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Water and Sustainable Agriculture

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Contents

Water and Sustainable Agriculture

Abstract Irrigated agriculture is a vital component of total agriculture that supplies many of the fruits, vegetables, and cereal foods, the grains fed to animals used as human food, and the feed to sustain work animals in many parts of the world. Consequently, agriculture is the largest user of fresh water globally, and irrigation practices sometimes are biologically, economically, and socially unsustainable: wasting water, energy, and money; drying up rivers and lakes; reducing crop yields; harming fish and wildlife; and causing water pollution. There is an urgent need to reduce the amount of water used by producing more food, profits, livelihoods, and ecological benefits at lower social and environmental costs. To ensure sustainable irrigation the conditions under which crops grow should remain stable over a prolonged period. At the same time, soil degradation (salt accumulation), mining of the ground water aquifers, and the negative impact of drainage water on the downstream environment should be minimized. Water management should therefore balance the need of water for agriculture and the need for a sustainable environment. Consequently, irrigation has to be closely linked with water-use efficiency with the aim of boosting productivity and improving food quality, especially in those areas where problems of water shortages or collection and delivery are widespread. Certain improvements are possible through deficit-irrigation strategies, which have been proved to be sustainable, avoiding irrational application of water. Currently, agriculture is undergoing significant changes in innovative irrigation, fertilizer technology, and agronomic expertise. These elements constitute a vital platform for sustainable agricultural success and for preventing environmental impairment. The following book presents several processes and their link with environmental irrigation, balancing environmental protection with improved agricultural production. Thus, sustainable irrigation must be based on applying uniform and precise amounts of water, based on rational agricultural knowledge of the plant's water needs.

Keywords Water use · Climate change · Land management · Sustainable agriculture · Deficit irrigation

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1 Introduction

Water is indisputably one of the most precious of all natural resources and the limiting factor in economic and social development (Chenoweth 2008). Freshwater resources globally are being over-exploited, polluted, and degraded and many systems are on the brink of collapse. At the same time, pressure has never been greater to provide drinking water as well as water for the economic development of a burgeoning world population. Water-resource management thus poses one of the great challenges for achieving ecologically sustainable development (Abu-Zeid 1998; Mariolakos 2007).

A growing world population is exerting increasing pressure on freshwater supplies. Global world population has exploded from 2.5 billion in 1,950–6 billion in 2000. By 2050, the world population could reach 10 billion or higher (UN 2007). In addition, to population pressures, there has also been an increase in water use per capita. The combination of these forces has led to worries about the adequacy of water supplies in the future.

Irrigation has allowed the world to overcome the potential food-supply problems associated with population growth. In many developing countries more than 90% of the water withdrawals are for irrigation (AQUASTAT 2005). In arid regions, irrigation is the essential for crop production. Similar for semi-arid and wet areas, irrigation boosts yields, attenuates the impact of droughts or, in the case of rice, minimizes weed growth. As stated by Bruinsma (2003), the average yields are generally higher under irrigated conditions as compared to rainfed agriculture. Globally only 18% of the cultivated area is irrigated (FAO 2005a), and 40% of food production comes from irrigated agriculture (UNCSD 1997). Both the water scarcity caused by using large amounts of water in irrigated agriculture and the importance of irrigation for crop production and food security induced several studies to quantify the different elements of the global water balance in space and time (Oki et al. 2001; Alcamo et al. 2003; FAO 2005b), to explore the importance of irrigated food production (Wood et al. 2000; Faures et al. 2002), and to assess the impact of climate change and climate variability in relation to global irrigation-water requirements (Döll 2002).

Worldwide, 278.8 million ha are equipped for irrigation, some 68% being is located in Asia, 17% in America, 9% in Europe, 5% in Africa, and 1% in Oceania. The largest areas of high irrigation density are found in northern India and Pakistan along the rivers Ganges and Indus, in the Hai He, Huang He, and Yangtze basins in China, and along the Nile river in Egypt and Sudan, among others. Irrigated lands produce 40% of the world's food supply, and the value of the output per cultivated area is extremely high (Dregne and Chou 1992). In addition, there is some evidence that the high productivity of irrigated agriculture has slowed the rate of deforestation. Agriculture is one of the primary reasons for deforestation in many countries, and increased yields (a change at the intensive margin) have decreased the need to expand the total land under cultivation (a change at the extensive margin). This is particularly important in mountainous regions because the steep slope of this land not only makes it difficult for crop production; it also increases its value in conservation against forest fires. Many changes in ecosystems increase their vulnerability, and therefore it is essential to adopt soil-conservation measures and to decrease erosion and runoff into water bodies (Schröter et al. 2005).

