Chapter 8
Suggested Crop Rotations to Increase Food Security and Reduce Water Scarcity

A. Zohry and S. Ouda

Introduction

Crop rotation is the production of different economically important plant species in recurrent succession on a particular field or group of fields (Bruns 2012). It is a critical feature of all organic cropping systems because it provides the principal mechanism for building healthy soils, a major way to control pests, and a variety of other benefits (Mohler 2001). Crop rotation means changing the type of crop grown on a particular piece of land from year to year. Crop rotation is one of the most effective agricultural control strategies. It involves arrangement of crops planted on same field; the succeeding crops should belong to different families (Huang et al. 2003). The planned rotation may vary from two, three year or longer period (Kamel et al. 2016). Some of the general benefits of using rotations are: improve or maintain soil fertility, improve soil structure (Raimbault and Vyn 1991), increase soil organic matter levels (Bremer et al. 2008), and enhance mycorrhizal associations (Johnson et al. 1992). Crop rotation reduces the spread of pests, which provide better weed control and interrupt insects and disease cycles (Karlen et al. 1994).

Crop rotation increased water use efficiency and improved crop nutrient use efficiency (Tanaka et al. 2005). It reduces risk of weather damage and thus reduces yield losses and that will increase net profit of farmers (Kaye et al. 2007). It could also improve grain quality and reduce grain yield variability (Varvel 2000). Furthermore, crop rotation could save on the applied irrigation water to crops (Ouda et al. 2016).

The appropriate choice of crops within the rotation and their sequence is crucial, where each crop species has slightly different characteristics, e.g., N demanding or N2 fixing (Mohler 2001), shallow or deep rooting, amount, and quality of crop residue returned. These characteristics along with existing biotic and abiotic factors determine the ultimate suitability of a break crop in a given cropping system (Malik 2010).

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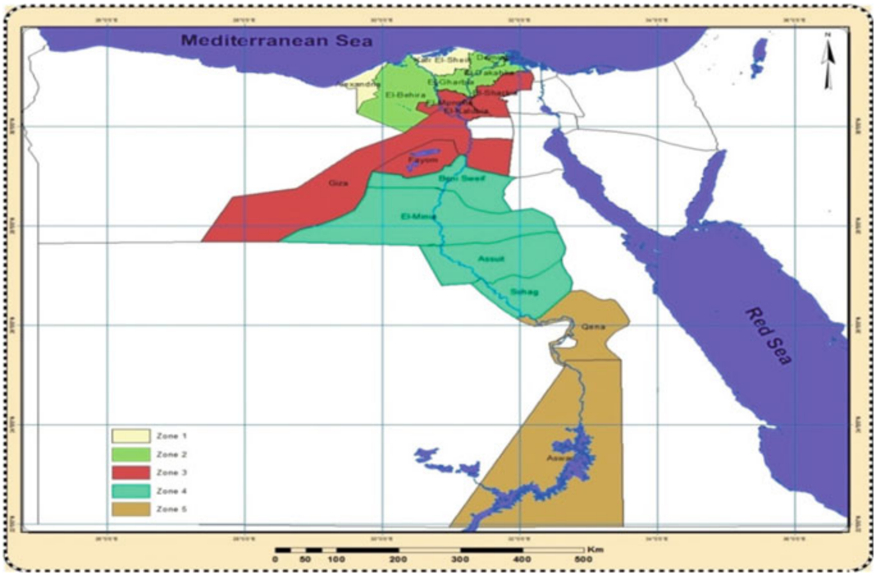

Fig. 8.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

Thus, using crop rotations could help in the sustainable use of natural agricultural resources as well as increase the agricultural productivity of unit land and unit of irrigation water under the prevailing conditions of water scarcity. As a result, the probability of attaining food security for strategic crops will increase and that will help in improving living standards and poverty elevation of rural population.

The objective of this chapter was to present the prevailing crop rotations in the different soil types of the five agro-climatic zones of Egypt. Furthermore, different crop rotations were suggested to be implemented in these agro-climatic zones to increase food production and save on the applied irrigation.

Figure 8.1 shows the five agro-climatic zones developed by Ouda and Noreldin (2017).

Water Requirements of the Crop Rotations

Both the values of monthly evapotranspiration (ETo) in each agro-climatic zone and the values of crop-specific coefficients (Kc) of the cultivated crops in the crop rotations are used in the calculation of water requirements. The BISm model (Snyder et al. 2004) was used to calculate values of ETo and Kc in 2016. The BISm calculates ETo using Penman–Monteith equation. The model provides an easy method to determine Kc values for a large number of crops, as affected by the weather in a certain region, irrigation method, as well as season length.

Table 8.1 presents the annual values of solar radiation (SRAD), maximum (TMAX), minimum (TMIN), and dew point (TDEW) temperatures, wind speed (WSEP), and ETo values in the five agro-climatic zones of Egypt in 2016.

Table 8.2 shows the planting and harvest dates as well as the season length of the selected crops.

The dates of Kc growth stages and values in the first, second, and third agro-climatic zones are presented in Table 8.3. The date of initial Kc (Kc_{ini}), the date of mid-season Kc (Kc_{ini}), and the date of end season Kc (Kc_{ini}) for the studied crop were similar in the first, second, and third agro-climatic zones as well as its values (Table 8.3).

Similarly, the date of Kc growth stages and its values was comparable in the fourth and fifth agro-climatic zones and it was different than its counterpart values in the first, second, and third agro-climatic zones (Table 8.4).

