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Improving agricultural water productivity: Between optimism and caution

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ABSTRACT

In its broadest sense, water productivity (WP) is the net return for a unit of water used. Improvement of water productivity aims at producing more food, income, better livelihoods and ecosystem services with less water. There is considerable scope for improving water productivity of crop, livestock and fisheries at field through to basin scale. Practices used to achieve this include water harvesting, supplemental irrigation, deficit irrigation, precision irrigation techniques and soil–water conservation practices. Practices not directly related to water management impact water productivity because of interactive effects such as those derived from improvements in soil fertility, pest and disease control, crop selection or access to better markets.

However, there are several reasons to be cautious about the scope and ease of achieving water productivity gains. Crop water productivity is already quite high in highly productive regions, and gains in yield (per unit of land area) do not necessarily translate into gains in water productivity. Reuse of water that takes place within an irrigated area or a basin can compensate for the perceived losses at the field-scale in terms of water quantity, though the water quality is likely to be affected. While crop breeding has played an important role in increasing water productivity in the past, especially by improving the harvest index, such large gains are not easily foreseen in the future. More importantly, enabling conditions for farmers and water managers are not in place to enhance water productivity. Improving water productivity will thus require an understanding of the biophysical as well as the socioeconomic environments crossing scales between field, farm and basin.

Priority areas where substantive increases in water productivity are possible include: (i) areas where poverty is high and water productivity is low, (ii) areas of physical water scarcity where competition for water is high, (iii) areas with little water resources development where high returns from a little extra water use can make a big difference, and (iv) areas of water-driven ecosystem degradation, such as falling groundwater tables, and river desiccation. However, achieving these gains will be challenging at least, and will require strategies that consider complex biophysical and socioeconomic factors.

1. Introduction

Water productivity is the ratio of the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water used to produce those benefits. In its broadest sense, it reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water consumed. *Physical water productivity* is defined as the ratio of agricultural output to the amount of water consumed – "more crop per drop" –, and *economic water productivity* is defined as the value derived per unit of water used and this has also been used to relate water use in agriculture to nutrition, jobs, welfare and the environment. The denominator of the water productivity equation is expressed in terms of either water supply or water depletion. Water is depleted when it is consumed by evapotranspiration (ET), is incorporated into a product, flows to a location where it cannot be readily reused, or if it becomes heavily polluted (Seckler, 1996; Molden et al., 2003).

The water productivity concept evolved from separate fields. Crop physiologists originally defined *water use efficiency* as carbon assimilated and crop yield per unit of transpiration (Viets, 1962), and then later as the amount of produce (biomass or marketable yield) per unit of ET. Irrigation specialists have used the term *water use efficiency* to describe how effectively water is delivered to crops

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and to indicate the amount of water wasted. But this concept provides only a partial view because it does not indicate the benefits produced, nor does it specify that water lost by irrigation is often reused by other uses (Seckler et al., 2003). The current focus of water productivity has evolved to include the benefits and costs of water used for agriculture in terrestrial and aquatic ecosystems.

Increasing WP is particularly appropriate where water is scarce compared with other resources involved in production. Reasons to improve agricultural water productivity include: (i) to meet rising demands for food from a growing, wealthier, and increasingly urbanized population in light of water scarcity, (ii) to respond to pressures to re-allocate water from agriculture to cities and ensure that water is available for environmental uses, and (iii) to contribute to poverty reduction and economic growth. For the rural poor, more productive use of water can mean better nutrition for families, more income and productive employment. Targeting high water productivity can reduce investment costs by reducing the amount of water that has to be withdrawn. Higher water productivity reduces the need for additional water and land resources in irrigated and rainfed systems. Enhancing water productivity is thus a critical response to growing water scarcity, including the need to leave enough water in rivers to sustain ecosystems to meet the growing demands of cities and industries (e.g., Hengsdijk et al., 2006).

Globally, the additional amount of water needed to support agriculture directly depends on gains in water productivity. With no gains, average annual agricultural ET could double in the next 50 years (de Fraiture et al., 2007). But with enough investments in improving water productivity the increase in global ET could be held down to 20–30%. Irrigation systems are already under pressure to produce more with reduced supplies of water. Allocations for irrigation are diminishing in many river basins because of increased demands from cities and the environment, and in response, efforts need to be aimed at increasing water productivity so that farmers can continue to produce.

In spite of the need for increasing, and the opportunities to increase, water productivity, gains are elusive due to a number of complex interacting factors. The objective of this paper is to present a comprehensive analysis of the water productivity concept, to identify promising approaches for its improvement and to identify key constraints that must be overcome.

