average consumption of 2,500 calories per day would require, on average, about 2.5 $m^3$ of water to produce. This is equal to over 1,000 $m^3$ per capita per year, which is the water poverty level declared by UNESCO.

In the Arab countries, rapid population growth since the mid-1970s has caused a shrinkage in per capita renewable water resources from an average of 2,925 $m^3$/year in 1962 to 1,179.6 $m^3$/year in 1992. It shrunk further to an alarming 743.5 $m^3$/year in 2011, which is below the poverty line of 1,000 $m^3$/year and far below the world average of 7,240 $m^3$/year. Fifteen Arab countries already face water scarcity, with average water availability per capita below the poverty line. Twelve countries are under the 500 $m^3$/year threshold set by the World Health Organization for severe scarcity, and seven countries are below 200 $m^3$/year. By 2030, the effects of climate change will have reduced renewable water resources by a further 20% and increased the frequency of droughts as a consequence of decreasing precipitation and increasing domestic and agricultural water demand as temperatures rise. We will also experience expanding seawater intrusion into coastal aquifers as sea levels rise and groundwater overexploitation continues (UNDP 2013).

The second major conventional water resource in the region is groundwater. Shallow and deep groundwater resources, within or across national boundaries, are recharged by precipitation and by rivers. In several countries, groundwater contributes more than 50% of the total water withdrawals, and in some areas it is the only resource available. Nonrenewable or fossil aquifers are used mainly for agricultural expansion and development. Most Middle Eastern countries draw heavily on groundwater to meet rising demand. Their overexploitation and depletion have severe environmental consequences in addition to depleting national assets. Mining groundwater resources has resulted in rapid depletion of aquifer reserves, salinization, and deterioration in water quality. In addition they are threatened by pollution from agricultural, industrial, and domestic activities (UNDP 2013).

In many countries of the Middle East, securing water needs for domestic use—let alone for agriculture, industry, and recharge—is a serious challenge

(FAO 2011). Current water supplies will not be sufficient for economic growth in many countries of the region. Water scarcity has already hampered development in several countries and is increasingly affecting others. It is essential that we make major changes in the way water is managed to alleviate poverty, promote economic growth, and prevent conflicts. The recent UNDP report on water referred to the ″water crises″ in the Arab region and suggested that ″resolving the crisis will require enduring progress towards political, social, economic, and administrative systems that shape the use, development, and management of water resources and water delivery in a more effective, strategic, sustainable, and equitable direction″ (UNDP 2013).

About 80% of the total water resources in the region are used to produce food. With fast-growing populations and improvements in living standards, more water is diverted to other priority sectors, such as domestic and industrial consumption, leaving less water for agriculture. Ironically, as water for agriculture is declining, more food is needed and food security in the region is being increasingly threatened. If nonagricultural consumption continues to grow at the present rates, the share of agriculture in several Middle Eastern countries will drop to 50% in 25 years. In several countries, such as Jordan, marginal-quality water will soon become the major source of irrigation water (Al-Karaki 2011).

Despite its scarcity, water continues to be misused. New technologies allow farmers to extract groundwater at rates far in excess of recharge, rapidly depleting centuries-old aquifers. The productivity of water in the region is still low, but it varies depending on crop and country. Water scarcity and mismanagement will also accelerate environmental degradation through soil erosion, soil and water salinization, and waterlogging. These are global problems, but they are especially severe in the dry areas (Pereira et al 2002).

The objectives of this paper are to

- highlight the chronic water scarcity and the general misconceptions regarding water savings associated with current traditional practices and methodologies.
- present the recently formulated comprehensive framework on water productivity (WP) to properly describe true water use and benefits.
- suggest some promising ways of coping with increased water scarcity, especially for sustainable natural resources and agricultural development.

## Untapped Water Resources: Limited

The majority of water resources in the dry areas—this includes surface and groundwater resources –are already tapped and used for various needs (UNDP 2013). The technical options listed below might provide additional water resources, but many constraints must be overcome.

