Crop Rotation: An Approach to Save Irrigation Water under Water Scarcity in Egypt

Samiha Ouda[1] and Abd El-Hafeez Zohry[2]

Abstract

Crop rotation is an agricultural management practice that could save on the applied irrigation water. The objectives of this paper were: (i) to calculate water requirements for a prevailing crop rotation in old land, new land and salt affected soil, in addition to sugarcane rotation in South Egypt; (ii) to suggest water saving rotations, calculate its water requirements and the saved irrigation water. Water requirements were calculated using BISm model. The results indicated that the proposed rotation in old land, the saved irrigation water amount could reach 1095, 1331 and 1546 m^3/ha in Lower, Middle and Upper Egypt, respectively as a result of cultivation on raised beds and intercropping (produce two crops with the same amount of water). In calcareous soil, 3160 m^3/ha could be saved if the proposed rotation was used. The proposed rotation in sandy soil can save low amount of water, i.e. 53, 67 and 152 m^3/ha in Lower, Middle and Upper Egypt, respectively. In salt affected soil, 3426 m^3/ha can be saved under the proposed rotation. The saved amount of irrigation water under proposed sugarcane rotations was 3596 and 7609 m^3/ha for spring and autumn rotations, respectively. Thus, crop rotation and intercropping can help in solving food insecurity problem through increase land productivity. Furthermore, it can save a sum of irrigation water and increase water productivity. These saved irrigation water amounts can be used to cultivate new areas and reduce food gap.

Introduction

Feeding adequately a population growing at an annual rate of 1.84%, with limited land and water resources, is considered the most important challenge for Egypt. As a result, there is a large gap between production of all strategic crops and its consumption, which increase importation of these crops putting a burden on the country's budget. Agriculture is a vital sector in Egypt's economy, accounting for 14.6% of GDP. More than 85% of the water withdrawal from the Nile is used for irrigated agriculture. Water availability, therefore has a direct influence on national food security. Thus, sustainable growth in agriculture relies on the use of the limited water resources in the most effective and efficient way. At present, surface irrigation used in over 80% of Egypt's cultivated land. Poor water management by the Egyptian farmers is contributing to a remarkable waste in irrigation water.

An agricultural management practice that could save on the applied irrigation water is the use of crop rotation. Furthermore, it could increase land and water productivity. Crop rotation is one of 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. Some of the general benefits of using rotations are to improve or maintain soil fertility, reduce the spread of pests, reduce risk of weather damage, and increase soil water management, which will be reflected on increasing net profit of farmers. The ultimate goal should be to offer alternatives of different forms of crop rotations with less water requirements and same proportions commodities (cereals, sugar crops, oil crops and forage crops), as compared to the prevailing crops rotations, which is less benefit to the soil with high water requirements. Kamel et al., (2010) revealed that appreciable differences in water consumptive between the prevailing rice rotation and proposed rotation. Water consumption of the prevailing exceeded those of the proposed system by 25.1 and 41.7% in case of the short and long term crop rotations, respectively. At present, it is estimated that wheat, clover, cotton, rice and maize

[1] Water Requirement and Field Irrigation Department; Soils, Water and Environment Research Institute; Agricultural Research Center; Egypt, E-mail: samihaouda@yahoo.com
[2] Crop Intensification Department; Field Crops Research Institute, Agricultural Research Center; Egypt

amount for 80% of the cropped area. Wheat and clover are the principle winter crops. In summer, cotton and rice are important cash crops, while maize and sorghum are major subsistence crops. The inclusion of sugar beet in winter in the crop structure resulted in severe competition with winter crop particularly faba bean and lentil which has led to an abrupt decline in the area cultivated by legumes. Intercropping and multiplicity of crop sequence are considered successful avenues to increase the cropped area without altering the area cultivated by the main crops in winter or summer. Intercropping is growing two or more crops in the same field, which allow using water and nutrients more efficiently (Eskandari et al., 2009). The advantages of intercropping are: it increase unit land productivity (harvest two types of crops from the same area), increase water productivity (use less water to irrigate two crops) and increase farmers income (reduce risks from crop failure) (Andersen, 2005).

