Chapter 1
Water Scarcity Leads to Food Insecurity

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Abstract This chapter provides an overview on the interrelation between water scarcity and food production. A general perception has been existed worldwide that agricultural water, as the major user, is often wasteful and has less value, compared to other uses. Additionally, water scarcity became more acute in many part of the world. Thus, there is a need to manage water resources more efficiently to produce more food with the same amount of water. Although irrigation is important to attain stable food production, over-irrigation is prevailing in many areas worldwide and it has many disadvantages. On the contrary, under-irrigation with less than crop water requirements causes stressful conditions to the growing plants leading to lower yield and consequently food insecurity. One of the effective water management practices is deficit irrigation application. It can use water resources more efficiently in the agricultural sector. It can maintain reasonable levels of production and it could improve yield quality. One might wonder whether application of deficit irrigation could contribute in increasing food availability. Although application of deficit irrigation involves loss in crop productivity, it also secures water to be use in cultivating more lands. However, on national level, will the production resulted from the new added area can compensate the loss attained by application of deficit irrigation. In this book, we answer the above question and shed the light on the role of deficit irrigation in securing food under water scarcity. We also tested whether deficit irrigation practice could positively contribute in reducing the loss in production of crops under the impact of climate change in 2030.

Keywords Water stress · Irrigation water management · Deficit irrigation · Climate change and food production · Climate change and agricultural soils

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1.1 Introduction

Demand for food was increased due to an exponential rise in population between 1961 and 2000 (Keating et al. 2014). In addition, food shortage is a problem facing over-populated developing countries. These countries need to double food production to meet the growing demand of food (FAO 2009). Thus, scientific and technological advances, institutional intervention, government policy, business investment and innovation should joint together to meet the demand for food (Keating and Carberry 2010). A second green revolution targeting nutrients and water use efficiency is one of the proposed solutions to meet the increase in food demand and tackle food scarcity in upcoming decades (Blum 2009). Furthermore, Foley et al. (2011) suggested solutions to food security that taking advantage of the advances in agriculture and reducing waste, whilst addressing shifting diets, enabled a doubling in agricultural production and a reduction in environmental impacts. Food wastage reduction, both food loss and waste, provide an opportunity to capturing more of the food that is produced for human consumption, which will help in increasing food security without increasing the environmental burden of production (Cole et al. 2018).

The concept of food security is based on three main pillars, food availability, food accessibility and food stability. Agriculture is concerned about food production and availability. Consequently, crops production is restricted by the availability of water, where water supply in irrigated agriculture is often the most critical factor limiting crop growth and yield. Maximum or potential crop yield is limited by climate and crop cultivar, assuming all the other factors affecting crop growth and yield are optimal (Karmakar et al. 2016). Consequently, environment deterioration arose as result of increased farm inputs and outputs in their attempts to increase food production. Moreover, farmers often achieve far less than 50% of the climatic and genetic yield potential for a given sowing date, cultivar choice and site (Karmakar et al. 2016)

1.2 Food Production Depends on Water Availability

Although 70% of the surface of the Earth is covered with water (Siddique and Bramley 2014), only about 2.5% is fresh water (Gleick and Palaniappan 2010). The majority of these amounts of water are trapped in glaciers, permanent snow, or aquifers (Farihi et al. 2013). The fresh water is divided in two types of resources: renewable and non-renewable water resources. Groundwater and surface water, such as the average flow of rivers on a yearly basis, are considered renewable water resources, whereas deep aquifers are considered non-renewable water resources (FAO 2003). Agriculture is the largest fresh water user on the planet, consuming more than two thirds of total withdrawals (Gan et al. 2013) and fresh water shortage is becoming critical in the arid and semiarid areas of the world (Forouzani and Karami 2011). A general perception has been existed worldwide that agricultural water as the major user, is often wasteful and has less value, compared to other uses (Jury and Vaux 2006). Furthermore, irrigation consumes a significant amount of energy, compared to other operations (Topak et al. 2010). In addition, rapid urbanization has caused conflict between the need for freshwater in agriculture and other sectors. Consequently, fresh water resources available to agriculture will need to be re-rationalized to satisfy the developmental needs of other sectors (Chai et al. 2016). Increasing the effective use of water resources in many parts of the world is required to enhance food security, where availability of water for food production becomes more acute (FAO 2012). Globally, 40% of annual food production comes from irrigated land, which consumes 70% of all fresh water withdrawals (FAO 2007).