2. Improving agricultural water productivity

2.1. Biophysical background of WP at the plant scale

Assessing the scope for gains in water productivity requires an understanding of basic biological and hydrological crop–water relations. How much more water will be needed for agriculture in the future is governed, to a large extent, by links between water, food and changes in diets. The amount of water that we consume when eating food depends on diet and also on the water productivity of the agriculture production system. The amount of water required for field crops and its relation to yield dominates the equation on the need for additional water for food.

For a given crop variety and climate there is a well-established linear relationship between plant biomass and transpiration (de Wit, 1958; Tanner and Sinclair, 1983; Steduto et al., 2007). Different kinds of plants are more water efficient in terms of the ratio between biomass and transpiration. More biomass production requires more transpiration because when stomata open, carbon dioxide flows into the leaves for photosynthesis and water flows out. Water outflow is essential for cooling and for creating liquid movement in the plant for transporting nutrients. Stomata close during drought, thereby limiting transpiration, photosynthesis and production. The most common crops, C3 crops such as wheat and barley, are less water-efficient than C4 crops such as maize and sugarcane. The most water-efficient crops are the CAM (crassulacean acid metabolism) crops such as cactus and pineapple.

These different plant types (C3, C4 and CAM) have evolved according to their different environments, and are classified primarily based on how they fix carbon dioxide in the photosynthetic process (Steduto, 1996).

To boost economic yield, plant breeders have developed varieties with a higher harvest index (the ratio of marketable grain yield to total crop biomass), achieving more economic produce per unit of transpiration. This breeding strategy has probably raised the potential for gains in water productivity more than any other agronomic practice over the last 40 years (Keller and Seckler, 2004). The harvest index for wheat and maize rose from about 0.35 before the 1960s to 0.5 in the 1980s (Sayre et al., 1997), when plant breeders of the green revolution focused their attention on these crops. But the rate of increase in the harvest index has slowed over the last 20 years as physiological limits are being reached, and, thus, there has been a slowdown in the rate of gains in water productivity that are achieved through this method.

In situations where yield is less than 40–50% of the potential, non-water factors such as soil fertility limit yield and crop water productivity per unit of ET (Tanner and Sinclair, 1983). Land degradation and nutrient depletion significantly constrain opportunities to increase water productivity. In these situations there is a synergistic effect when water practices that increase access to water at the right time or reduce land degradation processes are combined with other agronomic practices such as maintaining soil health and fertility, controlling weeds and disease and the timing of planting. Such synergistic interactions between production factors raise water productivity, especially when yield values are low, because most production resources are used more efficiently as yield levels rise (de Wit, 1992). When yields are above 40–50% of their potential, however, yield gains come at a near proportionate increase in the amount of ET (Fig. 1), thus incremental gains in water productivity become smaller as yields become higher. Raising yields from 1 to 2 tons per hectare (ha) will lead to much more gains in water productivity than doubling the yield from 4 to 8 tons per ha.

This relationship between transpiration and crop production has far-reaching consequences for water. Increases in food production in productive areas are achieved with near proportionate increases in transpired water. This is the reason why

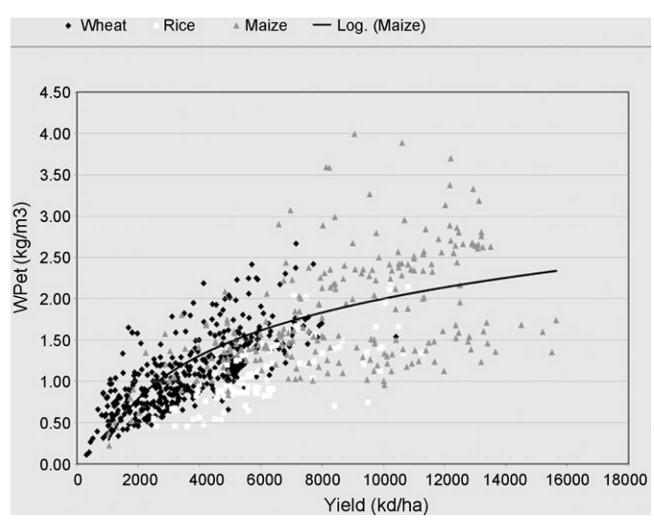

Fig. 1. A plot of yield versus water productivity shows that water productivity rises faster at lower yields and levels off at higher yields. *Source*: Adapted from Zwart and Bastiaanssen (2004).