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Evaluation of intercropping sesame in different planting densities with peanut grown within orange trees under deficit irrigation

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A field experiment was carried out during 2018 and 2019 summer seasons to test the interaction effect between two deficit irrigation treatments (DI1=100% ETo, DI2=80% ETo), plus control (FI= 120% ETo) and three planting densities (PD) of intercropped sesame (CS1=20% PD, CS2=40% PD, CS3= 60% PD) with peanut (100% PD) interplanted within orange trees on land and water productivities, as well as on farmer's profit. The results showed that the highest peanut and orange yields were obtained under application of FI-CS1 and the highest yield of sesame and its components were obtained under application of FI-CS3. Irrigation with DI1 slightly reduced the yield of the three crops, whereas irrigation with DI2 highly reduced the yield of the three crops. The highest value of land equivalent ratio (LER), water equivalent ratio (WER), farmer's total return and monetary advantage index were obtained under application of FI-CS1, with slight reduction under DI1 and high reduction under DI2. This study recommends orange farmers to interplant the sesame-peanut intercropping system (CS1) within young orange trees for additive farmer profitability and increasing LER and WER under either irrigation with FI or DI1.

Keywords: Land equivalent ratio, water equivalent ratio, farmer return, monetary advantage index

INTRODUCTION

Intercropping is a systematic approach that makes full use of nutrients and water resources, in addition to achieving agricultural biodiversity, which significantly increases yield in comparison with monoculture cultivation (Qin et al., 2013). Said et al. (2016) indicated that an intercropping system refers to two crops sharing the area and the applied water to one of them, which increase land and water use efficiency. Additionally, intercropping with legumes is very important for the sustainable use of agricultural lands, where legumes fix nitrogen from the air via a symbiotic relationship with rhizobium bacteria and increase mineral soil nitrogen content (Gao et al., 2013).

The citrus trees occupy a large area of the cultivated land of Egypt, where the orange cultivated area in 2021 was about 139,000 hectares, with a total production of 3.2 million metric tons (Bulletin of the Agricultural Statistics, 2021). As a result of being a crop with high economic value, high orange production is important for local consumption and for export. Interplanting within orange trees is a common practice, where some growers utilize the spaces between trees to increase land productivity, as well as improve their income. Interplanting economic important crops, such as edible oil crops within orange trees is essential for the Egyptian population to increase the production of these crops and reduce its deficit. This practice is encouraged by the relatively large empty area between orange trees. As evergreen trees, only 30% of the area between trees can be interplanted if the trees are older than three years (Hefny et al., 2020). Several investigations have been done on interplanting legume crops under citrus trees in Egypt. Abdel-Aziz et al., (2008) showed that orange fruit yield was enhanced and fruit drop was decreased when a legume cover crop was interplanting within the trees. El-Mehy and El-Badawy (2017) showed that interplanting summer legume crops (30% of its recommended planting density) within orange trees (10-year-old) using 75% of the recommended NPK resulted in an increase in the yield of these summer legume crops, as well as orange yield and substituted for 25% of the recommended NPK. Selim et al. (2020) reported an increase in mandarin yield (3-year-old trees) when soybean was interplanted under it, which allowed the cultivation of 50% of soybean density between mandarin trees and that increased orange fruit yield by 10%. However, there was no research done on interplanting an intercropping system containing a legume crop under orange trees.

Sesame (Sesamum indicum L.) and peanut (Arachis hypogaea L.) are important oilseed crops in Egypt, where the gap between sesame production and consumption 38% and a surplus in peanut production by 46% (CAPMAS, 2018). Therefore, intercropping sesame with peanut can partially contributes in increasing sesame productivity and consequently its national production. However, few studies have been conducted on intercropping sesame with peanut in Egypt, where Toaima et al. (2004) reported an increase in the yield of sesame and peanut, when its intercropping pattern was 2:2. Whereas, Abou-Kerisha et al. (2008) intercropped sesame (67% of its recommended planting density) with peanut (100% of its recommended planting density) and that resulted in higher growth and yield of both crops, compared it the sole planting. Thus, the optimal intercropping system can reduce inter-specific competition between sesame and peanut plants, allowing their foliage to receive sufficient solar radiation, thereby increasing their final yield. Abou-Kerisha et al. (2008) found that peanut yield and its components were significantly increased by reducing sesame plant densities.