Water requirements for the crops existing in the prevailing and suggested crop rotations were calculated. It is worth mentioning that water requirements for crops existing in the prevailing crop rotations were calculated under surface irrigation with 60% application efficiency, which is the prevailing system in the old lands, surrounding the Nile River. In the new lands existing around the old lands, modern irrigation systems are prevailing, namely sprinkler and drip systems. The use of either systems depends on crop type. Application efficiency of sprinkler and drip systems is 75 and 85%, respectively.

With respect to water requirements of the crops existing in the suggested crop rotation, we assumed that cultivation on raised beds will be implemented, where 20% of the applied irrigation water to surface irrigation could be saved (Abouelenein et al. 2010). Additionally, we assumed that improvement of the application efficiency of either sprinkler or drip system by 10% could be done through using irrigation scheduling (Taha 2012).

According to earlier research on water requirements of cowpea intercropped with maize system, Zohry et al. (2017) indicated that the applied water to maize was used

Table 8.1 Annual averages of weather elements and ETo values in the agro-climatic zones in 2016

Zone	SRAD ($MJ/m^2/day$)	TMAX (°C)	TMIN (°C)	WSED (m/s)	TDEW (°C)	ETo (mm/day)
Zone 1	19.3	26.4	18.4	2.7	14.0	5.1
Zone 2	19.4	27.7	18.2	2.6	13.4	5.4
Zone 3	20.4	30.3	15.3	2.2	9.4	6.1
Zone 4	22.1	28.6	14.1	2.1	4.8	6.9
Zone 5	22.5	33.1	16.8	2.0	2.9	7.8
Mean	20.8	29.2	16.6	2.3	8.9	6.3
Range[a]	3.2	6.7	1.6	0.7	5.1	2.7

[a]Range = Highest value minus lowest value

Table 8.2 Planting and harvest dates and season length for the selected crops

Crop	Planting date	Harvest date	Season length
Clover	15-Oct	1-Apr	169
Cotton	15-Apr	15-Aug	154
Faba bean	25-Oct	25-Apr	152
Flax	15-Nov	13-Apr	150
Maize	15-May	1-Sep	110
Onion	15-Nov	15-Apr	152
Rice	15-May	16-Sep	125
Sorghum	15-May	1-Sep	110
Soybean	15-May	25-Aug	103
Sugar beet	15-Oct	12-Apr	180
Sugarcane	15-Feb	14-Feb	365
Sunflower	15-May	15-Aug	93
Tomato (winter)	1-Oct	1-Mar	152
Tomato (summer)	1-May	1-Sep	124
Wheat	15-Nov	18-Apr	155

Table 8.3 Date of Kc growth stages and its values for the studied field crops in the first, second, and third agro-climatic zones

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Faba bean	29-Nov	24-Dec	25-Apr	0.29	0.99	0.21
Clover	26-Oct	3-Dec	1-Apr	0.26	1.13	0.40
Cotton	7-Apr	23-Jul	15-Aug	0.30	0.93	0.46
Flax	10-Dec	21-Jan	13-Apr	0.31	1.10	0.25
Lentil	10-Nov	24-Dec	25-Apr	0.23	0.99	0.21
Maize	6-Jun	3-Jul	1-Sep	0.24	1.04	0.58
Onion	30-Nov	24-Dec	15-Apr	0.30	1.19	0.54
Rice	14-Jun	30-Jun	16-Sep	0.37	1.02	0.78
Sorghum	1-Jun	30-Jun	1-Sep	0.20	1.06	0.50
Soybean	4-Jun	30-Jun	25-Aug	0.24	1.11	0.39
Sugar beet	11-Nov	4-Jan	12-Apr	0.27	1.15	0.95
Sunflower	2-Jun	25-Jun	15-Aug	0.24	1.09	0.37
Tomato (winter)	8-Nov	16-Dec	1-Mar	0.26	1.10	0.64
Tomato (summer)	1-Jun	2-Jul	1-Sep	0.25	1.10	0.65
Wheat	16-Dec	22-Jan	18-Apr	0.31	1.06	0.19

Table 8.4 Date of Kc growth stages and its values for the studied crops in the fourth and fifth agro-climatic zones

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Faba bean	30-Nov	25-Dec	25-Apr	0.26	0.99	0.18
Clover	27-Oct	4-Dec	1-Apr	0.26	1.15	0.40
Cotton	8-Apr	24-Jul	15-Aug	0.24	0.93	0.45
Flax	11-Dec	22-Jan	13-Apr	0.29	1.10	0.25
Lentil	11-Nov	25-Dec	25-Apr	0.21	0.99	0.18
Maize	7-Jun	4-Jul	1-Sep	0.19	1.03	0.58
Onion	30-Nov	25-Dec	15-Apr	0.28	1.19	0.54
Sorghum	2-Jun	1-Jul	1-Sep	0.16	1.06	0.50
Soybean	5-Jun	1 Jul	25-Aug	0.19	1.11	0.39
Sugar beet	12-Nov	5-Jan	12-Apr	0.23	1.15	0.95
Sugarcane	18-Apr	21-Oct	14-Feb	0.4	1.25	0.75
Sunflower	3-Jun	26-Jun	15-Aug	0.20	1.09	0.37
Tomato (winter)	9-Nov	17-Dec	1-Mar	0.22	1.10	0.64
Tomato (summer)	1-Jun	3-Jul	1-Sep	0.20	1.10	0.65
Wheat	17-Dec	23-Jan	18-Apr	0.29	1.08	0.17

by both cowpea and maize, when both crops were intercropped. Thus, we assumed that, for any intercropping system, the applied water to the main crop in the system is enough to fulfill the needs of the secondary crop in the system.

