TOWARDS FOOD SECURITY:
PROMISING PATHWAYS FOR INCREASING AGRICULTURAL WATER PRODUCTIVITY

by

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Abstract

Today the competition for scarce water resources in many places is intense. The lack of water in most developing countries, particularly those in arid and semi-arid regions, is the major constraint to producing food for hundreds of millions of people. Agriculture is central in meeting this challenge. On the globe, nearly 70% of the available water resources are allocated to food production and agricultural products but, unfortunately, with enormous water losses exceeding 50%.

To meet the acute freshwater challenges facing humankind over the coming 50 years and to fulfil the food gap to feed 8-9 billion people, directing all the efforts to improve water use and management in agriculture is now a must.

The hope lies in closing the gap in agricultural productivity and in realizing the unexplored potential through water management along with realistic changes in the policy agenda, production techniques and implemented strategies.

Many promising pathways for raising water productivity are available by adopting proven agronomic and water management practices. However, despite adequate technologies and management practices, achieving net gains in water productivity is facing numerous constraints with low adoption rates. The adoption of such techniques requires an enabling policy and institutional environment that aligns the incentives of producers, resource managers and society and provides a mechanism for dealing with trade-off.

This paper will examine in detail the promising pathways to achieving higher water productivity and the major constraints and it will also discuss the changes needed in the policy agenda and water management strategies highlighting the needed policy action.

Introduction

Historically irrigation represents between 70-80 percent of all water uses with some countries using 90 per cent or more for irrigation. This percentage is changing as more and more countries face water shortages. It is estimated that over 1 billion people now live in countries and regions where there is insufficient water to meet food and other material needs.

An outlook on the future, in the few coming years, by the year 2030, over 60 percent of the population will live in urban areas (UN 2003), claiming an increasing share of water abstraction. Much of this water will have to come from agriculture, not because agriculture is receiving the lion share of the available water, but, mainly due to the fact that there is a high potentiality to reduce water losses and increase water saving in the irrigation sector in comparison with the other sectorial water uses.

Reducing losses in this field would be a win-win solution, permitting not only to obtain an ample new water supply for meeting the needs of the expanded irrigated area and to fill the chronic food gap, but also to satisfy the increasing water requirements in the other sectors, thus eliminating the otherwise unavoidable conflicts.

FAO (2003) has estimated- that overall water use efficiency in irrigation ranges around 38 percent in developing countries and has projected only a minor increase in overall water use efficiency in the forthcoming decades.

Ways must be found to increase water use efficiency in both irrigated and rainfed agriculture and, also, integration of food production systems. It is equally essential that efforts are launched to keep the demand for water intensive food items within reasonable limits. Ingenious management and sound stewardship of the entire water resources are required.

Rather than water use efficiency, the concept of water productivity is now widely accepted as a measure of performance in agricultural water use. By definition it represents the output of any production process expressed per unit of a given input in this case water. Generally, it is clearly documented that water productivity levels in today large irrigation systems are well below the potential in many areas. A comparatively liberal supply and heavily subsidised water encourages inefficiency and lack of reliability (Molden et al. 2003).

Increasing the productivity of water in agriculture will play an important role in easing competition for scarce water resources, prevention of environmental degradation and provision of food security. The argument for this statement is simple by growing more food with less water, more water will be available for other natural and human uses (Molden and Rijsberman, 2001, Rijsberman 2001).

However, improving the productivity of water in agriculture through an appropriate water management is not an easy process. Significant challenges still remains in the areas of technological, managerial and policy innovation and adaptation, human resources development, information transfer and social environmental considerations. Our success and/or failure is a matter of our capability in finding sustainable solutions to the challenges.

Water productivity and its means

Water productivity in its broadest sense reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water used, where water use means either water delivered to a use or depleted by a use.

Physical water productivity is defined as the ratio of the mass of the agricultural output to the amount of water used and economic productivity is termed as the value derived per unit of water used.