Applying irrigation to cultivated crops is crucial to attain stable agricultural production, where the supply of water to crops done by artificial means. Irrigation also aids crop intensification and diversification in dry land areas thereby permitting multiple cropping per year (two to four crops) (Vlek et al. 2008). Furthermore, other intensification inputs, namely fertilizers and agricultural chemical are provided by irrigation (Kögler and Söffker 2017). Surface irrigation is still the most widely used technique despite its relatively poor application efficiency, which may cause water logging. Water logging is the saturation of the root zone with water that leads to reduced aeration, nutrient uptake, crop growth, and yield, carbon dioxide accumulates to a toxic level results in crop failure (Vlek et al. 2008). Furthermore, current rates of agricultural water use are unsustainable in many parts of the world, generating an urgent need to improve its management strategies (Lopez et al. 2017). Thus, irrigation water management in the current era of water scarcity need to be conducted most efficiently, aiming at saving water and maximizing its productivity (Johnson et al. 2001).

The sustainable water management concept refers to all practices that improve crop yield, and minimize non-beneficial water losses (Johnson et al. 2001). Additionally, improving irrigation water use efficiency, namely the ratio of consumed water to crop yield (Stanhill 1986), and water productivity, namely the ratio of applied water to crop yield (Kumar et al. 2010) are significant to attain the sustainability of water resources. This goal could be achieved through improved management practices on farm level using appropriate methods of irrigation scheduling. Irrigation scheduling is a process used to determine the amount of water applied to the crop and the timing for application; as it determines seasonal irrigation volume and crop yield (Fernandez and Cuevas 2010). Tanner and Sinclair (1983) stated that the primary aim of irrigation scheduling is to minimize wasteful losses of water (percolation beyond what is necessary for salt leaching, surface runoff and evaporation) and maximize transpiration, which is the beneficial loss of water due to its direct link with dry matter production. Thus, efficient irrigation scheduling aims to supply the crop with enough water to ensure optimum production while minimizing water loss and nutrient leaching (Fernandez and Cuevas 2010).

1.3 Water Scarcity Induces Water Stress

Water stress can be defined as the absence of adequate moisture necessary for normal plant growth to complete its life cycle (Zhu 2002). The lack of adequate moisture that leading to water stress is a common occurrence in rain fed areas, brought about by infrequent rains and poor irrigation (Wang et al. 2015). Similarly, in irrigated agriculture water stress could be also induced by water scarcity. Water stress affects every aspect of plant growth, including anatomy, morphology, physiology, and biochemistry (Zhu 2002). Decreasing water availability under drought generally results in limited nutrients uptake (Davari 2016). Another important effect of water deficit is the reduction of nutrient acquisition by the root and its transport to shoots (Farooq et al. 2009). Lowered absorption of the inorganic nutrients could result from interference in nutrient uptake and the unloading mechanism, which reduces transpiration flow (Garg 2003). Influence of drought on plant nutrition may also be related to limited availability of energy for assimilation of nitrate, phosphate, and sulfate (Baligar et al. 2001).

Under water stress, plants close their stomata to prevent dehydration, thus drastic reduction in transpiration rates occur (Taiz and Zeiger 2004), and production of abscisic acid increases by as much as 50-fold in leaves, which decreases leaf area due to lower-turgor-pressure cells, stomatal closure, the induction of senescence and ethylene production (Taiz and Zeiger 2013). Water stress also affects many important biochemical processes such as osmotic adjustment, antioxidant enzyme defense system, abscisic acid production, and lipid peroxidation (Sarto et al. 2016). The increase in Si in the plant can increase the efficiency of water use by some grasses (Sarto et al. 2017).

Under severe stress, the dehydration in mesophyll cells inhibits photosynthesis and water use efficiency decreases as a result (Taiz and Zeiger 2004). A reduction in water availability in plants leads to the reduction of cell solutes thus increasing the solute concentration. This causes the plasma membrane to become thicker, affecting the turgidity processes of cells, reducing the leaf area and causing stomatal closure. This results in a reduced rate of photosynthesis, influencing the plant development (Dias 2008).

