Crop Water Requirements and Irrigation Efficiencies in Egypt

M.A. Mahmoud and A.Z. El-Bably

Abstract Water scarcity is the major factor that limits the ambitious hopes to expand and increase the agricultural area to meet the present gap between food production and consumption. In areas like Egypt, located in an arid/semiarid region, where vegetation water requirement represents an important fraction of the total water consumption, the pressure of population growth and increasing domestic demand and other sectors for water represent other challenges for the agricultural sector. Agricultural activity in Egypt consumes from 80 to 85% of water resources. To meet these challenges, good water governance, which aims to reduce losses and increase benefits per unit of water, should be adopted. One of the most important ways to improve water use efficiency and optimize plant production is to provide crops only with the water they *need* based on the climate-plant-soil relationship.

There are many ways to increase water use efficiency, such as improving irrigation canals in old land to increase the conveyance efficiency; using a pressurized irrigation system in new reclaimed lands, in addition to water management practices on farm like laser land leveling; using the raised bed irrigation method, irrigation scheduling, intercropping, crop intensification, and mulching; using soil amendments and organic fertilizers; and using short and drought tolerance varieties. The integrated management for soil, water, and crops is very important to maximize crop yield and water productivity, so in this chapter, the author will provide an overview on how to maximize crop yield with minimal water use.

Keywords Egypt, Irrigation efficiency, Water management, Water requirements

---

M.A. Mahmoud (✉) and A.Z. El-Bably
Water Requirements and Field Irrigation Research Department, Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt
e-mail: mahmoud_abdalla96@yahoo.com; elbabli@gmail.com

A.M. Negm (ed.), *Conventional Water Resources and Agriculture in Egypt*,
Hdb Env Chem, DOI 10.1007/698_2017_42,

Contents

1 Introduction

Due to the growing and more affluent population, over the coming decades, the agricultural product demand will increase rapidly, with serious implications for the demand for agricultural water. Symptoms of the scarcity of water are increasingly apparent, threatening food production sustainability and ecosystem services. Improving water productivity will shrink the extra water requirements in agriculture [1]. Improving water productivity in rain-fed and irrigated agriculture decreases the need for extra water and is thus a critical reaction to growing water scarcity [2].

Egypt is located in North Africa in an arid and semiarid region. Water resources are limited, and the Nile River is the main source of freshwater. Egypt's population is growing rapidly, so the per capita water availability is continually decreasing. However, food production and industrial activities and productions should increase; therefore, water demand is expected to continuously increase for agriculture, industrial, and domestic sectors. Egypt is one of the most vulnerable countries to the impact of projected climate change [3]. This will cause more pressure on water resources to meet expected increases in crop water requirements, in addition to the new areas of agricultural production that is expected to continue to grow. Implications could include a reduction in crop yields. All of these challenges lead scientists and policymakers to search about how to maximize irrigation efficiency.

Agriculture plays a vital role in Egypt's economy contributing to about 15% of the gross domestic product and employing about 30% of the national workforce [4]. Over 95% of Egyptian agricultural land lies within the Nile Valley and Delta. There are three cropping seasons in Egypt, the summer season (April to October) and late summer season (July until October) and the winter season commencing from November to May. The main summer crops are cotton, maize, and rice, and the dominant winter crops are wheat, sugar beet, berseem (Egyptian clover), and broad beans. In addition, vegetable crops such as potato, tomato, and others are cultivated in all seasons. Sugarcane is growing mainly in Upper Egypt, while rice cultivates in the North Nile Delta. There are several areas in the West and East Delta which grow fruits and medical and aromatic plants.

2 Water Resources and Usage in Egypt

2.1 Water Resources

Water resources in Egypt are limited as follows [5]:

Nile River is the main source of water in Egypt. The Nile water comes from outside Egypt's borders; Egypt's per share according to the Nile water agreement with Sudan allocates 55.5 billion cubic meters (BCM)/year to Egypt.

Rainfall in Egypt happens only in the winter season as scattered showers. The effectively annual average amount of rainfall water is estimated to be 1.3 BCM/year. Due to the high temporal and spatial variability of the rainfall, this amount cannot be considered a reliable source of water.

Groundwater exists in the Sinai and the Western Desert aquifers that are generally deep and nonrenewable. The total amount of groundwater has been estimated to be about 40,000 BCM. However, the current extraction is estimated to be only 2.0 BCM/year. This may be due to the great depth of these aquifers up to 1,500 m and degradation of water quality at increasing depths.

Shallow groundwater in the Nile aquifer cannot be considered as a distinct source of water. Seepage losses from irrigation and drainage canals and the Nile and percolation losses from irrigated lands are the source of recharging this aquifer. This water must not be added to Egypt's water resources. Therefore, it is considered as a reservoir in the Nile River system with a huge capacity but rechargeable live storage of only 7.5 BCM/year. The current suction from this aquifer was estimated at 6.5 BCM in 2013.

Desalination of seawater in Egypt has been given little priority as a water resource due to the high cost of the treatment compared to other sources. There are several desalination practices on the coast of the Red Sea area to supply resorts and tourist villages with adequate clean water. Other desalination units of groundwater have been constructed at numerous locations in Sinai as a water source for Bedouins.

Treated domestic sewage is being reused as a source of irrigation with or without mixed freshwater. The total quantity of reused treated wastewater in Egypt was estimated to be 0.3 BCM in 2013.

