Agricultural Water Management Under Scarcity: 
A Need for a Paradigm Change
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Abstract: The dry areas worldwide are experiencing severe and growing water scarcity. Its impact on food security and the environment, could potentially lead to socio-political instability and conflicts in many countries. Agriculture, the largest consumer of water, receives a progressively smaller proportion of total water resources – while food demand continues to rise. It is therefore strategic for countries with scarce water resources to produce more food with less water.

Key words: water, agriculture, climate

Resumo: As áreas secas, em todo o mundo, estão enfrentando escassez severa e crescente de água. Seu impacto sobre a segurança alimentar e meio ambiente poderia levar à instabilidade sócio-política e conflitos em muitos países. A agricultura é o maior consumidor de água, mas vem recebendo uma proporção cada vez menor do total de recursos hídricos - enquanto a demanda por alimentos continua a subir. Por isso, é estratégico para os países com escassez de recursos hídricos, produzir mais alimentos com menos água.

Palavras-chave: água, agropecuária, clima

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Introduction

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

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 the next 20 years in many locations. This is equivalent to doubling available water resources. However, this will require 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 through 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; virtual water. Policy makers must make painful choices to rationalize water use while ensuring access to the poorest households.

Agriculture, Food Security & Water Scarcity

Water continues to be crucial; but is becoming increasingly scarce, especially in the dry environments, as populations grow and demand increases. The global average per capita available water is about 7000 m$^3$. In some countries, the current figure is below 100 m$^3$ per capita annual. Even in countries with relatively high levels of water per capita, the distribution of water is not uniform across the country and several areas suffer from water scarcity. Groundwater mining is common everywhere, reducing reserves and threatening water quality. In many countries securing water needs for domestic use – let alone for agriculture, industry and recharge – is a serious challenge (FAO 2011). Water scarcity has already hampered development in several areas, 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 conflict.

Agriculture is the major consumer of water. Over 80% of the total water resources 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 industry, leaving less water for agriculture. Ironically, as water for agriculture is declining, more food is needed and food security is being increasingly threatened in many countries.

Despite its scarcity, water continues to be misused. New technologies allow farmers to extract water at rates far in excess of recharge, rapidly depleting centuries-old aquifers. The productivity of water is still low but 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).

Untapped Resources are Limited

The vast majority of water resources in the dry areas, includes surface and ground water, are already tapped and used for various needs. A few technical
options (listed below) might provide additional water resources, but many constraints must be overcome.

(a) **Esalinization** is a potential new source but still expensive, and is mainly developed in oil rich countries. Seawater desalinization costs US$ 1.00-1.80 per m\(^3\). The lower costs sometimes reported are due to subsidized energy. As new technologies develop, costs may eventually become feasible for agricultural use, possibly using natural gas as a source of energy. However, the potential for major breakthroughs is limited by lack of sufficient research funding.

(b) **Marginal-quality water** development and use offers some promise. Potential sources include natural brackish water, agricultural drainage water, and treated effluent. Brackish water can either be utilized directly in agriculture or desalinated at low cost for human and industrial use. Treated effluent is an important source of water for agriculture of extreme scarcity. However, the health and environmental issues must first be resolved. Agricultural drainage is becoming an attractive option. In the last two decades, there has been considerable research on reuse of drainage water in agriculture and its impacts on the environment.

(c) **Rainwater harvesting** is a real recovery of lost water (evaporation and salt sinks) 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 due to lack of proper management. This loss occurs mostly in marginal lands, which occupy a major part of the dry areas. Development of water harvesting systems in these areas can save substantial amounts of water that is otherwise lost. ICARDA has demonstrated that over 50% of this water can be captured and utilized for agriculture if the right methods are used (Oweis et al. 2012). However, policies and socioeconomic aspects require special attention.

(d) **Water transfers** between water basins and between countries have been extensively discussed over the last two decades. Several countries are considered importing water. As water scarcity grows, the issues associated with cross-boundary water resources become more urgent. Internationally agreed laws and code of ethics need to be developed to ensure water rights and to open the way for innovative projects.

**Inadequate Coping Strategies**

Over the last few decades, substantial resources have been spent to increase food production in water scarce areas. The main strategies used to cope with water scarcity are not anymore adequate or effective.

(a) **Increasing yields**

The Green Revolution transformed food production through improved cultivars, which yielded more than twice the old ones, combined with better fertility and water management. Other examples also illustrate large yield increases through proper management of water and cropping systems. However, higher yields generally require more water consumption. While higher yields (production per unit area) reflect more efficient use of resources, the relationship between yield and transpiration is nearly a straight line. This means that by increasing yields we do not save water in the same proportion. Substantial increases in crop yields require larger water supplies, which may not be available. Thus, a yield-targeting strategy alone cannot solve the problem.