Worldwide water consumption in 2000 was 4–5 times that of 1,950 levels. Most of the obvious sources of water have been developed, and many that remain are marginal at best. Recently, many countries have increased their understanding of the importance of freshwater for environmental services, such as ecosystem health, as well as the environmental costs of water projects, such as habitat destruction (Hubbard et al. 2005; Ojeda et al. 2008; De Groot and Hermans 2009).

Soil salinity is a problem on irrigated arid lands, both reducing productivity and forcing land out of production. In many places with insufficient surface-water supplies, groundwater is used as a substitute. While the availability of groundwater has benefited the global food supply, its use as an input has progressed in an unsustainable manner. As much as 8% of food crops grown on farms use groundwater faster than the rate at which aquifers are replenished. Using irrigation in a more efficient manner will be necessary to protect water sources while still meeting objectives of food security (Huang et al. 2006; Turral et al. 2010; De Fraiture et al. 2010).

Globally, the world has enough water; however, the water is unevenly distributed. Industries and households are increasingly demanding water at the expense of agriculture. Agriculture uses approximately 70% of the total amount of water withdrawn to supply our current food needs. By 2030 the Food and Agriculture Organisation estimates that we will require 60% more food to feed the world's ballooning population. If agricultural production is to be sustainable, water resources must be used more efficiently while still increasing agricultural productivity. By using a range of agricultural techniques and technologies such as modern irrigation techniques, integrated pest management and biotechnology, farmers can produce higher yields with higher quality produce while making the most of precious water supplies (Burke et al. 1999; Playán and Mateos 2006; Metzidakis et al. 2008).

The plant-science industry is ready to address the challenge of increasing agricultural productivity, providing a range of products from seeds, chemical crop-protection products and biotechnology products. The industry strives to improve the quality and yields of their produce using the same amount of land by gaining access to knowledge and information that can help them make the correct choices to improve their livelihoods in a manner compatible with sustainable agriculture (Mannion 1995a; Lyson 2002; Huang et al. 2004).

Another well-known, often quoted fact is that irrigation uses 70% of the water in human use, with an efficiency of 40–50%. That is an increase of that efficiency to 80–90% with drip irrigation that would save half the water and would be the obvious solution to the world's water problems (Heermann et al. 1990).

More accurately expressed, irrigated agriculture is responsible for some 70% of all blue water withdrawn for human use. At the turn of the century, some 10%

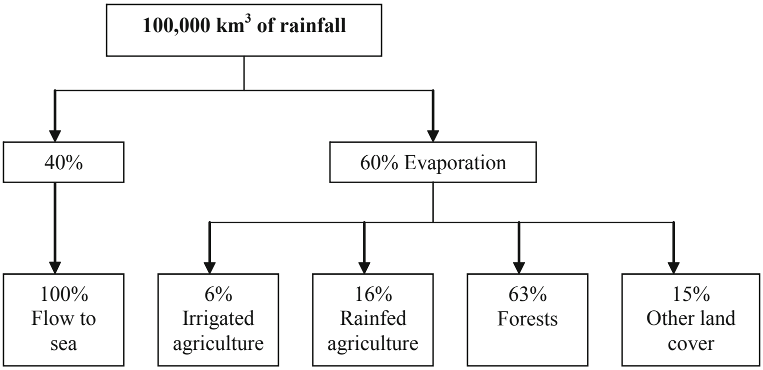

Fig. 1 Assessment of evapotranspiration from different land covers (source International Water Management Institute)

of all blue water, about 4,000 km^3, was withdrawn for human use (Rijsberman and De Silva 2006).

In other words, a bit less than 3% of all water (green and blue) was withdrawn for irrigated agriculture. According to International Water Management Institute (www.iwmi.cgiar.org) irrigated agriculture was responsible for some 6% of all evapotranspiration, while a further 16% was used consumptively by rainfed agriculture (Fig. 1). By contrast, natural ecosystems, from forests to wetlands, still use far more water than agriculture does.

It is also a misconception that irrigation efficiency can be increased, i.e. from 40 to 80%, which then would lead to major savings. In this sense, Seckler et al. (2003) pointed out that "irrigation efficiency" is a confusing term that has been defined in too many ways. Whether increased irrigation efficiency in a farmer's field does indeed save water depends heavily on the fate of the return flow (the drainage water and recharge to the groundwater). At the scale of the farmer's field, water productivity can be measured in units of output (the crop per drop) or as the value in monetary units. At the watershed scale, water productivity should be understood in the widest possible sense, *i.e.* including crop, livestock and fishery yields, wider ecosystem services and social impacts such as health, together with the systems of resource governance that ensure equitable distribution of these benefits (Ali and Talukder 2008; Haileslassie et al. 2009). In this sense, Zoebl (2006) pointed out that a split-up of domains is needed to properly define water-use efficiency for different perspectives: a universal or single menu cannot be applicable due to the technical and socio-economic diversity of issues and challenges.