Deficit irrigation was defined by Capra et al. (2008) as “the application of irrigation below the full crop evapotranspiration, which potentially improve water use efficiency and maximize profits through a reduction in capital and operating costs”. Thus, it is a sustainable method for using water resources, aiming to improve crop growth and yield by applying water below the required amount (Chai et al., 2016). Under the prevailing water deficiency in Egypt, application of deficit irrigation can be a promising practice that conserve irrigation water, and in the meantime attains yield close the one obtained with application of full irrigation amount. The effect of application of deficit irrigation was studied for several intercropping systems in Egypt. However, only one study by El-Mehy et al. (2023) has assessed the effect of deficit irrigation on sesame intercropping system with peanut. They applied deficit irrigation to sesame intercropped with peanut and sprayed the plants with anti-transpirant substances to help the plants resist water stress damage. They found that applying deficit irrigation (100% ETo) and spraying with K-Si saved 17% of the applied water and produced higher yield of both crops than the obtained under irrigation with 120% ETo without spraying.

The objective of the current study was to take advantage of the area between young orange trees to intercrop sesame with peanut under deficit irrigation, in order to increase land and water productivity, as well as farmer’s profit.

MATERIALS AND METHODS

A field experiment was conducted in El-Kassaseen Agricultural Experiments Research Station, Agricultural Research Center, Ismailia Governorate (Lat. 30° 35’ 30” N, Long. 32° 14’ 50” E, 10 m a.s.l.), Egypt during 2018 and 2019 summer growing seasons to study the effect of application of deficit irrigation on intercropped sesame at different planting densities with peanut in a 3-year-old orange orchard.

The average monthly weather data at the experimental site during both growing seasons were obtained from the following website: https://power.larc.nasa.gov/data-access-viewer/site (Table 1). Data of monthly weather were used to calculate monthly averages of reference evapotranspiration (ETo) values using Basic Irrigation Scheduling model (BISm) according to Snyder et al., (2004). The model uses Penman-Monteith equation presented in the FAO Irrigation and Drainage Paper (Allen et al., 1998) to calculate ETo values.

The soil of the experimental site was sandy. The mechanical and chemical analyses on soil depth of 60 cm were done by Soils, Water and Environment Research Institute, Agricultural Research Center (Table 2).

The effect of three irrigation treatments (120% ETo (control, FI), and two deficit irrigation treatments (100% ETo (DI1) and 80% ETo (DI2)), and three sesame planting densities intercropped with peanut (20, 40 and 60% of the recommended planting density) were studied in a strip plot design with three replicates, in addition to sole planting of peanut, sesame and orange. The sole planting of these crop was used to calculate the competitive ratios and farmer’s gross income and were not included in the statistical analysis. The applied irrigation water treatments were randomly assigned to the vertical strips and cropping systems were allocated in the horizontal strips.

Each strip plot area of 48 m2 (8 x 6 m) contained the studied intercropping systems, in addition to orange trees. The orange trees were grown in 3 × 4 m apart (840 trees per hectare). In all cropping systems, five ridges of peanut were planted in the orange orchard outside any tree canopy with a distance of 130 cm between the intercropping system and orange trees. Sesame was intercropped on the same ridges of peanut depending on the studied sesame planting density. Under 20% of sesame planting density, only one ridge of the five ridges was intercropped with peanut. Whereas, under 40 and 60% of sesame planting density only two and three ridges of the five ridges, respectively were intercropped with sesame.