### Desalination

Desalination is a potential new water source but is costly and has negative environmental impacts. Half of the world's desalinated water is produced in oil-rich countries of the region. Of this, a large proportion is used in agriculture with very low economic willingness to pay. Desalination capacity has rapidly increased in the last decade because of the increase in water demand and a significant reduction in desalination cost as a result of technological advances. Under the most favorable conditions, the cost of desalinated seawater has fallen below \$0.50/$m^3$ while in other locations the cost is near or above \$1.00/$m^3$. (Ghaffour et al. 2013). The lower costs reported are largely associated with either energy subsidizes or with ignoring environmental costs. As new technologies develop, costs may eventually become feasible to use desalinated water for agricultural use, possibly using natural gas as a source of energy.

### Marginal-Quality Water

The development and use of marginal quality water offer some promise. Potential sources include natural brackish water, agricultural drainage water, and treated sewage effluent. The Middle East has notable amounts of brackish water, mainly in groundwater aquifers, which can either be used directly in agriculture or desalinated at low cost for human and industrial use. Several freshwater aquifers have become brackish as a result of groundwater mining and seawater intrusion. Using brackish water in agriculture can contribute to food production and the environment, but it requires special scheduling to prevent land salinization and degradation of the ecosystem and to develop and select crops that can tolerate some level of salinity.

Treated effluent is an important source of water for agriculture in areas of extreme scarcity, such as Jordan and Tunisia, where it counts for about 25% of the country's water resources. In Egypt, 0.7 billion $m^3$ (BCM) per year of treated wastewater is being used in irrigation. It offers many advantages, as it lacks the uncertainties of surface water resources and can meet a proportional share of the rising water demand from urbanization and population growth. Many factors prevent the expansion of wastewater reuse, however, including social barriers, technical obstacles, and institutional and political constraints (UNDP 2013).

Agricultural drainage is becoming an attractive option. In the last two decades, there has been considerable research on the reuse of drainage water in agriculture and its impacts on the environment. In Egypt, the drainage water from agricultural lands is collected by an extensive drainage network and recycled in the system after mixing with freshwater downstream until it becomes too saline for productive use. Currently about 5.5 billion cubic meters (BCM) of drainage water are being reused, and this is expected to increase to about 10 BCM by the year 2017 (Abdel-Shafy and Mansour 2013).

### Rainwater Harvesting

This represents a real recovery of otherwise lost water and provides opportunities for decentralized, community-based management of water resources. In dry environments, hundreds of billions of cubic meters of rainwater are lost every year through runoff to salt sinks and evaporation from bare soil surfaces as a result of a lack of proper management and sustainable ecosystems development. ICARDA has demonstrated that over 50% of the otherwise lost water can be captured using water harvesting and can be used for agriculture (Oweis et al. 2012). The practice, principles, and methods will be elaborated later in this paper as it is also relevant to improving WP.

### Water Transfers

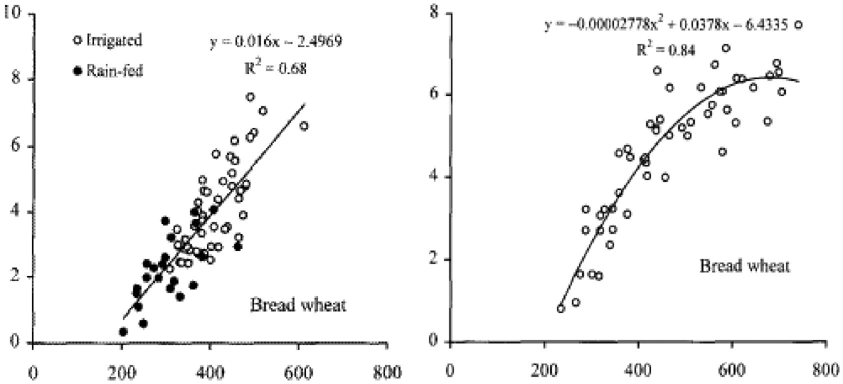
Transfers between water basins and between countries have been extensively discussed in the Middle East over the last few decades. Several countries have considered importing water from other basins. Two projects were proposed, including transportation by pipeline (Turkey's proposed "peace pipeline") and by ships (big tanks or "Medusa" bags). Both options depend on economic, political, and environmental measures. Interbasin transfers may also have significant ecological impacts on both the transferring and receiving basins that are yet to be examined. Attempts have also been made to transfer water by balloons and tankers, but the cost is still too high for agricultural purposes. The peace pipeline project to transfer water from Turkey to the Middle East was unsuccessful because of financial and political constraints (Render 2007). As water scarcity in the region grows, the issues associated with cross-boundary water resources become more relevant. Internationally agreed laws and codes of ethics need to be developed to ensure water rights and to open the way for innovative projects and better regional collaboration.