In Europe the directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy "Water Framework Directive" entered into force on 22 December 2000. The directive as one of the most substantial pieces of European Union water legislation combines the until then rather fragmented European Union water law (large number of directives dealing only with special aspects of water management such as waste water, dangerous substances, drinking water, etc.) in order to ensure sustainable water management.

Since the 1960s, the Common Agricultural Policy in the European Union has played a major role in supporting farmers. However, the present framework of this policy will cease in 2013. By that time, when the financial support and payments to producers are scheduled to decrease, the Water Framework Directive should have been completely implemented (by 2012). By requiring the full-cost principle, the implementation of the Water Framework Directive will probably lead to a water-price increase. The joint effects of water policies and decrease in Common Agricultural Policy payments will thus affect the viability of farming systems, especially in the case of irrigated farms. To date, scientists have partially investigated the impact of expected changes in parameters such as water price or Common Agricultural Policy payments on economic, social, and environmental sustainability of irrigated agricultural systems. In this context, Bartolini et al. (2007) for Italy reported that there is a clear trade-off between reducing the negative environmental impacts of agriculture and maintaining the livelihood of the sector. Overburdening farmers with increases in water prices could strongly influence the sustainability of the sector. Nevertheless, some specific crops such as non-intensive crop systems (rice and cereals) could sufficiently adapt to increased water prices (e.g. by reducing their water use or improving their irrigation system) Therefore, in these cases the water pricing could be a good economic mechanism in order to provide incentives for saving water. Furthermore, the results of this study highlight the need for more integrated analysis when setting such water policies. The economic viability of farming systems should also be taken into account in the design of policies and in particular of regulations related to water.

Water stress influences crop growth and productivity in many ways (Wanjura et al. 1990; Irmak et al. 2000). Most of the responses have a negative impact on yield but crops have different and often complex mechanisms to react to water shortages. Several crops and genotypes have developed different degrees of drought tolerance, drought resistance or compensatory growth to deal with periods of stress. The highest crop productivity is achieved for high-yielding varieties with optimal water supply and high soil-fertility levels, but under conditions of limited water supply, crops will adapt to water stress and can produce well with less water. In this sense of improving water productivity, there is growing interest in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield (Ali et al. 2007; Ali and Talukder 2008). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop; farmers are more inclined to use water more efficiently, and more water-efficient cash-crop selection helps optimise returns (Geerts and Raes 2009; Blum 2009). However, this approach requires precise knowledge of crop response to water, as drought tolerance varies considerably by species, cultivar, and growth stage.

In the many regions, soil moisture is generally limited and crop growth is stressed by drought during the growing season, resulting in decreased and unsustainable crop yields. Particularly for the arid and semi-arid areas, rainfall is low, making crop growth dependent on irrigation. However, in sloping fields, most of the crops are grown under rainfed conditions. Recent research has shown some practical techniques of rainwater harvesting (Li et al. 2002; 2007; Tian et al. 2003) but the cost to prevent runoff and harvest rainwater on sloping lands can be very high (Zhang et al. 2004). On the other hand, it may not be practical to irrigate fields on a large scale using only harvested rainwater.

Sustainable development requires pragmatic management of land–water resources through positive and realistic science-based planning that balances the ecosystem's carrying capacity with respect to human expectations (Sophocleous 2000; Melloul and Collin 2003; Mariolakos 2007). The aim must be not only environmental harmony, but also long-term sustainability of natural resources with economic efficiency as its intent so as to meet the needs of the current generation without compromising the ability of future generations to meet their own needs (Costanza 1995).

Conceptual understanding and operational procedures applicable to improving system management and performance, and management changes in individuals and organizations are the changes necessary to meet the urgent needs in irrigated agriculture. Urgent needs relate to productivity, water scarcity, and managing the environment.

There is an urgent need to reduce the amount of water used for agriculture by producing more food with high quality, profit, livelihoods, and ecological benefits at less social and environmental costs per unit of water used. Water productivity defined in physical terms is the ratio of the mass of agricultural output to the amount of water used. In an economic sense, water productivity reflects the value derived per unit of water applied. Improving physical water productivity in irrigated and rainfed agriculture reduces the need for additional water and is thus a critical response to increasing water scarcity (Molden et al. 2007).

This review shows some urgent changes needed and defines the conceptual and operational strategies that can address the needs and accomplish the sustainability of irrigation systems. Research needs to provide methods for improved productivity, for more effective use of water supplies while making available additional irrigation water, and for approaching environmental sustainability in irrigated agriculture.

2 Water and Agriculture

Agriculture represents the first, traditional life-supporting economic sector closely linked to establish cultural and ethical values of land and water on which traditional societies are built. Water in agriculture is largely associated with irrigation. The worldwide area equipped with irrigation expanded from 139 million ha in 1961–277 million ha in 2003 (FAO 2007). According to Bhattarai et al. (2007), the investments in irrigation have increased rural incomes, resulting in greater