Chapter 3
Egypt Faces Water Deficiency, and Food Insufficiency

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Abstract This chapter provided an overview of the situation of Egypt with respect to its natural resources. It discussed the climate of Egypt and its relation to the growing season of cultivated crops and water requirements of these crops. It also presented the quantity of water resources, the management of irrigation water, and irrigated agriculture, as well as its food production. It also reviewed soil resources in Egypt and population pressure on land and water resources. This chapter also tackled the issue of food gaps in Egypt. Five food gaps were discussed, namely wheat, maize, faba bean, edible oil crops, and summer forage crops. It also reviewed the previous research on the application of deficit irrigation to mono crops and to intercropping systems.

Keywords Climate · Water and soil resources · Food gaps · Deficit irrigation

3.1 Introduction

Egypt is located on the Northeastern corner of Africa on the Mediterranean Sea between latitudes 22° and 32° N, and between longitudes 24° and 37° E. The total area of Egypt is 1,001,450 km^2, with a land area of 995,450 km^2. The Egyptian terrain consists of vast desert plateau interrupted by the Nile Delta and Valley, which occupy about 4% of the total area of Egypt (Fig. 3.1). The Nile Delta and Valley divided the desert land of Egypt into the western desert (represents two third of Egypt territory) and the eastern desert. In addition, Sinai Peninsula located on eastern part of Egypt represents 6% of the Egypt area. Sinai Peninsula is located in Asia continent, which makes Egypt a transcontinental country (Omran 2017).

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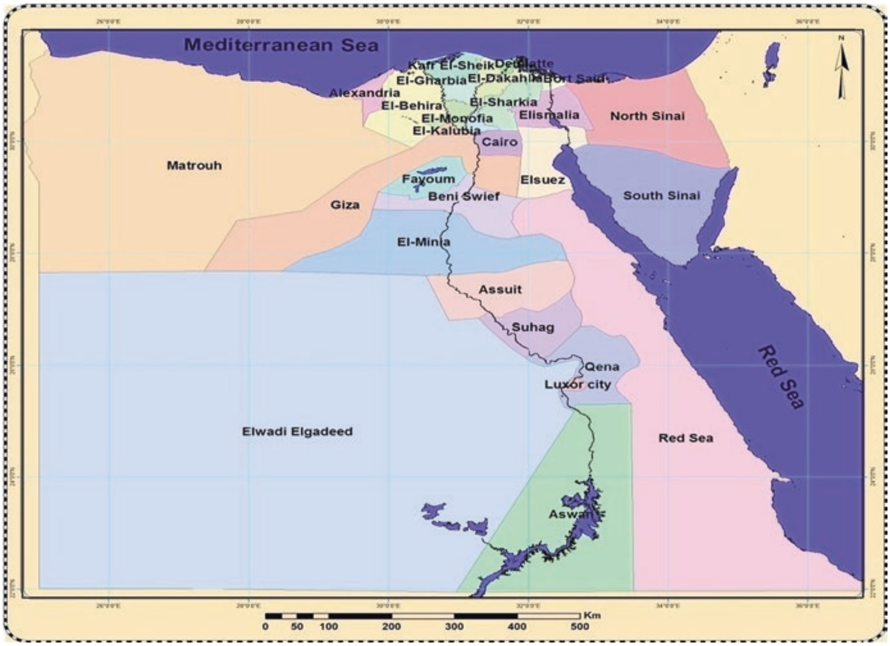

Fig. 3.1 Map of Egypt

Egypt is bordered by Libya in the west, by the Gaza Strip and the Red Sea in the east, and by Sudan in the south. The inhabited area of the country is confined to the Nile Delta and Valley. The Nile Delta covers the area from Cairo to the shoreline of the Mediterranean Sea, between the cities of Damietta in the east and Rashid in the west. A narrow strip from south of Cairo to Aswan represents the Nile Valley (Morsy et al. 2017).

This chapter provided an overview of the situation of Egypt with respect to its natural resources, food production, and population pressure on land and water resources. It also reviewed the previous research on the application of deficit irrigation to crops.

3.2 Climate of Egypt

There are four distinguished seasons in Egypt: winter (from December to February), spring (from March to May), summer (from June to August) and autumn (from September to November). The climate of Egypt is characterized by hot dry summers and mild winters with winter Mediterranean climate. Most of Egypt is a desert and can be classified as arid, with the exception of the slightly wetter Mediterranean coast, which can be considered semi-arid. The rain is relatively low, irregular, and unpredictable, where it is the highest along the Mediterranean, where it average about than 200 mm/year. Precipitation rates drop quickly as one moves away from the coast. It average to 20 mm/year in Middle Egypt to 2 mm/year in Upper Egypt (EEAA 2010).

El-Fandy (1948) stated that mid-latitude weather regime is prevailing during the winter season, which is characterized by the frequent passage of upper westerly troughs associated with surface depressions. Thick layers of low and medium clouds cover the northern part of Egypt and sometimes extend to the south during the passage of these depressions along the east Mediterranean. These cloud clusters are usually associated with torrential rain and in many cases with thunder storms. The minimum value of maximum temperature occurs in the winter, where maximum temperature tends to reach its maximum value of 18 °C over the northern part and 24 °C over the southern part with small gradient of temperature. Minimum temperature during winter could reach 3 °C over middle of Egypt region. Wind speed could reach as minimum as 1.5 m/s in the winter. In addition, the difference between north and south values of downward short wave radiation is large (Morsy et al. 2017).

The main climatic feature within the spring season is the southward shift of the tracks of depressions known as desert or Khamasen depressions. After the passage of the depression, northerly winds prevail over Egypt with possible strong guests that cause rising sand (dust) in open areas especially in Upper Egypt (El-Fandy 1948). Furthermore, there is a gradient of maximum temperature intensifies during spring season over northern part and decline over the rest of Egypt, where it is between 21 °C over the northern part and 36 °C over the southern part. Minimum temperature during spring season is around 12 °C covers most of Egypt (Morsy et al. 2017).

The main forcing during the summer season is the westward extension of the Indian monsoon low pressure, which provides Egypt with hot and humid north easterly surface winds. Occasionally, during the summer season, the Indian monsoon low pressure is weakened and shrinks towards the east, allowing the sub-tropical high pressure. As a consequence, a rather mild and dry north westerly wind invades the northern parts of Egypt (Hasanean and Abdel Basset 2006). The maximum value of maximum temperature occurs in the summer, where its gradient intensifies during summer over northern part and decline over the rest of Egypt. A minimum temperature of 21 °C during summer season is the prevailing over all Egypt, except latitudinal band from 28 to 30 °N. Wind speed could reach a maximum value of 4 m/s in the summer. Additionally, downward short wave radiation has a weak gradient in the summer (Morsy et al. 2017).

During the autumn season, Egypt is under the influence of northward extension of Sudan monsoon along Red Sea with southward extension of upper air trough that cause heavy rain over the eastern part of Egypt (Hasanean and Abdel Basset 2006). Maximum temperature during summer season ranges from 30 °C to 42 °C with maximum core over Upper Egypt. A dominant minimum temperature of 15 °C during autumn season occurs over all Egypt, except north and south east parts (Morsy et al. 2017).

3.2.1 Growing Seasons of the Cultivated Crops

The characteristics of climate of each season determinate crops growth periods and crops water requirements. The relationships between climate, crop, water and soil are complex with many biological processes involved (Rao et al. 2011). There are two main crop growing seasons in Egypt: winter and summer seasons. The winter season starts as early as October and ends in May. Most of winter field and vegetable crops are cultivated in November, with few exceptions. Egyptian clover, legume crops (faba bean, and lentil), sugar beet, pea and strawberry could be cultivated early in October. Fall sugarcane could also be cultivated in September and October and its season length is 16 months (Ouda 2019). Table 3.1 shows planting and harvest dates of some winter field and vegetable crops.

Summer season starts between 15th of April to 15th of May for all crops, except cotton and spring sugarcane. Cotton is cultivated in March and its season length is 7 months. Spring sugarcane is cultivated between February and March and its season length is 12 months. Some summer vegetable crops must be cultivated as early as in February, i.e. watermelon. Whereas, the suitable planting month for fruit trees in Egypt is February (Ouda 2019) (Table 3.2).

