Moroccan Journal of Agricultural Sciences
Vol 2 No 4 (2021): (December 2021), 182-193
Crop Production and Environment

Decreasing maize production-consumption gap by intercropping with upland rice using different planting densities under deficit irrigation

Ahmed M. SHEHA — Crop Intensification Research Department, Field Crops Research Institute, Agricultural Research Centre, Egypt
Ashraf S. M. ABD EL-LATTEF — Rice Research Department, Field Crops Research Institute, Agricultural Research Centre, Egypt
Samiha OUDA — Water Requirements and Field Irrigation Research Department, Soils, Water and Environment Research Institute, Agricultural Research Center, Egypt

A two-year field experiment was conducted in 2018 and 2019 at Gemmiza Agricultural Research Station (Lat. 31.03° N, Long. 30.88° E, 8 m a.s.l.); Gharbia Governorate; Egypt. The aim was to use untraditional sowing method to intercrop maize with upland rice using three maize planting densities (25, 37.5 and 50% of its recommended density) and application of two deficit irrigation treatments (irrigation every 9 and 12 days), in addition to irrigation every 6 days (control) and to study its effect on the yield of both intercrops, competitive relationships and farmer's income. The results indicated that the highest value of rice yield and its components were found under irrigation every 6 days and 25% maize planting density intercropped with rice. Whereas, the highest value of maize yield and its components were found under irrigation every 9 days and 50% maize planting density intercropped with rice, which also obtained the highest land and water equivalent ratios, area time equivalent ratio, and land equivalent coefficient. Furthermore, the highest total income and monetary advantage index were obtained under irrigation every 9 days and 50% maize planting density intercropped with rice. Thus, these results implied that intercropping maize with upland rice can solve part of the maize production-consumption gap through increasing its production without using additional lands or water.

Keywords: Land and water equivalent ratios, percentage of land saved, area time equivalent ratio, land equivalent coefficient, monetary advantage index, Rice, Maize, Egypt

Introduction

Maize is an important crop for both food and feed. It is an important component of global food security due to its genetic and management practice changes that helped in increasing its yield over the last century (Costa et al., 2017). In Egypt, maize in the main cultivated summer crop with large cultivated area, namely 895,065 hectares in 2019, with mean productivity of 7.78 ton/ha and total national production of 6,963,606 ton (Ministry of Agriculture and Land Reclamation, 2019). However, there is still a gap between maize production and consumption in Egypt estimated at around 45%. This gap can be diminished by intercropping maize with other crops to increase its cultivated area and its production. Therefore, it is important to assess the effect of different maize intercropping systems with other crops on its productivity and feasibility.

Intercropping is a planting system involving cultivation of two crops (main and secondary) to attain better use intercepted light, it permits root contact with more soil, increase microbial activity, reduce pests and weeds and increase the yield of these crops (Hauggaard-Nielsen et al., 2006).

Intercropping is playing a role in altering the microclimate of the intercrops by changing the pattern of dispersal through wind, and rain (Zang et al., 2015). Furthermore, successful intercropping system directly depends on proper farm management, namely spatial arrangement of crops and planting density to reduce the competition for resources and increase the efficiency of the system (Porto et al., 2011), and that usually leads to increasing productivity of the intercrops, when compared to monoculture (Batista et al., 2016). It was documented that implementing intercropping systems can attain water saving and increase water use efficiency (Yang et al., 2011; Lithourgidis, 2011; Coll et al, 2012; Hu et al., 2015). Several successful intercropping system with maize have been implemented in Egypt, for example maize intercropped with tomato (Mohamed et al., 2013) and maize intercropped with peanut (Sherif et al., 2005), maize intercropped with soybean (Sherif and Gendy, 2012).

Paddy rice is the main competitor for maize in the Egyptian cropping pattern. Paddy rice is a semi aquatic crop that requires high irrigation amount for proper growth and development and consequently its water use efficiency is low. The cultivated area of paddy rice in Egypt is 543,148 hectares with mean productivity of 8.83 ton/ha with total production of 4,795,997 ton (Ministry of Agriculture and Land Reclamation, 2019). Egypt is self-sufficient with respect to paddy rice and have a surplus to export every year. Nevertheless, due to water shortage in Egypt, there is a remarkable success in breeding new upland rice cultivars requiring less irrigation water amounts than paddy rice cultivars (Gaballah et al., 2020). Furthermore, there are large efforts for expanding the cultivation of the upland rice cultivars released in Egypt to replace the paddy rice cultivars and to conserve water. Another way could be used to attain water saving in rice cultivation by either prolonging irrigation intervals without causing high grain yield losses or growing water-stress tolerant cultivars (Mady, 2004).

