ADAPTING AGRICULTURE AND WATER MANAGEMENT TO WATER SCARCITY IN DRY ENVIRONMENTS

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EXECUTIVE SUMMARY

The Middle East, like other dry areas worldwide, is experiencing severe and growing water scarcity. This is impacting on food security and the environment, and could potentially lead to socio-political instability and even conflicts between 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 essential for countries across the region to produce “more crop per drop”.

Conventional approaches aim to increase crop yields (land productivity) and introduce modern irrigation systems – but this approach has major limitations. Higher crop yields generally require more water. Modernizing irrigation systems may not result in substantial and real water savings; they increase efficiency within the farm, but not overall at basin or landscape level.

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 biological, economic, environmental, nutritional and/or social returns per unit of water used. Research has shown that it is feasible to double water productivity in the Middle East in the next 20 years. However, this will require changes in cropping patters, irrigation approaches, crop improvement strategies, policies and institutions; and greater investment in research and capacity development (Molden et al 2010).

Water productivity can be increased through technologies such as deficit irrigation, supplemental irrigation, water harvesting and improved irrigation technologies. Simultaneously, cropping patterns should be modified, to increase cultivation of highly water

productive crops while relying on virtual water to for crops with low water productivity. Policy makers must make painful choices to rationalize water use while ensuring access to the poorest households.

AGRICULTURE, FOOD SECURITY AND WATER SCARCITY

Development and stability in the Middle East, from pre-historic times, have been shaped by access to water – for example, in the early civilizations along the Tigris, Euphrates and Nile rivers. Water continues to be crucial; but is becoming increasingly scarce as populations grow and demand increases. The average annual per capita renewable supplies of water in Middle East countries is now below 1500 m^3, compared to the global average of about 7000 m^3. Availability was 3500 m^3 in 1960 and is expected to fall below 700 m^3 by the year 2025. In some countries such as Jordan, the current figure is about 150 m^3. Groundwater mining is common throughout the region, 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).

Increasing pressure on water resources will, unless effectively tackled, escalate conflicts and severely damage the already fragile environment in the region. This is particularly true for countries that share water resources. Two-thirds of the Arab people depend on water flowing from outside the Arab countries; about one-fourth live in countries with no perennial water supplies. Considering the importance given to national sovereignty, and the fact that international laws on shared water resources are still inadequate, there is a risk of potential conflicts between two or more countries in the Middle East (FAO, 2011).

Current water supplies will not be sufficient for economic growth in the Middle East region, except in Turkey and Iran. 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.

Agriculture is the major consumer of water. 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 industry, 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. Even if non-agricultural water consumption remains unchanged for the next 50 years, the share of agriculture is projected to drop from 80% to about 50% during this period. If non-agricultural consumption continues to grow at present rates, the share of agriculture will drop to 50% in 25 years. In several countries such as Jordan, marginal-quality water will become the major source of irrigation water.

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 in the region 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 WATER RESOURCES ARE LIMITED

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

1. ***Desalinization*** is expensive, and is currently used only in countries where energy is cheap. For example, in the Gulf region, part of the desalinized water is used for irrigation; and about 913 billion m^3 of fresh water are produced annually for some 18 million inhabitants. 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 research funding.

2. ***Marginal-quality water*** development and use offers some promise. Potential sources include natural brackish water, agricultural drainage water, and treated effluent. Substantial amounts of brackish water exist in dry areas that can either be utilized directly in agriculture or desalinated at low cost for human and industrial consumption. Treated effluent is an important source of water for agriculture in areas of extreme scarcity, e.g. in Jordan and Tunisia, where it counts for about 25% of the country's water resources. Egypt currently produces about 5 billion m^3 per year of recycled water from the city of Cairo. However, the health and environmental issues associated with effluent-irrigation must first be resolved.

Agricultural drainage water is becoming an attractive option. It creates an additional resource for agriculture while protecting natural resources from deterioration. In the last two decades, there has been considerable research on reuse of drainage water in agriculture and its impacts on the environment. In Egypt, reuse increased from 2.6 billion m^3 per year in the 1980s to over 10 billion m^3 in 2010. Two new projects will bring the total reused drainage water to approximately 7.2 billion m^3 per year, some 12% of Egypt's total water resources.