Reuse of nonconventional water sources such as treated sewage water and agricultural drainage water cannot be added to Egypt's freshwater resources. Using these sources is a recycling process of the fresh Nile water which has been previously used. The total amount of reused water was about 13 BCM in 2013. The reuse practices increased the overall system efficiency as comparable to the efficiency of new irrigation systems.

2.2 Sectoral Water Demand

Due to a rapid increase in population and improving living standards as well as the industrialization policy encouraged by the government, water requirements in Egypt are increasing continuously. Water demand can be characterized in classes representing the major items on the demand side of the water balance according to [5] as the following:

- *The agriculture sector* represents the largest consumer of water resources; it consumes more than 85% of Egypt's per share of Nile water yearly.
- *Municipal water requirements* include water needs for major urban and rural villages. Municipal water demand was estimated to be 10 BCM in 2013. Municipal water production is diverted from two sources, surface water and groundwater, which represent about 83% and 17%, respectively, of total municipal water demand.
- *The industrial sector* is vital to social and economic progress. The water requirement for the industrial sector was 2.50 BCM/year during the year 2013.

In summary, there exists a 20 BCM/year gap between the availability and the demand for water. This gap is overcome by water recycling. The overall efficiency of the Nile system in Egypt is about 75%. By the year 2020, water requirements are expected to increase by 20% (15 BCM/year) [5]. The main consumer of freshwater is irrigated agriculture. Globally, irrigated land contributes to more than 40% from food production [6]. Water availability is a major challenge facing agricultural sustainable development in Egypt. Water resources in Egypt are highly limited [7]. Renewable water resources are estimated at 57.3 BCM/year, almost 97% of which originates from the Nile River [8].

3 Water Scarcity in Egypt

Freshwater is an increasingly limited resource [9]. As world population increases and standard of living is improved, the water need is expected to increase. Huge areas worldwide will suffer from water scarcity during the growing seasons, and natural environments may be affected [10]. The available per capita of freshwater in Egypt has fallen from 1,893 m^3 in 1959 to 900–950 m^3 in 2000 [11]. Further, the average per capita of the available water in Egypt reached about 710 cm^3 in 2014, and it is expected to reach to about 350 cm^3 by 2050 [12]. In Egypt, the water shortage amounts to 13.5 BCM/year and is expected to increase continuously. This water shortage is remunerated by using drainage reuse which subsequently declines water quality. By 2025 the water shortage is expected to be 26 BCM/year in the case of using the same current policies [13].

The economic and political factors are the major driving forces to water scarcity in Egypt, in addition to the population growth, physical variables (land expansion and water resources), and social factors (quality of life, poverty, crop pattern, consumer's behavior, and imbalanced distribution of water) [14]. Rapid population increase, increased urbanization, food security concerns, and the expected potential climate change impacts are increasing the attention given to more efficient and sustainable water management in Egypt [15]. The major challenge facing water resources in Egypt is the limited availability of supply resources. There are many challenges found on the demand side, such as water surface evaporation loss, seepage losses, evaporation losses, and infiltration losses from aquatic weeds in canals and agricultural lands, as well as imperfection in control gates, the efficiency of water distribution operation, expansion of agricultural lands such as sugarcane and rice areas, and extra pumping rates from wells and lack of extraction control in deep groundwater, use of sprinkler irrigation, damages in drip irrigation systems, low distribution efficiency in drinking water network, and weak public awareness in domestic water division [13].

4 Crop Water Requirements and Irrigation Efficiencies in Egypt

Water requirements for various crops depend mainly on evapotranspiration which is affected by weather parameters, management, and environmental factors. Also water requirements for the same crop differ from one place to another depending on the agro-metrological zone, irrigation system, variety, and management. Data in Tables 1, 2, and 3 represent the optimum water requirements as m^3/feddan for winter, summer, and nili (late summer) crops, respectively, which are grown in the main three regions in Egypt (Delta, Middle Egypt, and Upper Egypt) under surface irrigation. Application efficiency reached 80% at farm level according to [16].

Irrigation efficiency mentions to the amount of water removed from the source of the water that is used by the crop. This value is determined by water distribution characteristics, management of irrigation system, crop water use rates, and soil and weather conditions. Ideal water efficiency for crop irrigation means reducing losses in evaporation, runoff, or subsurface drainage and however increasing production [17].

Utilization efficiency for water resources in Egypt is very low. Large amounts of irrigation water are being lost during water transmission from Aswan High Dam to fields. The recorded data indicated that the irrigation water at the Aswan Dam has increased by about 20% from 2000 to 2009. However, the losses during the transferring irrigation water from Aswan High Dam to fields due to evaporation and transpiration have increased by 30.90% and 35.46% in 1985 and 2005,

Table 1 The optimum water requirements for winter crops (m^3/feddan) at farm level of the main three regions in Egypt on 2016 [16]

Winter crops	Delta	Middle Egypt	Upper Egypt
Wheat	1,984	2,070	2,727
Broad bean	1,779	1,864	2,550
Barley	1,511	1,492	2,040
Fenugreek	1,689	1,740	2,379
Lupines	1,216	1,100	1,511
Chick peas	1,689	1,740	2,379
Lentil	1,156	1,015	1,395
Temp. clover	1,160	889	1,237
Clover	2,741	3,028	3,974
Flax	1,511	1,492	2,040
Onion	1,910	1,947	2,520
Sugar beet	2,384	2,581	–
Garlic	1,910	1,947	2,520
Medical and aromatic crops	1,600	1,616	2,209
Vegetables	1,601	1,458	1,956
Miscellaneous crops	1,723	1,731	2,321