Simply, water productivity means growing more food or gaining more benefits with less water. In other words, the more: we produce with less water or even, with the same amount of water; the less: the need for infrastructure development, the competition for water; the greater, the local food security and the more: water for agriculture, household and industrial uses and the more that remains in nature (Hamdy and Lacirignola, 2005).

Food, water and productivity links

The amount of water consumed in producing today's diets is on average 1,200 m3/P yr but with large variations between different world regions (Rockstrom et al., 1999). It varies from 600 m3/P yr in the poorest regions up to 1,800 m3/P yr in richest regions with the most meat based diets.

The food production in hot arid regions requires relatively much more water per kilo biomass as compared with cool climate regions. The consumptive water use in the latter regions is almost about 3 m3/kg cereal whereas it is much less in the former regions amounting to nearly 0.38 m3/kg (Fraiture et al.,2004) (Table1). Differences in yield are, however, also mirroring differences in management and the economic status of the countries. According to Rockstrom (2003), the net amount of water required for an acceptable nutritional level based on 80% vegetarian, 20% animal has been estimated as 1,300 m3/P yr, whereas for purely vegetarian is about half of that.

Table 1 – Crop water productivity for selected importers and exporters of cereals

Selected Exporters Countries			
Selected exporters 1995	**Exporters as % of world's total**	**Water productivity in kg/m^3**	**% met by irrigation**
USA Canada West Europe Argentina Australia India	48% 10% 10% 7% 5% 3%	1.26 0.88 1.59 0.49 0.54 0.34	15% 4% 5% 5% 28% 41%
Exporters Average	=	***0.81***	***26%***
Selected Importers Countries			
Selected importers 1995	***Importers as % of world's total***	***Water productivity in kg/m^3***	***% met by irrigation***
Japan China Egypt Indonesia Iraq Sub Sahara Africa	14% 14% 4% 5% 1% <1%	0.73 0.75 0.78 0.51 0.21 0.19	73% 46% 97% 23% 89% 2%
Importers Average	=	***0.49***	***4%***
World Average Average weighted by the countries total production		***0.60***	***34%***

In assessing tomorrow's water needs to feed the two billion increase in population, we must also take into account what will be the water needed to eradicate the poor people under nourishment. With a water productivity at the current level, the additional consumptive water needs can be calculated to another 3,800 km3/yr by 2025, growing to 5,600 by 2050. The 3,800 km3/ye is a huge amount and close to all the water withdrawals at present to support municipal, industrial and irrigation needs. The most important questions are: *how and where to find all this water or, alternatively, what the options and the possibilities to be followed to meet the tremendous increase in the water demand?*

Water productivity: the net gains

Despite adequate technologies and management practices, achieving net gains in water productivity is rather difficult due to numerous reasons, among them:

- gains achieved by one group often come at the expense of another;
- incentive systems do not support the adoption of existing technologies, and
- gains are often captured by more powerful users and the poor are left behind.

However, what is to be stressed here is that, in spite of the above mentioned constrains, net gains in water productivity are to be potential in certain areas having specific features, such as:

- areas where poverty is high and water productivity is low; where improvement could particularly benefit the poor. For the rural poor more productive use of water can mean better nutrition for families, more income, productive employment and greater equity;
- areas with physical water scarcity and intense competition for water where gains in economic water productivity are possible;
- areas where water resources development is limited; targeting high water productivity can reduce investment costs by reducing the amount of water that has to be withdrawn; and
- areas of water degraded eco-system such as falling ground-water tables, river dessication and intense competition for water.

The importance of increasing the water productivity, particularly in the arid regions, and in improving food security was studied by Cai and Rosegrant (2003). Their analysis of water productivity at global and regional levels through a holistic modelling framework (IMPACT-Water) showed that from 1995 to 2025 water productivity will increase. The global average water productivity of rice and other cereals will increase from 0.39 kg m^{-3} to 0.52 kg m^{-3} and from 0.67 kg m^{-3} to 1.01 kg m^{-3} respectively. Both the increase in crop yield and improvement in basin efficiency contribute to the increase in water productivity, but the major contribution comes from increase in the crop yield.