Crop rotations could be used as a strategy to save on the applied irrigation water because it could consist of crops with medium to low water requirements. In addition, using improved agricultural management practices in cultivating these crops could reduce the applied irrigation water. Previous research in Egypt demonstrated that improved agricultural management practices, such as raised beds cultivation could save a good percentage of irrigation water, improved the growth environment for the growing crops and increased the yield of these growing crops, which positively reflected on farmer's net revenue (Abouenein et al., 2009 and 2010). Using these crop rotations will help in the sustainable use of natural agricultural resources; 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 livings standard and poverty elevation of rural population.

The objectives of this paper are: (i) to calculate water requirements for a prevailing crop rotation in old land, new land and salt affected soil, in addition to sugarcane rotation in south Egypt; (ii) to suggest water saving rotations, calculate its water requirements and the saved irrigation water.

Materials and methods

The prevailing crop rotation is implemented in three years. In each year, the cultivated area is composed of three hectares. Each hectare is divided into three parts and each part is cultivated with winter and summer crops. The prevailing rotation is usually cultivated using the traditional method, i.e. narrow furrows or flat cultivation. This cultivation method is characterized by high applied irrigation water and high fertilizer consumption.

Prevailing rotation in the old land

This crop rotation is prevailing in the Nile Delta and valley, which known as old land and represents the most fertile soils in Egypt. These types of soils are now poor in organic matter content and available nitrogen due to the intensive agricultural system and discontinuation of silt deposits after the construction of the Aswan High Dam. Contentious growing of exhaustive crops like cereals lowered organic matter and reduced microbial activity, which resulted in less ability to hold water and less availability of nutrients in root zones. Intensive cropping pattern is existed, where 2 or 3 crops are cultivated each year. Surface irrigation system is the main irrigation system with 60% application efficiency. The cultivated crops in these areas are wheat and clover as winter crops, whereas cotton and maize are cultivated in the summer.

Crop rotations in the new reclaimed land

In new reclaimed lands, calcareous or sandy, soils are deficient in macro and micro nutrients. Therefore, there is a need for fertilizer application under intensive agriculture. Nitrogen fertilizer use approximately double, while phosphorus application increased by 70%. The rate of application of basic nutrients (N, P and K) is very high 372 kg/ha. Nitrate leaching to the water body has become a great concern as a potential source of water pollution. Break down of rotation increase concentration of single crop within an area increases pest infestation deprive certain elements and accumulate allelopathy. Calcareous soil exists in

West Delta governorates, such as El-Behira. Surface irrigation is the system used in these areas. The popular cultivated crops are wheat, clover and sugar beet in the winter. In the summer: tomato, maize and soybean are the popular crops.

Regarding to sandy soil, many constrains are exist to maintain sustainability, such as, low soil fertility, ineffective biological N-fixation, poor irrigation water management and high water table levels and soil salinity in some areas. Sprinkler or drip system prevailed in this region, with application efficiency 80 and 95%, respectively. Wheat, clover and sugar beet or the favorite winter crops, as well as maize and peanut are the favorite summer crops

Crop Rotation in salt affected soil

The majority of salt affected soils in Egypt are located in the Northern Nile Delta. About 900,000 hectares of Egypt's agricultural lands are suffering from salinity build-up problem. Across Egypt's agricultural land profile, salt-affected soils represent about 60 and 25% in North and South Nile Delta regions, respectively. Surface irrigation system with fresh water, agricultural drainage and mixed water. There are several problems there, such as high water table, seawater intrusion and increase in soil salinity. Surface irrigation is prevailing in this area. Clover, wheat and sugar beet are winter crops preferred by the farmers in this area. Maize and rice are preferred summer crops.