N.B: 1 feddan = 0.42 ha

Table 2 The optimum water requirements for summer crops (m^3/feddan) at farm level of the main three regions in Egypt on 2016 [16]

Summer crops	Delta	Middle Egypt	Upper Egypt
Cotton	3,945	4,351	5,591
Rice	5,200	–	–
Corn	2,754	3,001	3,814
Sorghum	2,832	3,102	3,952
Soybean	3,034	3,324	4,235
Sugarcane	7,643	8,642	11,443
Sesame	2,913	3,191	4,065
Ground nut	2,913	3,191	4,065
Onion	3,864	4,230	5,386
Henna	4,450	4,900	6,365
Chatters	5,229	5,951	7,829
Sunflower	2,277	2,539	3,288
Green fodder	2,429	2,709	3,507
Medical and aromatic crops	4,035	4,474	5,782
Vegetables	2,970	3,306	4,290
Miscellaneous crops	3,702	4,104	5,258

N.B: 1 feddan = 0.42 ha

respectively, and reached 33% in 2010. The efficiency of the field irrigation system is about 50% [18].

Table 3 The optimum water requirements for nili crops and fruits (m^3/feddan) at farm level of the main three regions in Egypt on 2016 [16]

Summer crops	Delta	Middle Egypt	Upper Egypt
Corn	2,450	2,603	3,215
Sorghum	2,450	2,603	3,215
Onion	3,088	3,295	4,183
Sunflower	2,142	2,270	2,825
Vegetables	2,730	2,899	3,582
Miscellaneous crops	2,785	2,960	3,679
Fruits			
Evergreen	5,047	5,583	7,250
Deciduous	5,632	6,408	8,432

N.B: 1 feddan = 0.42 ha

5 Sustainable Water Use and Management to Cope with Water Scarcity

In order to secure the stability of food production globally under climate change condition [19], increasing water use efficiency in agricultural systems is very important for agricultural production, industrial and municipal purposes, and ecosystem health. Egypt can utilize the available quantity of water resources through expansion of less-water-consuming crops and reducing areas of high-water-consuming crops like rice and sugarcane, as well as enhancing the water supply system efficiency by detecting leakages, improving irrigation conveyance and distribution efficiency, and, in addition, introducing water conservation tariffs which might contain several kinds of crop or land taxes, water pricing, production charges, or subsidies for conservation of water and introducing public awareness for the society of a new water culture based on conservation principles [14]. The Egyptian national food security strategy is influenced particularly by growing cash crops on new lands, decreasing the areas of sugarcane and rice, increasing the cereal production on old lands, and giving attention to positive effects of the market-oriented economy [20].

Strategies for water saving in agriculture do not only include irrigation practices, but they extend into the other areas affecting on-farm water application including cultivation methods, varieties, and benefits of land leveling [21, 22]. Other water-saving strategies include covering canals with effective reaches, the timing of land irrigation, removing aquatic weeds in water passes, and turning sugarcane areas to beet in old lands. In addition, suitable pumping rates from deep groundwater aquifers using high-efficiency irrigation systems like sprinkler and drip irrigation systems in newly reclaimed lands were suggested as proposed planning alternatives which would completely eliminate Egypt's water shortage in 2025 [13].

There are many strategies to sustain water use and management in the agriculture sector to reduce water scarcity. These strategies are related to irrigation system management, farm practices, and breeding programs.

5.1 Increasing Irrigation Efficiency on Mesqa and Marwa level in Old Lands

The irrigation system in Egypt starts from the Aswan High Dam to the confluence of the two river branches Rosetta and Damietta with the Mediterranean Sea. It is a very complicated system; water passes many and through principle canals, main canals, branch canals, tertiary canals called Mesqa, and a field ditch that is called Marwa. The overall irrigation efficiency in Egypt is very low about 40–60%, due to evaporation, seepage, deep percolation, and transpiration from aquatic crops in irrigation canals. The cultivated area in Egypt is only 7.9 million feddan, about 3.3% from the total land area. This area is distributed as 9% oases and deserts, 12% new lands, and 79% old lands. The irrigation efficiency in the old land which has the main cultivated area in Egypt is about 40–60%. Thus, it is essential to improve the irrigation system and hence efficiency in the old land [23]. Several changes have the potential to reduce surface evaporation from free water, seepage, and aquatic weeds so irrigation efficiency increases such as changing earth field ditches called Mesqas to canals or pipelines, changing water abstraction from multi-point in the Mesqa to one point in the top end of the raised Mesqa, and changing the control from upstream to downstream [14].