At present, nearly 80% of the world's population is exposed to high levels of threat to water security (Bunn 2016). The misuse of water resources (Ouda and Zohry 2018a), and the lack of infrastructures to supply water (Abou Zeid 2002) are some of the main reasons for scarcity of water. Many parts of the world experience acute water scarcity and that requires increasing the effectiveness of agricultural water resources usage and reduces the excessive irrigation for enhanced food security (FAO 2007). To cope with water scarcity without reducing the irrigated area, different options are available. One of these options is better forecasting of soil moisture and requirement of crops for water through combining weather predictions and hydrological modeling, supported by data using new technologies for environmental monitoring and Earth observations from space (Ravazzani et al. 2017).

Another option could be done, namely cultivation of short season crops. In Egypt, this practice was successful in saving large amounts of water, where short season rice cultivars replaced long season cultivars resulted in water saving by 15% (Abd El-Megeed et al. 2016). MacDonald et al. (2017) reported that developing new farming systems could intensify land and water use. Said et al. (2016) indicated that implementing intercropping systems, where two crops share the area and the applied water to one of them is another alternative to cope with water security. Furthermore, reducing non-productive water consumption, through improved crop water management, use of techniques to reduce soil evaporation, capture surface run-off, and improve soil infiltration capacity and efficiency of irrigation systems could help in expanding irrigation and increasing food production (Cole et al. 2018). It is necessary for irrigation management in these areas to shift from emphasizing production per unit area towards maximizing the production per unit of water consumed, which is called water productivity (Rekaby et al. 2016). All that will improve agricultural water practices and lead to gains in global crop production. Not only scarcity in water quantity is becoming obvious, but also in quality, where is become to be obvious in regions where rainfall is abundant too (Capra et al. 2008).

1.4 Deficit Irrigation and Water Scarcity

Deficit irrigation application can be very useful in reducing the demand for water in the agriculture sector. Deficit irrigation is the practice of deliberately under-irrigating a crop, where its irrigation water supply is reduced relative to that needed to meet its maximum evapotranspiration (English and Nuss 1982). Another terminology for deficit irrigation is the application of irrigation below the full crop evapotranspiration, which potentially improve efficiency and maximize profits through a reduction in capital and operating costs (Capra et al. 2008). Kögler and Söffker (2017) indicated that deficit irrigation is a crop cultivation practice allows saving up to 20–40% irrigation water with yield reductions below 10%, leading to more efficient water use. However, conducting deficit irrigation by increasing the duration between irrigation intervals or by omitting one or more irrigation event could causes several negative effects on growth and reduces yield (Zhu 2002). The knowledge of crop water use and its response to water deficits should include identification of critical crop growth stages and the impacts on yield (Oweis and Hachum 2003).

Adopting deficit irrigation principles implies the acceptance of a certain level of reduction in yield level (Hamdy et al. 2005). As long as that certain level of yield reduction is low, there is a high possibility that farmers will adopt it. The saved irrigation water from application of deficit irrigation could be used to irrigate new lands to produce more crops and compensate for the loss in productivity. There are several basic recommended deficit irrigation strategies that minimize yield losses. Sustain deficit irrigation; in which reduced amount of irrigation is applied during all the growing season (Fernandes-Silva et al. 2018) is one of these strategies. Regulated deficit irrigation is another strategy contributes in water saving and low yield losses (Capra et al. 2008). This strategy is divided into stage-base deficit irrigation and partial-root system irrigation (Chai, et al. 2016). Moreover, precise irrigation scheduling is crucial for regulated deficit irrigation, which aims to induce a mild water stress to the plant to save water and improve crop yield (Jones 2004). Maintaining optimum crop yield under water deficit conditions has stimulated researchers to explore new irrigation technology, systems, and strategies to improve water use efficiency and water productivity (Fernandes-Silva et al. 2018).