Crop Rotations in Egypt

We presented in this section the prevailing crop rotation in each agro-climatic zone. This prevailing crop rotation was modified and another crop rotation was suggested. The modification was done with the aim of increasing land and water productivity.

The First Agro-climatic Zone

Crop Rotation in Calcareous Soil

The prevailing crop rotation in the calcareous soil of the first agro-climatic zone is presented in Fig. 8.2. In this rotation, wheat precedes sunflower in the same piece of

Year 1	Year 2	Year 3
Wheat Sunflower	Barley Maize	Clover (full season) Tomato
Barley Maize	Clover (full season) Tomato	Wheat Sunflower
Clover (full season) Tomato	Wheat Sunflower	Barley Maize

Fig. 8.2 Prevailing crop rotation in the calcareous soil of the first agro-climatic zone

land in the first section, as well as barley precedes maize in the second section. Both crop sequences are expected to cause soil deterioration. Furthermore, the rotation contains only one legume crop, namely clover.

The suggested crop rotation (Fig. 8.3) included a legume crop in each section to improve soil properties. Soybean replaced sunflower in the first section, and faba bean replaced barley in the second section. Moreover, two intercropping systems were included, namely cowpea intercropped with maize in the second section and sunflower intercropped with in the third section. Cowpea intercropped with maize resulted in reduction in maize-associated weeds (Zohry 2005) and an increase in maize yield by 10% (Hamd-Alla et al. 2014). Detailed description in cowpea intercropped with maize system exists in Chap. 3.

In the third section, sunflower intercropped with tomato was preceded by clover. In this intercropping system, shading by sunflower plants is presented to tomato plants, which improved fruit set and consequently yield quality (Abdel 2006). Detailed description in sunflower intercropped with tomato system exists in Chap. 7.

Table 8.5 shows that the total applied water to the prevailing rotation was higher than the suggested rotation by 3351 m^3/ha, which is equal to 20% of the applied water to the prevailing rotation.

Crop Rotation in Salt-Affected Soil

The prevailing crop rotation in the salt-affected soil contained salinity-tolerant crops. However, sugar beet and wheat preceding rice have harmful effect on the soil. Further-

Year 1	Year 2	Year 3
Wheat Soybean	Faba bean Cowpea/maize	Clover (full season) Sunflower/tomato
Faba bean Cowpea/maize	Clover (full season) Sunflower/tomato	Wheat Soybean
Clover (full season) Sunflower/tomato	Wheat Soybean	Faba bean Cowpea/maize

Fig. 8.3 Suggested crop rotation in calcareous soils of the first agro-climatic zone

Table 8.5 Water requirements for the prevailing and suggested crop rotations in the calcareous soil of the first agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	6417	Wheat	5134
Sunflower	8367	Soybean	6694
Barley	5450	Faba bean	4251
Maize	9350	Cowpea/maize	7480
Clover (full season)	9433	Clover (full season)	7546
Tomato	10,700	Sunflower/tomato	8560
Total	49,717		39,665
Saved amount per hectare		3351	
Percentage of saving		20	

more, this rotation is expected to consume large amount of irrigation water because rice is cultivated twice and both sugar beet and clover have high water requirements. In addition, it contained only one legume crop (Fig. 8.4).

To overcome the consequences of cultivating two cereal crops (winter and summer) in the same piece of land, fahl clover could be cultivated after rice and before wheat, as an early winter crop in the first section of the rotation (Fig. 8.5). Fahl clover is a variety of Egyptian clover, which has stem branching ability, rapid growth, and large forage yield. It is only cut once and it could be cultivated as early winter crop in September and stays until the beginning of November, where its growing season is between 60 and 70 days (Bakheit et al. 2016). Sheha et al. (2014) reported that cultivation of fahl clover before sugar beet and after rice increases sugar beet yield as a result of nitrogen fixation, which accelerates the microbial activity of the soil. In this three-crop sequence, wheat is cultivated in November and harvested in April. Rice is cultivated in May and harvested in August, and then, fahl clover is cultivated September and harvested in early November.

Year 1	Year 2	Year 3
Sugar beet Rice	Clover Maize	Wheat Rice
Wheat Rice	Sugar beet Rice	Clover Maize
Clover Maize	Wheat Rice	Sugar beet Rice

Fig. 8.4 Prevailing crop rotation in salt-affected soil of the first agro-climatic zone

Year 1	Year 2	Year 3
Wheat Rice Fahl clover	Faba bean/sugar beet Tomato	Clover (full season) Sunflower
Faba bean/sugar beet Tomato	Clover (full season) Sunflower	Wheat Rice Fahl clover
Clover (full season) Maize	Wheat Rice Fahl clover	Faba bean/sugar beet Tomato

Fig. 8.5 Suggested crop rotation in salt-affected soil of the first agro-climatic zone of Egypt

Fig. 8.6 Faba bean intercropped with sugar beet

In the second section of the rotation, faba bean intercropped with sugar beet was included (Fig. 8.6). In this system, sugar beet is cultivated with 100% of its recommended planting density and faba bean is cultivated using 25% of its recommended planting density. As a result, the farmer could obtain 100 and 25% of sugar beet and faba bean yield, respectively (Abd El-Zaher and Gendy 2014).

Water requirements for the crops existing in the prevailing and suggested crop rotations are presented in Table 8.6. It is worth noting that leaching requirements for the cultivated crops were considered to be 10% of the applied irrigation water for each crop. The table revealed that the amount of saved irrigation water as a result of implementing the suggested rotations will be 3418 m^3/ha, which represents 16% of the total applied water to the prevailing rotation.