## Traditional Coping Strategies

Over the last few decades, substantial resources have been spent to increase food production in water-scarce areas. The following strategies used to cope with water scarcity are no longer adequate or effective.

### Increasing Yield Requires More Water

The Green Revolution transformed food production by increasing grain yields several-fold through improved cultivars, better fertility, and water management. Many examples illustrate large yield increases through the proper management of water and cropping systems. However, higher crop yields generally require more water use. While higher yields (production per unit area) reflect more efficient use of the resources, the relationship between biological yield and evapotranspiration is nearly linear (fig. 7-1a). When this relation is nonlinear, higher yields will need even higher rates of water use mainly because of increased evaporation associated with more irrigation and/or precipitation (fig. 7-1b). It is true that the relationships of other yield components, such as grain yield, differ from that of biological



(a) Evapotranspiration (mm)
Yield (t/ha)

(b) Applied water (mm)
Yield (t/ha)

**Figure 7-1.** Relation between grain yield and evapotranspiration (a) and applied water (b) for bread wheat in Aleppo, Syria. *Source:* Zhang and Oweis 1999.

yield (as other factors affect the harvest index), but the relationships are generally positive. Increasing yields are still possible with improved crop varieties, better fertility and cultivation practices, and water management, but this will need a greater supply of water. This is not to say that there is no room for increasing a specific crop yield per unit of land without additional water, as this is possible by improving the harvest index and transpiration efficiency and by suppressing evaporation. But those potential increases are rather limited and may not contribute substantially to solving the water scarcity and food security issues of this region.

Farmers adopt three strategies to improve water use efficiency:

- reducing evaporation from the soil surface, deep percolation and residual water in the root zone.
- Improving the crop's transpiration efficiency.
- Increasing the harvest index.

The three processes are not independent, as targeting specific traits to improve one process may have detrimental effects on the other two, but there may also be positive interactions (Farquhar et al. 2004). Except for increasing the transpiration efficiency, the other processes require more water to increase yields. Drought-tolerant varieties, for example, yield better under drought conditions than water responsive varieties, but their higher yields may use more water.

Drought-tolerant varieties, among other factors, have deeper roots than other varieties, and thus can extract more water from the soil profile when the soil-water level is lower from deeper layers. The extra water taken by a drought-tolerant variety will not be available for crop use in the following season. This means that by increasing yields we do not necessarily save water proportionally. Breeders, especially under rainfed systems, often correlate yield increases with the total amounts of precipitation received during the season and usually do not measure or estimate the actual evapotranspiration. Ignoring residual water in the soil before and after the crop season and soil water movements during the season often underestimates actual crop water use. We usually use more water, which is hidden and not apparent to water users, and a false impression of water saving is often attributed to the crop or to the system.

Generally, substantial increases in crop yields require larger supplies of water, which may not be available. Thus, a yield-targeting strategy, alone, cannot solve the water shortage problem.

## Improving Irrigation Efficiency: The Scale Issue

The term ″efficiency″ refers to the ratio of output to input. It is widely used in irrigation system design, evaluation, and management. Farm irrigation performance is based on four fundamental and interrelated efficiency terms: conveyance, application, distribution, and storage. The first two are the most relevant. Water conveyance efficiency is the ratio of water diverted from the source to that delivered to the farm. It reflects water losses from the conveyance system mainly through seepage, evaporation, and consumptive use by weeds. Irrigation application efficiency is the ratio of the water stored in the plant root zone to that applied to the field. It mainly reflects losses of water through deep percolation and runoff.

Water ″losses″ implied in the above efficiency terms are mostly not real losses. Seepage from irrigation canals and losses from field-level deep percolation are largely recoverable, as they normally join adjacent groundwater and springs. Runoff losses end up in fields downstream. Drainage water can also be recycled and used several times before becoming too saline, as has been done in Egypt (Van Steenbergen and Abdel Dayem 2007). Although most of these "losses" are recoverable, engineers strive to minimize them, as their recovery implies some costs to the user and other implications.

These efficiencies are essential for the design, monitoring, and performance evaluation of irrigation systems, but we must remember some caveats. Increasing application and conveyance efficiencies saves water at the farm level but not necessarily at the scheme or basin level, as lost water can be recycled and reused downstream. And higher irrigation efficiency implies better irrigation performance—but not necessarily higher agricultural production (Kijne et al. 2002).