Sugarcane rotations in Upper Egypt

Sugarcane crop is considered very exhaustive to the soil, requires great quantities of irrigation water, fertilizers and labor force. It is a perennial crop usually stays in field for three years (two ratoons, in addition to the yield of new cane). Thereafter, the soil requires more special sustainable rotation to conserve soil fertility. Sugarcane belt is located in the Southern governorates, where 90% is grown in El-Minia, Suhag, Qena and Aswan governorates. Usually, fields are left fallow after latter ratoon during winter, then, farmers grow grain sorghum. Wheat and Egyptian clover are usually grown in sugarcane rotation (Zohry, 1994).

Calculations of water requirements

Water requirements for crops in each rotation were calculated using BISm (Snyder et al., 2004). The model was written using MS Excel to help people plan irrigation management of crops. The BISm application calculates evapotranspiration (ET) using the Penman-Monteith (P-M) equation (Monteith, 1965) as presented in the United Nations FAO Irrigation and Drainage Paper (FAO, 56) by Allen et al., (1998). For ET calculations, the station latitude and elevation must also be input. The BISm model was used to calculate monthly ET values as an average over 10 years, from 2004 to 2013 in the selected areas. After calculating daily means by month, a cubic spline curve fitting subroutine is used to estimate daily ET rates for the entire year. To calculate water requirements for each crop, the model requires planting and harvest dates as input, then the model calculates crop coefficient (kc). The model also account for water depletion from root zone. Therefore, it requires to input total water holding capacity and available water. These values were obtained from previous research done in The "Water Requirements and Field irrigation Research Department, Soils, Water and Environment Research Institute, Agricultural Research Center", Egypt. The model calculates the amount of applied water for each crop and the date of application, which mainly depends on the water depletion from root zone.

Results and Discussion

Crop rotations in the old land

Figure (1) showed that the prevailing rotation contained winter legume forage crop, (clover), winter and summer cereal crops (wheat and maize) and fiber crop (cotton). The figure also showed that clover is cultivated before maize and before cotton. This practice improves soil fertility and soil sustainability. However, cultivating maize after wheat is exhausting for the soil because both of them are cereal crops.

Year 1	Year 2	Year 3
Clover Maize	Wheat Maize	Clover (short season) Cotton
Clover (short season) Cotton	Clover Maize	Wheat Maize
Wheat Maize	Clover (short season) Cotton	Clover Maize

Figure (1): Prevailing crop rotation in the old land in Egypt

In the suggested rotation (Figure 2), all crops are cultivated on raised bed to reduce the applied irrigation water and fertilizer. In the first part of the rotation, cotton is relay intercropped with wheat (wheat is cultivated in November and cotton is cultivated in March and harvested in September). The benefits of this system are to increase wheat cultivated area by the area assigned to be cultivated by cotton and to save the first two irrigations for cotton. Under this system, the farmer obtained two yields: the same cotton yield as if it was planted solely and 80% of wheat yield, compared to sole wheat planting (Zohry, 2005b).

In the second part of the rotation, clover is planted as winter crop to increase land fertility. In the summer season, maize in intercropped with soybean to increase land and water productivity (Ouda et al., 2007). Maize and soybean were intercropped 2 rows of maize with 2 rows of soybean in one hectare. In this case, maize yield under intercropping was 75% of its counterpart under sole cultivation. Furthermore, soybean yield under intercropping was 80% of its counterpart under sole cultivation. This can be attributed to that intercropping involves planting two crops that differed in growth habits; phonological characteristics and productivity on the same unit of land (IITA, 1980). Typically, C4 cereal crop, such as maize is the dominant plant species, whereas C3 legume crop, such as soybean is the associated or secondary species. Canopy structures and rooting systems of cereal crops are generally different from those of legume crops. Maize roots can penetrate deeper in the soil (1.7 m) than soybean roots (1.3 m) (Allen et al., 1998). Furthermore, maize can form higher canopy structures than soybean. This suggests that the component crops probably have differing spatial and temporal use of environmental resources. Intercrops may make use of environmental resources such as radiation, water and nutrients more efficiently than mono crops (Willey, 1990).