Table 8.6 Water requirements for the prevailing and suggested crop rotations in salt-affected soil of the first agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Sugar beet	10,010	Wheat	5646
Rice	12,760	Rice	10,208
Wheat	7058	Fahl clover	3188
Rice	12,760	Faba been/sugar beet	8008
Clover	10,377	Tomato	9416
Maize	10,285	Clover (full season)	8302
		Maize	8228
Total	63,250		52,996
Saved amount per hectare (m^3/ha)		3418	
Percentage of saving (%)		16	

The Second Agro-climatic Zone

Crop Rotation in Sandy Soil

In sandy soil of Egypt, farmers tend to cultivate large areas of peanut in this type of soil. However, continuous cultivation of peanut results in continuous decline in peanut yield due to deterioration of soil microbial community (Wang and Chen 2005). It reduces the diversity of bacteria in both species and quantity, lowers the number of fungi species, and increases mold quantity (Xie et al. 2007).

The prevailing crop rotation in the sandy soil (Fig. 8.7) included peanut in two of its three sections. Furthermore, wheat preceded peanut and sugar beet preceded maize. In addition, the rotation contained only one legume crop, namely clover.

The suggested crop rotation (Fig. 8.8) contains legume crops in each section. In the first section of the rotation, the system of maize intercropping with peanut (Sherif et al. 2005) is implemented. Dahmardeh (2013) indicated that intercropping maize

Year 1	Year 2	Year 3
Clover (full season) Peanut	Sugar beet Maize	Wheat Peanut
Wheat Peanut	Clover (full season) Peanut	Sugar beet Maize
Sugar beet Maize	Wheat Peanut	Clover (full season) Peanut

Fig. 8.7 Prevailing crop rotation in the sandy soil in the second agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Wheat Maize/peanut	Pea Sunflower Maize (late)	Clover (full season) Maize
Pea Sunflower Maize (late)	Clover (full season) Maize	Wheat Maize/peanut
Clover (full season) Maize	Wheat Maize/peanut	Pea Sunflower Maize (late)

Fig. 8.8 Proposed crop rotation in the sandy soil of the second agro-climatic zones of Egypt

with peanut was advantageous, compared to both sole crops of maize and peanut, where productivity of the unit land was increased. Detailed description of the system is presented in Chap. 7.

In the second section of the rotation, three-crop sequence was implemented, where pea preceded sunflower and followed by late-season maize (cultivated in July). In this system, pea is cultivated in September and harvested in February in the following year. In March, sunflower is cultivated and harvested in June. In July, maize is cultivated as late crop in July and harvested in October before the cultivation of winter crops in November. In the third section of the rotation, full season clover preceded maize.

Sprinkler or drip systems are the prevailing irrigation systems in this type of soil. Table 8.7 indicates that the suggested rotation could save 273 m^3/ha, which accounts for 2% of the total applied water to the prevailing rotation.

Table 8.7 Water requirements for the prevailing and suggested crop rotations in sandy soil of the second agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	7880	Wheat	4812
Peanut	8933	Maize/peanut	8040
Wheat	5347	Pea	3588
Peanut	8933	Sunflower (early)	6306
Sugar beet	8535	Maize (late)	9867
Maize	8970	Clover (full season)	7092
		Maize	8073
Total	48,598		47,778
Saved amount per hectare (m^3/ha)		273	
Percentage of saving (%)		2	

Crop Rotation in Clay Soil

The prevailing crop rotation in the clay soil of the second agro-climatic zone (Fig. 8.9) included two legume crops, namely faba bean and clover. However, continuous cultivation of maize after wheat could have bad effect on soil properties.

In the first section of the rotation (Fig. 8.10), three-crop sequence was implemented, where wheat followed by maize followed by fahl clover. In this system, wheat is cultivated in November and harvested in April, maize is cultivated in May and harvested in September, and fahl clover is cultivated in September and harvested in the first week of November before the following winter crop (Zohry et al. 2017).

In the second section of the rotation, relay intercropping cotton on wheat system (Zohry 2005) was implemented. Furthermore, Zhang et al. (2008) stated that in relay intercropping cotton on wheat system fertilizer use efficiency increased, which could reduce environmental risks of leaching it to groundwater. Detailed description of the system is presented in Chap. 3.

In the third section of the rotation, faba bean is followed by maize intercropping with tomato system (Mohamed et al. 2013). Abdelmageed et al. (2003) indicated that this system is implemented by the farmers and is very popular. Furthermore, maize could modify the micro-climate for tomato and protect the tomato fruits from sun damage. Incidence of powdery mildew that occurs in tomato plants was reduced when maize is intercropped with it (Hao 2013). Ijoyah and Fanen (2012) stated that different patterns of roots (deep for tomato and shallow for maize) exploit soil moisture and nutrients in different soil layers, which minimize plants competition.

Changing monoculture cultivation in the prevailing rotation to intercropping systems in the suggested rotation resulted in irrigation water saving. The saved amount was 1525 m^3/ha or 9% of the applied irrigation water to the prevailing crop rotation (Table 8.8).