3.2.2 Water Requirements of the Cultivated Crops in Egypt

Water requirement of the cultivated crops is influenced by the type of the growing season and the length of its growing season. Water requirements of a crop is defined as the amount of water need to be applied to the growing plants during its growing season to substitute water losses from its surface and from the soil surface, to insure healthy growth and attain optimal productivity. Two main components, in which

Table 3.1 Planting and harvest dates for the selected winter field and vegetable crops

Crop	Planting date	Harvest date	Season length (days)
Faba Bean	25-Oct	25-Apr	152
Clover	15-Oct	1-Apr	169
Flax	15-Nov	13-Apr	150
Lentil	25-Oct	25-Mar	152
Sugar beet	15-Oct	12-Apr	180
Wheat	15-Nov	18-Apr	155
Fall sugarcane	51-Oct	15-Feb of the following year	480
Potato	1-Nov	1-Feb	93
Strawberry	1-Sep	15-May	257
Tomato	1-Oct	1-Mar	152
Peas	1-Sep	30-Nov	91
Onion	15-Nov	15-Apr	152
Watermelon	15-Feb	30-Jun	136

Source: Ouda (2019)

Table 3.2 Planting and harvest dates for the selected summer field and vegetable crops

Crop	Planting date	Harvest date	Season length (days)
Cotton	15-Mar	15-Aug	154
Maize	15-May	1-Sep	110
Rice	15-May	16-Sep	125
Sorghum	15-May	1-Sep	110
Soybean	15-May	25-Aug	103
Sunflower	15-May	15-Aug	93
Wheat	15-Nov	18-Apr	155
Spring sugarcane	15-Feb	14-Feb	365
Cucumber	15-Mar	15-Jun	93
Eggplant	1-Apr	1-Aug	130
Pepper	1-Apr	8-Aug	130
Potato	1-Aug	28-Nov	120
Tomato	1-May	1-Sep	124

Source: Ouda (2019)

crop water requirement depends on them, namely reference evapotranspiration and seasonal crop coefficients.

3.2.2.1 Reference evapotranspiration

Reference evapotranspiration (ETo) is the total amount of water lost from the field by both soil evaporation and plant transpiration (Gardner et al. 1985). It is a key component in irrigation scheduling for crops and water requirement calculation. Various equations have been developed to estimate ETo. The Penman-Monteith equation (Allen et al. 1998) is widely recommended because of its detailed theoretical base and its accommodation of small time periods. It was also indicated that the Penman-Monteith method exhibited excellent performance in both arid and humid climates (Shahidian et al. 2012).

Ouda and Noreldin (2017) indicated that there is evidences of an increasing trend in ETo values calculated from 30-year interval (1986–2015) illustrated by higher mean values of ETo in the 10-year interval (2006–2015), compared to the mean value of 20-year time interval (1996–2015) (Fig. 3.2).

3.2.2.2 Seasonal Crop Coefficients

Seasonal crop coefficients (Kc) takes into account the relationship between atmosphere, crop physiology, and agricultural practices (Snyder et al. 2004). Multiplication of ETo by Kc values results in the value of crop evapotranspiration (ETc, or water consumptive use by the crop). Table 3.3 presents the values of Kc (initial, middle and end season) and ETc value of different crops cultivated in the winter season. The table indicated that spring sugarcane has the highest ETc values as a result of its long

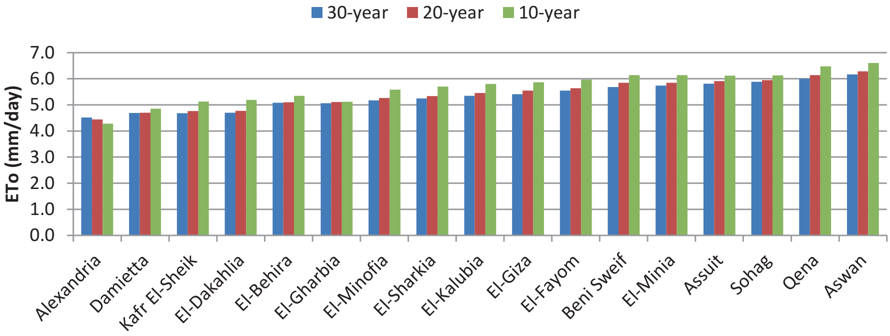

Fig. 3.2 Comparison between averaged values of ETo over 10, 20 and 30 years. (Source: Ouda and Noreldin 2017)

Table 3.3 Crop coefficient (Kc) and crop evapotranspiration (ETc) values for different winter field and vegetable crops

Crop	Kc_{ini}	Kc_{mid}	Kc_{end}	ETc (mm)
Barley	0.29	1.11	0.19	380
Faba bean	0.27	0.99	0.19	411
Clover	0.25	1.15	1.15	635
Flax	0.29	1.10	0.25	589
Lentil	0.22	0.99	0.19	402
Wheat	0.30	1.08	0.18	455
Sugar beet	0.25	1.15	0.95	604
Fall sugarcane	0.83	1.25	0.75	2982
Potato	0.26	1.09	1.24	232
Strawberry	0.20	0.70	0.70	694
Sweet potato	0.23	1.10	0.69	423
Tomato	0.23	1.10	0.64	395
Peas	0.19	0.98	0.98	340
Onion	0.28	1.19	0.54	581
Watermelon	0.26	1.00	0.75	751

Source: Ouda (2019)

growing season, namely 12 months. In addition, the value of ETc of watermelon is ranked second because its growing season started in February and ended in June resulted in high values of ETo. The third highest value of ETc is found for sugar beet as a result of its long growing season, namely 6 months (Table 3.3).

For field crops grown in the summer season, the highest value of ETc is found for rice, sorghum and cotton. Furthermore, three vegetable crops have the highest value of ETc, namely eggplant, potato and cucumber (Table 3.4).

To calculate water requirements of a crop, irrigation application efficiency is considered in the calculation. In Egypt, the common used values of irrigation application efficiency are 60, 75 and 85% for surface, sprinkler and drip, respectively.

Table 3.4 Crop coefficient (Kc) and crop evapotranspiration (ETc) values for different summer field and vegetable crops

Crop	Kc_{ini}	Kc_{mid}	Kc_{end}	ETc (mm)
Cotton	0.27	0.99	0.63	675
Maize	0.21	1.03	0.58	690
Rice	0.34	0.61	0.47	757
Sorghum	0.18	1.06	0.50	717
Soybean	0.21	1.11	0.39	684
Sunflower	0.21	1.09	0.37	616
Wheat	0.23	0.85	0.85	480
Cucumber	0.20	0.91	0.86	728
Eggplant	0.20	0.98	0.83	824
Pepper	0.22	1.10	0.69	546
Potato	0.22	1.10	0.65	788
Tomato	0.23	0.90	0.70	479

Source: Ouda (2019)

3.3 Water Resources of Egypt

3.3.1 Water Resources Quantity

Water resources in Egypt are very limited, where more than 95% of it is received from outside of its international borders. The Nile River is the main water resource in Egypt. Egypt shares the Nile water with nine countries (Sudan, Ethiopia, Eritrea, Tanzania, the Democratic Congo, Uganda, Burundi, Rwanda, and Kenya). Egypt also lies at the end of the Nile's route toward the sea. The annual share of Nile River water was determined in an international agreement by 55.5 billion cubic meters (BCM). The High Aswan Dam is the major regulatory facility on the river. The annual share of the Nile is stored in Lake Nasser. The Nile water is driven from the dam downstream by intensive network of canals through several types of control structure (Ministry of Water Resources and Irrigation 2005).

Groundwater is one of the most important resources after the Nile River. Ground water is the portion of the water beneath the surface of the earth that can be collected with the wells, tunnels, drainage galleries, or that flows naturally to the earth's surface via seeps or springs (Ashour et al. 2009). There are different groundwater aquifers with variable importance for exploitation in the Nile river region. They are ranging from shallow local aquifers, recharged by rainfall, to deep non-replenish aquifers. The first category comprises groundwater in the Nile Valley and Delta system. The second aquifer category is the non-renewable type, which is located in the Western Desert-Nubian Sandstone Aquifer (Abdel-Shafy and Kamel 2016). The current total abstraction of the groundwater is only 2.0 BCM per year as a result of great depth, up to 1500 m in some area (Ministry of Water Resources and Irrigation 2013).