## Modernizing Irrigation Systems: The Fallacy

Many countries strive to convert traditional surface irrigation to modern systems, such as drip and sprinklers, which achieve higher water application efficiency. The lower efficiency of surface systems is mainly a consequence of low application efficiency. As indicated above, these losses occur at the field level, but often are partially or fully recovered at the scheme or basin levels by recycling drainage and runoff water or by pumping deep percolation losses from groundwater aquifers. (In some occasions these losses are not recovered, as they may join salt sinks or be stored in unreachable locations.) Of course, these are important losses to the farmer, as the recovery has a cost—still, they are not total losses at the larger scale.

Reducing field losses by converting to modern systems will not create substantial additional water resources. In Egypt, individual farmers along the Nile and over the Delta lose on average about 55% of the water they apply through surface irrigation systems in runoff and deep percolation (an application efficiency of 45%). However, the lost water is continuously recycled through the drainage system and groundwater pumping. Only about 10% of the Nile water in Egypt is lost to the sea, which brings the system's overall efficiency to about 90%. Surface irrigation system losses must be understood in the context of scale to evaluate the real nature of losses across the system.

Modern systems such as sprinkler and drip irrigation are meant to be efficient. However, they can be efficient only if they are managed properly. Often they are no more efficient than traditional surface systems because of poor management. It was reported that the modern drip systems in the Jordan Valley are operated at an application efficiency of about 56% or less. Drip irrigation can be very efficient only if the system is well designed and maintained, and if irrigation scheduling is in accordance with crop water requirements. If management is lax, drip irrigation methods become very inefficient, as farmers operate the system much longer than necessary. Surface systems can perform very well if designed and operated properly (Shatanawi et al. 2005). Surge flow furrow irrigation can achieve over 75% application efficiency (Oweis and Walker 1990). Selection of the appropriate irrigation system may not depend solely on its application efficiency, but on physical and socioeconomic conditions at the site.

It is well established that modern irrigation systems can achieve higher crop productivity. But this is achieved not by reducing system losses in deep percolation and runoff, but rather through better control, higher irrigation uniformity, reduced irrigation frequency (less crop moisture stress between irrigations), better fertilization (fertigation), and other factors. In some modern systems, such as drip systems, real water savings can be achieved by reducing evaporation losses, where the wetted soil surface is limited and mulches can be used to further reduce evaporation. The increased land productivity, however, comes at a cost: higher capital, higher energy consumption, and more maintenance requirements. Successful conversion requires a developed industry, skilled engineers, technicians, and farmers, and regular maintenance (Oweis 2012).

Modern systems are most successful in areas where water is scarce and expensive, so that farmers can recover the system cost by reducing irrigation losses and increasing productivity. Where water is cheap and abundant, farmers have little incentive to convert to modern systems. In fact, improving surface irrigation systems through land leveling and better water control may be more appropriate for most farmers in developing countries. The vast majority of irrigation systems worldwide are surface irrigation; this is unlikely to change in the near future. A wise strategy is to invest more in improving surface irrigation, while simultaneously encouraging the use of modern systems when conditions are favorable (Oweis 2012).

## Managing Demand: Not Working

Although water is extremely scarce in the Middle East, it is generally supplied free of charge or at a low and highly subsidized cost (Cosgrove and Rijsberman 2000). Farmers have little incentive to restrict their use of water or to spend money on new technologies to improve the use of available water. International agencies, donors, and research institutes are advocating pricing schemes for water based on total operational costs. Although it is widely accepted in the region that water pricing would improve efficiency and increase investment in water projects, the concept of pricing presents enormous practical, social, and political challenges.

Traditionally, water is considered to be God's gift, to be distributed free to everyone. There is additional pressure from farmers for subsidized inputs. There is also a fear that once water is established as a market commodity, prices will be determined by the market, leaving the poor unable to buy water even for household needs. Downstream riparian countries fear that upstream countries may use international waters as a market commodity in the negotiations on water rights.

One cannot ignore these very real concerns. Innovative solutions are therefore needed to put a real value on water in order to improve efficiency but at the same time abiding by cultural norms and ensuring that people have sufficient water for basic needs. Subsidies for poor farmers may be better provided in areas other than water, so that the subsidies do not encourage inefficiency. Countries must strengthen the recent trend to recover the running costs (operation and maintenance) of irrigation supply systems.