In the third part of the rotation, faba bean is intercropped with sugar beet as winter crops to reduce faba bean production-consumption gap and increase land and water productivity because no extra irrigation water or fertilizer is applied to faba bean. Sugar beet in cultivated by 100% of its recommended planting density in one hectare and faba bean is cultivated by 25% of its recommended planting density in one hectare. As a result, the farmer can obtain 100 and 25% of sugar beet and faba bean, respectively (Nofal 2012). For summer crops, cowpea is intercropped with maize to increase maize yield and reduced associated weeds. No additional water will be applied for cowpea (Zohry, 2005a). Under this system, the farmer use 100% of plant seeding rate of maize and obtain about 10% increase in maize yield. Regarding to cowpea, the farmer use 50% of plant seeding rate of cowpea and obtain 50% of the yield. Furthermore, it increased farmers profit (Abou-Keriasha et al., 2011). Thus, the proposed rotation contains winter and summer cereal crops (wheat and maize) and winter and summer forage crops (clover and cowpea). The rotation also contains winter and summer legume crops (faba bean and soybean), summer fiber crop (cotton) and winter sugar crop (sugar beet). These diversities in the crops associated in the proposed rotation can serve as a remedy to food insecurity problem exists in Egypt.

Year 1	Year 2	Year 3
Wheat/cotton	Sugar beet/faba bean Maize/cowpea forage	Clover Maize/soybean
Clover Maize/soybean	Wheat/cotton	Sugar beet/faba bean Maize/cowpea forage
Sugar beet/faba bean Maize/cowpea forage	Clover Maize/soybean	Wheat/cotton

Figure (2): Proposed crop rotation in the old land in Egypt.

Water requirements for old land rotations under

Water requirements for the crops cultivated in the prevailing rotation are 45937, 50262 and 53366 m^3 for three hectare in Nile Delta, Middle Egypt and Upper Egypt, respectively (Table 1). Regarding to the proposed rotation, total water requirements for the cultivated crops are 45937, 50262 and 53366 m^3 for three hectares in Nile Delta, Middle Egypt and Upper Egypt, respectively. However, if we use the suggested crop rotation, the saved irrigation amount per hectare will be 1095, 1331 and 1546 m^3/ha in Nile Delta, Middle Egypt and Upper Egypt, respectively (Table 1). These results proved that adopting the proposed crop rotation could reduce the applied water and save large amount to be use in cultivating new lands.

Table (1): Water requirements for crops cultivated in prevailing and proposed rotation in the old land

Rotation	Water requirements in (m^3/ha)		
	Nile Delta	Middle Egypt	Upper Egypt
Prevailing			
Clover	8530	8850	9080
Maize	6111	7542	7953
Clover (short season)	4265	4425	4540
Cotton	15720	16470	17290
Wheat	5200	5433	6550
Maize	6111	7542	7953
Total	45937	50262	53366
Proposed			
Wheat/cotton	16384	17155	18688
Clover	6824	7080	7264
Maize/soybean	4889	6034	6362
Sugar beet/faba bean	9667	9967	10050
Maize/cowpea	4889	6034	6362
Total	42652	46269	48727
Saved water for 3 ha (m^3)	3285	3994	4639
Saved water (m^3/ha)	1095	1331	1546

Crop rotation in calcareous soil

An example of a prevailing rotation is presented in (Figure 3), where surface irrigation is used in this rotation. The figure reveals that the rotation contained winter and summer legume crops (wheat and maize), a winter forage crop (clover), vegetable crop (tomato), legume crop (soybean) and sugar crop (sugar beet). Thus, the selected crops are suitable to sustain soil fertility; however it does not save irrigation water.