Assuming that such expectations are valid future options, in order to increase water productivity and ensure food security in the next 25 years, it is to be evident that investments in agricultural infrastructure and agricultural research might have higher pay-offs than investments in new irrigation (Fan et al., 1999).

Increasing the water productivity is the appropriate answer to meet the future challenges towards water and food security, particularly in the arid and semi-arid regions where water supply is becoming more and more restricted due to source availability and financial constraints.

However, this implies large improvements in the basin efficiency in order to increase significantly the water productivity and reduce water withdrawal constraints.

Water productivity and MDG's development

Improving agricultural water productivity is of crucial importance in meeting the complex challenges the agricultural sector is already facing, particularly the ones regarding the Millennium Development Goals on the path towards freeing humanity of extreme poverty and hunger and ensuring environmental sustainability.

This would lead us to what are the options and tools to be implemented that could lead us to reasonable answers to meet our future water and food need in order to reduce rural hunger and alleviate poverty. The key element is mainly a matter on the way we are using and managing our water resources in the agriculture sector. The sustainable use of water in irrigated agriculture is not one way solution but it consists of crucial issues and options to be put all together to provide a better understanding of the problems and their consequences, possible solutions and the interconnections and trade-offs among them. An intensive work is needed to modernize irrigated agriculture, through technological upgrading and institutional reform will be essential in ensuring much-needed gain in water productivity. This will not only require changes in attitude, but, also well targeted investments in infrastructure modernization, institutional restructuring and upgrading of the technical capacities of farmers and water managers.

Improving the productivity of water in agriculture requires the integrated efforts of many players. This does not fall in the domain of one group of specialists, but, rather requires the efforts of breeders, natural resource management specialists, physical scientists, sociologists and above all the synergistic efforts of the farmers and the water resources managers.

At present, if our knowledge is combined to the maximum effect, a notable improvement in agricultural water productivity could be achieved and thereby meeting the complex challenge: *producing more food of better quality while using less water per unit of output.*

Increasing water productivity and why it is needed

Politically and technically it is well recognised that improving water productivity in agriculture is the immediate answer to the question: *whether we will be able to produce enough food to feed the burgeoning population in the developing countries and get it to where it needs?*

However, to answer the raised question, major efforts are still needed on: *how can water productivity be increased in the agricultural sector and what are the different promising pathways to be developed?* Evidently, achieving greater water productivity to resolve the water crisis will not happen automatically, it will require great efforts but it is possible specially in developing countries, where water productivity is far below potential. For cereals grains, as an example, the range in water productivity in dry biomass produced is between 0.2 and 1.5 kilogram per cubic meter. As a rule of thumb, the value should be about 1 kilogram per cubic meter (IWMI, 2000). If a country's demand for grains grows by 50%, one way to match this rise is to increase water productivity by 50%. Meeting this challenge will require a far greater effort and significant changes in how water is managed (Hamdy et al., 2003).

Experiences and learned lessons demonstrate that the adoption of techniques to improve water productivity require an enabling policy and institutional environment that aligns the incentives of producers, resource managers and society and provides a mechanism for dealing with trade-off (Molden, 2007).

Increasing water productivity: major principles

The key principles for improving water productivity at field, farm and basin level, which apply regardless or whether the crop is grown under rainfed or irrigated conditions are:

(i) to increase the marketable yield of the crop per each unit of water transpired;
(ii) to reduce all out flows (e.g.: drainage, seepage and percolation, including evaporation outflows, other than the crop stomatal transpiration), and
(iii) to increase the effective use of rainfall, stored water and water of marginal quality.

