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Sustainable intensive cropping to reduce irrigation-induced erosion: Changing cropping sequence under sprinkler irrigation practice: Changing cropping sequence under sprinkler irrigation practice

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The objective of this paper was to evaluate the effect of four crops sequence (one conventional and three suggested) on the applied irrigation amount, the resulted yield and soil nitrogen percentage as indicators of the existence of soil loss. These crops sequences were: farmer's crop sequence (FCS) and three crop sequences implemented using improved management practices (maize, clover then wheat (CS_1); cowpea, clover then wheat (CS_2) and cowpea intercropped with maize, clover then wheat (CS_3). The results indicated that the applied water for wheat was respectively reduced by 16, 18 and 19% in CS_1, CS_2 and CS_3 and yield was increased by 30, 55, and 43%, compared to the FCS. For maize, the applied water was reduced by 15% in CS_1 and CS_3 and yield was increased by 5 and 8%, respectively, compared to the FCS. The highest value of soil nitrogen percentage was obtained from cultivation of CS2, as a result of existence of cowpea and short season clover. In conclusion, optimizing the applied irrigation water to maize and wheat and increasing number of legume in the crop sequence can be one of the factors that improve soil water holding capacity and reduce soil loss.

INTRODUCTION

Sustainable crop production intensification provides opportunities for optimizing crop production per unit area. Irrigation is vital to food production, but soil erosion during irrigation threatens the long-term productivity of irrigation (Komissarov and Gabbasova, 2017). Furthermore, irrigated agriculture in most semiarid and arid soils have thin, erodible surface soil horizons, which make it prone to irrigation-induced erosion and to rapid productivity loss, if not well managed (Bjorneberg et al., 2008). Irrigation-induced erosion occurs as a result of application of high amount of irrigation water, which increase runoff (Sojka et al., 2007). Sprinkler systems are the most widely used in the world and is regarded as a favorable type of irrigation (Komissarov and Gabbasova, 2017), especially in low properties land. Ideally, the system is designed and managed to have all applied water infiltrate into the soil where it was applied, thus there is no runoff or soil erosion (King and Bjorneberg, 2010). However, sprinkler type, nozzle pressure and nozzle size influence runoff and soil erosion by affecting application rate, wetted area, and droplet size (Bjorneberg and Sojka, 2002). Increases of water application efficiency of sprinkler-irrigation system is considered the most effective way to control soil loss, where runoff is eliminated as well as erosion (King and Bjorneberg, 2011).

Inclusion of legumes as a cover crops to replace bare fallows summer crop and between winter crops cultivation is one of the suggested management practices that reduce soil erosion (Lal, 2015) and it can be used as nutrient supply (Thorup-Kristensen et al., 2003) and to mitigate nitrate leaching (Gabriel et al., 2012). Furthermore, integrating crop cover into common crop sequence presents an opportunity to increase soil carbon sequestration and organic matter in low organic matter soils (Poeplau and Don, 2015). Because biomass production is low in such soils, increasing soil organic content is particularly challenging. Legume crops cover play an important role by adding more atmospheric N2 through fixation where the available N limits C sequestration (García-González et al., 2018).

Another avenue to reduce runoff and erosion is intercropping, especially with legume crops (Dwivedi et al., 2015). In intercropping systems, one crop shares its life cycle or part of it with another crop (Eskandari et al., 2010), which improves soil fertility, increases land productivity and saves applied irrigation water (Kamel et al., 2010). Deep roots of legume crops penetrate far into the soil and use moisture and nutrients from deeper soil layers, whereas shallow roots of cereal crops fix the soil at the surface and thereby help to reduce erosion (Machado, 2009). Kariaga (2004) compared between cowpea intercropped with maize system and bean intercropped with maize system regarding soil erosion and found that cowpea preforms as best cover crop than bean reducing soil erosion. Furthermore, Hamd-Alla et al., (2014) indicated that cowpea intercropped with maize system has many advantages, for example it increased maize yield by 10% and reduced associated weeds. In low fertile soils, legume and cereal intercropping systems can increase soil fertility via raising its organic content and available nitrogen fixed by the legume (Megawer et al., 2010).