Year 1	Year 2	Year 3
Wheat Tomato	Sugar beet Soybean	Clover Maize
Clover Maize	Wheat Tomato	Sugar beet Soybean
Sugar beet Soybean	Clover Maize	Wheat Tomato

Figure (3): Prevailing crop rotation in calcareous soil in Egypt

In the suggested rotation (Figure 4), all crops are cultivated on raised bed to save on the applied irrigation water and fertilizer. The proposed rotation includes variety of crop group. It contains a winter sugar crop (sugar beet), winter and summer legume crops (faba bean and soybean) winter and summer cereal crops (wheat and maize), a vegetable crop (tomato) and winter and summer forage crops (clover and cowpea). In the first part of the rotation, applied water for faba bean will be saved (Nofal 2012). In the second part of the rotation, wheat will take its water requirements. Intercropping maize with tomato (summer crops) will save the applied irrigation water for maize. Tomato yield will increase by 13%. Regarding to maize, 60% of the recommended planting density will and maize yield will be 80% of its counterpart of sole planting (Abd El-Aal and Zohry 2003). In the third part of the rotation, the applied water for clover will be applied. In the summer season, intercropping cowpea with maize will save the applied water for cowpea.

Year 1	Year 2	Year 3
Sugar beet/faba bean Maize/soybean	Wheat Tomato/maize	Clover Maize/cowpea forage
Wheat Tomato/maize	Clover Maize/ cowpea forage	Sugar beet/faba bean Maize/soybean
Clover Maize/cowpea forage	Sugar beet/faba bean Maize/soybean	Wheat Tomato/maize

Figure (4): Proposed crop rotation in calcareous soil in Egypt.

Water requirements for prevailing rotation were 47958 and 38477 m^3. The proposed rotation could save 3160 m^3 (Table 2).

Table (2): Water requirements for crops cultivated in prevailing and proposed rotation in calcareous land.

Rotation	Water requirements (m^3/ha)
Prevailing	
Wheat	5017
Tomato	13170
Clover	8210
Maize	6069
Sugar beet	9561
Soybean	5931
Total	47958
Proposed	
Sugar beet/faba bean	7649
Maize/soybean	4856
Wheat	4013
Tomato/maize	10536
Clover	6568
Maize/cowpea	4856
Total	38477
Saved water for 3 ha (m^3)	9481
Saved water (m^3/ha)	3160

Crop rotation in sandy soil

Figure (5) showed the prevailed crop rotation in sandy soil. There are a winter forage crop (clover), winter and summer cereal crops (wheat and maize), a sugar crop (sugar beet) and a winter legume crop (peanut) included in the rotation. All these crops suitable and maintain soil fertility, except sugar beet followed by maize and wheat followed by peanut.

Year 1	Year 2	Year 3
Clover Maize	Wheat Peanut	Sugar beet Soybean
Sugar beet Maize	Clover Maize	Wheat Peanut
Wheat Peanut	Sugar beet Maize	Clover Maize

Figure (5): Prevailed crop rotation in sandy soil in Egypt

The proposed crop rotation (Figure 6) indicated that sunflower can intercrop with soybean, where the recommended intercropping pattern should be 2:2, respectively **(**El-Yamani et al., 2010**)**. Sesame intercropped with peanut saved all the applied water to sesame. In this system, peanut planting density is 100%, compared to its sole planting and intercropped sesame density is 25% from its recommended planting density (Abou-Kerisha et al., 2008). The proposed rotation included winter and summer forage and cereal crops. It also contains oil summer crops (sunflower and sesame) and sugar crop.

Year 1	Year 2	Year 3
Clover Maize/cowpea forage	Wheat Peanut/sesame	Sugar beet/faba bean Maize/potato
Sugar beet/faba bean Sunflower/soybean	Clover Maize/cowpea forage	Wheat Peanut/sesame
Wheat Sesame/peanut	Sugar beet/faba bean Maize/potato	Clover Maize/cowpea forage

Figure (6): Proposed crop rotation in sandy soil in Egypt

In sandy soil, the crops grown in both rotations; prevailed and proposed were irrigated with sprinkler or drip system. The proposed rotation saved low amount of water, i.e. 53, 67 and 152 m^3/ha in Lower, Middle and Upper Egypt, respectively. The reduction in the amount of applied water is due to replacing maize with sunflower intercropped with soybean, which has lower water requirements than maize (Table 3).