The first principle relates to the need to increase crop yields on values. *The second one* aims at decreasing all losses, except crop transpiration. The *third principle* aims at making use of alternative water resources. *The second and third principles* should be considered parts of basin-wide integrated water resources management (IWRM) for water productivity improvement.

The three principles apply at all scales, from plant to field and agro-ecological levels. However, option and practices associated with these principles require approaches and technologies at different spatial scales. The productivity of water expressed as mass per unit of water transpired (or ET) is a basic measure of water productivity, valid at any scale. Some promising pathways to increase the productivity of water at each scale of interest are described below.

Opportunities for increasing water productivity at farm level

To increase crop per drop, either production must be increased keeping water constant or the same amount of production must be maintained while using less water. There are a number of different strategies by which farmers can improve water productivity values, including the following:

- ***Increasing the productivity per unit of water consumed (transpiration).***

  There are several possibilities to enhance the production per unit transpiration:

- *changing crop varieties*. Plant breeding plays an important role in developing varieties that yield more mass per unit transpiration. For example by reducing the growth period while keeping the same yield, the production per unit transpiration increases;

- *crop substitution.* Different crops vary dramatically in their water use, and in their economic returns. Farmers can switch from a more to a less water consuming crop or switch to a crop with higher economic or physical productivity per unit of water consumed by transpiration;

- *deficit, supplemental or precision irrigation.* With sufficient water control, as well as by irrigation strategies that may not meet full evaporative requirements, but instead, increase return per unit of transpiration, it is possible to achieve more productivity per unit of water;

- *improved water management.* Better timing of water supply or better timing of the crop cycle can reduce stress at critical crop growth periods leading to increased yields. By increasing reliability of supply, farmers are motivated to invest more in other agricultural inputs leading to higher output per unit of water;

- *improving non-water inputs* in association with irrigation strategies that increase the yield per unit of water consumed; agronomic practices such as land preparation and fertilization can increase the return per unit water.

• ***Reducing non-beneficial evaporation or flows to sinks***

The first task to reduce non-beneficial depletion is to carefully identify these flows, remembering that water diverted primarily for agriculture may serve other beneficial purposes. Lessening of non-beneficial evaporation can be achieved by reducing evaporation from water applied to irrigated fields through irrigation technologies (e.g., drip irrigation), agronomic practices (e.g., mulching), changing crop or planting dates to match periods of less evaporative demands. Other action could be by controlling evaporation from fallow land by decreasing area of free water surface, decreasing non-beneficial or less-beneficial vegetation and controlling weeds. Also, the interventions that reduce irrecoverable surface runoff or deep percolation are recommended in order to reduce water flows to sinks.

• ***Pollution control: water pollution***

One of the major problems seriously affecting the availability of the water resources and the degradation of water quality are now major causes leading to water scarcity in most developing countries. Stopping and controlling water pollution can effectively increase the available water resources for the re-use. The water resources pollution is to a great extent a function of the water return flows quality. This implies minimizing the mobilization of salts into recoverable irrigation return flows as well as shunting saline or otherwise polluted water directly to sinks. In addition, further efforts should be directed towards reducing pollution entering irrigation water supplies through return flows of municipal and industrial uses as well as those originated from rainfed and irrigated agriculture.

• ***Reallocating water among uses***

Reallocating water from lower to higher value uses (from agriculture to municipal and industrial uses or from low value to higher value crops) will generally not result in any direct water saving, but it can dramatically increase the economic productivity of water. Because downstream commitments may change, such reallocation can have serious legal, equity and other social considerations that must be addressed.

• ***Tapping uncommitted outflow***

Even with present level of infrastructure development, there is much out flow beyond downstream commitments that could be tapped.
This can be done by improving management of existing facilities to obtain more beneficial use from existing water supplies. A number of policy, design, managed and institutional interventions may be helpful allowing for an expansion of irrigated areas, increased cropping intensity or increased yield within the service areas. Another approach to be practiced is by adding storage facilities so that more water is available during drier periods. Storage take many forms including reservoir impoundments, groundwater aquifers, small tanks and ponds on farmer’s fields.