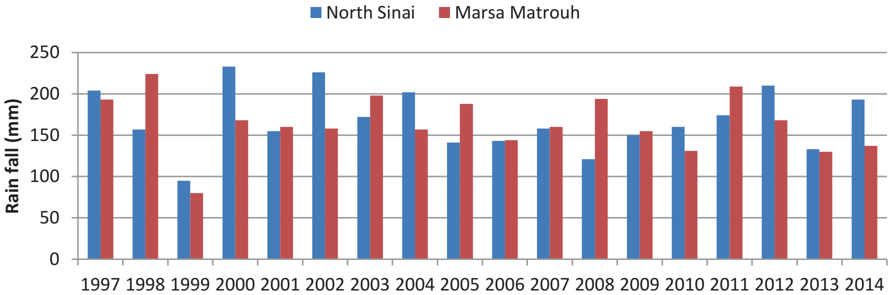

Fig. 3.3 Annual values of rain fall (mm) from 1997 to 2014 in North Sinai and Marsa Matrouh governorates. (Source: Ouda et al. 2016)

Rain is the third important water resource in Egypt. Rain falls in the winter only and its amount in the Egyptian north coast varies ranging from 130 to 150 mm in the northwestern coast and from 80 mm (west of Al-Arish) to 280 mm (at Rafah) in the northeastern coast. This rate decreases after 20 kilometers south of the Mediterranean in both areas. The effective rainfalls on the northern strip of the Nile Delta are calculated by 1.3 BCM/year (http://www.emwis-eg.org). Figure 3.3 showed rain fall values from 1997 to 2014 in North Sinai and Marsa Matrouh located on eastern and western coast of the Mediterranean Sea. The figure showed high temporal and spatial variability in rain fall amounts. Therefore, the rain fall in Egypt cannot be considered as a reliable source.

The total annual water resources in Egypt are 55.5 BCM obtains from the Nile, 2.0 BCM from ground water, 1.3 BCM from rain, which add to 58.8 BCM. The major amount of water consumption come from agriculture, namely about 62.3 BCM. Drinking water uses 8.7 BCM and industry uses about 7.5 BCM. These three amounts add up with total of 78.5 BCM. Thus, there is a gap estimated by about 20 BCM/year between available water resources and the demand for water. This gap is overcome by recycling agricultural drainage water to be used in irrigation (Ministry of Irrigation and Water Resources 2014).

The reuse of agricultural drainage water in irrigation has been adapted as an official policy since the late seventies by mixing it with Nile water (fresh water) in the main and branch canals. However, the reuse of agricultural drainage water is not considered as independent resource. It is only used to fill the gap between water supply and demand.

3.3.2 Irrigation Water Management

Agriculture water demand is one of the serious pressures on water sector in Egypt, since 85% of total available water is consumed in agriculture and most of the on-farm irrigation systems are low efficient coupled with poor irrigation management (Abou Zeid 2002). Irrigation water management becomes increasingly important in the presence of the expected low water supplies. In order to avoid the underestimation or overestimation of crop water consumption, knowledge of the exact water loss through actual evapotranspiration is necessary for sustainable development and environmentally sound water management (Shideed et al. 1995). One of the suggestions to attain the sustainable use of water resources is to develop agro-climatic zones. In this procedure, a particular region can be divided into agro-climatic zones based on homogeneity in weather variables that have the greatest influence on crop growth and yield (Doorenbos and Kassam 1979). An agro-climatic zone is a land unit in terms of major climate, superimposed on length of growing period i.e. moisture availability period (FAO 1983). As a result, crops growth periods, water requirements and irrigation scheduling are dependent on weather conditions.

Noreldin et al. (2016) uses 30-year of weather elements to form (1985–2014) to develop agro-climatic zones in the Nile Delta and valley, where the agricultural areas are located. Their results defined seven ago-climatic zones. Although climatic normals (the arithmetic average of a climate element over a 30-year interval) is sufficiently long to filter out many of the short-term inter-annual fluctuations and anomalies (NCDC 2002), variability in weather elements from year to year was observed worldwide, as well as in Egypt. Colder winters and hotter summers were prevailing in the past few years in Egypt. Thus, a rational decision was made by Ouda and Noreldin (2017) to use 20-year and 10-year intervals of weather elements to develop agro-climatic zones in Egypt using data from 1995 to 2014 and it was compared with the values obtained from 30-year interval. The average values of ETo over the three intervals was close to each other, where it was 5.64, 5.43 and 5.36 mm/day for 10-year, 20-year and 30-year values of ETo, respectively. They also found out that using 10-year period of weather elements to develop agro-climatic zones resulted in higher values of ETo in each zone, compared to 20-year ETo values and 30-year ETo values (Fig. 3.4).

3.4 Soil Resources of Egypt

The main soil groups in Egypt are Arenosols and Leptosols represents 26 and 25%, respectively (FAO 2005). According to Hegazi et al. (2005), four agro-ecological zones can be identified based on soil characteristics and water resources, namely the old lands, the new lands, the rain fed and the oases.

The old lands are located in the Nile Valley and Delta Regions. It covers a total area of 2.38 million hectares or about 68% of the total cultivated area. It is characterized by alluvial soils (clay to loamy). As stated by the FAO (2005), available phosphorous is generally moderate, and available potassium (soluble and exchangeable) is high in most of Egyptian alluvial soils. The Nile River is the main source for irrigation in the old lands, where surface irrigation is practiced.

On the other hand, the new lands are located mainly on both the east and west fringes of the Nile Delta and Valley and scattered over various areas in the country, where it covers 1.01 million hectares. Sandy and calcareous soils are prevailing in these areas, where micronutrients are above the critical limits, and levels of available phosphorus, potassium and micronutrients are fairly low (Hegazi et al. 2005). These areas are recently reclaimed and became productive lands. The newly

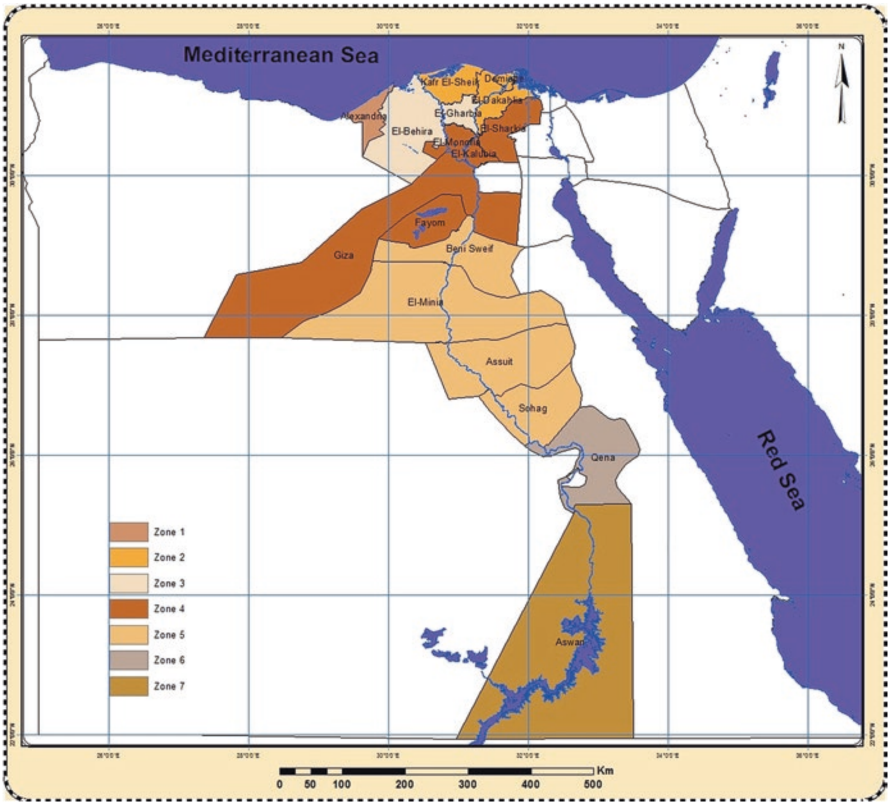

Fig. 3.4 Map of agro-climatic zones of Egypt using 10-year of ETo values

reclaimed lands are viewed as an opportunity for increasing agricultural production and ensuring food security in the country. Groundwater is the source of irrigation water in these areas, where sprinkler and drip irrigation are practiced.