Table (3): Water requirements for crops cultivated in prevailing and proposed rotation in sandy soil

Rotation	Water requirements (m^3/ha)		
	Lower Egypt	Middle Egypt	Upper Egypt
Prevailing			
Clover (sprinkler)	8213	8500	8750
Maize (drip)	5002	5740	6381
Sugar beet (drip)	7521	8273	9101
Maize (drip)	5002	5377	6131
Wheat (sprinkler)	4850	5335	5869
Peanut (drip)	5802	6052	6252
Total	36390	39277	42484
Proposed			
Clover (sprinkler)	8213	8500	8750
Maize/cowpea (drip)	5002	5740	6381
Sugar beet/faba bean	7521	8273	9101
Sunflower/soybean (drip)	4843	5176	5676
Wheat (sprinkler)	4850	5335	5869
Sesame/peanut (drip)	5802	6052	6252
Total	36231	39076	42029
Saved water for 3 ha (m^3)	159	201	455
Saved water (m^3/ha)	53	67	152

Crop rotations in Salt affected soils

An example prevailing rotation is illustrated in Figure (7). The rotation is characterized by intensive rice cultivation to leach salts away from root zone. Furthermore, the rotation contains forage, cereal and sugar crops. However, maize cultivation after wheat and rice after sugar beet are exhausting to the soil.

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

Figure (7): Prevailing crop rotation in salt affected soil in Egypt

Cultivation on raised beds is the main characteristic of the proposed rotation (Figure 8). Cultivation of short season clover after rice and before wheat increased soil fertility, compared to wheat and rice cultivation only (Sheha, et al., 2015). Furthermore, the rotation contains winter and summer cereal crops, forage crops winter and summer forge crops. Furthermore, it contains sugar crop and fiber crop.

Year 1	Year 2	Year 3
Wheat Rice Clover (short season)	Sugar beet/faba been Maize/cowpea forage	Wheat/cotton
Sugar beet/faba been Maize/cowpea forage	Wheat/cotton	Wheat Rice Clover (short season)
Wheat/cotton	Wheat Rice Clover (short season)	Sugar beet/faba been Maize/cowpea forage

Figure (8): Proposed crop rotation in salt affected soil in Egypt

Cultivating crops in salt affected soil requires application of leaching requirements to wash salts away from root zone. Table (4) includes water requirements for both prevailing and proposed crop rotations without leaching requirements. The proposed rotation will save 3426 m^3/ha.

Table (4): Water requirements for crops cultivated in prevailing and proposed rotation in salt affected land.

Rotation	Water requirements (m^3/ha)
Prevailing	
Clover	8720
Maize	6361
Wheat	5600
Rice	13740
Sugar beet	9667
Rice	13740
Total	57828
Proposed	
Wheat	4480
Rice	10992
Clover (short season)	2790
Sugar beet/faba bean	7734
Maize/cowpea forage	5089
Wheat/cotton	16464
Total	47549
Saved water for 3 ha (m^3)	10279
Saved water (m^3/ha)	3426

Prevailing crop rotation for sugarcane

Farmers follow this rotation in large area and in most fertile soil in Upper Egypt. Nevertheless, this rotation suffers irregularities in income and work organization and the scarcity of seeds (stakes) to plant the fourth year. In this rotation, sugarcane occupied half the area, stays in field for 3 years and renews every year. Cane is grown in autumn and the

Egyptian clover of one cut as a cover crop is always ploughed in the soil before planting cane. The field is divided to six fields and this necessitates the design of preliminary years before starting the rotation. Furthermore, cane occupies half the area. This rotation is characterized by cultivation of wheat, clover and legumes in the winter and grain sorghum in the summer (Figure 9).