Leng and Hall (2019) reported that the upland rice cultivars are able to grow without standing water in aerobic soils thus make irrigation of upland rice similar to wheat or maize. This feature could allow rice to be a candidate in an intercropping system as a main crop. Intercropping maize with upland rice was recently studied worldwide (Ali et al., 2009; Kombiok et al., 2011; Dewi et al. ,2014; Iwuagwu et al., 2019). However, in Egypt, there was only one research paper published on this subject by Abou-Elela (2013). The author studied the effect of three irrigation intervals and planting distribution of maize on the yield of both crops. He concluded that land equivalent ratio was 1.3 averaged over the two growing seasons, which implied the advantage of this intercropping system. However, the effect of deficit irrigation on the maize and rice intercropping system and the efficiency of water utilization by the system was not studied.

In Egypt, the current situation of water shortage encourages the use of deficit irrigation in irrigated crops. Deficit irrigation practice is considered as a key contributor to water saving technology on field level. Deficit irrigation is defined by Chai et al., (2016) as “an irrigation practice characterized by application of irrigation water below the full required amounts for optimal growth and yield, aiming at improving the response of plants to the certain degree of water deficit in a positive manner, and improving crop’s water use efficiency”. Application of deficit irrigation during the whole growing season was found to cause lower yield losses (Sofo et al., 2012). A comparison was made between maize yield from deficit irrigation applied during the vegetative stage and deficit irrigation applied during the whole growing season revealed that yield loss was increased by 10-20% in the first case, compared to the second case (Domínguez et al., 2012). Furthermore, effect of water deficiency on upland rice have been extensively studied worldwide (Bouman et al., 2005 and 2006; Kato et al., 2006a and b; Kato et al., 2007; Akinbile, 2010; Crusciol et al., 2013; Dingkuhn et al., 2015). Yet, there was no research done in Egypt on the response of the yield of upland rice to application of deficit irrigation.

The objective of this investigation is to use untraditional sowing method to intercropped maize with upland rice using three maize planting densities and application of two deficit irrigation treatments, as well as to study its effect on the yield of both crops, competitive relationships and farmer’s income.

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Materials and Methods

A two-year field experiment was conducted during the summer seasons of 2018 and 2019 at Gemmiza Agricultural Research Station (Lat. 31.03° N, Long. 30.88° E, 8 m a.s.l.), Gharbia Governorate, Agricultural Research Center, Egypt. The aim of this investigation was to use untraditional sowing method to intercrop maize with upland rice using three maize planting densities and application of two deficit irrigation treatments and study its effect on maize and rice yield, land and water equivalent ratios and farmer’s return.

The daily meteorological data of the experimental site in 2018 and 2019 were obtained from the following website: https://power.larc.nasa.gov/data-access-viewer/. The values of the weather elements were averaged and presented in Table 1. These data were used to calculate monthly reference evapotranspiration (ETo) values using Penman-Monteith equation, as presented in the United Nations FAO Irrigation and Drainage Paper by Allen et al. (1998). This equation is included in Basic Irrigation Scheduling model (BISm, Snyder et al., 2004).

Chemical and physical soil analyses of the experimental site before sowing were conducted by the standard method of Page et al., (1982) and Tan (1996) as shown in Table 2 and 3.

Strip plot design with three replicates was used, where irrigation water intervals were randomly assigned to the vertical strips and intercropping systems were allocated to the horizontal strips. Each strip plot area was 44.0 m2 (5 m X 8.8 m).

The studied treatments were:

Irrigation treatments

• Irrigation every 6 days (FI, full irrigation of rice)

• Irrigation every 9 days (DF1, deficit irrigation of rice)

• Irrigation every 12 days (DF2, deficit irrigation of rice)

Intercropping systems

• Maize (25% planting density) intercropped with upland rice (80% planting density, Figure 1A)

• Maize (37.5% planting density) intercropped with upland rice (80% planting density, Figure 1B)

• Maize (50% planting density) intercropped with upland rice (80% planting density, Figure 1C)

In addition, sole upland rice and sole maize (100% planting density) were cultivated for comparison purposes and were not included in the statistical analysis.