Rice yield increased by 11.4% under Mesqa improvement. This increase is due to good water availability by the equity distributing between the tail and head of the Mesqa. The irrigation water applied was decreased as mean of 15.55% and water use efficiency was increased [24]. The Irrigation Improvement Project (IIP) was one of the main irrigation projects for using modern methods in land networks and on-farm development. Land leveling/tillage and rehabilitation of main and branch canals especially Mesqas (replace earth Mesqa with pipeline) were included. This promotes cooperation between the irrigation directorate and farmers by forming water user associations in irrigation distribution management [25]. Integrated Irrigation Improvement and Management Project (IIIMP) is expected to achieve additional positive effects on water distribution, quality, quantity, equity, timeliness, and water savings by replacing earth Marwa with pipeline and other technical assistance required for establishing water boards and water user associations [26]. Under the World Bank-funded IIP from 1996 to 2006 and IIIMP, the main objective of the two projects is improving the management of irrigation and drainage in the Nile Delta of Egypt. The specific objectives of the irrigation modernization are to enhance equitable water distribution, water quality, and water use efficiency and ultimately to increase agricultural production and decrease poverty. Irrigation improvements under the IIP have taken place at the Mesqa level, Mesqa for the tertiary level of irrigation canals, while IIIMP has taken place at the Marwa level, the term Marwa is used for the infrastructure at farm levels. Modernization of the Marwas under IIIMP is ongoing currently at selected areas. Seepage losses from the Mesqas are reduced by the piping of the tertiary canals, in addition allowing for pressurized water delivery. Similar improvements have newly been made to selected Marwas under IIIMP [27].

5.2 Using Pressurized Irrigation System in Newly Reclaimed Lands

Using modern irrigation system such as sprinkler and drip irrigation system in newly reclaimed lands is one of the most common strategies to cope with water scarcity in Egypt, because these systems save irrigation water and maximize efficiency. Moreover, these techniques can help overcome unsuitable soil, topography, climate, and water quality conditions. Drip irrigation is the best irrigation system when using saline water because it causes the highest irrigation application efficiency. Moreover, it causes less salt accumulation in the soil, prevention of leaf burn, and short irrigation frequency which prevents the soil from drying. Also, it helps to avoid higher peaks in salt concentration through continuous leaching of salts away from the wetted area accumulating at the wetting edges away from the active root zone [28]. Drip irrigation saves about 30–50% of irrigation water compared to surface irrigation, moreover reduces waterlogging and salinization, and achieves irrigation efficiency up to 95% [29].

Irrigation application efficiency can be designed as 60%, 75%, and 90% for surface (border, basin, and furrow), sprinkler, and drip irrigation, respectively [30]. Using drip and sprinkler irrigation systems in the newly reclaimed land in the desert is required, and it is prohibited to use flood irrigation in these places because of the high permeability of these soils and low water holding capacity [14]. Sprinkler irrigation saves water, time, and financial costs and can provide additional income generation [31]. Drip irrigation could be used as a possible solution for the problems of water scarcity [32].

5.3 On-Farm Water Management Practices to Maximize Water Productivity

Many agricultural practices on farm level could be applied in Egypt and could enhance productivity by implementing the following:

Laser land leveling is a very important practice to enhance water use efficiency and rationalize irrigation water through decreasing losses such as runoff and deep percolation, especially for high-water-consuming crop such as rice and sugarcane. Land leveling prevents water logging and water stress, and also it reduces water runoff, so the application uniformity is enhanced which thus contributes to increased crop production [33]. Laser land leveling reduces deep percolation and runoff by 8% and 24%, respectively, compared to non-leveled fields in Tajikistan [34]. Land leveling has a positive influence on the reduction of water applied because it minimizes surface runoff especially of the highest-water-consuming crops like sugarcane and rice [14]. Mechanization management in soil preparation and laser leveling with transplanting could decrease irrigation water applied for rice by 29% and increase water use efficiency [35].

Raised beds is one of planting methods as another on-farm practice that is effective to save irrigation water. Raised beds were originally used in row crops, but nowadays there are many researchers that have indicated the importance of this planting method to apply on non-row crops like rice, clover (berseem), and wheat. Growing berseem on raised seed beds is a successful practice to save irrigation water by 18% and, moreover, increase fresh and dry yield from 20 to 26% and 23 to 28%, respectively, compared to the traditional growing on flat soil [36]. Raised bed planting method with deficit irrigation saved about 1,600 and 1,500 m^3 water/ha and increased water productivity by 30 and 45% for maize and wheat, respectively, compared to farmers' practice with full irrigation practice [37]. Transplanting rice in bottom of beds can save a large amount of irrigation water ranging from 27 to 38% and increased irrigation water productivity by 56–66% without yield reduction or even slight yield increase [38–40].

Alternate furrow irrigation is one of the most applicable on-farm practices to reduce irrigation water applied and irrigation costs and increase crop yield, so it improves water productivity. Corn yield increased and irrigation efficiency improved with applied alternate furrow irrigation practice [41–43]. Alternative furrow irrigation technique saved about 22% and 42% from applied irrigation water compared to irrigating each furrow and basin irrigation, respectively, for cotton plants. This technique can increase water productivity without any yield reduction [44]. Alternative furrow irrigation can save about 30% compared to traditional furrow irrigation, in addition to slight increased on cotton yield [45].

Alternative root drying or partial root-zone drying can save a considerable amount of irrigation water especially for vegetables and fruit plants under drip irrigation system. This practice increased water use efficiency by 40% and increased yield by 43% per vine of wine grapes compared to traditional drip system [46]. Partial root-zone drying enhances irrigation water with respect to controls [47]. Applying alternative root drying strategies for potatoes and tomatoes could save 20–30% of irrigation water compared to fully irrigated plants. This technique increases significantly the potatoes marketable yield by 15% due to better size distribution [48].

Deficit irrigation, that is irrigated plants with amounts of water less than that required for full irrigation without any reduction in crop yield. Deficit irrigation allows for better water use efficiency compared to full irrigation, as presented experimentally for many crops [49, 50]. Also water-saving strategies can be used such as regulated deficit irrigation, that is, to irrigate in drought-sensitive stages of growth with minimum amounts of irrigation water [19].