Peanut variety Giza6 and sesame variety Shandweel3 were sown on May 19th and May 14th in 2018 and 2019 summer seasons, respectively. Intercropped peanut and sesame were planted on ridges of 60 cm width. Peanut plants were thinned to one plant/hill at 10 cm apart, whereas sesame plants were thinned to two plants/hill at 20 cm apart under intercropping or sole culture. Sole peanut plants were sown on one side of the ridge at 10 cm apart and were thinned to one plant/hill. Sole sesame plants were sown on ridges at 20 cm apart and were thinned to two plants/hill.

Fertilizer application for peanut was as Mono calcium super phosphate (15.5% P2O5) at the rate of 476 kg/ha applied during land preparation for sole and intercropping systems. At sowing, all experimental units received 47.6 kg N/ha as booster dose of ammonium sulfate (20.6% N) and 119 kg/ha of potassium sulphate (50% K2O) for peanut in both sole and intercropping systems.

In the sole sesame, N as ammonium sulfate was applied at the rate of 142.8 kg/ha. For intercropped sesame, 20, 40, and 60% of the previous dose was applied. The N fertilizer was applied in three equal doses at 20, 35 and 50 days after sowing. Both N and K fertilizers were applied via irrigation water. Other agricultural practices were done as recommended by the Egyptian Ministry of Agriculture and Land Reclamation.

For orange, farmyard manure at the rate of 47.6 m3/ha, as well as calcium super phosphate (15.5% P2O5) at the rate of 36.9 kg P2O5/ha were added in the beginning of November as a common fertilizer practice done every year for orange. Phosphoric acid applied at the rate of 4 liter/ha every 15 days. Potassium fertilizer in the form of potassium sulfate (48% K2O) was added at the rate of 57.6 kg K2O/ha during land preparation. Nitrogen fertilizer as ammonium nitrate (33.5% N) was added in the rate of 288 kg N/ha at the rate of 12 kg/ha every week. The studied cultivar was Valencia (summer) orange and it was harvested on 14th and 18th of April respectively for 2018 and 2019 growing seasons.

Irrigation system

The used irrigation system was drip and established on both sides of the tree trunk at a distance of one meter. Each tree provided with two drippers (discharge 4 L/h) and the time of operation was 4 hours/day (32 L/tree/day) throughout the period of study. The studied crops have a separate irrigation network other than the one used for orange trees to prevent fertilizers mixing. Irrigation was done every 3 days. The required irrigation water for each crop, as well as water consumptive use were calculated using BISm model (Snyder et al., 2004).

The collected data

• Peanut: Soil samples were taken from rhizosphere of peanut at 60 days after peanut sowing to estimate total count of rhizobia (cfu/g soil) and available nitrogen content (mg/100 g soil). These analyses were done in General Organization for Agricultural Equalization Fund, ARC, Giza, Egypt.

• Leaf chlorophyll a and chlorophyll b (mg/l) contents were analyzed at 60 days after peanut sowing by General Organization for Agricultural Equalization Fund, ARC, Giza, Egypt. The leaves (blade only) of three plants were separated, dried in an oven set at 75o C until reaching constant mass (approximately 48 h), and weighed.

• At harvest, ten plants were randomly chosen from each plot and number of pods/plants, number of seeds/plants, seed yield/plant (g) and oil percentage in seeds were measured. Pod yield (ton/ha) was determined from measuring pods weight of each plot, then added them together.

• Sesame: At harvest, ten plants were randomly chosen from each plot and number of capsules/plants, 100-seed weight (g) and seed yield/plant (g). Seed yield (kg/ha) was determined from measuring pods weight of each plot, then adding them together.

• Orange: Fruit yield (ton/ha) was obtained at the harvest of orange trees.

Competitive relation

Land equivalent ratio (LER)

LER defines the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield (Mead and Willey, 1980). In our research, sesame intercropped with peanut interplanted within orange trees, thus there were three crops involved. Khasanah et al., (2020) indicated that the LER equation can be readily expanded for more than two components as follows:

LER = LERs + LERp + LERo (1)

Relative yield of sesame (LERs) = YIs/Ys (2)

Relative yield of peanut (LERp) = YIp/Yp (3)

Relative yield of orange (LERo) = YIo/Yo (4)

Where: Ys, Yp and Yo are the yields of, sesame, peanut and orange as sole crops, respectively, YIs, YIp and YIo are the yields of sesame, peanut and orange as intercrops, respectively.