Land preparation

Untraditional sowing method, different from the farmer method in the surrounding areas, was used in this investigation. Land ploughing was done twice, then the land was divided to plots. The area of each plot was 44.0 m2 (5 m x 8.8 m). It was divided into three sunken seed beds (2.0 m width and 5.0 m length) for upland rice cultivation. Each sunken seed bed was separated by ridges (0.7 m width, 5.0 m length, and 0.3 height) for maize cultivation (Figure 1). This method was developed by the first author of this investigation (Sheha sowing method), where irrigation was applied directly to rice and maize take its required water through seepage of the applied water to rice. This method is different than the farmer method, where farmers sow dry rice seeds in the nursery, and after one month rice seedlings transplanted to the field on ridges.

During land preparation, potassium sulfate (48% K2O) was applied in the rate of 60 kg/ha.

Upland rice cultivation

Intercropped (80% of recommended planting density) and sole (100% of recommended planting density) upland rice cultivar Giza179 was sown in dry soil after soaking in water for 24 hours, in 23rd of May in both growing seasons (25 plant/m2). Calcium super phosphate (15.5% P2O5) was applied at a rate of 480 kg/ha during land preparation for either sole or intercropped upland rice. For intercropped rice, nitrogen fertilizer was added in the form of ammonium nitrate (33.5% N), with the rate of 153.6 kg N/ha in three equal doses, added 14, 24 and 45 days after sowing, respectively. For sole rice, 192.0 kg N/ha in three doses was applied in the same dates as in intercropped rice. For both sole and intercropped rice, 60 kg/ha of potassium sulfate (48% K2O) was applied 60 days after planting.

Harvest was done 29/9/2018 and 30/9/2019 in the first and second season, respectively. Ten individual plants of upland rice were taken from each experimental plot. Plant height (cm), number of panicle per plant, number of grain per panicle, 100-grain weight (g), sterility percentage (%), and grain weight per plant (g), amylose content (%) were measured. The yield of each plot was harvested, weight and added together to measure grain yield (ton/ha).

Maize cultivation

Intercropped and sole maize hybrid TWC 360 (yellow) was sown in the same days as in upland rice in both seasons. For interplanted maize, three planting densities were studied, namely 25% of its recommended planting density, planted on the ridges in hills with 50 cm between them (one plant/hill in both sides), 37.5% of its recommended planting density, planted with 35 cm between them (one plant/hill in both sides) and 50% of its recommended planting density, planted with 25 cm between them (one plant/hill in both sides). For sole maize, it was planted according to the recommended planting density.

For intercropped maize, nitrogen fertilizer was added in the form of ammonium nitrate (33.5% N), with the rate of 72.0, 108 and 144 kg N/ha for 25, 37.5 and 50% maize planting density, respectively in three equal doses added 14, 24 and 45 days after sowing, respectively. For sole maize, 288 kg N/ha in three equal doses was applied in the same dates as in intercropped maize.

Harvest was done in the first of September in both seasons. At harvest, ten individual plants were taken from each experimental plot and the following characters were measured: plant height (cm), ear height (cm), ear leaf are (cm), ear length (cm), number of grains per ear, weight of grain per ear (g), 100-seed weight. The yield of each plot was harvested, weight and added together to measure grain yield (ton/ha).

Competitive relationships

Land equivalent ratio (LER): LER is 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). LER is calculated for each of the maize intercropped with rice as follows:

LER = (YMR/YMM) + (YRM/YRR)

Where: YMR and MRM= intercropped maize yield and intercropped rice yield, respectively, YMM, YRR= Pure stand yield of sole maize and rice, respectively.

Area Time Equivalent Ratio (ATER): ATER provides more realistic comparison of the yield advantage of intercropping over solid cropping than LER in terms of time taken by component crops in the intercropping systems. ATER was calculated by formula developed by Hiebsch (1980):

ATER = [(RYM X TM) + (RYR X TR)]/T

Where: RYM = relative yield of maize crop in mixture, TM = duration (in days) of maize crop, RYR = relative yield of rice in mixture, TR = duration (in days) of rice, T = total duration of the intercropping system in days.

When ATER value is larger than 1.0, it implies yield advantage. If ATER value is equal to 1.0, it implies no effect of intercropping, whereas, if ATER value is lower than 1.0, yield disadvantages exist.

Land equivalent coefficient (LEC): LEC is a measure of interaction concerned with the strength of relationship and was calculated according to Adetiloye et al. (1983) as following:

LEC = LM x LR

Where: LM = relative yield of maize and LR = relative yield of rice.