The rain fed areas include approximately 0.13 million hectares of land located in the north coastal areas. About 70% of such area lies in the North Western coastal sub-zone of the country in Marsa Matrouh governorate, while the rest lies in the eastern one in North Sinai. Although these areas may not appear significant in relation to the total agricultural land, they are important for local communities. Finally, the oases are characterized by alluvial, sandy and calcareous soils. They cover a total area of 40,000 hectares. Groundwater is the main source for irrigation.

3.5 Population Impacts on Per Capita Water and Land

Egypt has a total population of 95.2 million inhabitants in 2017 mainly concentrated in the Nile Delta and Valley (CAPMAS 2018). The Egyptian population almost doubled during the last three decades, between 1986 and 2016 (CAPMAS 2017).

Uneven distribution of the population exists in Egypt, where they are living on only 4% of the total area. The recent census statistics revealed that around 43% of the population lives in Lower Egypt (Port Said, Suez, Ismailia, Sharqia, Damietta, Qalyubia, Gharbia, Menufyia, Kafr El- Sheikh, Behira, and Alexandria governorates). In the Greater Cairo (Cairo, Giza, and Qalubia governorates), around 25% of the total population live. Around 22% of the total population inhibit Middle Egypt (Fayoum, Beni Sweif, and Minia governorates), whereas around 16% of them inhibit Upper Egypt governorates (Assuit, Sohag, Qena, Luxor and Aswan). Border governorates, namely Marsa Matrouh, El-Wadi El-Gedid, Red sea, North Sinai and South Sinai have very low population, less than 2% of the total population. Reclamation of new lands provides an opportunity to absorb the increasing population and improving the demographic distribution of the country.

The high population growth rate put high pressure on the government of Egypt to supply clean water for domestic use and for agriculture to produce food. Egypt has passed the threshold of water scarcity and it reached the value of 600 m^3/capita/year (Ministry of Irrigation and Water Resources 2014). Thus, Egypt is recently transferred from the situation of water abundant to water deficiency.

Furthermore, because the Egyptian population is living on only 4% of Egypt area and characterized with high growth rate, arable land per capita was reduced from 0.09 hectare in 1961 to 0.03 hectares in 2016. Land holdings in Egypt are very small, with 89% of land holdings smaller than 1.3 hectares (FAO 2015).

3.6 Irrigated Agriculture and Food Production

Irrigated agriculture is the main contributor in food production in Egypt, which consumed 85% of its water resources. Surface irrigation is the prevailing system in the old lands with 50–60% water application efficiency on farm level. Farmers are used to plant crops in basins, where they broadcast seeds, or they plant seeds on furrows. This practice results in application of a large amount of irrigation water. Under furrow irrigation, water runoff could cause soil erosion and loss in fertility (Sojka et al. 2007). In addition, fertilizer leaching is also a consequence of application of large irrigation amounts, causing groundwater pollution (Abouelenein et al. 2010).

In the new lands, sprinkler and drip systems are prevailing and surface irrigation is prohibited by the law. Small areas of the new lands irrigated using canals originated from the Nile River, but most of the new lands irrigated using groundwater. Nevertheless, the revenue obtained from most of the already reclaimed areas is low compared to its full potential due to inefficient use of land and water resources, inferior or absence of agriculture background, weakness or absence of extension services that deal with the specific needs of the new lands, poor agricultural credit and low input supply. Additionally, other problems exist in the new lands, namely degradation of soils through salinity and alkalinity. The high evapotranspiration rate and/or combination with high groundwater level in some areas cause salinity accumulation, especially in the northern part of the Nile Delta (Mohamedin et al. 2011).

Table 3.5 National cropping pattern in Egypt in 2014/15 growing season and its water requirements

	Cultivated area (ha)	Water requirements (m^3)
Winter crops		
Wheat	1,354,844	8,825,826,373
Faba bean	34,418	178,997,045
Clover	624,741	5,948,296,442
Onion	148,173	1,244,936,988
Tomato	70,173	347,661,962
Potato	102,285	339,729,364
Sugar beet	231,193	1,955,202,088
Other crops	680,278	2,858,335,063
Total	3,246,104	21,698,985,326
Summer crops		
Cotton	100,349	1,264,924,487
Rice	506,249	5,896,134,782
Maize	938,329	9,259,942,383
Soybean	14,130	147,263,643
Sunflower	6585	48,883,220
Potato	53,110	385,322,673
Tomato	89,825	824,943,808
Cowpea	516	1,032,000
Sugarcane	134,656	4,271,214,589
Fruit trees	524,763	9,789,068,856
Other crops	682,329	8,735,940,296
Total	3,050,840	40,624,670,737
Grand total	6,296,944	62,323,656,063

Source: Ouda and Zohry (2018)

The prevailing cropping pattern in both old and new lands contains diversifies number of field, vegetable and medicinal crops, in addition to fruit trees (Table 3.5). Ouda and Zohry (2018) estimated total water requirements for the prevailing cropping pattern in the old lands by 49.5 BCM. Whereas, in the new lands, they reported that water requirements for the prevailing cropping pattern were estimated by 12.9 BCM. Thus, the total amount of irrigation water required to irrigate the old and new cultivated area is 62.3 BCM (Table 3.5).

3.7 Food Gaps in Egypt

The steady increase in the population from year to year, the decline in land productivity due to cessation of the implementation of crop rotation after agriculture liberalization law in 1980s, and the incompatibility of the fertilization regimes with cultivated crops have cause food shortage in many important crops. Additionally, reduced productivity of the cultivated crops obtained by some farmers in both the old and new lands is due to their wrong on-field practices. The typical farmer practices in the old lands includes mono cropping in both growing seasons, low land leveling, furrow cultivation, and application of large amount of irrigation water as a result of using fixed time interval, regardless of crop needs. As a result, fertilizer leaching occurred, as well as loss in soil fertility. Whereas, in the new lands, mono cropping is also practice by the farmers. Although sprinkler or drip systems are used, the farmer depended on his experience to decide the appropriate amount of irrigation water to apply in each irrigation event. The farmer applies irrigation water every 3 days for summer crops and every 4 days for winter crop. Fertilizer is broadcasted on the ground before irrigation, which leads to fertilizer leaching, as a result of applying large amount of irrigation water.

3.7.1 Wheat Production-Consumption Gap

Wheat is very important crop in Egypt, where its production does not fulfil its consumption, which generates a need to increase its production. Egypt was used to be self-sufficient in almost all basic food commodities in the 1960s, with the exception of wheat. Wheat self-sufficiency ratio (domestic production in relation to consumption) was 70% during that time. Between the 1970s and the 1980s, the self-sufficiency ratio declined dramatically for most products, where it was an indication of serious food gaps in Egypt (Metz 1990). Under the current situation of water deficiency, it is crucial to develop improved management package to increase its national production.

Ouda and Zohry (2017) thoroughly assessed solutions to the wheat production-consumption gap using data published in 2014. The study divided Egypt into three regions, Lower, Middle and Upper Egypt (Fig. 3.5).

From their study, Table 3.6 showed that under traditional cultivation of wheat in Lower Egypt had the highest percentage of wheat production, and population consumption. Whereas, Middle Egypt had the lowest percentage of wheat production and Upper Egypt had the lowest percentage of population consumption. Self-sufficiency ratio (total production divided by total consumption) was the highest in Upper Egypt and the lowest in Middle Egypt. Under these conditions, the average wheat self-sufficiency ratio was 51%.