Maize and wheat are two important crops in Egypt. These two crops are successfully cultivated in sandy soils under sprinkler system. The productivity of these two crops is usually lower than its counterpart cultivated in clay soil of Egypt. This is due to the existence of low fertility levels and high water infiltration rate of this type of soil (Ouda et al., 2010). Furthermore, farmers practice regarding water and fertilizer application are characterized by excessive application, which inhibit the benefits of using these two production inputs (Taha, 2012). Thus, productivity of these two crops can be enhanced through using improved agricultural management practices that boost growth environment, reduce runoff and increase final yield. Furthermore, improper management of irrigation water under sprinkler system causes low application efficiency and increases runoff.

Thus, the objective of this paper was to evaluate the effect of four crops sequence (one conventional and three suggested) on the applied irrigation amount, the resulted yield and soil nitrogen percentage as indicators of the existence of soil loss in sandy soil under sprinkler irrigation system.

MATERIALS AND METHODS

Two field experiments were carried out at El-Minia Governorate (latitude= 28.05°, longitude= 30.44° and elevation above sea level= 40.0 m); Middle Egypt during the two growing seasons of 2015/16 and 2016/17 in a sandy soil under sprinkler irrigation. The aim of this investigation was to evaluate the effect of four crop sequences of maize and wheat on the applied irrigation water, yield and soil nitrogen content as indicators of soil loss. The first crop sequence is the conventional practice by the farmer (FCS) in the surrounding areas in cultivating maize and wheat, which includes low land leveling, fixed irrigation intervals, high applied amounts of water and low application efficiency, in addition to low fertilizer use efficiency. The other three suggested crop sequences implemented using improved management practices, namely precise land leveling, irrigation scheduling and fertigation in 80% of irrigation time. The three suggested crop sequences were maize, short season clover then wheat (CS1); cowpea, short season clover then wheat (CS2); and cowpea intercropped with maize, short season clover then wheat (CS3). The experimental design was complete blocks design with four replications. The size of a single experimental plot was 21 m2. The total soil N%, available P and K values were respectively 0.008%, 8.31 and 64.00 mg/kg, averaged over 60 cm depth. Soil chemical analysis was determined according to Jackson (1958). Physical and chemical analyses, as well as soil moisture constants, are presented in Table 1.

A solid-set sprinkler system was used. The rotary sprinkler (type Rc160) has 0.87 to 1.23 m3/hr discharge at 2.10 to 2.5 bars nozzle pressure, with spacing of 9 x 7 meters between laterals and sprinklers. A differential pressure tank was connected to the sprinkler irrigation system to inject fertilizer via irrigation water.

Reference evapotranspiration (ETo), crop evapotranspiration and irrigation amounts were determined using BISm model (Snyder et al., 2004).

Table 2 presents weather data and ETo values in both growing seasons in the studied site. There was no rain in El-Minia governorate either in winter or summer.

Farmer’s crop sequence (FCS)

In imitating farmer practices, land preparation was done by ploughing the land twice, where low leveling was applied. Irrigation water was applied every three days for maize and every four days for wheat. The farmer depends on his experience to decide the appropriate amount of irrigation water to apply in each irrigation event, which leads to applying large amount of irrigation water. The farmer broadcasts fertilizer on the ground before irrigation, which leads to fertilizer leaching.

Maize followed by wheat is the cultivated crops in the FCS sequence. Maize (SC130 hybrid) was sown on 12/5/2016 and 11/5/2017 in the first and second season, respectively using 27 kg of maize grains per hectare. Maize plants were harvested on 1/9/2016 and 25/8/2016 in the first and second season, respectively. Wheat (Sids12 cultivar) was sown on 15/11/2015 and 17/11/2016 in the first and second season, respectively. Wheat recommended planting density was applied using 144 kg grains per hectare. The wheat crop was harvested on 15/4/2016 and 11/4/2017 in the first and second season, respectively.