(b) **Improving irrigation efficiency**

The term ‘efficiency’ generally refers to 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. The first two are most relevant:
i. 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.

ii. 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.

Water ‘losses’ implied in the above efficiency terms are mostly on paper, not real losses. Seepage from irrigation canals and field deep percolation losses are largely recoverable from adjacent groundwater or springs. Runoff losses end up in fields downstream. Drainage water is also recycled and used several times before becoming too saline. Although most of these losses are recoverable, engineers strive to minimize them as reuse implies some costs to the user and probably other implications.

These efficiencies are essential for 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.

(c) Modernizing irrigation systems

Many countries strive to convert from traditional surface irrigation to modern systems such as drip and sprinklers, which deliver higher water application efficiency. The lower efficiency of surface systems is due to higher deep percolation and runoff losses. As indicated above, these losses occur at the field level but may be partially or fully recovered at the scheme or basin levels by recycling drainage and runoff losses or by pumping deep percolation losses from groundwater aquifers. Of course these are important losses to the farmer and recovering this water has a cost – but these are not total losses at the larger scale. Reducing losses by increasing irrigation efficiency (modern systems) will not create additional water resources. Irrigation losses in Egypt for example are recycled through the drainage systems several times before becoming too saline for agricultural use.

Modern systems such as sprinkler and drip irrigation can be efficient only if they are managed properly. In many areas they are no more efficient than surface systems because of poor management. In fact, surface systems may be better under certain circumstances especially as farmers understand them well. Selection of the appropriate system depends on the physical and socioeconomic conditions at the site.

Modern systems increase productivity not by reducing system losses in deep percolation and runoff, but through better control, higher irrigation uniformity and frequency, better fertilization and other factors. The benefits, however, come at a cost: capital, energy and maintenance. Successful conversion requires developed industry, skilled engineers, technicians and farmers, and regular maintenance. 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. When 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 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

Although water is extremely scarce in dry areas, it is generally supplied free or at low and highly subsidized cost (Cosgrove & 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 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 as 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 for improving 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 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 forms of demand management will reduce demand for water in agriculture but may not increase agricultural production. This will benefit other water use sectors but will not contribute to increased food security.

Water Productivity; A Broader Concept

Improving irrigation efficiency, although necessary for better irrigation systems performance, does not reflect many aspects of agricultural water use, especially the returns to water used. Water productivity (WP) is the return or the benefits derived from each cubic meter of water consumed. This return may be biophysical (grain, meat, milk, fish etc), socio-economic (employment, income), environmental (carbon sequestration, ecosystem services) or nutritional (protein, calories etc.), (Molden et al. 2010). 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 higher landscape scale. 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 water productivity is a scale or level-dependent issue requiring a multidisciplinary approach (Molden et al. 2010).

Drivers to improve WP vary with scale. At the field scale it is desirable to maximize the biophysical WP 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 WP 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 WP 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 WP relevant to the population.

These changes can be achieved in the following ways (Kijne et al 2003):

**Increasing the productivity per unit of water consumed.** This can be achieved through: Using improved crop varieties; growing alternative crops; applying deficit, supplemental, or precision irrigation; improved water management; optimizing non-water inputs; and ensure policy reform and public awareness.

**Reducing non-beneficial water depletion:** Reducing evaporation from water applied; Reducing evaporation from fallow land; Reducing water flows to sinks; Minimizing salinization of return flows; Shunting polluted water to sinks; Reusing return flow.

**Reallocating water among uses:** Reallocating water from lower- to higher-value uses; tapping uncommitted outflows to be used for productive purposes; improving management of existing facilities; policy, design, management and institutional interventions Reducing delivery requirements; adding storage facilities infrastructures.

**Water vs. Land Productivity**

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.

**Livestock Water Productivity**

Livestock are important providers of human food and nutrition in addition to other essential services and income (meat, milk, eggs, blood, hides, cash income, farm power, and manure for fuel and soil nutrient replenishment). They support livelihoods of both the poor and the wealthy in rangelands, rainfed and irrigated crop-livestock agro ecosystems. Livestock production covers about 60% of the land area of developing countries including rangelands and mixed crop-livestock systems. Just like other agricultural production systems, demand for livestock products is increasing which will place substantial new demands on water resources, especially for feed production (Peden et al. 2007).

A livestock water productivity framework was developed through the “Comprehensive Assessment of Water Management” which provided a better understanding of livestock-water interactions. The framework identifies four basic livestock development strategies that can lead to more productive and sustainable use of water resources. These strategies are often needed simultaneously (Peden et al. 2007).