Water pricing and other tools of demand management will reduce the demand for water in agriculture but may not improve agricultural production or poor farmers' livelihoods. It will benefit other water use sectors, but will not contribute to increasing food security.

## Water Productivity: A Comprehensive Framework

Improving irrigation efficiency, although necessary for the better performance of irrigation systems, does not reflect many aspects of agricultural water use, especially the returns to water used. Water productivity is the return or the benefits derived from each cubic meter of water consumed. This return may be biophysical (grain, meat, milk, fish, etc.), socioeconomic (employment, income), environmental (carbon sequestration, ecosystem services), or nutritional (protein, calories, etc.). Table 7-1 presents a range of water productivity values for selected agricultural products. It may be worth mentioning that for each product and productivity type, the range indicates the high and low performances of the production system.

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.) can be reused within the same domain or at a higher landscape scale. More specifically, depleted water includes evaporation, transpiration, water quality deterioration, and water incorporated into the product or plant tissues. Water recycled in the farming system may not be totally lost as implied by evaluating irrigation efficiencies. Water is defined not only by its amount but also by its quality and the time it is available. Various water qualities have different productivities, and it is necessary to establish some benchmarks and thresholds to standardize the unit of water for comparison. The timing of the application has a notable impact on water productivity. Here, the storage (in the soil, in groundwater aquifers, or in surface storage) plays an important role in applying water to crops in time to maximize water productivity.

It is now well understood that water productivity is a scale- or level-dependent issue requiring a multidisciplinary approach (Molden et al. 2010). Drivers to improve it vary with scale. At the field scale it is desirable

**Table 7-1. Water productivity values (biophysical, economic, nutritional, and energy) of selected agricultural products**

| | WATER PRODUCTIVITY | | | |
|---|---|---|---|---|
| **Product** | **kg/m$^3$** | **\$/m$^3$** | **Protein g/m$^3$** | **Calories/m$^3$** |
| **CEREALS** | | | | |
| Wheat (\$0.2/kg grain) | 0.2–1.2 | 0.04–0.30 | 50–150 | 660–4000 |
| Rice (\$0.31/kg) | 0.15–0.6 | 0.05–0.18 | 12–50 | 500–2000 |
| Maize (\$0.11/kg) | 0.30–2.00 | 0.03–0.22 | 30–200 | 1000–7000 |
| **LEGUMES** | | | | |
| Lentils (\$0.3/kg) | 0.3–1.0 | 0.09–0.30 | 90–150 | 1060–3500 |
| Fababeans (\$0.3/kg) | 0.3–0.8 | 0.09–0.24 | 100–150 | 1260–3360 |
| Groundnut (\$0.8/kg) | 0.1–0.4 | 0.08–0.32 | 30–120 | 800–3200 |
| **VEGETABLES** | | | | |
| Potato (\$0.1/kg) | 3.0–7.0 | 0.3–0.7 | 50–120 | 3000–7000 |
| Tomato (\$0.15/kg) | 5.0–20.0 | 0.75–3.0 | 50–200 | 1000–4000 |
| Onion (\$0.1/kg) | 3.0–10.0 | 0.3–1.0 | 20–67 | 1200–4000 |
| **FRUITS** | | | | |
| Apples (\$0.8/kg) | 1.0–5.0 | 0.8–4.0 | negligible | 520–2600 |
| Olives (\$1.0/kg) | 1.0–3.0 | 1.0–3.0 | 10–30 | 1150–3450 |
| Dates (\$2.0/kg) | 0.4–0.8 | 0.8–1.6 | 8–16 | 1120–2240 |
| **OTHER** | | | | |
| Beef (\$3.0/kg) | 0.03–0.1 | 0.09–0.3 | 10–30 | 60–210 |
| Fish (\$1.35\$/kg) | 0.05–0.1 | 0.07–1.35 | 17–34 | 60–175 |

*Source:* Molden et al. 2007.