If the LER > 1, it suggests that the land utilization of intercropping is higher than that of monoculture. If LER < 1, it shows that land utilization of intercropping is lower than that of monoculture.

Water equivalent ratio (WER)

WER was used to quantify the efficiency of water use by an interplanting system of each legume crop under orange trees. It is defined as the total water needed in sole crops to produce the equivalent amount of the species yields on a unit area of intercrop (Mao et al., 2012). WER was calculated for each crop interplanted under orange trees as follows:

WER = WERs + WERp + WERo (5)

(6)

Where: Yint,s, Yint,p and Yint,O are the yield of interplanted sesame, interplanted peanut and ora nge, respectively. WUint,s,WUint,p and WUint,O are water consumptive use interplanted sesame, interplanted peanut and orange. Ymono,s, Ymono,p and Ymono,O are the yield of mono sesame, peanut and orange, respectively. WUmono,s, WUmono,p and WUmono,O are water consumptive use by sesame, peanut and orange.

If the WER > 1, it suggests that the water utilization of interplanting is higher than that of monoculture and that imply advantage in implemented interplanting system. If WER < 1, it shows that water utilization of interplanting is lower than that of monoculture and that imply disadvantage.

Economic evaluation

Total return (TR)

TR is calculated by multiplying the yield with its unit price (USD). The price of each studied crop and orange fruits presented are market price in 2019. The prices were 1452, 1419 and 80 USD/ton for sesame, peanut and orange fruits, respectively (exchange rate is 1 USD =31 EGP).

Monetary advantage index (MAI)

MAI values are based on land equivalent ratio (LER). It provides clear information on the economic advantage of the interplanting system. The MAI was calculated as follows (Ghosh 2004):

MAI= [Value of combined intercrops x (LER–1)]/LER (7)

Statistical Analysis

Analysis of variance of the results of each season was performed. The measured variables were analyzed by ANOVA using MSTAT-C statistical package (Freed, 1991). Mean comparisons were performed using the least significant differences (LSD) test with a significance level of 5% (Snedecor and Cochran, 1988).

RESULTS AND DISCUSSION

Effect of applied irrigation water and peanut cropping system on total count of rhizobia, available nitrogen content and leaf chlorophyll

The results in table 3 indicated that all the studied traits were significantly affected by irrigation water treatments and cropping systems in both growing seasons. The highest values of the total count of rhizobia in the rhizosphere of peanut, and available soil nitrogen content were recorded when peanut received the full irrigation amounts (FI) and 20% of sesame intercropped with it (CS1). It was clear from the table that increasing sesame planting density negatively decreased these two traits, as well as applying both deficit irrigation treatments. The reduction in the total count of rhizobia in the rhizosphere of peanut, and available soil nitrogen content were low under DI1, namely 3 and 5%, respectively, compared to its value under FI. Moreover, the reduction was high under DI2, namely 7 and 15%, respectively compared to its value under FI.

Prudent et al., (2016) reported that low water availability in the soil negatively affect symbiotic N fixation, where its function is highly sensitive to water stress, and that consequently negatively affects soil available nitrogen. Similar results were obtained by Streeter (2003) in soybean, where a depression in N content in the leaves and pods of stressed soybean plants accompanied by a marked decline in N fixation activity during the water deficit period.

Furthermore, the values of chlorophyll a and b in peanut leaves were also the highest under the application of FI and it was reduced by the reduction in the applied irrigation water under deficit irrigation treatments. Arunyanark et al. (2008) reported a depression in leaf chlorophyll contents under water stress.

Effect applied irrigation water and peanut cropping system on peanut yield and its components

The results in table 4 showed that peanut yield and its components were significantly affected by cropping system and the interaction between irrigation treatments and peanut cropping systems. The highest values of peanut yield and its components were obtained under FI application and the lowest sesame planting density in CS1. It can be also noticed that the peanut pod yield was higher in the second season, compared to the first season as a result of peanut residual effect, as a legume crop, in the rhizosphere (Table 4). Kirihetti (2018) stated that an amount of fixed N returned to the soil as crop residue was observed after legumes cultivation.