3. Rainwater harvesting: 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.

4. Water transfers between water basins and between countries have been extensively discussed in the Middle East over the last two decades. Several countries are considering importing water. Two options are transportation by pipeline (Turkey's proposed 'peace pipeline') and by ship or barrage (big tanks or 'Medusa' bags). Both options depend on economical, political, and environmental measures, which are yet to be examined. In West Asia and North Africa, attempts have been made to transfer water by balloons and tankers but the cost is still too high for agricultural purposes. The project to transfer water by pipelines from Turkey to Middle East countries was unsuccessful because of economic and political reasons. Such projects can only be realized with cooperation and trust between the various parties. As water scarcity in the region 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.

CONVENTIONAL COPING STRATEGIES: INADEQUATE

Over the last few decades, huge resources have been spent to increase food production in water scarce areas. Below, we describe the main strategies used.

1. Increasing yields requires more water

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.

2. Higher irrigation efficiency may not mean higher productivity

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.

3. Modernizing irrigation systems may not really save water

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).

4. Demand management/water pricing

Although water is extremely scarce in the Middle East, 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 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 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, THE NEW APPROACH

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).

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). 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.

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.

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

1. Increasing the productivity per unit of water consumed

- ***Improved crop varieties*** that give higher yields per unit of water consumed, or the same yields with less water.

- ***Alternative crops:*** switching to crops with lower water demand, or to crops with higher economic or physical productivity per unit of water consumed.
- ***Deficit, supplemental, or precision irrigation:*** offer better water control, and increase the returns per unit of water consumed.
- ***Improved water management:*** better timing of irrigation to reduce stress at critical crop growth stages, leading to increased yields; or by increasing the reliability of water supplies so that farmers invest more in other inputs, leading to higher output per unit of water.
- ***Optimizing non-water inputs:*** in association with irrigation strategies that increase WP, agronomic practices such as land preparation and fertilization can increase the returns per unit of water.
- ***Policy reform and public awareness:*** water use and valuation policies should be geared towards controlling water use, reducing water demand, safe use and disposal of water, and encouraging collective water management by users.

2. Reducing non-beneficial water depletion

- ***Reducing evaporation from water applied*** to irrigated fields through specific irrigation technologies (e.g. drip irrigation) or agronomic practices such as mulching, or changing planting dates to match periods of low evaporative demand.
- ***Reducing evaporation from fallow land***, decreasing the area of free water surfaces, decreasing non-beneficial vegetation, controlling weeds.
- ***Reducing water flows to sinks***—by interventions that reduce recoverable 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.

3. Reallocating water among uses

- ***Reallocating water from lower- to higher-value uses.*** Reallocation 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 greater benefits from existing water supplies.
- ***Policy, design, management and institutional interventions*** can stimulate 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, which are available in most wet years. This will make more water available for release during drier periods.

PRACTICES TO INCREASE AGRICULTURAL WATER PRODUCTIVITY

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). ICARDA and other research centers have 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. The following section describes some practices that can substantially increase agricultural water productivity:

Deficit Irrigation

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).

Water 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.

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).

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.

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 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 slow adoption of the many available technologies. Policy reforms can bring about a substantial change in the way we manage water resources. Water is the biggest constraint to sustainable development in the Middle East. The region will soon face a water crisis unless several strategic changes are made:

a) ***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: the return from a cubic meter of water rather than a square meter of land.

b) ***Change current land use and cropping patterns*** to more water-efficient crops and cropping systems. Many crops that are grown in water-scarce areas are in fact unsuitable for these conditions; more efficient alternatives are available. New cropping patterns need to be studied – based on comparative advantages of each agro-ecology – to replace inefficient crops, reduce water demand and increase competitiveness.

c) ***Change the way water is valuated*** to truly reflect the scarcity conditions. Since water is generally a common or shared resource, equity and sustainability issues must be carefully considered when policies are being developed.

d) ***Change trade policies*** to import goods with high water demand for production. Large amounts of water cross borders as virtual water. This needs to be adjusted to reduce water demand and support existing farming systems and associated socioeconomics.

e) ***Change the attitude towards regional cooperation.*** Water use efficiency may be improved at the farm level but will not be maximized unless it is tackled at the basin level. This requires regional cooperation, particularly among countries that share river basins. Water scarcity, and associated environmental problems across basins must be tackled collectively by neighbors, through data exchange, transparency and collective policies and decision-making.

f) Change from disciplinary to integrated approach. Narrowly focused or discipline-based research is not adequate. Productivity can be maximized only if all production elements are optimized; this requires integrating natural resource management (including water management) with crop improvement and farming systems research, to develop productive, sustainable agricultural systems.

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