The study also revealed that using improved production package in the old lands to increase wheat total production and could contribute in saving part of the applied irrigation water and use it to cultivate new areas in the new lands. The suggested improved production package included hanging traditional cultivation to raised beds and implementing intercropping systems for wheat, where wheat plants share the cultivated area and the applied irrigation water with other crops, namely with tomato (Abd El-Zaher et al. 2013; Fig. 3.6a). Cotton relayed on wheat system (Lamlom et al. 2018; Fig. 3.6b) was also suggested. Other wheat intercropping systems were suggested, i.e. wheat intercropped with sugar beet system (Abou-Elela

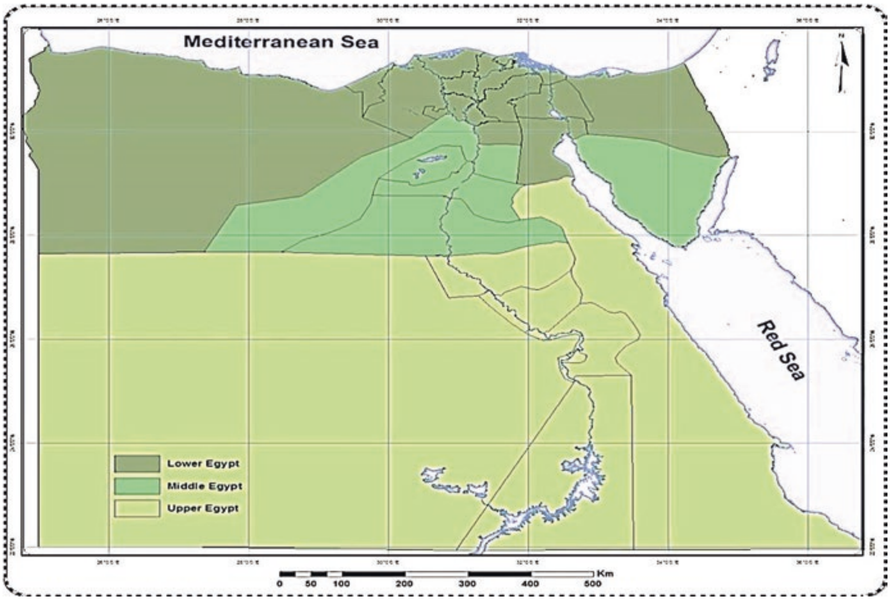

Fig. 3.5 Map of major regions in Egypt

Table 3.6 Percentage of wheat production, population consumption and self-sufficiency on region level in 2014 under traditional cultivation

	Production (%)[a]	Consumption (%)[a]	Self-sufficiency (%)[a]
Lower Egypt	61	61	51
Middle Egypt	19	22	46
Upper Egypt	20	17	61

[a]Calculated by the authors from Ouda and Zohry (2017)

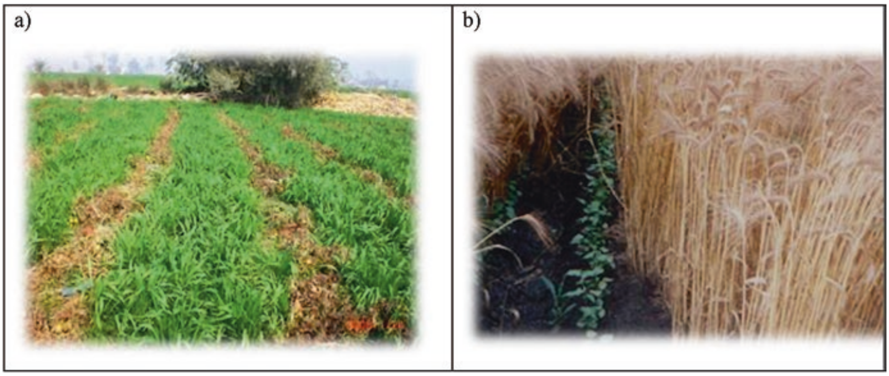

Fig. 3.6 Wheat intercropping system with tomato (**a**) and cotton relay intercropped with wheat (**b**)

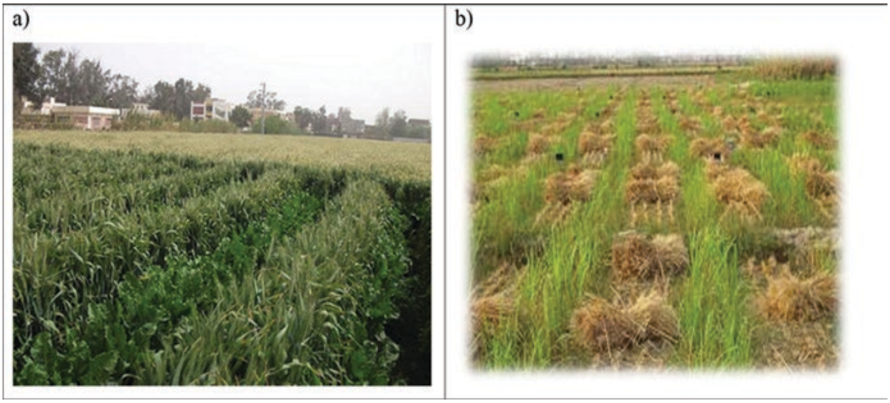

Fig. 3.7 Wheat intercropped with sugar beet (**a**) and wheat intercropped with sugarcane (**b**)

Table 3.7 Percentage of increase in wheat production, and self-sufficiency on region level in 2014 under using improved production package

	Percentage of increase in production (%)[a]	Self-sufficiency (%)[a]
Lower Egypt	64	83
Middle Egypt	58	73
Upper Egypt	40	85

[a]Calculated by the authors from Ouda and Zohry (2017)

2012; Fig. 3.7a), wheat intercropped with sugarcane system (Ahmed et al. 2013, Figure 3.7b), and wheat intercropped under fruit trees.

Table 3.7 showed that total wheat production under these practices could be increased, compared to its value under traditional cultivation, and consequently wheat self-sufficiency ratio could be increased. Thus, total wheat production in Lower Egypt was increased by 64%, whereas it was increased by 58 and 40% in Middle and Upper Egypt, respectively. The average self-sufficiency ratio could be increase from 51% to reach 81% (Ouda and Zohry 2017).

In more recent study done in 2019 for wheat production in 2017, population was increased to 95.2 million inhabitants and wheat production-consumption gap was increased to 57%. The study revealed that implementing improved management practices and wheat intercropping systems could reduce the gap to 35% (unpublished data). Dawoud (2017) indicated that population increase by 1% could result in an increase in wheat consumption by about 1.29% and an increase in the gap by 1.98%. He also reported that an increase in the domestic production by 1% could result in a decrease in wheat consumption by about 0.73% and could cause a decrease in wheat production-consumption gap by about 1.11%.

3.7.2 Maize Production-Consumption Gap

Maize is a dual-purpose crop for food and feed. It has become a very vital component of global food security due to genetic and management practice improvements that increased its yield over the past century (Grassini et al. 2017). There are three main summer crops in Egypt competing for the available arable area, namely maize, rice and cotton. The cultivated area of maize is the highest among these three crops.

Zohry and Ouda (2017a) studied maize production-consumption gap in 2013 in three regions of Egypt under traditional maize cultivation. Table 3.8 revealed that the highest percentage of maize production, and consumption existed in Lower Egypt. On the contrary, the lowest percentage of maize production, and consumption existed in Upper Egypt. The average maize self-sufficiency ratio under these conditions was 53%.

They also indicated that implementing improved production package, as well as intercropping systems for maize, namely maize intercropped with tomato (Mohamed et al. 2013; Fig. 3.8a), maize intercropped with soybean (Metwally et al. 2018a; Fig. 3.8b), maize relay on potato system (Ibrahim 2006; Fig. 3.9a), maize intercropped with cowpea (Hamd-Alla et al. 2014; Fig. 3.9b) and maize intercropped with peanut (Metwally et al. 2018b) resulted in reduction in this gap.