1.5 Climate Change, Water Scarcity and Food Security

Global and regional climates have already begun changing. Climate change is directly or indirectly attributed to human activity that alters the composition of the global atmosphere, in addition to natural climate variability observed over comparable time periods (Karmakar et al. 2016). The models that describe global climate are mathematical representations of physical and dynamical processes to simulate the interaction within and in between the atmosphere, land surface, oceans and sea ice (Dettinger 2005). IPCC (2007) reported that "the global atmospheric concentration of carbon dioxide, methane and nitrous oxide has increased from pre-industrial era to 2005. The annual carbon dioxide concentration growth rate was larger during the last 10 years' average (1995–2005, 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960–2005, average 1.4 ppm per year) although there is year-to-year variability in growth rates". In order to limit global warning in 2100 to 2 °C above pre-industrial levels, annual emissions from the agricultural sector must be reduced by 1 giga ton of carbon dioxide equivalents per year by 2030 (Wollenberg et al. 2016). Currently available interventions, such as sustainable intensification of dairy production and alternate wetting and drying in irrigated rice to achieve emission efficiencies will be necessary, as well as innovative policies to promote sequestering soil carbon (Cole et al. 2018).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013) stated that "the magnitude of stress on water resources is expected to increase as a consequence of climate change, in addition to future population growth and urbanization as a consequence of land-use change". According to the scenarios described in the IPCC Special Report on Emissions Scenarios, changes in precipitation and temperature may lead to changes in runoff and water availability (Cisneros et al. 2014). Previous research projected that climate change will intensify and accelerate the hydrological cycle, which will result in more water being available in some parts of the world and less water being available in other parts of the world (most of the developing world) (IPCC 2013). Weather patterns are predicted to be more extreme. The regions adversely affected by climate change will experience droughts and/or possible flooding, which could affect food production

(Elsaeed 2012). Moreover, as a result of sea level rise, intrusion of saline water in low coastal areas could occur, which will influence the quality of fresh water aquifers (Bates et al. 2008). The combined effect of higher temperature and the reduction of water availability in regions affected by falling precipitation could result in an increase of crop evaporative demands, following by reduction in crop yield, where temperature restrains crop growth (FAO 2005).

The UNEP (2013) reported that climate change will affect the extent and productivity of both irrigated and rain fed agriculture across the globe, increasing crop water demand and decreasing crop productivity in many regions. FAO (2012) predicted that by 2030, the world population will grow beyond 7.5 billion inhabitants, which will have a significant impact on water usage for food. They also predicted that food demand will increase by 50% and water use in irrigation will increase by 30%. In Egypt, Alkitkat (2017) projected that the Egyptian population in 2030 will increase by 32%, compared to the population value recorded in 2014. Accordingly, the demand for food is expected to increase. For example, the demand for wheat is expected to increase by 53% (Ouda and Zohry 2017), for maize by 40% (Zohry and Ouda 2017a) and for faba bean by 68% (Zohry and Ouda 2017b). Furthermore, de Fraiture and Wichelns (2010) indicated that, under a pessimistic low yield scenario in 2050, water consumption by the crops will increase by 53% and lands needed to achieve food production goals will increase by 38%.

1.6 Climate Change and Agricultural Soil

Soils has a major role in supplying macro and micro nutrients to all kinds of crops grown in it, thus they are important for food security. Because climate is one of the most important factors affecting the formation of soil, climate change could result in soil deterioration (Karmakar et al. 2016) and consequently it has the potential to threaten food security through its effects on soil properties and processes (Pimentel 2006). Increased temperature is likely to have a negative effect on carbon allocation to the soil, leading to reductions in soil organic carbon and creating a positive-feedback in the global carbon cycle (Wan et al. 2011). Increased temperatures lead to increased carbon dioxide release from soils to the atmosphere leads to more increases in temperature (Cole et al. 2018). Rising atmospheric carbon dioxide levels, elevated temperature, altered precipitation and atmospheric nitrogen deposition caused by climate change, affect soil chemical, physical and biological functions (IPCC 2007).