*Note:* \$ = USD.

to maximize the biophysical water productivity of a specific crop or product. At the farm level, the farmer would like to maximize the economic return from the whole farm, involving one or multiple crops or products. At the country level, the drivers for improved water productivity are food security and exports. At the basin level, competition between sectors, equity issues, and conflicts may drive WP issues. It is important to note that the water productivity concept provides a standardized way of comparing crops and production areas and for determining what to grow and where. Determination of cropping patterns should take into consideration drivers at all scales and all types of water productivity relevant to the population.

In water-scarce areas, water, not land, is the most limiting resource to agricultural development. Accordingly, the strategy of maximizing agricultural production per unit of land (land productivity) may not be appropriate for water-scarce areas. Instead, a strategy based on maximizing the production per unit of water is more relevant. Fortunately, practices for increasing water productivity also improve land productivity to some extent. A tradeoff needs to be made to optimize the use of both water and land resources (Oweis and Hachum 2009). This will require substantial changes in the way we plan and implement agricultural development, which will require a paradigm shift in national policies regarding water use and agriculture. These changes can be achieved in the following ways (Kijne et al 2003).

- Increasing the productivity per unit of water consumed through improved crop varieties; alternative crops (by switching to crops with lower water demand or to crops with higher economic or physical productivity); deficit, supplemental, or precision irrigation; improved water management with better timing of irrigation; and optimizing non-water inputs (such as agronomic practices, policy reform, and public awareness).
- Reducing non-beneficial water depletion by reducing evaporation from soil surfaces in irrigated fields and from fallow land; reducing water flows to sinks (such as salt lakes and the sea); minimizing salinization of return flows and shunting polluted water to sinks to avoid the need to dilute with freshwater; reusing return flows through gravity and pump diversions to increase the irrigated area.
- Reallocating water among uses, including from lower- to higher-value uses, which can dramatically increase the economic productivity of water; tapping uncommitted outflows to be used for productive purposes and improving the management of existing facilities; policy, design, management, and institutional interventions to reduce delivery requirements; adding storage facilities to store and regulate the use of uncommitted outflows.

### Practices to Increase Agricultural Water Productivity

There is a great potential to increase agricultural water productivity, especially in developing countries. A wide gap exists between the biological crop returns to water in developed and developing countries (fig. 7-2). Narrowing this gap appears to be feasible and within reach.

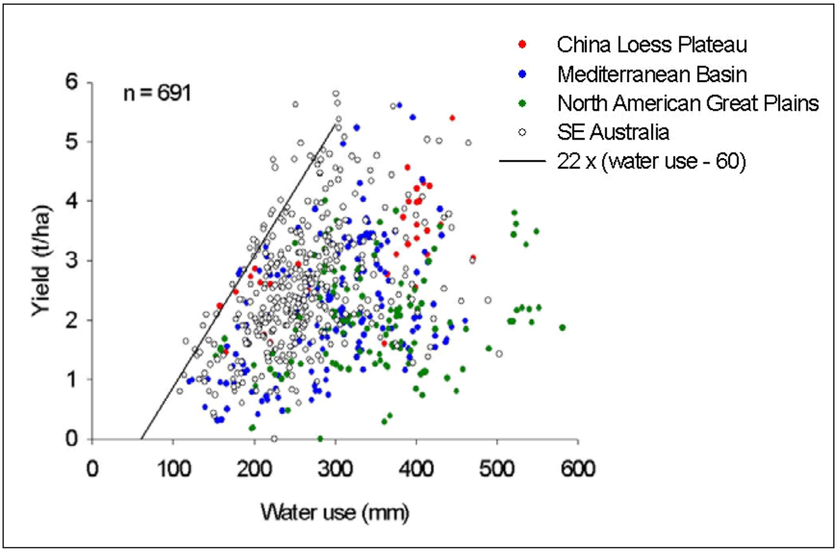


**Figure 7-2.** Variations between yield and crop water use for wheat in different regions of the world. *Source:* Adapted from Sadras and Angus 2006.

The potential increase is greatest in rainfed agriculture—where, in addition, greater public investment is the most feasible (Rockström et al. 2010). Research has shown that a cubic meter of water can produce several times the current levels of agricultural output through the use of efficient water management practices. This is especially relevant when considering benefits beyond the biophysical and including those of an economic and environmental nature (Ilbeyi et al. 2006).

The following sections describe practices that can substantially increase agricultural water productivity.