Plot area	First preliminary	Second Preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
$^{1}/_{6}$	Egyptian clover (one cut) New cane	1st Ratoon	2nd Ratoon	Fallow Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum	Egyptian clover (one cut) New cane	1st Ratoon
$^{1}/_{6}$	Legume Grain sorghum	Egyptian clover (one cut) New cane	1st Ratoon	2nd Ratoon	Fallow Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum	Egyptian clover (one cut) New cane
$^{1}/_{6}$	Wheat Grain sorghum	Legume Grain sorghum	Egyptian clover (one cut) New cane	1st Ratoon	2nd Ratoon	Fallow Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum
$^{1}/_{6}$	Legume Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum	Egyptian clover (one cut) New cane	1st Ratoon	2nd Ratoon	Fallow Grain sorghum	Wheat Grain sorghum
$^{1}/_{6}$	Wheat Grain sorghum	Legume Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum	Egyptian clover (one cut) New cane	1st Ratoon	2nd Ratoon	Fallow Grain sorghum
$^{1}/_{6}$	Legume Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum	Wheat Grain sorghum	Legume Grain sorghum	Egyptian clover (one cut) New cane	1st Ratoon	2nd Ratoon

Figure (9): Prevailing sugarcane rotation in Upper Egypt.

The proposed autumn sugarcane rotation (Figure 10) is characterized by using intercropping with sugarcane, which allow saving of the applied water to the intercropped crop as it use the applied water to sugarcane (Zohry, 2005a). Thus, intercropping faba bean or onion with autumn planted sugarcane can be done. Under that system, intercropping two rows of faba bean between sugarcane ridges or five rows of onion with sugarcane was successful and profitable (Farghly, 1997 and Zohry, 1997). Furthermore, cowpea is intercropped with grain sorghum to improve soil fertility, as cowpea is a legume crop (Abou-Keriasha et al., 2011). Intercropping maize and soybean could replace grain sorghum, which use similar irrigation water. Sunflower is also cultivated in this rotation, as well as maize. Thus, this rotation consumes similar amount of irrigation water as prevailing rotation. However, intercropping increases water and land productivity as more than one crop consumed the same amount of applied water and more than one crop was harvested from the same piece of land area.

Plot area	First preliminary	Second Preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
$^{1}/_{6}$	Egyptian clover (one cut) New cane + Faba bean	1st Ratoon	2nd Ratoon	Faba bean Grain sorghum	Wheat Soybean + Maize	Faba bean Grain sorghum	Egyptian clover (one cut) New cane + Faba bean	1st Ratoon
$^{1}/_{6}$	Faba bean Grain sorghum	Egyptian clover (one cut) New cane +	1st Ratoon	2nd Ratoon	Faba bean Grain	Wheat Maize + Soybean	Faba bean Grain	Egyptian clover (one cut) New cane

Plot area	First preliminary	Second Preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
		Onion			sorghum		sorghum	
1/6	Wheat Grain sorghum + Cowpea	Faba bean Grain sorghum + Cowpea	Egyptian clover (one cut) New cane + Faba bean	1st Ratoon	2nd Ratoon	Clover Grain sorghum	Wheat Soybean	Faba bean Grain sorghum
1/6	Clover Grain sorghum	Wheat Sunflower	Faba bean Maize + Soybean	Egyptian clover (one cut) New cane + Onion	1st Ratoon	2nd Ratoon	Clover Grain sorghum	Wheat Maize + Soybean
1/6	Wheat Sunflower	Clover Grain sorghum	Wheat Maize	Clover Maize + Cowpea	Egyptian clover (one cut) New cane + Faba bean	1st Ratoon	2nd Ratoon	Clover Sunflower
1/6	Faba bean Grain sorghum	Wheat Grain sorghum + Cowpea	Clover Maize + Soybean	Wheat Grain sorghum	Clover Maize	Egyptian clover (one cut) New cane + Onion	1st Ratoon	2nd Ratoon

Figure (10): Proposed autumn sugarcane rotation in Upper Egypt.