A decline in soil organic matter levels lead to a decrease in soil aggregate stability, infiltration rates and increase in susceptibility to compaction, run-off and susceptibility to erosion (Gorissen et al. 2004). Furthermore, increased salinization and alkalization would occur in areas where evaporation increased or rainfall decreased (Varallyay 1994). Transient salinity increases as capillary rise dominates, bringing salts into the root zone on sodic soils. Increased subsoil drying increases concentration of salts in the soil solution. Conversely, the severity of saline scalds due to secondary salinization may decline as ground water levels fall in line with reduced rainfall (Karmakar et al. 2016). Moreover, salinization can also be a consequence of expected climate change, as the rise of sea level and sea water intrusion occur (Várallyay 2010). Climate change can affect soils build up due to an increase of the evapotranspiration through the increase in air temperature (Várallyay 2004). Higher rate of evapotranspiration will increase capillary transport of water and solutes from the groundwater to the root zone. The degradation cause by climate change was summarized by Várallyay (2010) in increasing soil erosion and that should be balanced by the increasing soil conservation effect of more dense and permanent vegetation.

Avoiding soil degradation under climate change through technologies and farm practices that maintain ground cover to minimize erosion and nutrient runoff will be important (Karmakar et al. 2016). Efficient water management under climate change can reduce soil erosion, thus soil degradation. Sojka et al. (2007) indicated that water management practices, such as monitoring crop water use, increasing application efficiency, timing considerations based on crop needs, soil water storage capacity, as well as water application method and intensity can play a major role in reducing soil erosion under furrow irrigation practice. Furthermore, intercropping with legumes can be an excellent practice for controlling soil erosion and sustaining crop production (Dwivedi et al. 2015). Deep roots of legume crops penetrate far into the soil and use moisture and nutrients from deeper soil layers, whereas shallow roots of cereal crops fix the soil at the surface and thereby help to reduce erosion (Machado 2009). Growing legumes with cereals results in nitrogen fixation in the soil and consequently increase in soil organic content (Hauggaard-Nielsen et al. 2006).

Precision agriculture techniques will enable reduced use of agri-chemicals and water that match supply with demand and limit losses (Cole et al. 2018). Crop rotation can play an important role in reduction of greenhouse gases fluxes from the soil by more efficient management of carbon and nitrogen flows in agricultural ecosystems (Cerri et al. 2004). An emerging approach to reducing fertilizer requirements is by reconstituting the nitrogen fixing function in plant cells. This approach relies on using synthetic biology for direct engineering of nitrogenase into the mitochondrial matrix of plants (Allen et al. 2017).

It is noticeable now that climate change is unavoidable and farmers are already living with its impacts. Farmers practice adaptation to climate change through simple measures, namely changing sowing date, implementing intercropping systems, and changing irrigation schedule (Ouda and Zohry 2018b). However, more transformative changes to farming systems will be required, namely changes to business structure, portfolio management, off-farm investments and geographical diversification (Robertson and Murray-Prior 2016). Advance innovations for increasing photosynthetic potential (Parry et al. 2011), radiation use efficiency or modifying canopy architecture (Robertson and Murray-Prior 2016) could applied to increase yield potential, thus reduce food insecurity.

1.7 Research Question

One might wonder whether application of deficit irrigation can contribute in increasing food availability. Although application of deficit irrigation involves loss in crop productivity, it also secures water to be use in cultivating more lands. However, on national level, will the production resulted from the new added area could compensate the loss attained by application of deficit irrigation. In this book, we answer the above question and shed the light on the role of deficit irrigation in securing food under water scarcity. We assessed the potential effect of application of deficit irrigation to four winter crops grown in Egypt, namely Egyptian clover, sugar beet, onion and tomato. These four crops have a surplus in their production. We also assessed possibility of saving an amount of irrigation water from these four crops and use it to cultivate new areas with wheat. Wheat is an important crop in Egyptian daily diet and has the major food production-consumption. We tested weather application of deficit irrigation to wheat cultivated on raised beds will increase its national production, in addition to implementing intercropping systems for wheat with other crops and used the saved water from the suggested four crops could to irrigate new areas with wheat will increase its production and reduce its food gap.

We also tested whether deficit irrigation application, as well as the other suggested practices could positively contribute in reducing the loss in wheat production under the impact of climate change in 2030.

1.8 Conclusion

There is an urgent need for effective management of water resources used in agriculture to overcome the prevailing situation of water scarcity. Application of deficit irrigation practice is good candidate to attain sustainable use of water resources without sacrificing food production.

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