Increasing water productivity: strategy selection

Deep analysis of the forementioned strategies can be seen clearly that within each of these broad strategies, more detailed measures can be identified. The choice of strategy for increasing water productivity will be guided by economic and social factors. Existing water rights will often constraint choices, especially when there are options of reallocation. In such cases, the basis of water rights may need to be reconsidered. Local availability of water will be an important consideration dictating in improvement strategy. In choosing among various strategies, cost effectiveness is a central consideration.

Of interest to indicate that the previous presented strategies include a wide range of variable options. A part of those options are related to plant physiology which focus on making transpiration more efficient or productive and some are dealing with agronomic practices by the aim of reducing evaporation, beside others, those focussing on farm agricultural engineering approaches in order to make water application more precise and more efficient. Indeed the presence of such variable options is clearly indicate that many of these different strategies could be combined together and that each strategy is complementary to the other. However, it is important to distinguish carefully between the different strategies as they require specialist skills that are significantly different. Also, it is equally important to distinguish the level at which we are measuring water productivity even, at farm level, we can have different values depending on whether we focus on the plant, the field or the whole farm.

Crop per drop improvement and food security

Increasing agricultural output per drop of water depleted, i.e. increasing crop water productivity, will allow more food to be grown with less water. There is tremendous potential for water productivity gains in rainfed and irrigated areas. This will require a combination of agronomic, economic and social interventions including crop breeding, soil and fertility management, irrigation water management and water rights and allocation of blue water supplies. Some of the approaches for increasing crop water productivity and the expected gains in both irrigated and rainfed agriculture are discussed below.

Irrigated agriculture: on-farm integrated water management

In irrigation production gains can be made with a shift in irrigation management practices. Policies of water resources management should look at the whole set of technical, institutional, managerial, legal and operational activities required to plan, develop, operate and manage the water resources systems at all scale, i.e. farm, project, basin and national scale, while considering all sectors of the economy that depend on water. Economic constraints are particularly important in developing sustainable water management options. This means that sustainable development and use of water resources should be computable with the principles of sustainable economic activities.

The strategy for integrated natural-resources management should respond to the urgent need for improved productivity using less water at the farm level. Focus should be directed towards developing on-farm packages for increased water productivity and soil and water qualities as well as on the conservation and sustainable utilization of renewable groundwater resources.

For reducing water losses in irrigated agriculture and thereby increasing crop water productivity close attention is required to water flow paths-reducing unproductive evaporation and eliminating flows that encourage salinisation, high water tables or cause ecologic damage.

Adoption of deficit irrigation

Deficit irrigation is an optimising strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (English et al.,1990). The adoption of deficit irrigation implies that the relationship between yield and water deficit has to be well known when planning deficit irrigation. In addition, it requires knowing the appropriate knowledge on crop water use and response to water deficits within the whole cropping period and during the critical growth stages. Implementation of deficit irrigation although seems to be a sounding strategy for water saving and improving crop water productivity, yet, the decision on optimal strategies under varying conditions is a complex one, especially in rainfed areas where year to year amount and rain distribution vary much. Furthermore, selection of the optimal strategy is greatly influenced by the level of water scarcity. Indeed, the existing literature on deficit irrigation does not provide firm and ready to use information, hence, there is a great need for application research in this area.

From the practical point of view, there are different ways to manage deficit irrigation. The irrigator can reduce the irrigation depth, refilling only part of the root-zone soil water capacity, or reduce the irrigation frequency by increasing the time interval between successive irrigations. In surface irrigation, wetting furrows alternatively or placing them further part is one way to implement deficit irrigation.

However, whatever, the approach to be followed for managing deficit irrigation, the gaining benefits in optimising water use and improving water productivity is a function of different important management factors including the selection of crop variety, the crop rotation, sowing dates, crop density, soil fertility management and weed, pests and diseases control.