Suggested crop sequences

The suggested crop sequences were maize, short season clover then wheat (CS1), cowpea, short season clover then wheat (CS2) and cowpea intercropped with maize, short season clover then wheat (CS3). Land preparation was done by ploughing the land twice and proper land leveling was applied. Irrigation scheduling for the either wheat or maize grown under the suggested crop sequences was done using BISm model (Snyder et al., 2004). Fertigation was applied in 80% of irrigation time, which increase fertilizer use efficiency (Taha, 2012).

Sole or intercropped maize with cowpea were planted in the same dates as in FCS using 100% of the recommended density. Grains were sown on one side of narrow furrows (70 cm width), 25 cm distance between grains. Sole or intercropped cowpea (Cream cultivar) were sown in 11/5/2016 and 5/5/2017 in the first and second season, respectively using 60 or 30 kg of cowpea seeds per hectare for 100 or 50% of its recommended planting density. Sole cowpea was sown on one side of the narrow furrow (70 cm width), with 20 cm distance between seeds. First cut of cowpea was done on 11/7/2016 and 4/7/2017 in the first and second season, respectively. Second cut of cowpea was done on 20/8/2016 and 17/8/2017 in the first and second season, respectively. In cowpea intercropping with maize system, cowpea was sown on one side of the narrow furrow (70 cm width) and maize was planted on the other side with 50% and 100% of the recommended rate for cowpea and maize, respectively. No fertilizer was applied to cowpea under this intercropping system.

The recommended planting density of short season clover (Fahl cultivar), planted in 16/9/2016 and 11/9/2017 in the first and second season, respectively, was 60 kg of seeds per hectare. Harvest was done in 19/11/2016 and 14/11/2017 in the first and second season, respectively.

Applied fertilizers amounts

The recommendation of Ministry of Agriculture and Land Reclamation in Egypt was applied with respect to fertilizer for all the studied crops. Nitrogen fertilizer was added for maize (sole or intercropped) in the rate of 360 kg N/ha of ammonium nitrate (33.5% N), in five equal doses at 15, 25, 35, 45 and 55 days from planting. Maize was also fertilized with 74.4 kg P2O5/ha of calcium super phosphate (15.5% P2O5) and potassium sulphate (48.8% K2O) in the rate of 58.6 kg K2O/ha, both were applied during land preparation.

Nitrogen fertilizer was added for cowpea in the rate of 96 kg N/ha of ammonium nitrate (33.5% N) 15 days after planting, where the activity of nitrogen fixing bacteria in the soil was limited. In addition, 74.4 kg P2O5 ha-1 of calcium super phosphate (15.5% P2O5) was added during land preparation.

Nitrogen fertilizer was added for short season clover in the rate of 72 kg N/ha of ammonium nitrate (33.5% N), 20 days after planting as a result of low activity of the symbiosis bacteria in the soil. Calcium super phosphate (15.5% P2O5) was also added as 37.2 kg P2O5/ha during land preparation.

Nitrogen fertilizer was added for wheat as 288 kg N/ha in the form of ammonium nitrate (33.5% N) in five equal doses at 20, 40, 55, 70 and 85 days after planting. Phosphorus fertilizer was applied in the form of single super phosphate (15.5% P2O5) as 74.4 kg P2O5/ha and was incorporated into the soil during land preparation. Potassium in the form of potassium sulphate (48.8% K2O) as 58.6 kg K2O/ha was applied during land preparation.

For all the studied crops, seeds yield was recorded on the basis of experimental plot area by harvesting all plants, weighted it, and then all the plots were combined together as ton per ha. The biomass of all studied crops was removed from the field after harvest. Dry weight of cowpea and short season clover (ton/ha) were measured. In the second season, the experiment was implemented on the same area used for the first season.

Statistical analysis

The obtained data for each season were subjected to statistical analysis of complete randomized blocks design with four replications according to Gomez and Gomez (1984). Least Significant Differences (LSD) at 5 % levels of probability was used for comparing means.