Surge irrigation is applied as cycles of on and off from the stream which is delivered to the head of furrows. This technique saves a large amount of irrigation water and improves irrigation water productivity [51, 52]. In Egypt this technique is very important to maximize water productivity especially in heavy clay soils. On and off cycles give an appropriate chance to close soil cracks and decrease deep percolation. Surge irrigation practice reduces the irrigation water necessary during application by 14.5% and 18.6% for wheat and maize, respectively, while yield increased by 7% and 7.87% for wheat and maize, respectively [53]. Irrigation efficiency increased by 11.66% and 28.37% for the cutback and surge irrigation methods, respectively [32].

Schedule irrigation is applying a metric that identifies when to irrigate and by how much. It is very important to know the accurate crop water requirement depending on crop stages. Schedule irrigation leads to enhancing water use through decrease on on-farm water losses due to evaporation and can enhance crop yield.

Nighttime irrigation is important to improve water productivity through reducing evaporation during daytime hours and produce healthy plants. Farmers should irrigate crops at night, because it reduces losses of evaporation which are carried out during sunlight and tail end losses to drainage system if there is no abstraction of freshwater during night time [14].

Supplemental irrigation is one of the important strategies that is used in arid areas through applying small amounts of irrigation water to winter crops that are normally grown under rain-fed conditions [54]. Many of the agronomic practices for improving the efficiency of water use rain-fed systems and depend on reducing water losses by runoff, soil evaporation, deep percolation, and competing weeds. Supplemental irrigation technique is used to overcome periods of low rainfall or high temperatures, and it is suggested to improve crop production [19].

5.4 Sustainable Use of Groundwater

According to MWRI [5], extraction from deep groundwater aquifers in Sinai and the Western Desert is estimated to be only 2.0 BCM/year and 6.5 BCM in 2013 from shallow groundwater in the Nile aquifers.

The quality of the groundwater in the Nile areas especially in North Nile Delta is expected to be affected strongly by the impact of sea level rise combined with changes of Nile River flows, which will lead to an increase in the salinity levels of the groundwater [55]. In addition, current and future human activities, especially extensive and unplanned groundwater abstraction, are resulting in degradation of the availability of groundwater resources. Serious negative socioeconomic impacts can follow as a consequence. In the Nile Delta, extensive groundwater abstraction is also a very significant factor that increases seawater intrusion, and groundwater wells which were beyond salinization zones in the past are consequently showing upcoming of saline or brackish water [56].

There is a gap in information and implementation of groundwater resources development sustainability and protection of the environment in Nile Delta as a regional strategy. In addition, there is deficit knowledge about groundwater quality deterioration [57]. So, detailed studies should be applied to include all groundwater resources and data on quality deterioration in the Nile Delta aquifers, as well as hydrological studies of all groundwater resource aquifers in whole Egypt including Sinai and the Western Desert to define the available quantities and the secure yield of abstraction for sustainable use.

5.5 Reuse of Drainage Water

The importance of using nonconventional water resources like the reuse of drainage water, treated wastewater, and desalination of brackish and seawater are becoming increasingly important around the world particularly in water-scarce areas. Optimization of the use of water resources in Egypt is implemented via recycling industrial and domestic wastewater, reuse of drainage water, and desalination [14]. The reuse of agricultural drainage water in Egypt is considered as an integral addition to the water sources. Pumping stations of the government and farmers' small diesel pumps extract water from drainage ditches and put it directly in the irrigation canals to reuse in agriculture irrigation; these actions have increased the country's water resources by 20% [58]. Water shortage in Egypt is 13.5 BCM/year and it expected to increase continuously. This water shortage is compensated by the reuse of drainage which deteriorates the water quality [13].

5.6 Modification of Cropping Pattern

Using the optimum cropping pattern which achieves the maximum water return from the unit of water, it is a main factor to cope water scarcity in Egypt. Moreover it should have priority in the next years especially cropping patterns which save irrigation water. Expansion of less-water-consuming crops and reducing areas of high-water-consuming crops like rice and sugarcane is one of the encouraged strategies to cope with water scarcity in Egypt [14]. The main problem for water distribution engineers in Egypt lie in the free cropping pattern. These difficulties resulted from the randomized distribution of crop along the network canals, with their different areas [7].

Planting drought- and salt-tolerant crop species as amaranth, Andean lupin, and quinoa may result in more resilient high-value cash crop products and crop rotations [19]. As water scarcity is considered a main limitation for agricultural expansion, high efficient crop patterns are recommended to minimize the consumed water amount [7].

6 Breeding for High Water Use Efficiency Crops

Breeding programs for the different crops always have two strategies to cope with water shortage. The first strategy is to introduce short-duration varieties especially for a high-water consumer such as rice. The Egypt's rice program developed many rice varieties such as Giza 177 and Sakha 102 which require less water consumption. These varieties reduce the duration from seed to seed by 40 days [59]. Replacing long-duration varieties by new short-duration varieties is an encouraging way to save irrigation water in Egyptian agriculture. Rice is a great example for short-duration varieties. Maize, wheat legumes, and cotton are other examples. The reduction in the number of days means a reduction in a number of irrigations and consequently in the water quantity used [14]. Cultivating short-duration rice varieties saved about 18% of the water deliveries needed compared to long-duration rice varieties [35].