Application of DI1 and implementing the three intercropping systems with peanut slightly reduce peanut yield and its components. This could be partially attributed to the role of peanut roots play in increasing soil nitrogen content through N fixation process, which is known to improve soil aggregate stability (Rücknagel et al., 2016), as well as water holding and infiltration (Wick et al., 2017). However, irrigation with DI2 and implementing the three intercropping systems with peanut highly reduce peanut yield and its components. The average peanut yield reductions under irrigation with DI2 were 18, 20 and 23% for CS1, CS2 and CS3, respectively over the two growing seasons. Thus, there is an opportunity to save irrigation water to the studied intercropping systems by application of DI1, which result in low yield losses in peanut yield in both growing seasons. These obtained results were supported by the findings of El-Mehy et al. (2023), where they reported a 16% reduction in peanut yield under irrigation with 80% ETo, compared to the value obtained under irrigation with 120% ETo.

The high values of peanut yield and its components under application of FI can be explain by the fact that water is essential to the turgidity of leaf cells, lengthening of stem cells, as well as photosynthesis process, as mentioned by Aydinsakir et al. (2016). They also stated that lower applied irrigation amount has negative effects on peanut yield components, such as number of pods, and seed weight per plant. Furthermore, Junjittakarn et al. (2014) reported that water deficiency negatively affects plant growth in peanut, which negatively affected seed formation and development, total seed yield.

The percentage of oil in peanut seeds was the highest under DI1 and was the lowest under DI2. Similar results were obtained by Gomaa et al. (2021), who stated that oil percentage recorded the highest values with irrigation after depletion of 40% of available soil water. Ouda et al., (2018) stated that the oil percentage in peanut seeds increased under irrigation with 100% ETo, compared to application of 120% ETo. Whereas Rathore et al., (2021) found that relative to full irrigation, irrigating peanut with amount of 60 and 50% ETc, significantly reduced oil content by 8–12%.

Effect of applied irrigation water and peanut cropping system on sesame yield and its components

All the obtained sesame yields and their components were significantly affected by irrigation treatments and peanut cropping systems. The highest values of sesame yield and its components were obtained under FI application and the highest sesame planting density in CS3 (Table 5). The results also showed that sesame yield was higher in the second season, which can be attributed to the decomposition of the peanut crop residues, and the release of growth-promoting substances that benefit the subsequent crop (Arcand et al., 2014).

Reducing the applied irrigation water from FI to DI1 and implementing the three intercropping systems of sesame with peanut slightly reduce sesame yield and its components (Table 5). This could be attributed to the low reduction in available soil nitrogen content under DI1 (Table 3) could have a positive effect in increasing the ability of sesame roots to withstand lower water application than the available under FI. The low reduction in sesame yield under its intercropping systems with peanut could encourage farmers to apply deficit irrigation. Nevertheless, the reduction in sesame yield and its components under irrigation with DI2 and implementing the three intercropping systems with peanut was high. The average sesame yield reductions under DI2 were 24, 24 and 26% for CS1, CS2 and CS3, respectively as an average over the two growing seasons, compared to application of FI. This result implied that CS3, which has the highest planting density, namely 100% peanut + 60% sesame, could compete with peanut more than the other studied cropping systems on water, which resulted in higher yield reduction under CS3 for both sesame and peanut (Table 5). It was reported that limited water supply to sesame adversely affects seed yield and its components (Ozkan and Kulak 2013). Furthermore, Pandey et al. (2021) reported a reduction in sesame yield by 28% in drought conditions.