Their results indicated (Table 3.9) that implementing the suggested improved production package could increase total maize production by 64, 66 and 55% in

Table 3.8 Percentage of maize production, population consumption and self-sufficiency on region level in 2014 under traditional cultivation

	Production (%)[a]	Consumption (%)[a]	Self-sufficiency (%)[a]
Lower Egypt	54	61	47
Middle Egypt	28	22	69
Upper Egypt	18	17	56

[a]Calculated by the authors from Zohry and Ouda (2017a)

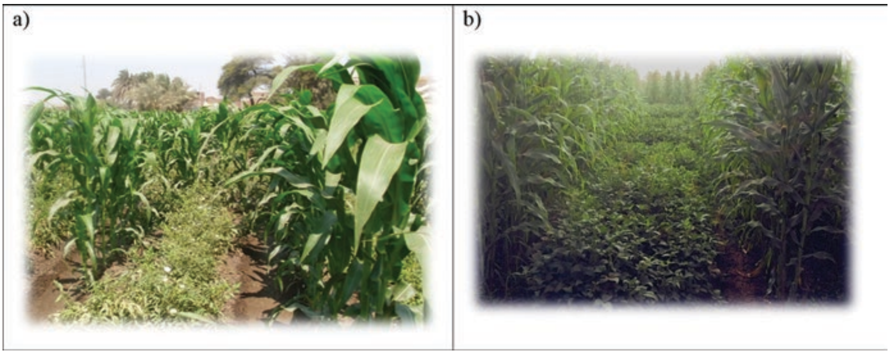

Fig. 3.8 Maize intercropped with tomato (**a**) and maize intercropped with soybean (**b**)

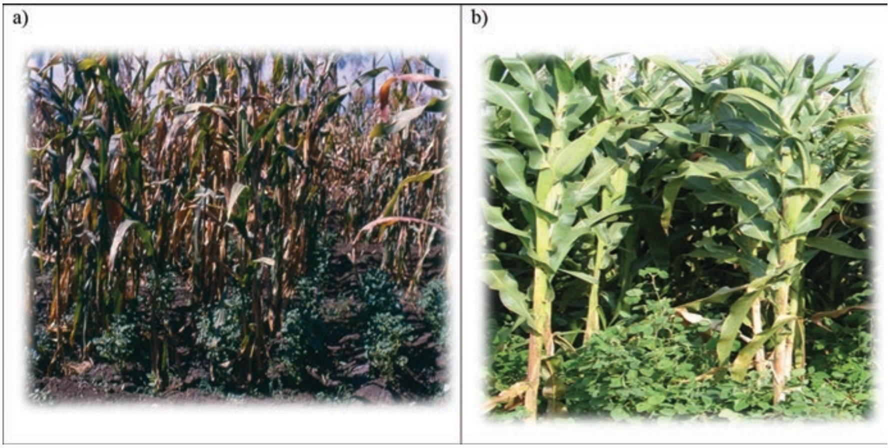

Fig. 3.9 Relay intercropped maize with potato (**a**) and maize intercropped with cowpea (**b**)

Table 3.9 Percentage of increase in maize production, and self-sufficiency on region level in 2014 under using improved production package

	Percentage of increase in production (%)[a]	Self-sufficiency (%)[a]
Lower Egypt	64	76
Middle Egypt	66	115
Upper Egypt	55	86

[a]Calculated by the authors from Zohry and Ouda (2017a)

Lower, Middle and Upper Egypt, respectively compared to its value under traditional cultivation. Table 3.9 also showed that self-sufficiency ratio was increase in the three regions, with the highest value existed in Middle Egypt, namely 115%. The average self-sufficiency ratio was 86%.

3.7.3 Faba Bean Production-Consumption Gap

Faba bean is one of the main cultivated winter pulses seeds in Egypt. It has been very poplar diet for the Egyptians due to its high nutritional value. However, its cultivated area has sharply declined as a result of the expansion in sugar beet cultivation, where sugar beet is more profitable than faba bean.

Zohry and Ouda (2017b) revealed that 90% of faba bean production under traditional cultivation came from Lower Egypt, so was the highest percentage of consumption and the highest self-sufficiency ratio. Both Middle and Upper Egypt produced very low percentage of faba bean and also have the lowest self-sufficiency ratios (Table 3.10). The average faba bean self-sufficiency ratio was 27%.

Table 3.10 Percentage of faba bean production, population consumption and self-sufficiency on region level in 2014 under traditional cultivation

	Production (%)[a]	Consumption (%)[a]	Self-sufficiency (%)[a]
Lower Egypt	90	61	40
Middle Egypt	2	22	3
Upper Egypt	8	17	13

[a]Calculated by the authors from Zohry and Ouda (2017b)

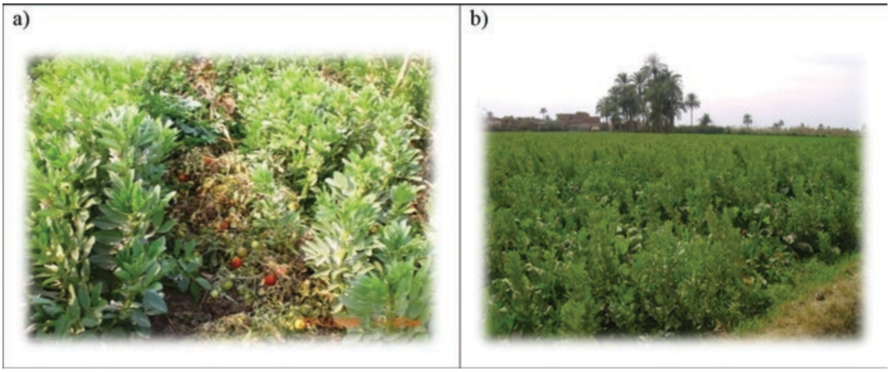

Fig. 3.10 Faba bean intercropped with tomato (**a**) and with sugar beet (**b**)

They also indicated that applying the improved management package and intercropping systems for faba bean increased faba bean national production and could attain self-sufficiency of faba bean. The suggested faba bean intercropping systems are namely faba bean intercropped with tomato (Ibrahim et al. 2010, Figure 3.10a), faba bean intercropped with sugar beet (Abd El-Zaher and Gendy 2014, Figure 3.10b), faba bean intercropped with sugarcane (Farghly 1997, Figure 3.11a) and faba bean intercropped under fruit trees (Figure 3.11b).

3.7.4 Edible Oil Production-Consumption Gap

During the 1960s, the self-sufficiency proportion of edible oil in Egypt was 95% (El-Hamidi and Zaher 2018). This proportion has declined to reach 32% in 2017. Table 3.11 showed the production, consumption and self-sufficiency of five oil crops in 2016, which are the most important edible oil crops in Egypt. These crops are cotton seeds, soybean, sunflower, maize embryos and flax seeds. Cotton seeds used to be the main edible oil crop in Egypt. A decline in the cultivated area of cotton was reported recently as a result of its high production costs. Similarly, declines in the cultivated area of soybean and sunflower were reported due to the preference of the farmers to cultivate either maize or rice to attain more revenue. Whereas, the

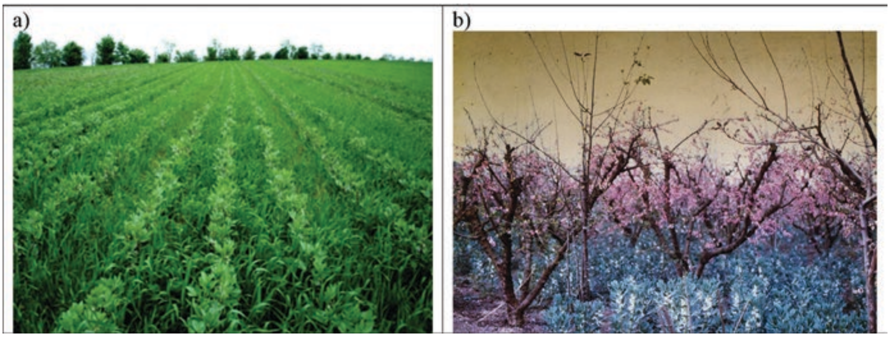

Fig. 3.11 Faba bean intercropped with sugarcane (**a**) and under fruit trees (**b**)

Table 3.11 Production, consumption, and self-sufficiency of major oil crops in Egypt in 2016

Crop	Production (000 ton)	Consumption (000 ton)	Difference (000 ton)	Self-sufficiency (%)
Flax	8	16	−8	50.00
Cotton	83	83	0	100.00
Soybean	47	869	−822	5.41
Sesame	50	64	−14	78.13
Sunflower	22	82	−60	26.83

Source: Central Agency for Public Mobilization and Statistics (2018)

cultivated area of flax is low, as a result of high competition with either wheat or Egyptian clover, where both crops are more important to the farmers.