1. improving the sourcing of animal feeds;
2. enhancing animal productivity (products, services, and cultural values) through better veterinary care, genetics, marketing of animal products, and value-added enterprise;
3. Improving watering and grazing practices to avoid degradation of land and water resources; and providing quality drinking water.

Drinking water is essential for animal production, but the amount needed is very small compared with that consumed by animal feed. The efficiency with
which water is used to produce feed and that with which feed is converted into animal products and services largely determines livestock biophysical water productivity. There is widespread perception that livestock water productivity is low compared to crops water productivity. This is true for some animal products but not for all. Nutrition and economic livestock water productivities can be high and justify the water used. In addition, specific nutrients essential for humans may not be found in other food products, hence producing them at any water cost is justified. In Developing country contexts livestock-water interactions are important and under-researched. There are huge opportunities to improve the productivity of water associated with livestock production (Peden et al. 2007).

**High Water-Productive Practices**

Research has shown that it is feasible to at least double the current productivity of water used in agriculture. 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 techniques. Following are selected practices that can substantially increase agricultural water productivity:

**a) Deficit Irrigation**

1. Irrigation schedules should be modified to increase WP. In water-scarce areas, irrigating for less than maximum yield per unit land (deficit irrigation) could save substantial amounts of water. The saved water could be used to irrigate new lands and thus produce more food from the available water. Guidelines for crop water requirements and irrigation scheduling to maximize water productivity are yet to be developed for the important crops in dry areas. This must be done as a priority.

   In deficit irrigation, 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 due to the higher availability of storage space in the crop root zone. Results on wheat, obtained from farmers’ fields trials in Syria reported 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 (Pereira et al. 2002).

**b) Rainwater Harvesting**

Steppe or rangeland areas, which cover the vast majority of the world’s dry areas, are facing rapid environmental degradation and declining livelihoods for local populations. Precipitation in these areas is generally too low and poorly distributed for viable crop production. One potential solution is water harvesting, 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 WP and economic viability of crop production (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 (Oweis et al. 1999, 2001). Water harvesting can provide water for crops, trees, domestic use, livestock etc. It also directly reduces soil erosion and land degradation.

Unfortunately, the introduction of systems which 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 absence of long-term government policies.

(c) **Supplemental Irrigation**

Shortage of soil moisture in rainfed agriculture often occurs during the most sensitive growth stages (flowering and grain filling), affecting crop growth and yield. Supplemental irrigation can substantially increase yield and water productivity, using a limited amount of water applied during critical crop growth stages, and to alleviate moisture stress during dry spells. Unlike full irrigation, the timing and amount of supplemental irrigation cannot be determined in advance owing to rainfall randomness.

Average WP of rain in wheat cultivation 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 yields more than 2.5 kg grain/m$^3$, i.e. in the same environment; supplemental irrigation gives WP twice as high as full irrigation. Clearly, water resources are better allocated to supplemental irrigation when other physical and economic conditions are favorable. In highland areas, supplemental irrigation can be used to plant winter crops early, avoiding frost and improving yields. In the highlands of Turkey and Iran, for example, early sowing with 50 mm of supplemental irrigation almost doubled the yields of rainfed wheat and barley, and gave WP as high s 3-4 kg/m$^3$ (Ilbeyi et al. 2006).

(d) **Alternative cropping patterns**

Current land use and cropping patterns must be 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. This should include greater use of water efficient crops and varieties, and more efficient crop combinations. In cases of extreme water scarcity it may become viable to import ‘virtual water’ in the form of products – but imports from developing countries could threaten their food security. Choice of alternative crops and farming systems should be based on careful analysis of 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 only gradually, and will often require policy support to encourage adoption.

(e) **Precision Irrigation**

Improved technologies that are currently available can at least double the amount of food produced – with no increase in water consumption – if implemented correctly. Implementing precision irrigation, such as micro- and sprinkler irrigation systems, laser leveling and other techniques can substantially improve 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 more profitable, more efficient water management practices to replace traditional methods; and where necessary, to provide incentives to bring about technological change.

**The challenge of Change**

“Business as usual” is no longer an option for agricultural water management in the water-scarce areas. Unless strategic changes are made, these areas 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 slow adoption of available technologies. Policy reforms can bring about a substantial change in the way we manage water resources. The following strategic changes need to be made:

1. The emphasis should change from land to water.
2. Current land use and cropping patterns may change to more water-efficient crops and cropping systems.
3. Change the way water is valued to truly reflect the scarcity conditions.
4. Trade policies adjusted to import goods with high water demand for production.
5. The approaches should change from disciplinary to integrated ones.

**Literature Cited**