The second strategy is breeding drought-tolerant plants and varieties through genetic transfer or agronomic practices. Breeding programs introduced new rice varieties that are more drought-tolerant and achieved higher yield with less water applied. Aerobic rice saves about 40% from irrigation water applied through irrigating every 12–15 days compared to the same varieties under conventional irrigation [60]. Developed types of rice withstanding drought, “Oraby 1 and 2,” consume 50% of the water when grown in furrows compared to traditional rice without any reduction of productivity [61]. The hybrid rice varieties as the Egyptian hybrid “1” and “2” produce higher yield from 14 to 16 ton/ha, while it saves more than 20% from irrigation water [62]. Stresses can be overcome from mild to medium levels by agronomic practices. This can include using different crops through increased salinity and drought tolerance according to their stress adaptation mechanisms to enhance crop productivity [19].

7 Integrated Water Management for Sustainable Agriculture

The integrated water management for sustainable agriculture in Egypt includes many approaches. Some of these approaches are related to water deliveries from Aswan High Dam to farmer’s fields in all old agricultural lands. In addition, these approaches also include water harvesting techniques in rain-fed places and integrated management for groundwater resources. The other approaches are related to on-farm practices to rationalize water use and maximize water productivity under different irrigation water resources (Nile River, rain-fed, and groundwater). It is summarized in the following:

- Determining the optimum water requirement and irrigation scheduling for various crops (field crops, fruits, and vegetables)
- Applying the new irrigation systems in new reclaimed lands as sprinkler and trickle irrigation systems and, moreover spreading surface irrigation methods which save irrigation water and improve irrigation water efficiency in old lands
- Studying deficit irrigation and withholding in noncritical physiological growth stages, in addition to cultivated drought-tolerant varieties
- Reducing the areas of high-water-consuming crops like sugarcane and rice and replacing with sugar beet and maize
- Using different cropping patterns which cope with water scarcity

- Expanding use of nontraditional water resources such as treated wastewater, drainage water, and desalinization considering water validity approaches as water quality, kind of crops, soil type, kind of irrigation system, and management
- Using new technology like geographic information systems and remote sensing to determine crop areas and irrigation requirements
- Introducing various water harvest techniques to use these collected water as a supplemental irrigation on sensitive physiological stages for crops in rain-fed areas
- Applying hydrological studies of all groundwater resource aquifers in Egypt including Sinai and the Western Desert to define the available quantities and the secure yield of abstraction for sustainable us
- Studying the projected impacts of climate change on crop water requirements and agricultural productivity
- Expansion of improvement of Mesqas and Marwas on surface irrigation systems in the old land to improve irrigation efficiency and increase crop productivity
- Introducing integrated management for drainage systems, fertilizers programs, soil amendments, and pest and weed control to enhance crop productivity
- Introducing and expanding programs for extension specialists and farmers showing them new technologies and the outputs of new studies in the field of irrigation and agriculture production
- Suggesting an integrated management program for salt-affected soil to enhance its productivity

8 Conclusions and Recommendations

Due to the current and the expected increase in water scarcity in Egypt, we could conclude the following points to maximize crop yield with minimal water use:

- The expansion of improvement on surface irrigation system in old agricultural lands through improvement of Mesqas and Marwas. Moreover, applying on-farm practices which cause increase in water use efficiency as laser land leveling, raised beds, alternative furrow irrigation, deficit irrigation, surge irrigation, irrigation scheduling, and night irrigation
- The spreading use of pressurized irrigation systems such as sprinkler and trickle in new reclaimed lands and desert and in addition applying on-farm practices such as irrigation scheduling, night irrigation, and partial root-zone drying for drip irrigation
- Improving water harvesting techniques in rain-fed areas in the North West coast area and using these water harvesting techniques in supplemental irrigation on critical crop physiological stages
- The expanding use of nonconventional water resources such as desalination of seawater and reuse of drainage water and groundwater under integrated water management for sustainable agriculture