Hassan and Shafique (2011) suggested solutions to reduce edible oil production-consumption gap using three crops (cotton seeds, sunflower and soybean) in 2007 through increasing its cultivating area, without indicating how they were going to increase its area. They indicated that the cultivated area of cotton could be increased by 145%, the cultivated area of sunflower could be increased by 870% and the cultivated area of soybean could be increased by 495%. The rise in the production of these three crops could increase the self-sufficiency of edible oil from 32% to 84%. In 2007, the total population was 79.5 million inhabitants.

Zohry and Ouda (2018a) indicated that the total cultivated area of cotton, sunflower, soybean, maize and flax could be increase through implementing intercropping systems and cultivation of three-crop sequences. Regarding cotton, it can be relied intercropped with wheat and onion (Lamlom et al. 2018) to increase its production. With respect to sunflower, it could be intercropped with summer tomato, sugarcane and under fruit trees. It could be also relay intercropped with wheat and could be cultivated as early summer crop after sugar beet and faba bean. With respect to soybean, it can be intercropped with maize (Metwally et al. 2018a), it can be intercropped with sorghum (Abou-Keriasha et al. 1993), it can be intercropped with sugarcane (Eweida et al. 1996, Figure 3.12a) and it could be intercropped

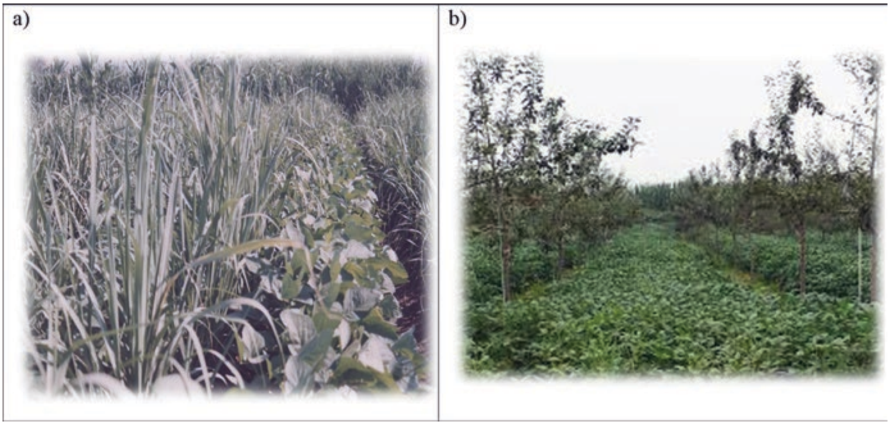

Fig. 3.12 Soybean intercropped with sugarcane system (**a**) and soybean intercropped under apple trees (**b**)

under fruit trees (El-Mehy and El-Badawy 2017, Figure 3.12b). It could also relay intercropped with wheat and it could be cultivated as early summer crop after sugar beet and faba bean. Regarding maize, it could be intercropped with summer tomato, peanut, and sorghum. Finally, flax could be intercropped with sugar beet and faba bean.

Using the data published in 2015 by the Ministry of Agriculture and Land Reclamation in Egypt, they calculated the potential increase in the cultivated area of these five crops, where the actual area was 1,062,495 hectares under traditional cultivation and could became 2,043,618 hectares under the suggested intercropping systems, which represent an increase by 90% of the total cultivated area, compared to its area in 2015. The production of these extra 90% cultivated area could increase the edible oil self-sufficiency from 33% to 62% (Zohry and Ouda 2018a).

3.7.5 Summer Forage Production-Consumption Gap

Zohry and Ouda (2018b) calculated the contribution of intercropping systems and cultivation of three-crop sequences in increasing the cultivated area of summer forage crop, where its production-consumption gap was estimated by 90%. The authors suggested using two legume forge crops, namely cowpea and fahl clover (a short season clover variety) to attain double benefits; increase the supply of forage crops and improve soil fertility. Cultivation of fahl clover as an early winter crop after maize, rice or sorghum crops and before the following winter crop was suggested. Furthermore, implementing intercropping systems of cowpea with maize, sunflower, sorghum and under fruit trees was also suggested. Their results indicated that an increase by 1647% in the cultivated area of both crops could be attained if intercropping systems and cultivation of three-crop sequences will implemented.

3.8 Deficit Irrigation and Crops Production

Several studies have been done in Egypt on the assessment of deficit irrigation effects on crop productivity, as well as the amount of saved irrigation water.

3.8.1 Effect of Deficit Irrigation on Winter Crops

3.8.1.1 Wheat

Skipping the last irrigation event for wheat at flowering stage cultivated in clay soil under surface irrigation resulted in high yield losses fluctuated between 28% for cv. Misr2 and 7% for cv. Misr1 (Elhag 2017). Abdelkhalek et al. (2015) indicated that skipping the last irrigation applied for wheat in loamy clay soil under surface irrigation resulted in 12% saving in the applied water, with 6% yield losses. Ouda et al. (2007) indicated that skipping the last irrigation for wheat at maturity stage reduced yield by 13%, whereas this percentage was reduced to 7% under spraying $MgCO_3$ as an anti-transpirant compound during vegetative stage and skipping the last irrigation at maturity stage.

Taha and Ouda (2016) indicated that application of deficit irrigation to wheat grown in sandy soil under sprinkler system and fertigation in 80% of irrigation time, where 11% saving in the applied water resulted in 2% yield losses. Whereas, fertigation in 60% of irrigation time resulted in saving the same amount of irrigation water with higher yield losses, namely 8%. The low percentage of yield losses under fertigation in 80% of irrigation time was resulted from increasing fertilizer use efficiency. Furthermore, Abdelraouf et al. (2013) indicated that application of 75% of wheat water requirements under sprinkler irrigation in sandy soil resulted in only 3% reduction in wheat yield as a result of applying 100% of NPK via fertigation pump. This technology resulted in reduction in fertilizer leaching, and improved plants growth and reduced yield losses.

Noreldin et al. (2015) tested the effect of reducing the applied irrigation water by 25 and 20% to wheat irrigated with either drip or sprinkler systems, respectively grown in sandy soil. They found that wheat yield was reduced by 20 and 18%, respectively. Because these yield losses were high under either system, they simulated the effect of reducing only 10% of the applied water under either system on wheat yield using CropSyst model (Stockle et al. 1994). Under these circumstances, yield losses became 3 and 4%, under drip and sprinkler systems respectively. Abdrabbo et al. (2013) indicated that saving 20% of the applied water to wheat in clay soil resulted in 8% yield losses under clay soil. Karrou et al. (2012) revealed that application of 78% of full irrigation of wheat grown in clay soil under surface irrigation resulted in 5% yield losses.

Simulation of deficit irrigation effects was also done. Ouda et al. (2015) simulated the effect of deducting 5% of full irrigation of wheat with fresh water

(Ec = 0.6 dS/m) and full irrigation of poor quality water (Ec = 6.3 dS/m) using CropSyst model and they found that yield losses were 5 and 6% under fresh and poor quality water, respectively. Ouda et al. (2010a) simulated the effect of reducing the applied irrigation water to wheat grown in clay soil under surface irrigation using Yield-Stress model (Ouda 2006). Their findings reported 3% yield losses under 20% saving in the applied irrigation water. Similarly, Ouda et al. (2007) simulated the effect of skipping the last irrigation applied for wheat in clay soil under surface irrigation. They indicated that water saving was 13% and yield losses was 2%. Ouda et al. (2008a) reported that simulation of the application of deficit irrigation, namely 20% reduction in full irrigation to wheat resulted in only 3% reduction in its yield. Furthermore, simulation of the effect of 30% in full irrigation to wheat resulted in 5% reduction in wheat yield.

3.8.1.2 Egyptian Clover

Khalil and Abouelenein (2012) reported that application of 70% of full irrigation to Egyptian clover grown in clay soil under surface irrigation resulted in 17% yield losses. Whereas, Abouelenein et al. (2010) showed that application of 70% of full irrigation to Egyptian clover resulted in 11% yield losses under surface irrigation in clay soil. Furthermore, simulation of the application of deficit irrigation to Egyptian clover grown in clay soil under surface system using Yield-Stress model (Ouda 2006), where 90% of full irrigation was applied resulted in 5% yield losses (Ouda et al. 2010b).