The proposed spring sugarcane rotation (Figure 11) is characterized by intercropping summer crops with sugarcane, where these crops will obtain their water requirements from the applied water to sugarcane. Intercropping soybean or sesame with spring planted sugarcane, where two rows of soybean or sesame will be planted between sugarcane ridges, was successful and profitable **(**Eweida et al., 1996 and Abou-Keriasha et al., 1997). Similar to autumn sugarcane rotation, summer crops, such as sunflower, soybean and maize could replace grain sorghum in some areas in the rotation. Furthermore, intercropping maize and cowpea, as well as maize and soybean could be implemented.

Plot area	First preliminary	Second Preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
1/6	Egyptian clover (one cut) New cane + Soybean	1st Ratoon	2nd Ratoon	Faba bean Grain sorghum	Wheat Soybean + Maize	Faba bean Grain sorghum	Egyptian clover (one cut) New cane + Soybean	1st Ratoon
1/6	Wheat Grain sorghum	Egyptian clover (one cut) New cane + Sesame	1st Ratoon	2nd Ratoon	Faba bean Grain sorghum	Wheat Maize + Soybean	Faba bean Grain sorghum	Egyptian clover (one cut) New cane + Sesame
1/6	Faba bean Grain sorghum + Cowpea	Faba bean Grain sorghum	Egyptian clover (one cut) New cane + Soybean	1st Ratoon	2nd Ratoon	Clover Grain sorghum	Wheat Soybean	Faba bean Grain sorghum
1/6	Clover Grain	Wheat Sunflower	Faba bean	Egyptian clover (one cut)	1st Ratoon	2nd Ratoon	Clover Grain	Wheat Maize +

Plot area	First preliminary	Second Preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
	sorghum		Maize + Soybean	New cane + Sesame			sorghum	Soybean
$^1/_6$	Wheat Sunflower	Clover Grain sorghum	Wheat Maize	Clover Maize + Cowpea	Egyptian clover (one cut) New cane + Soybean	1st Ratoon	2nd Ratoon	Clover Sunflower
$^1/_6$	Faba bean Grain sorghum	Wheat Grain sorghum + Cowpea	Clover Soybean	Wheat Grain sorghum	Clover Maize	Egyptian clover (one cut) New cane + Sesame	1st Ratoon	2nd Ratoon

Figure (11): Proposed spring sugarcane rotation in Upper Egypt.

Amount of saved irrigation water under proposed rotations

The amount of saved irrigation water using the proposed spring rotation was calculated to be 3,596 m^3/ha (Table 5).This amount resulted from intercropping soybean or sesame with sugarcane. This amount of water was supposed to be applied to either crop under sole planting. Thus, it was saved because either crop obtained it from the applied water to sugarcane. Similarly, under proposed autumn rotation, the saved amount was 7,609 m^3, as a result of intercropping faba bean or onions (Table 5).

Table (5): Saved amount of irrigation water under proposed sugarcane rotations.

	Prevailing rotation		Proposed rotation	
	Spring	Autumn	Spring	Autumn
Applied water per hectare (m^3/ha)	19,708	20,958	19,708	20,958
Amount of saved water (m^3/ha)	--	--	3,596	7,609

Conclusion

Climate change in expected to negatively affect water resources in Egypt and worsen water scarcity situation already existed. Thus, we are forced to think about unconventional procedures to increase crops production, maintain irrigation water and conserve it to be used in cultivating new lands. These procedures need to be easy implemented by farmers, does not involve any extra cost and result in an increase in farmer's net revenue. Crop rotation and intercropping can help in solving food insecurity problem through increase land productivity. Furthermore, implementing crop rotation and intercropping can save a sum of irrigation water and increase water productivity. These saved irrigation water amounts can be use to cultivate new areas and reduce food insecurity.

The proposed sugarcane (autumn or spring) rotations can maintain soil fertility (legumes versus cereals), increase water productivity (an amount of water irrigate two crops) and increase land productivity (two crops harvested from the same area). As a result, farm income can increase and livelihood of the farmers can be improved.

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