Year 1	Year 2	Year 3
Faba bean Tomato	Clover (2 cuts) Cotton	Wheat Maize
Wheat Maize	Faba bean Tomato	Clover (2 cuts) Cotton
Clover (2 cuts) Cotton	Wheat Maize	Faba bean Tomato

Fig. 8.9 Prevailing crop rotation in the clay soil of the second agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Wheat Maize Fahl clover	Cotton relay intercropped on wheat	Faba bean Maize/tomato
Cotton relay intercropped on wheat	Faba bean Maize/tomato	Wheat Maize Fahl clover
Faba bean Maize/tomato	Wheat Maize Fahl clover	Cotton relay intercropped on wheat

Fig. 8.10 Proposed crop rotation in the clay soil of the second agro-climatic zone of Egypt

Table 8.8 Water requirements for the prevailing and suggested crop rotations in clay soil of the second agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Faba bean	6117	Wheat	5346
Tomato	11,400	Maize	7974
Wheat	6683	Fahl clover	3507
Maize	9967	Cotton/wheat	16453
Clover (2 cuts)	3467	Faba bean	4894
Cotton	14,233	Maize/tomato	9120
Total	51,867		47,294
Saved amount per hectare (m^3/ha)		1525	
Percentage of saving (%)		9	

The Third Agro-climatic Zone

Crop Rotation in Salt-Affected Soil

The prevailing crop rotation in salt-affected soil of the third agro-climatic zone contained clover cultivated twice as short season and full season. It also contained cotton, wheat, and rice cultivated once (Fig. 8.11).

Regarding the suggested crop rotation (Fig. 8.12), it contained cotton relay intercropped on wheat system (Zohry 2005), three-crop sequence system (sugar beet, rice, and then fahl clover; Sheha et al. 2014) and two-crop sequence (full season clover followed by maize).

Water requirements for prevailing and suggested crop rotations in salt-affected are presented in Table 8.9. The results in that table indicated that 1539 m^3/ha or 7% saving in the applied irrigation water to the prevailing rotation.

Year 1	Year 2	Year 3
Clover (2 cuts) Cotton	Clover (full season) Maize	Wheat Rice
Wheat Rice	Clover (2 cuts) Cotton	Clover (full season) Maize
Clover (full season) Maize	Wheat Rice	Clover (2 cuts) Cotton

Fig. 8.11 Prevailing crop rotation in the salt-affected soil in the third agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Cotton relay intercropped on wheat	Sugar beet Rice Fahl clover	Clover (full season) Maize
Sugar beet Rice Fahl clover	Clover (full season) Maize	Cotton relay intercropped on wheat
Clover (full season) Maize	Cotton relay intercropped on wheat	Sugar beet Rice Fahl clover

Fig. 8.12 Suggested crop rotation in the salt-affected soil of the third agro-climatic zone of Egypt

Table 8.9 Water requirements for the prevailing and suggested crop rotations in salt-affected soil of the third agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (2 cuts)	4613	Cotton/wheat	15,315
Cotton	11,532	Sugar beet	8226
Wheat	8012	Rice	12,246
Rice	15,308	Fahl clover	3858
Clover (full season)	11,532	Clover (full season)	9226
Maize	12,448	Maize	9958
Total	63,445		58,829
Saved amount per hectare (m^3/ha)		1539	
Percentage of saving (%)		7	

Crop Rotation in Clay Soil

The prevailing crop rotation in the third agro-climatic zone contained the traditional crop sequences, namely wheat followed by maize, full season clover followed by sunflower, and short season clover followed by cotton (Fig. 8.13).

Year 1	Year 2	Year 3
Wheat Maize	Clover (2 cuts) Cotton	Clover (full season) Sunflower
Clover (full season) Sunflower	Wheat Maize	Clover (2 cuts) Cotton
Clover (2 cuts) Cotton	Clover (full season) Sunflower	Wheat Maize

Fig. 8.13 Prevailing crop rotation in the clay soil of the third agro-climatic zone of Egypt

In the suggested crop rotation (Fig. 8.14) and in the first section, cowpea intercropped with maize system (Hamd-Alla et al. 2014) is cultivated after wheat.

In the second section of the crop rotation, another three-crop sequence was cultivated. In this sequence, clover is cultivated in September and harvest in April, soybean is cultivated as an early summer crop in May and harvested in the end of July, and sunflower is cultivated in August and harvested in October before cultivation of the winter crop in November.

In the third section, cotton could be relay intercropped with onion (Zohry 2005) to increase land profitability. In this system, onion plays a vital role in reducing some cotton insects, such as cotton leafworm (Badawy and Shalaby 2015). Detailed description of the system is presented in Chap. 3 (Fig. 8.15).

Table 8.10 shows that the applied irrigation water to the suggested rotation will be lower than the applied amounts to the prevailing rotation. Implementing the suggested crop rotation could save 907 m^3/ha, which amounts to 5% of the applied water to the prevailing rotation.

Year 1	Year 2	Year 3
Wheat Cowpea/maize	Clover (full season) Soybean (early) Sunflower	Cotton relay intercropped on onion
Clover (full season) Soybean (early) Sunflower (late)	Cotton relay intercropped on onion	Wheat Cowpea/maize
Cotton relay intercropped on onion	Wheat Cowpea/maize	Clover (full season) Soybean (early) Sunflower

Fig. 8.14 Suggested crop rotation in the clay soil of the third agro-climatic zone of Egypt

Fig. 8.15 Cotton relay intercropped with onion

Table 8.10 Water requirements for the prevailing and suggested crop rotations in clay soil of the third agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	7283	Wheat	5826
Maize	11,317	Cowpea/maize	9054
Clover (full season)	10,483	Clover (full season)	8386
Sunflower	10,233	Soybean (early)	5691
Clover (2 cuts)	4193	Sunflower (late)	6834
Cotton	10,483	Cotton/onion	15,480
Total	53,992		51,271
Saved amount per hectare (m^3/ha)		907	
Percentage of saving (%)		5	