References

1. Nangia V, de Fraiture C, Turral H (2008) Water quality implications of raising crop water productivity. Agric Water Manag 95:825–835. doi:10.1016/j.agwat.2008.02.014
2. Molden D, Oweis TY, Pasquale S, Kijne JW, Hanjra MA, Bindraban PS, Bouman BAM, Cook S, Erenstein O, Farahani H, Hachum A, Hoogeveen J, Mahoo H, Nangia V, Peden D, Sikka A, Silva P, Turral H, Upadhyaya A, Zwart S (2007) Pathways for increasing agricultural water productivity. In: Molden D (ed) Water for food, water for life: a comprehensive assessment of water management in agriculture. Earthscan/IWMI, London/Colombo, pp. 279–310
3. Batisha AF (2012) Adaptation of sea level rise in Nile Delta due to climate change. Earth Sci Clim Chang 3:1–5. doi:10.4172/2157-7617.1000114
4. Lowder SK, Skoet J, Singh S (2014) What do we really know about the number and distribution of farms and family farms in the world? ESA Working Paper No. 14-02. Food and Agriculture Organization of the United Nations, Rome
5. MWRI (2014) Water scarcity in Egypt. Ministry of Water Resources and Irrigation, Giza
6. FAOSTAT (2006) FAOSTAT agriculture data, food and agriculture organization of the United Nations. Available at: http://faostat.fao.org/. Accessed 23 June 2006
7. Zaghloul SS (2013) Consideration of the agricultural problems as a base of water resource management in Egypt. Seventeenth International Water Technology Conference, IWTC17, Istanbul, 5–7 November
8. FAO (2011) Food and Agriculture Organization of the United Nations (FAO) (2011, July 7). FAO country briefs: Egypt. http://www.fao.org. Retrieved 12 July 2011, from FAO website
9. WFD (2000) WFD, 2000/60/EC: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
10. Jury WA, Vaux HJ (2007) The emerging global water crisis: managing scarcity and conflict between water users. Adv Agron 95:1–76
11. Abd-El-Hai M (2002) Current and emerging issues for economic analysis and policy research CUREMIS II NENA. FAO. INP. In: Rural non-farm employment workshop
12. El-Agroudy NM, Mohamed EAEF, Mokhtar S, Hasan HBA (2016) The water crisis with Nile basin countries and its impact on the water security of Egypt. Int J ChemTech Res 9:101–107
13. Omar MEDM, Moussa AMA (2016) Water management in Egypt for facing the future challenges. J Adv Res 7:403–412. doi:10.1016/j.jare.2016.02.005
14. Abdin AE, Gaafar I (2009) Rational water use in Egypt. In: El Moujabber M, Mandi L, Trisorio-Liuzzi G, Martín I, Rabi A, Rodríguez R (eds) Technological perspectives for rational use of water resources in the Mediterranean region. CIHEAM, Bari, pp. 11–27
15. Gohar AA, Ward FA (2011) Gains from improved irrigation water use efficiency in Egypt. Water Resour Dev:1–22. doi:10.1080/07900627.2011.598132
16. Central Agency for Public Mobilization and Statistics (2014) Annual report for irrigation water and water resource statistics, Egypt
17. Yang CM (2012) Technologies to improve water management for rice cultivation. Crop Environ Bioinforma 9:193–207
18. MALR (2009) The sustainable agricultural development strategy towards 2030. Ministry of Agriculture and Land Reclamation, Cairo
19. Jacobsen SE, Jensen CR, Liu F (2012) Improving crop production in the arid Mediterranean climate. Food Crop Res 128:34–47. doi:10.1016/j.fcr.2011.12.001
20. El-Gafy IK, El-Ganzori AM, Mohamed AI (2014) Decision support system to maximize economic value of irrigation water at the Egyptian governorates meanwhile reducing the national food gap. Water Sci 27:1–18. doi:10.1016/j.wsj.2013.12.001
21. Hama T, Nakamura K, Kawashima S, Kaneki R, Mitsuno T (2011) Effects of cyclic irrigation on water and nitrogen mass balances in a paddy field. Ecol Eng 37:1563–1566
22. De Miguel A, Martínez-Hernández V, Leal M, González-Naranjo V, De Bustamante I, Lillo J, Martín I, Salas JJ, Palacios-Díaz MP (2013) Short-term effects of reclaimed water irrigation: *Jatropha curcas* L. cultivation. Ecol Eng 50:44–51

23. Malashkhia N (2003) Social and environmental constraints to the irrigation water conservation measures in Egypt. Master Thesis, Lund University, Sweden
24. MALR (1998) Assessment of Egypt's rice policy and strategies for water management. Sector of Economic Affairs, Ministry of Agriculture and Land Reclamation, Cairo
25. Alnagar D, Zwarteveen M (2003) Policies and strategic options for water management in the Islamic countries. In: International hydrological programme, Tehran, 15–16 Dec
26. Sabour Consultant (2004) Terms of reference for the tendering of consulting services for the Integrated Irrigation Improvement and Management Project (IIIMP) and instruction to tenderers
27. Simons G, Terink W, Badawy H, van den Eertwegh G, Bastiaanssen W (2012) Egypt: assessing the effects of farm-level irrigation modernization on water availability and crop yields. Final report (Summer 2011 and Winter 2011/2012), p 127
28. Dasberg S, Or D (1999) Drip irrigation. Springer-Verlag, Berlin, 162 pp
29. World Bank (2006) Reengaging in agricultural water management: challenges, opportunities, and trade-offs. Water Food Team, Agriculture and Rural Development Department, World Bank, Washington, DC
30. EU (2007) Water saving potential. Part 1 – Report. ENV.D.2/ETU/2007/001r
31. Rizk MA, Fayed MH, Osman MS, Ali KYM (2011) Productivity of some summer forage crops under sprinkler irrigation in newly reclaimed soil conditions. Plant Prod Mansoura Univ 2:1061–1072
32. Van der Kooij S, Zwarteveen M, Boesveld H, Kuper M (2013) The efficiency of drip irrigation unpacked. Agric Water Manag 123:103–110. doi:10.1016/j.agwat.2013.03.014
33. Allam MN, El Gamal F, Hesham M (2005) Irrigation systems performance in Egypt. In: Lamaddalena N, Lebdi F, Todorovic M, Bogliotti C (eds) Irrigation systems performance, Options Méditerranéennes: Série B. CIHEAM, Bari, pp. 85–98
34. Abdullaev I, Hassan MU, Jumaboev K (2007) Water saving and economic impacts of land leveling: the case study of cotton production in Tajikistan. Irrig Drain Syst 21:251–263
35. Mostafa H, Fujimoto N (2014) Water saving scenarios for effective irrigation management in Egyptian rice cultivation. Ecol Eng 70:11–15. doi:10.1016/j.ecoleng.2014.04.005
36. Stone JF, Reeves HE, Taegaya T (1985) Irrigation water requirements under wide-space furrow irrigation. In: Keyes G, Ward T.J (eds) Development and management aspects of irrigation and drainage systems. IR Division, ASCE, San Antonio, pp 462–468
37. Karrou M, Oweis T, Abou El Enein R, Sherif M (2012) Yield and water productivity of maize and wheat under deficit and raised bed irrigation practices in Egypt. Afr J Agric Res 7:1755–1760. doi:10.5897/AJAR11.2109
38. Meleha ME, El-Bably AZ, Abd Allah AA, El-Khoby WM (2008) Producing more rice with less water by inducing planting methods in north Delta, Egypt. J Agric Sci Mansoura Univ 33:805–813
39. El-Atawy GS (2012) Saving irrigation water and improving water productivity in rice cultivation by inducing new planting method in North Delta, Egypt. J Soil Sci Agric Eng Mansoura Univ 3:587–599
40. Mahmoud MA (2015) Yield and water productivity of rice on raise beds, irrigation intervals and ammonia gas injection at North Nile Delta. J Soil Sci Agric Eng Mansoura Univ 6:1373–1387
41. Nasri M, Khalatbari M, Farahani HA (2010) The effect of alternate furrow irrigation under different nutritional element supplies on some agronomic traits and seed qualitative parameters in corn (*Zea mays* L.) J Cereal Oilseeds 1:17–23
42. Kashiani P, Saleh G, Osman M, Habibi D (2011) Sweet corn yield response to alternate furrow irrigation methods under different planting densities in a semi-arid climatic condition. Afr J Agric Res 6:1032–1040
43. Abd El-Halim A (2013) Impact of alternate furrow irrigation with different irrigation intervals on yield, water use efficiency, and economic return of corn. Chil J Agric Res 73:175–180. doi:10.4067/S0718-58392013000200014