#### *Deficit irrigation*

Irrigation is usually scheduled to satisfy full crop water requirements to achieve the maximum crop yield per unit of land. Irrigation schedules in water-scarce areas should be adjusted to maximize water productivity. Deficit irrigation is a practice in which irrigation is deliberately scheduled to provide less than full crop water requirements, exposing the plants to some moisture stress, and somewhat lowering the crop yield per unit of land (lower land productivity). It has been found, however, that if deficit irrigation is well scheduled, the percentage reduction in yield arising from the reduced amount of irrigation is smaller than that of the associated water saving. This means that more yield per unit of water used is achieved with deficit irrigation (higher water productivity) (fig. 7-3). The water saved could be used to irrigate new lands—as land is usually more limiting than water—and thus produce more food from the water available.

Results for rainfed wheat obtained from farmers' field trials in Syria show significant improvement in water productivity at lower application rates of supplemental irrigation than at full irrigation. This is especially clear as farmers, in general, tend to over-irrigate. The highest water productivity for applied irrigation was obtained at rates between one-third and two-thirds of that achieved with full irrigation, in addition to rainfall (Pereira et al 2002). One important merit of deficit irrigation in rainfed systems is the greater potential for benefiting from unexpected rainfall because of the higher availability of storage space in the crop root zone.

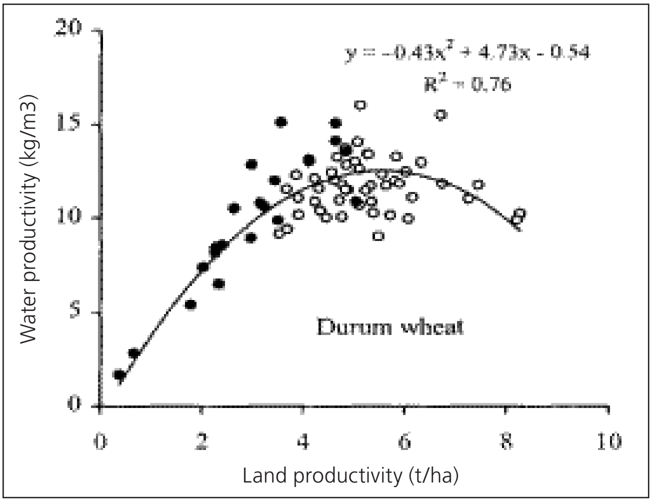


**Figure 7-3.** Relationship between water productivity and land productivity for durum wheat in a Mediterranean environment.
*Source:* Zhang and Oweis 1999.

However, guidelines for crop water requirements and irrigation scheduling to maximize water productivity are yet to be developed for the important crops in dry areas. In particular, it is necessary to develop further the water production functions for various crops and work with economists on evaluating the merits of deficit irrigation and its optimization. National policies, however, need to be adjusted to reward farmers using deficit irrigation by maximizing their returns with improved supplemental irrigation

### *Supplemental irrigation*

A shortage of soil moisture in rainfed agriculture often occurs during the most sensitive growth stages, affecting crop growth, yield, and water productivity. Supplemental irrigation can substantially increase yield and water productivity by applying limited amounts of water during critical crop growth stages to alleviate moisture stress during dry spells. Unlike full irrigation, this practice is used in rainfed areas where precipitation is the main source of water for the crops and farmers normally practice dryland farming if no water source for irrigation is available. Also, the timing and amount of supplemental irrigation cannot be determined in advance given the randomness of the rainfall. The average water productivity of rain in wheat cultivation in the dry areas of West Asia and North Africa ranges from about 0.35 to 1.00 kg of grain/$m^3$. However, water used in supplemental irrigation yields more than 2.5 kg of grain/$m^3$, i.e., in the same environment; supplemental irrigation gives a water productivity twice as high as full irrigation. (Oweis and Hachum 2009).

In the highlands, supplemental irrigation can be used to plant winter crops early, avoiding frost and improving yields. In the highlands of Turkey and Iran, early sowing with 50 mm of supplemental irrigation almost doubled the yields of rainfed wheat and barley and gave water productivity as high as 3 to 4 kg/$m^3$ (Ilbeyi et al. 2006). Clearly, water resources are better allocated to supplemental irrigation when other physical and economic conditions are favorable.