The Fourth Agro-climatic Zone

Crop Rotation in Sandy Soil

The prevailing crop rotation in the sandy soil of the fourth agro-climatic zone (Fig. 8.16) is similar to the one existed in the second agro-climatic zone with one difference, namely maize is replaced by sorghum. Sorghum is very popular crop in the fourth and fifth agro-climatic zones. It could withstand the high temperature

Year 1	Year 2	Year 3
Clover (full season) Peanut	Sugar beet Sorghum	Wheat Peanut
Wheat Peanut	Clover (full season) Peanut	Sugar beet Sorghum
Sugar beet Sorghum	Wheat Peanut	Clover (full season) Peanut

Fig. 8.16 Prevailing crop rotation in the sandy soil in the fourth agro-climatic zone of Egypt

prevailing in these zones. However, cultivation of peanut twice and sugar beet once causes spread of soil nematodes.

In the first section of the suggested crop rotation (Fig. 8.17), sesame replaced peanut as a non-host nematode. In the second section of the rotation, three-crop sequence was implemented where fahl clover cultivation followed peanut cultivation and preceded wheat cultivation.

In the third section of the crop rotation, faba bean was followed by cowpea intercropped with sorghum system. Abou-Keriasha et al. (2011) indicated that sorghum yield was increased under intercropping it with cowpea by 8%, compared to sole sorghum planting. Furthermore, associated weeds with sorghum were decreased by 81%, compared to sole planting of sorghum. The existence of cowpea is very important as a feed summer crop in this rotation. Description of the system is presented in Chap. 6).

Implementing the suggested crop rotation in the sandy soil of the fourth agro-climatic zone could result in saving the applied irrigation water for the prevailing crop rotation by 6%, which amounts for 972 m^3/ha, compared to the applied amount for the prevailing rotation (Table 8.11).

Year 1	Year 2	Year 3
Clover (full season) Sesame	Wheat Peanut	Faba bean Cowpea/sorghum
	Fahl clover	
Wheat Peanut Fahl clover	Faba bean Cowpea/sorghum	Clover (full season) Sesame
Faba bean Cowpea/sorghum	Clover (full season) Sesame	Wheat Peanut Fahl clover

Fig. 8.17 Suggested crop rotation in the sandy soil in the fourth agro-climatic zone of Egypt

Table 8.11 Water requirements for the prevailing and suggested crop rotations in sandy soil of the fourth agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	8613	Clover (full season)	7752
Peanut	9013	Sesame	8555
Wheat	6493	Wheat	5844
Peanut	9013	Peanut	8112
Sugar beet	9107	Fahl clover	4172
Sorghum	10,167	Faba bean	6500
		Cowpea/sorghum	9150
Total	52,406		50,085
Saved amount per hectare (m^3/ha)		774	
Percentage of saving (%)		4	

Crop Rotation in Clay Soil

The crops cultivated in the prevailing crop rotation contained two legume crops, namely full season clover and faba bean. Furthermore, sorghum is preceded by wheat, where both are cereal crops (Fig. 8.18).

In the first section of the suggested crop rotation, full season clover was followed by sunflower intercropped with tomato system (Chap. 7, Abdel 2006). In the second section of the rotation, three-crop sequence was cultivated, where fahl clover was cultivated between sorghum and wheat. In the third section of the rotation, faba bean was followed by soybean intercropped with maize system (Chap. 3; Sherif and Gendy 2012) (Fig. 8.19).

Irrigation water saving by 3068 m^3/ha could be attained when the suggested rotation is implemented. This amount represents 14% of the applied water to the prevailing crop rotation (Table 8.12).

Year 1	Year 2	Year 3
Clover (full season) Tomato	Faba bean Maize	Wheat Sorghum
Wheat Sorghum	Clover (full season) Tomato	Faba bean Maize
Faba bean Maize	Wheat Sorghum	Clover (full season) Tomato

Fig. 8.18 Prevailing crop rotation in the clay soil in the fourth agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Clover (full season) Sunflower/tomato	Wheat Sorghum Fahl clover	Faba bean Soybean/maize
Wheat Sorghum Fahl clover	Faba bean Soybean/maize	Clover (full season) Sunflower/tomato
Faba bean Soybean/maize	Clover (full season) Sunflower/tomato	Wheat Sorghum Fahl clover

Fig. 8.19 Suggested crop rotation in the clay soil in the fourth agro-climatic zone of Egypt

Table 8.12 Water requirements for the prevailing and suggested crop rotations in clay soil of the fourth agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	9433	Clover (full season)	7546
Tomato	14,433	Sunflower/tomato	11,546
Wheat	8117	Wheat	6494
Sorghum	13,167	Sorghum	10,534
Faba bean	7217	Fahl clover	4319
Maize	12,750	Faba bean	5774
		Soybean/maize	10,200
Total	65,117		55,913
Saved amount per hectare (m^3/ha)		2901	
Percentage of saving (%)		13	

The Fifth Agro-climatic Zone

Crop Rotations for Sugarcane

Crop rotation in the fifth agro-climatic zone is called sugarcane rotation because sugarcane is the main crop in it. In this rotation, sugarcane occupies one half of its area. The rotation contains six sections and implemented in eight years, where there are two preliminary years. These two preliminary years allow the farmers to produce new cane every year to produce good quality sugarcane.