44. Thind HS, Buttar GS, Aujla MS (2010) Yield and water use efficiency of wheat and cotton under alternate furrow and check-basin irrigation with canal and tube well water in Punjab, India. Irrig Sci 28:489–496
45. Mahmoud MA, El-hendawy AA, Awad MY (2016) Water productivity of some cotton varieties and yield under different irrigation methods. Assiut J Agric Sci 47:203–216
46. Da la Hera ML, Romero P, Gomez-Plaza E, Martinez A (2007) Is partial root-zone drying an effective irrigation technique to improve water use efficiency and fruit quality in field-grown wine grapes under semiarid conditions? Agric Water Manag 87:261–274
47. Sadras VO (2009) Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. Irrig Sci 27:183–190
48. Jensen CR, Battilani A, Plauborg F, Psarras G, Chartzoulakis K, Janowiak F, Stikic R, Jovanovic Z, Li G, Qi X, et al (2010) Deficit irrigation based on drought tolerance and root signalling in potatoes and tomatoes. Agric Water Manag 98:403–413
49. Fereres E, Soriano MA (2007) Deficit irrigation for reducing agricultural water use. J Exp Bot 58:147–159
50. Fan X, Li F, Xiong Y, An L, Long R (2008) The cooperative relation between non-hydraulic root signals and osmotic adjustment under water stress improves grain formation for spring wheat varieties. Physiol Plant 132:283–292
51. Coupal RH, Wilson PN (1990) Adopting water-conserving irrigation technology: the case of surge irrigation in Arizona. Agric Water Manag 18:15–28
52. Horst MG, Shamutalov SS, Gonçalves JM, Pereira LS (2007) Assessing impacts of surge-flow irrigation on water saving and productivity of cotton. Agric Water Manag 87:115–127
53. Abdel-Maksoud HH, Othman SA, Khater AN (1999) Combined effect of surge irrigation and N-forms on water and N-utilization for wheat and maize crops. In: Third conference on-farm irrigation agroclimatology, Egypt, 25–27 Jan 1999
54. Oweis T, Pala M, Ryan J (1998) Stabilizing rainfed wheat yields with supplemental irrigation and nitrogen in a Mediterranean climate. Agron J 90:672–681
55. Dawoud MA (2004) Design of national groundwater quality monitoring network in Egypt. Environ Monit Assess 96:99–118
56. Abdelaty IM, Abd-elhamid HF, Fahmy MR, Abdelaal GM (2014) Investigation of some potential parameters and its impacts on saltwater intrusion in Nile Delta aquifer. J Eng Sci Assiut Univ Fac Eng 42:931–955
57. Mabrouk MB, Jonoski A, Solomatine D, Uhlenbrook S (2013) A review of seawater intrusion in solid the Nile Delta groundwater system – the basis for assessing impacts due to climate changes and water resources development. Hydrol Earth Syst Sci Discuss 10:10873–10911. doi:10.5194/hessd-10-10873-2013
58. Barnes J (2014) Mixing waters: the reuse of agricultural drainage water in Egypt. Geoforum 57:181–191. doi:10.1016/j.geoforum.2012.11.019
59. RRTC (1998) The annual report of the National Rice Program
60. RRTC (2010) Annual report. Sakha, Kafr El-Sheikh, Egypt
61. Soliman S (2010) Dry rice. http://digital.ahram.org.eg/articles.aspx?Serial= 292651&eid=162
62. El-Mowafi H (2010) Egypt on top of global rice productivity. http://digital.ahram.org.eg/articles.aspx?Serial=1095486&eid=5764