Effect of applied irrigation water and peanut cropping systems on orange yield

The results in table 6 showed that orange yield was significantly affected by irrigation treatments in the second growing season only, by cropping systems in the first season only and by the interaction between irrigation treatments and cropping systems in both growing seasons. Table 6 also showed an increase in orange yield in the second growing season, compared to the value obtained in the first growing season, which implied that the residual effect of the interplanted cropping systems of sesame and peanut had a positive effect of orange trees and resulted in an increase in its yield in the second season. Similar results were obtained by Zohry et al. (2020), when they interplanted legume crops within orange trees.

The highest orange yield was obtained under application of FI to CS1. Orange yield was reduced under application of both deficit irrigation treatments, with higher percentage under application of DI2. The reduction in orange yield was 3 and 4% under DI1 and DI2, respectively. This low percentage of reduction in orange yield was due to the application of deficit irrigation treatments during the growing season of the intercropping system of sesame and peanut only. Whereas, in the rest of the growing season of orange, the required irrigation amount was applied to orange trees.

George and Jeruto (2010) indicated that intercropping under orange trees eliminate growth of weeds, which compete with orange trees on fertilizer and water.

Competitive relation

Land equivalent ratio (LER)

The results in table 7 indicated that the highest value of LER was found under application of FI to CS3 and interplanted within orange trees in both growing seasons, namely 2.27 and 2.33 in the first and second season, respectively. Hefny et al., (2020) obtained a value of LER of 2.13 when they interplanted an intercropping system of sunflower and watermelon within orange trees.

Application of DI1 for CS3 attained higher value of LER than the one obtained from application of FI to CS1 or CS2, namely 2.25 and 2.31 in the first and second season, respectively. The above results proved that this cropping system achieved yield advantages and attained efficient utilization of land resources by growing three crops in the same time. Furthermore, a noticeable reduction was found when DI2 was applied to the three studied cropping system in both growing seasons. Similar results were obtained by El-Mehy et al. (2023), where the values of LER of sesame intercropped with peanut were slightly reduced as the applied irrigation was reduce from 120% ETo to 100% ETo and it were highly reduced when the applied irrigation was reduced from 120% ETo to 80% ETo.

Water equivalent ratio (WER)

The values of WER in table 8 indicated that the highest value of WER was obtained when FI was applied to CS3 and interplanted within orange trees in both growing seasons, namely 2.27 and 2.31 in the first and second season, respectively. Furthermore, irrigation of CS3 with DI1 attained higher values of WER, than the obtained under application of FI to CS1 or CS2, namely 2.23 and 2.29 in the first and second season, respectively. These results implied more efficient use of irrigation water under application of DI1, compared to application of FI, which implied an opportunity to save irrigation water by applying DI1 in both growing seasons. Application of DI2 highly reduced the values of WER in both growing seasons.

El-Mehy et al. (2023) reported higher values of WER under irrigation with 120% ETo and lower values of WER under irrigation with 80% ETo when sesame was intercropped with peanut.

Economic evaluation

The results in table 9 showed that the highest farmer’s total return (TR) can be obtained by application of FI to CS1 interplanted within orange trees, followed by application of DI1 to CS1 in both growing seasons, where TR was reduced by only 1% in both growing seasons. Furthermore, the application of DI2 to the three studied cropping systems highly reduced TR.

Similar trend was obtained for monetary advantage index (MAI), where application of FI to CS1 interplanted within orange trees attained the highest values of MAI, followed by application of DI1 to CS1in both growing seasons, where MAI was reduced by only 2% in both growing seasons. Whereas, MAI values were highly reduced under the application of DI2 to the three studied cropping systems. Similar trend was obtained by El-Mehy et al. (2023), where application of 80% ETo highly reduced the values of TR and MAI, compared to application of 120% ETo to sesame intercropped with peanut.

CONCLUSION

Under the prevailing water deficiency in Egypt, application of deficit irrigation can be a promising practice that conserve the applied irrigation water, and in the meantime attains yield close the one obtained with application of full irrigation amount. The current study recommends farmers to interplant the sesame-peanut intercropping system (20% sesame + 100% peanut) with the young orange trees and irrigate it with either 120% ETo or 100% ETo for additive farmer profitability and increasing land and water productivities.

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