3.8.1.3 Sugar Beet

El-Darder et al. (2017) indicated that saving 23% of the applied water to sugar beet grown in sandy soil under sprinkler system resulted in 8% yield losses. Whereas, sugar beet yield losses were 7% and water saving was 22%, when sugar beet was irrigated with drip system. In sandy loam soil of Behira governorate of Egypt, Mehanna et al. (2017) studied the effect of application of deficit irrigation on sugar beet yield and they found that 33% saving in the applied irrigation water reduced yield by 18%. Eid and Ibrahim (2010) tested the effect of saving 17% of the applied irrigation water to sugar beet grown under surface irrigation in salt affected soil, where irrigation was done using fresh water and they found that percentage of yield reduction was 14%.

3.8.1.4 Other Winter Crops

– **Faba bean:** Sallam et al. (2014) indicated that application of deficit irrigation to faba bean grown in salt affected soil under surface irrigation, where 17% of the applied water was saved resulted in 12% yield losses. Ouda et al. (2010c) simulated the effect of application of 80% of full irrigation to faba bean grown in clay soil under surface irrigation and they found that this amount of water saving reduced yield by 5%.

- **Barley:** Ouda et al. (2007) indicated that omitting the last irrigation for barley at maturity stage reduced yield by 10%, whereas this percentage was reduced to 6% under spraying with $MgCO_3$ as an anti-transpirant compound during vegetative stage and omitting the last irrigation at maturity stage.
- **Onion:** Taha et al. (2019) indicated that saving 20% of the applied water to onion grown under sprinkler system in sandy soil reduced yield by 8%. Zayton (2007) studied the effect of skipping the last irrigation on the applied irrigation water and the yield of onion. He found that 20% of the applied irrigation water was saved and 15% the yield was lost. Ouda et al. (2010d) simulated the effect of applying 80% of full irrigation to onion grown in clay soil under surface system, where onion yield losses were 5%.

3.8.2 Effect of Deficit Irrigation on Summer Crops

3.8.2.1 Maize

Maize is another important crop in Egypt, where its consumption is higher than its production. Azab (2016) indicated that 15% yield losses for maize could be occurred under skipping the second irrigation (25 days after germination). Kubota et al. (2016) compared between the effect of conventional irrigation interval for maize grown in clay soil under surface irrigation (14 days) and prolonged irrigation interval on maize yield and they found that water saving was 8% with almost no yield losses under prolonged irrigation interval. Taha and Ouda (2016) indicated that application of deficit irrigation to maize grown in sandy soil under drip system and fertigation in 80% of irrigation time, where 14% saving in the applied water resulted in 12% yield losses. Whereas, fertigation in 60% of irrigation time resulted in saving the same amount of irrigation water with higher yield losses, namely 17%. The low percentage of yield losses under fertigation in 80% of irrigation time was resulted from increasing fertilizer use efficiency. El-Sherif and Ali (2015) indicated that the yield of maize grown in silty clay soil under surface irrigation was reduced by 14%, when irrigation water was reduced by 10%. Abd El-Halim (2015) compared between the applied water to maize cultivated on conventional furrows and maize cultivated on alternative furrow irrigation every 14 days. He found that using alternative furrow irrigation resulted in saving 7% of the applied irrigation water with only 2% yield losses.

Karrou et al. (2012) indicated that 30% saving in the applied irrigation to maize under surface irrigation in clay soil resulted in 8% yield losses. Abou Kheira (2009) reported that yield losses in maize cultivated in loamy clay soil using surface drip system was 4% under 11% water saving, whereas, 13% saving in the applied irrigation water under furrow irrigation using gated pipes resulted in 18% yield losses.

Tantawy et al. (2007) indicated that saving 20% of the applied water to maize grown in clay soil under surface irrigation resulted in 7% yield losses. Ouda et al. (2007) reported that applying deficit irrigation to maize, where 10% saving in the applied irrigation water resulted in 6% yield losses in clay soil under surface irrigation. Ouda et al. (2008b) simulated the effect of saving 20% of the applied irrigation water to maize grown under surface irrigation in clay soil. Their results indicated that 6% yield losses can occur. In another experiment, Ouda et al. (2006) simulated the effect of saving 20% of the applied water to maize grown in clay soil under surface irrigation using Yield-Stress model (Ouda 2006) and they found that maize yield was reduced by only 5%.

3.8.2.2 Soybean

Deficit irrigation effects on soybean were also studied. El-Sherif and Ali (2015) indicated that the soybean grown in silty clay soil under surface irrigation was reduced by 13%, when irrigation water was reduced by 10%. In a field experiment conducted in clay soil for soybean under surface irrigation, 10% saving in the applied irrigation water to it resulted in 3% yield reduction (Ouda et al. 2008c). Ouda et al. (2007) reported that applying deficit irrigation to soybean, where 10% saving in the applied irrigation water resulted in 8% yield losses in clay soil under surface irrigation. In a simulation study done by Ouda et al. (2010e) on the effect of deficit irrigation applied to soybean grown in clay soil under surface irrigation using Yield-Stress model (Ouda 2006), they indicated that saving 15% of the applied resulted in 5% reduction in the yield. Ouda et al. (2007) simulated the effect of deficit irrigation on soybean grown in silty clay soil under surface irrigation using Yield-Stress model (Ouda 2006). Their results indicated that saving 10% of the applied resulted in 4% reduction in the yield.

3.8.2.3 Other Summer Crops

- **Tomato:** Application of 80% of full irrigation to tomato grown in clay loam soil under subsurface drip system resulted in 15% yield losses (Abdelhady et al. 2017). Shalaby et al. (2014) indicated that saving 25% of the applied irrigation water to tomato grown under drip system in calcareous soil resulted in 9% yield losses. Additionally, Kamal and El-Shazly (2013) reported that 7% losses in tomato yield grown under drip system in calcareous soil occurred when 75% of full irrigation was applied.
- **Peanut:** Application of deficit irrigation to peanut grown under drip and sprinkler systems in sandy soil resulted in 20% saving in the applied water under both systems and 11 and 12% yield losses (El-Habbasha et al. 2015).
- **Sesame:** Elshamly et al. (2013) indicated that application of deficit irrigation to sesame grown in sandy soil under sprinkler system, where 14% of the applied water was saved, resulted in only 5% yield losses. Application of five irrigations

to sesame grown in clay soil under surface irrigation resulted in 26% saving in the applied irrigation water, compared to application of seven irrigations with only 6% yield losses (Tantawy et al. 2007).

3.8.3 Deficit Irrigation to Intercropping Systems

The effect of deficit irrigation under intercropping systems were studied for sunflower intercropped with peanut system under sprinkler system (El-Mehy et al. 2018) and under drip system (Ouda et al. 2018). Water saving was 16 and 15%, for sprinkler and drip systems, respectively. Yield losses for both sunflower and peanut were 4 and 3% under sprinkler and drip systems, respectively. Furthermore, saving 14% of the applied water to sunflower intercropped with soybean system under surface irrigation in clay soil resulted in 5% yield losses for both crops (Darwesh et al. 2016). Ouda et al. (2007) indicated that saving 6% of the applied irrigation water to soybean intercropped with maize, with 1:2 soybean to maize pattern cultivated in clay soil under surface irrigation resulted in losses by 13 and 5% for soybean and maize, respectively. Whereas, yield losses in sole planting of soybean and maize were 7 and 11% under the same percentage of saved water.

3.9 Conclusion

Egypt is blessed by suitable weather allows the cultivation of variety of crops. The Nile River is also a bless, where it is the main source of water for irrigation and consequently food production. Lots of valuable studies were conducted in Egypt to study the effect of water management on the final yield of crops. Other studies were done to test the effect of application of deficit irrigation on the yield of the crops and the amount of saved water. These studies revealed that there is high potential to save irrigation water with low yield losses. These studies also implied that water productivity could be increased under deficit irrigation. The saved irrigation water will permit the cultivation of new areas and increase food production.

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