Beside the crop management practices soil characteristics such as depth, texture, structure and crusting, salinity and fertility are major soil factors affecting the water productivity. Those soil factors are governing the maximum amount of water that can be stored and hence the effective length of the growing season. In dry areas, tillage (form, depth, frequency and timing) and soil surface management, all, play an important role in enhancing water productivity.

Soils of good characteristics and through an appropriate crop management practices, both, can considerably increase the efficient use of available water from precipitation and irrigation and, thereby, maximizing its use through increasing the water supply to crops, increasing their transpiration and reducing evaporation from the soil surface (Gregory, 1991).

Water productivity improvement under rainfed agriculture

It is quite evident that huge amounts of water are being consumed in connection with food production. However, the amount available on the planet does not change. In agriculture, although much of the debate is focussed on irrigated crop production, the world, in fact, depends for most of its food on rainfed agriculture (Rockstrom, 2001). The rainfed areas plays an important role in the production of food in many countries around the world. They cover more than 80% of the land areas for cropping throughout the world and produce some of 60% of the total production (Harris, 1991).

In arid and semi-arid countries, particularly those characterised with growing water scarcity, water is a crucial component to achieve food security. In those countries to achieve improved food self sufficiency, i.e. to produce more food to feed the increasing growing population will require an increase in the water supply which is nowadays questionable. But in such countries there exists at the same time a huge window of opportunity since most of the farmers rely on rainfed agriculture.

In those water stressed areas, producing with less water, may be the only option to ensure food security.

The challenge involves nothing less than a revolution in terms of upgrading rainfed agriculture where present yield levels are under of low values 0.5 to 1.0 ton grains per hectare leading to extremely low water productivity.

In rainfed areas dry spell occurrence is a key constraint and, therefore, an entry point for upgrading. Mitigation of dry spells with on-farm water harvesting or supplemental irrigation can potentially triple water productivity.

A 10 fold variation of water productivity in terms of value of output per water depleted has been observed – due largely to how water is managed. Prospects for such an upgrading must be scrutinised and the mechanisms for a successful implementation identified and assessed. Management implications and social acceptance are key conditions. In this regard, in rainfed dry areas, the productivity of both irrigation water and rain-water is improved when they are used conjunctively (Table 2). When supplementing rainfall by irrigation the rain-water productivity (WPR) on average increased from 0.96 to 1.11 kg m^{-3} (Oweis, 1997). Furthermore, research from ICARDA and others showed that using irrigation water conjunctively with rain-water more wheat is produced per unit of water than if used alone in fully irrigated areas where rainfall is neglected (Oweis and Hachum, 2003).

Table 2. Rain-Water Productivity (WP_R) combined Rain and Irrigation Water Productivity (WPR_{+I}) and Irrigation Water Productivity (WP_i) of bread-wheat grains in Northern Syria

Year	**Rain** (mm)	**WP_R** (kg m^{-3})	**S_i** (mm)	**WPR_{+I}** (kg m^{-3})	**WP_i** (kg m^{-3})
1991/92	351	1.04	165	1.16	1.46
1992/93	287	0.70	203	1.23	2.12
1993/94	358	1.08	175	1.17	1.43
1994/95	318	1.09	238	1.08	1.06
1995/96	395	0.91	100	0.90	0.73
Mean water Productivity	-	0.96	-	1.11	1.36

Source: Oweis and Hachum (2003).

Under rainfed agriculture supplemental irrigation and its positive impact in improving both yield production and water productivity is receiving the attention of many researchers in the arid regions. However, there is and urgent need to upgrading the implemented strategies with greater focussing in rain feed areas on optimising supplemental irrigation using the limited available water from renewable resources. Equally, we have to establish the proper pathways to ensure generalization and transferability of the research results among dry region. The concept of integrated research sites has to be promoted together with work on agro-ecological characterization and modelling to develop the strategies and technology packages to be extended and transferred to other larger dry areas.

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