RESULTS

pplied irrigation amounts for each crop sequence

Table 3 presents the amounts of applied water for the farmer practice and the three crop sequences. The results indicate that there were significant differences between either the applied water for maize or wheat in the farmer’s practice and the other three crop sequences. This result was observed in both growing seasons. Using the suggested crop sequences resulted in reduction of the applied irrigation water by 15% for maize when it was planted in CS1 and CS3, compared to FCS averaged over the two growing seasons. Similarly, water savings by 16, 18 and 19% for wheat in CS1, CS2 and CS3, respectively occurred, compared to FCS averaged over the two growing seasons.

Yield of the cultivated crops in each crop sequence

Table 4 indicated that there was no significant difference between the yield of maize under FCS and the suggested crop sequences. In the second growing, a significant difference was found in maize yield between the FCS and either the CS1 or the CS3. The results also showed an increase in maize yield by 5 and 8% for the previous crops sequences, compared to the FCS.

With respect to wheat yield, the results showed significant differences between wheat yields under the FCS and the suggested crop sequences in both growing seasons. Furthermore, wheat yield was increased by 30, 55, and 43% in the CS1, CS2 and CS3, respectively compared to its value in the FCS (Table 4).

The results in Table 4 also showed significant differences in the yield of short season clover in the CS1, CS2 and CS3 in both growing seasons. These differences could be attributed to the residual effect of the preceding crop in the crop sequence. In CS2, cowpea preceded short season clover resulted higher yield for short season clover. Moreover, the inclusion of short season clover in the CS1, CS2 and CS3 before wheat could result in improving soil quality.

Additionally, there was a significant difference between the yield of sole cowpea in CS2 and the
Additionally, there was a significant difference between the yield of sole cowpea in CS2 and the
intercropped cowpea in CS3, as a result lower plant density under intercropping system (Table 4). Inclusion of pure stand of cowpea in the CS2 resulted in more positive effect on soil fertility, compared to its effect when it is intercropped with maize, which is a soil exhausting crop.

Effect of the suggested crop sequences on soil nitrogen content

Table 5 presents soil nitrogen percentage after the cultivation of each crop in the FCS, CS1, CS2 and CS3 in the first growing season. Results indicated that cultivation of maize and wheat in the FCS resulted in 38 and 13% increase in soil nitrogen percentage, compared to the initial value as a result of application of the mineral nitrogen fertilizer. The results also indicated that high percentage of increase in soil nitrogen was obtained when short season clover was included in the suggested crop sequences. The highest value of soil nitrogen percentage was obtained from cultivation of CS2, as result of existence of cowpea and short season clover. The value of the increase in soil nitrogen percentage was 100 and 125% for cowpea and short season clover, respectively.

In the second growing season and under FCS, lower value of soil nitrogen percentage was obtained for maize, compared to the first growing season. However, lower value than the initial value of soil nitrogen percentage was recorded after wheat cultivation (Table 6).

In general, higher values of soil nitrogen percentage were observed in the second season due to the residual effect of legume crops in all the suggested crop sequences. The highest value of soil nitrogen percentage was found when cowpea and short season clover were cultivated in CS2, where its values were 138 and 150%, respectively (Table 6).

DISCUSSION

Improper management of irrigation water under sprinkler system in Egypt causes an increase in runoff and deep percolation, reduces yield and increases soil loss. In this investigation we applied improved management practices by implementing precise land leveling, irrigation scheduling and fertigation in 80% of irrigation time to three crop sequences with maize and wheat to reduce the applied irrigation water, to increase yield and to improve soil nitrogen percentage. We also compared the outcomes from implementing these crop sequences with the conventional farmer sequence of maize followed by wheat cultivated using low soil leveling, fixed irrigation intervals, high amount of irrigation water and low irrigation water application efficiency and low fertilizer use efficiency. Our results indicated that applying the improved management practices to the suggested crop sequences resulted in a reduction of the applied irrigation water to both maize and wheat and an increase in its yield, compared to farmer crop sequence. The reduction in the applied water can be partially attributred to irrigation scheduling. Tanner and Sinclair (1983) stated that the primary aim of irrigation scheduling is to minimize wasteful losses of water (percolation beyond what is necessary for salt leaching, surface runoff and evaporation) and maximize transpiration, which is the beneficial loss of water due to its direct link with dry matter production.