In the first preliminary year, new cane introduced in the rotation, whereas in the second preliminary year, the first ratoon is produced from the cane cultivated in the first preliminary year, and new cane is introduced in the underneath section. In the first year of the rotation, second ratoon is produced from the first ratoon cultivated in the second preliminary year, and new cane is introduced in the underneath section. This procedure continues to the end of the rotation. Thus, in the first year of the rotation and after the two preliminary years, new cane, first and second ratoon exist in each year.

Sugarcane plants are grown under surface irrigation with 60% application efficiency, which consumes large amount of irrigation water not only because it has long growing season, but also it has large above-ground biomass. Cultivation on raised beds is not suitable for sugarcane plants because of its large above-ground biomass.

In Egypt, sugarcane could be cultivated twice as a fall or spring crop. The fall sugarcane is cultivated in September and October and harvested after 16 months. Fallow exists before the new cane in each year of the rotation (Fig. 8.20).

The spring sugarcane is cultivated in February and March and harvested after 12 months. In this rotation, clover is cultivated and harvested before new cane cultivation, where two cuts of clover can be harvested (Fig. 8.21).

To increase land and water productivity in both fall and spring sugarcane rotation, intercropping systems could be implemented with sugarcane. Sugarcane offers a unique potential for intercropping because it is planted in wide rows (100 cm) and takes several months to develop its canopy, during which time the soil and solar energy go to waste (Nazir et al. 2002). The growth rate of sugarcane during its early growth stages is slow, with leaf canopy providing sufficient uncovered area for growing another crop (Watto and Mugera 2015). In this case, the intercropped crop will not need any extra irrigation water as it will use the applied water to sugarcane to fulfill its required water. Furthermore, intercropping on sugarcane provide extra income for farmers during the early growth stage of sugarcane.

In the suggested fall crop rotation (Fig. 8.22), faba bean, onion, or wheat could be intercropped on the new cane. In faba bean intercropping with sugarcane system (Fig. 8.23a), faba bean is cultivated in October in two rows with 50% of its recommended planting density (Farghly 1997). Intercropping with faba bean has the greatest potential to fix nitrogen (Shoko and Tagwira 2005). Since nitrogen fertilizer is a substantial cost component of sugarcane cropping system, the use of faba bean as a secondary crop in the system plays a considerable role in reduction of production costs (El-Geddawy et al. 1988).

Regarding onion intercropped with sugarcane, the system is very successful in south Egypt. Hossain et al. (2004) stated that onion exerted the least detrimental effect

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Fallow New cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) New cane	1st Ratoon
Faba bean Sorghum	Fallow New cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (one cut) New cane
Wheat Sorghum	Lentil Sorghum	Fallow New cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow New cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow New cane	1st Ratoon	2nd Ratoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow New cane	1st Ratoon	2nd Ratoon

Fig. 8.20 Prevailing fall sugarcane crop rotation in the fifth agro-climatic zone of Egypt

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) New cane	1stRatoon
Faba bean Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (one cut) New cane
Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon

Fig. 8.21 Prevailing spring sugarcane crop rotation in the fifth agro-climatic zone of Egypt

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Fallow Faba bean/new cane	1stRatoon
Faba bean Sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Onion/new cane
Wheat Sorghum	Lentil Sorghum	Fallow Wheat/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Wheat/new cane	1stRatoon	2ndRatoon

Fig. 8.22 Suggested fall sugarcane crop rotation in the fifth agro-climatic zone of Egypt

on the emergence and tillering of sugarcane and final yield of sugarcane. Higher yield of cane due to intercropping with onion was reported as it reduces the incidence of some insects in sugarcane (Parashar et al. 1979). In this system, onion is planted in October in two rows with 80% of its recommended planting density (Zohry 1997).

Another successful intercropping system for wheat is intercropping with sugarcane (Fig. 8.23b). In this case, wheat will not need any extra irrigation water as it will use the applied water to sugarcane to fulfill its required needs for water. Furthermore, intercropping wheat on sugarcane provides extra income for farmers during the early growth stage of sugarcane. Under intercropping wheat with sugarcane system (Fig. 8.4), sugarcane is cultivated in September and wheat is cultivated in November with 40% of its recommended planting density and then wheat is harvested in April. This system produces 40% of wheat yield with no reduction in sugarcane yield (Ahmed et al. 2013).

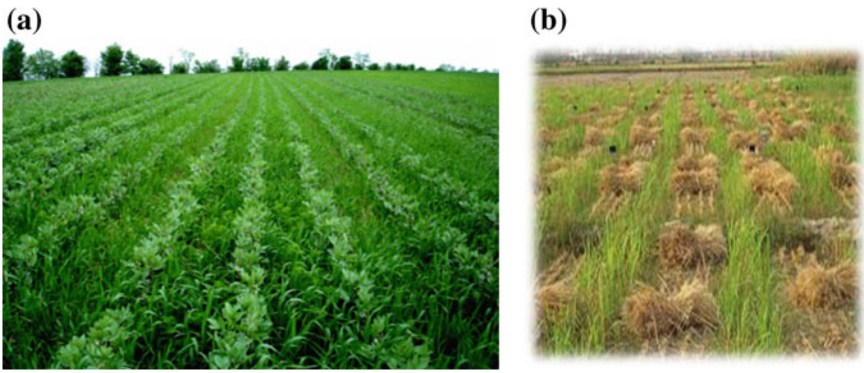

Fig. 8.23 Faba bean intercropped with sugarcane (**a**) and wheat intercropped with sugarcane (**b**)

In the suggested spring sugarcane rotation (Fig. 8.24), intercropping with new sugarcane could be implemented, where soybean, sesame, or sunflower is intercropped. Intercropping soybean with sugarcane (Fig. 8.25a) is a common practice by the farmers in this area (Abou-Keriasha, et al. 1997). According to Sundara (2000), soybean is one of the important intercrop suitable and compatible with sugarcane. This is mainly due to the fact that soybean has adapted well to the climatic conditions in this area. Details of this system are presented in Chap. 7.