### *Rainwater harvesting*

Precipitation in much of the dry areas is generally too low and poorly distributed for viable crop production. One potential solution is water harvesting, which is defined as the process of concentrating precipitation through runoff and storing it for beneficial use. This brings the amount of water available to the target area closer to the crop water requirements, increasing water productivity and the economic viability of crop production. In areas with higher rainfall, much of the water flows as runoff, eroding fertile soils and leaving the soil profile with little moisture for plant growth. With climate change, rainfall intensities are expected to increase, making things even worse. Water harvesting reduces the runoff velocity and allows more time for infiltration, increasing soil water storage and combating land degradation (Oweis et al. 2012).

A wealth of information on traditional indigenous water harvesting practices is available. 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. Modern practices based on indigenous knowledge, including contour ridges, semicircular bunds, runoff strips, etc., are now available for farmers to use. Water harvesting can provide water for crops, trees, domestic use, livestock, etc. Unfortunately, the introduction of systems that have been extensively tested under similar conditions elsewhere is usually not accepted by the target groups. Several other constraints hinder the wider development of water harvesting systems, including technology inadequacy, lack of community involvement, poor design and implementation, land tenure issues, inadequate institutional structures, and an absence of long-term government policies. Integrated watershed management approaches should be used in the planning of water harvesting where upstream-downstream interactions may be considered (Oweis et al. 2012).

### *Alternative cropping patterns*

Current land use and cropping patterns must be changed if more food is to be produced from less water. New land use systems that respond to external as well as internal factors must be developed based on water availability. These systems should include greater use of water-efficient crops and varieties and more efficient crop combinations. The choice of alternative crops and farming systems should be based on a careful analysis of the biophysical factors as well as the returns from the water used, including income, social, and environmental aspects. New cropping patterns, in particular, must be introduced gradually and will often require policy support to encourage adoption (Molden et al. 2007). In cases of extreme water scarcity it becomes necessary to supplement national food production with imports of ″virtual water″ in the form of products that are less water productive nationally.

### *Precision agriculture and irrigation*

Precision agriculture is the close control of the amounts, timings, and variability of water application and other agricultural inputs to the crop and the system. It provides a way of monitoring the food production chain and managing both the quantity and quality of agricultural produce (Adamchuk and Gebbers 2010). Improved technologies that are currently available can at least double the amount of food produced—with no increase in water consumption—in other words, doubling water productivity. Implementing precision irrigation on laser-leveled land with uniform fertility and other techniques can substantially improve water application and distribution and result in high water productivity. Spatial variations, at the field level, of nutrients and soil-water can be minimized with precision agriculture, resulting in better management and improved outputs (Pereira et al. 2002).

## The Challenge of Change

“Business as usual” is no longer an option for agricultural water management in the water-scarce Middle East. Unless strategic changes are made, the region will face increasing water and food insecurity. New thinking should drive new strategies and approaches backed by concrete action at the country and local levels. Regulatory and legislative reforms in the water sector are needed, rationalizing use and attracting more investment while protecting the most vulnerable sections of the population. Policy support and funding for research and building human and institutional capacity are essential to stimulate technological innovation. Local policies often contribute to the slow adoption of available technologies. Policy reforms can bring about a substantial change in the way we manage water resources. The region will soon face a water crisis unless several strategic changes are made.

- Change the emphasis from land to water. The traditional strategy of maximizing yield per unit of land is appropriate when land is the limiting resource for agriculture. Where water is the limiting resource, strategies should focus, instead, on maximizing water productivity. Policies should foster this change by creating an enabling environment for adoption whereby farmers maximize their profit.

- Change current land use and cropping patterns to more water-productive crops and cropping systems. New cropping patterns need to be studied—based on the comparative advantages of each agroecology—to replace inefficient crops, reduce water demand, and increase competitiveness.
- Change the way water is valued to truly reflect the conditions of scarcity. Since water is generally a common or shared resource, equity and sustainability issues must be carefully considered when policies are being developed.
- Change trade policies to import goods that have a high water demand. Large amounts of water cross borders as virtual water. This needs to be adjusted to reduce water demand and support existing farming systems and the associated socioeconomics.
- Change the attitude toward regional cooperation. Water productivity may be improved at the farm level, but it will not be maximized unless it is tackled at the basin level. This requires regional cooperation, particularly among countries that share river basins.
- Change from a disciplinary to an integrated approach. Narrowly focused or discipline-based research is not adequate to maximize water productivity. Developing productive, sustainable, agricultural systems requires integrating natural resource management with crop improvement and farming systems research.

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