Furthermore, Taha (2012) indicated that using irrigation scheduling for maize and wheat resulted in 28 and 25% water saving compared to the amount applied by the farmer. The increase in the yield of maize and wheat under the suggested crop sequences could be attributed to the application of fertilizer through fertigation in the crop sequences, which minimizes fertilizer losses and increase fertilizer use efficiency, compared to farmer practices (Taha and Ouda 2016). In addition, Hamd-Allah et al., (2014) indicated that low productivity of wheat was obtained when maize continuously preceded it. Moreover, Sheha et al., (2014) reported that cultivation of short season clover before wheat increased its yield. In addition, McCallum et al., (2004) indicated that inclusion of legumes in a cropping sequence can improve soil porosity and structure for the benefit of the following crops.

Zohry (2005) reported that intercropping cowpea with maize resulted in yield increased by 10%, as a result of reduction in the associated weeds competing with maize plants. In addition, Hamd-Alla et al., (2014) stated that reduction in biological predators that attack maize plants was observed when cowpea was intercropped with maize. Gharnbari et al. (2010) indicated that in cowpea and maize intercropping system, an increase in the absorbed photosynthetically active radiation by cowpea occurred, which positively influence maize plants. Kariaga (2004) concluded that cowpea intercropping systems reduces runoff through maintaining ground cover, which results in reduction of soil erosion as well as reduction in water evaporation and improved conservation of soil moisture (Gharnbari et al., 2010).

Our results also showed that the pure stand of cowpea produced higher yield, compared to cowpea intercropped with maize as a result of higher plant density, in addition to the inter-specific competition between cowpea and maize under intercropping system (Dhar et al., 2013). Osborne et al. (2010) indicated that inclusion of a legume crop in the crops sequence influence specific microorganism populations in the rhizosphere. Furthermore, legume crops have the ability to facilitate the absorption of P and K in the soil by cereal crops, in addition to its role of providing N through N-fixing Rhizobium (Ferguson et al., 2013).

The results also indicated that high percentage of increase in soil nitrogen was obtained when short season clover was included in the suggested crop sequences. The highest value of soil nitrogen percentage was obtained from cultivation of CS2, as a result of existence of cowpea and short season clover.

In general, higher values of soil nitrogen percentage were observed in the second season due to the residual effect of legume crops in all the suggested crop sequences. These findings are supported by what was found by Dalal and Mayer (1986) and Liu et al., (2005) and what was found by Bado et al., (2006) who stated that N2-fixing legumes supply N to the subsequent crops through fallen senescent leaves and below ground parts, leading to an increase in succeeding crop yield. Hassan et al., (2010) indicated that legumes mobilize P in the soil during its growth, which increases P uptake of the following cereals. Whereas, Ferguson et al., (2013) indicated that legumes have the ability to remove calcium and magnesium from the soil more than cereals and replace it with hydrogen, which results in removing OH- ions and increases H+ thus lowering the soil pH.

CONCLUSION

The above results implied that using irrigation scheduling reduced the applied water to the studied crop sequences and maximized application efficiency, minimized runoff and percolation losses, which positively reflected on final yield of maize and wheat. Using fertigation resulted in increasing fertilizer use efficiency. Inclusion of legume crops in the cropping sequences facilitates the absorption of P and K in the soil by cereal crops, in addition to its role in providing N through N-fixing Rhizobium. Furthermore, legumes mobilize P in the soil during their growth, which increases

P uptake of the following cereals. Thus, all the above results implied that using irrigation scheduling resulted in reduction in soil losses. Although there was an increase in the total applied water per year, maintaining soil cover throughout the year with legume crop as in suggested crop sequences can diminish the harm effect of application of large irrigation amounts, compared to cultivation of maize and wheat only in FCS.

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