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Clover (2 cuts) Soybean/new cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) Soybean/new cane	1st Ratoon
Faba bean Sorghum	Clover (2 cuts) Sesame/new cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sesame/new cane
Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Soybean/new cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sunflower /new cane	1st Ratoon	2nd Ratoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Soybean/new cane	1st Ratoon	2nd Ratoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sunflower /new cane	1st Ratoon	2nd Ratoon

Fig. 8.24 Suggested spring sugarcane crop rotation in the fifth agro-climatic zone of Egypt

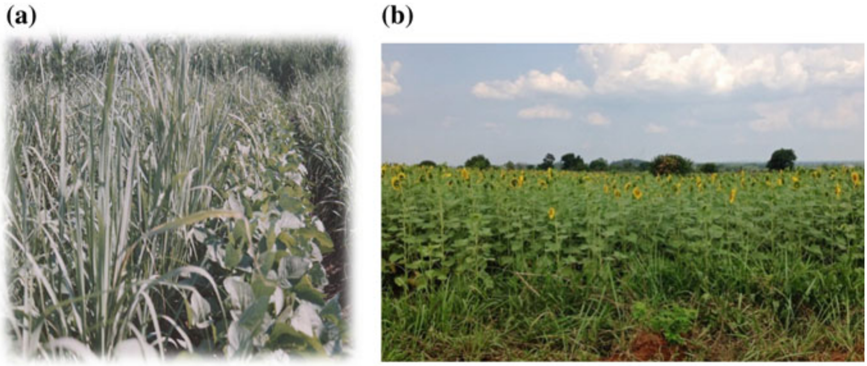

Fig. 8.25 Soybean intercropped with sugarcane (**a**) and sunflower intercropped with sugarcane (**b**)

In intercropping sesame with spring sugarcane system, the competition over solar radiation between sesame plants and sugarcane plants was low and does not negatively affect sugarcane yield because of the morphological characteristics of sesame leaves being erect and does not cause any shading over the growing sugarcane plants. Sesame's recommended planting density is 50% in its intercropping system with sugarcane (Abou-Keriasha et al. 1997).

El-Gergawi et al. (2000) intercropped sunflower with sugarcane (Fig. 8.25b). However, Abou-Keriasha et al. (1997) indicated that competition over solar radiation between sunflower plants and sugarcane plants was high because sunflower plants are longer than sugarcane plants in that growth stage.

The results in Table 8.13 indicated that both the prevailing and the suggested fall sugarcane rotation consumed 1,887,523 m^3 of irrigation water in the eight years of its duration. However, this amount of water is used to irrigate 70 crops in the prevailing rotation and 78 crops in the suggested rotation. For that reason, the suggested rotation has higher water productivity, in addition to having higher land productivity due to the implemented intercropping systems.

Likewise, in the prevailing spring sugarcane rotation (Table 8.14), the 78 crops cultivated in it consumed 1,746,635 m^3 of irrigation water. Whereas, the suggested spring sugarcane rotation consumed the same amount of irrigation water by 86 crops cultivated in it. Thus, the suggested rotation has higher water productivity and land productivity.

Table 8.13 Water requirements for the prevailing and suggested fall sugarcane rotations in the fifth agro-climatic zone of Egypt

	Prevailing fall rotation		Suggested fall rotation	
	Total amount (m^3)	No. of cultivated crops	Total amount (m^3)	No. of cultivated crops
First preliminary	193,828	11	193,828	12
Second preliminary	223,394	10	223,394	11
First year	252,111	9	252,111	10
Second year	243,578	8	243,578	9
Third year	243,578	8	243,578	9
Fourth year	243,728	8	243,728	11
Fifth year	243,578	8	243,578	10
Sixth year	243,728	8	243,728	11
Total	1,887,523	70	1,887,523	78

Table 8.14 Water requirements for the prevailing and suggested spring sugarcane rotations in the fifth agro-climatic zone of Egypt

	Prevailing spring rotation		Suggested spring rotation	
	Total amount (m^3)	No. of cultivated crops	Total amount (m^3)	No. of cultivated crops
First preliminary	176,217	12	180,368	13
Second preliminary	205,783	11	209,934	12
First year	234,500	10	238,651	11
Second year	225,967	9	230,118	10
Third year	225,967	9	230,118	10
Fourth year	226,117	9	230,268	10
Fifth year	225,967	9	230,118	10
Sixth year	226,117	9	230,268	10
Total	1,746,635	78	1,779,839	86

Conclusion

In overpopulated countries like Egypt, there is a gap between production and consumption of cereal crops, oil crops, sugar crops, legume crops, and forage crops. Thus, unconventional procedures are needed to increase crops productivity, manage irrigation water more efficiently, and increase crops production in short time. This magic solution could be attained by implementing crop rotation that includes intercropping systems. Thus, sustainable use of land and water resources could be attained by implementing crop rotations.

Different soil types in each agro-climatic zone required different crops in each rotation. Improving soil properties could be obtained by inclusion of legume crops in the rotation and/or implementing intercropping systems with legume crop as companion crop. Water saving occurs as a result of implementing intercropping systems on raised beds with the suggested crop rotation. Our analysis showed that increasing the number of crops included in the rotation through intercropping system could consume less amount of water, compared to the amount consumed by the prevailing rotations in all the agro-climatic zones of Egypt.

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