Percentage of land saved (LS, %): It indicates that lands saved from intercropping that could be used for other agricultural purposes. It was calculated according to Willey (1985) as followed:

LS (%) = 100 - (1/LER) X 100

Competitive ratio (CR): CR is an index which gives a more desirable competitive ability for the crops and also is more advantageous (Dhima et al., 2007). The CR is calculated according to the following formula:

CRM = (LERM / LERR)(ZRM /ZMR)

CRR = (LERR / LERM)(ZMR /ZRM)

Where: LERM = (YMR/YMM), LERR = (YRM/YRR)

If CRM < 1, there is negative benefit and the crop can be grown in association. If CRM > 1, there is negative benefit. The reverse is true for CRR.

Aggressivity (A): Aggressivity is another index represents a simple measure of how much the relative yield increase in crop (maize) is greater than that of crop (rice) in an intercropping system. Aggressivity values were determined according to Mc-Gilchrist (1965):

AMR= [YMR/(YMM X ZMR)] [YRM/(YRR X ZRM)]

ARM= [YRM/(YRR X ZRM)] [YMR/(YMM X ZMR)]

Where: AMR and ARM =aggressivity value for maize and rice, respectively. ZMR =sown proportion of maize (in mixture with rice). ZRM =sown proportion of rice (in mixture with maize).

If AMR = 0, both crops are equally competitive, if AMR is positive, maize is dominant, if AMR is negative then is dominated crop.

Relative crowding coefficient (RCC): RCC estimates the relative dominance of one species over the other in the intercropping system (De Wit, 1960). It was calculated as follows:

K = KM X KR

KM = YMR X ZRM / [(YMM – YMR) X ZMR]

KR = YRM X ZMR / [(YRR – YRM) X ZRM]

Where, YMM = pure stand yield of maize, YRR = pure stand yield of rice, YMR = intercrop yield of maize; YRM = intercrop yield of rice; ZRM = the respective proportion of maize in the intercropping system; ZRM = the respective proportion of rice in the intercropping system.

Economic evaluation

Total income (TI, USD per ha)

TI is calculated by multiplying the yield with its unit price (USD). The price of each studied maize and rice presented by market price in 2018 and 2019 were used. The prices are as follows: maize and rice are 212.4 and 285.9 USD/ton, respectively.

Monetary advantage index (MAI, USD per ha)

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

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

Crop water relation

Surface irrigation was the irrigation system used in this study. Irrigation was applied using cutthroat flume. Evapotranspiration (ETo) values in the studied growing seasons were calculated using Pennman-Montieth equation (Allen et al., 1998) included in BISm model (Snyder et al., 2004).

Applied irrigation water

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

Where: AIW= depth of applied irrigation water (mm), ETo= reference evapotranspiration (mm/day), I= irrigation intervals (days), Ea= irrigation application efficiency of the irrigation system (60%), LR= leaching requirements (equal 1.0).

Water consumptive use (WCU)

Soil samples were collected two days before and after each irrigation treatment from three successive layers (20 cm each) to determine soil moisture content. Water consumptive use was estimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

Where: WCU = water consumptive use (mm), i= number of soil layer, θ2= soil moisture content after irrigation (%, by mass), θ1= soil moisture content just before irrigation (%, by mass), Bd= soil bulk density, (g/cm3), d= depth of soil layer (mm).

Water equivalent ratio (WER)

The water equivalent ratio is used to quantify system level water use efficiency (Mao et al., 2012). The WER is defined by determining the total water use that is needed in sole crops to produce the equivalent of the species yields on a unit area of intercrop with the associated water use as follows:

Where: Yint,m and Yint,r are the yield of intercropped maize and rice, respectively. WUint is water consumptive use by the intercropped crops. Ymono,m and Ymono,r are the yield of mono maize and rice, respectively. WUmono,m and WUmono,r are water consumptive use by mono maize and rice, respectively. When WER is higher than 1.0, it implies advantage of the intercropping system.

Statistical analysis

The data were statistically treated using the analysis of variance (ANOVA) for randomized complete block design and the least significant difference (LSD) according to Freed (1991) was used for mean separation ($P \leq 0.05$).

Results and Discussion

Rice crop

The results in table 4 clearly showed that all upland rice yield components were significantly affected by irrigation intervals ($P \leq 0.05$), intercropping systems between maize and upland rice ($P \leq 0.05$) and the interaction between them ($P \leq 0.05$). Furthermore, the means of rice yield components from irrigation intervals, intercropping systems between maize and upland rice and the interaction between them were significantly different. These results were true in both studied seasons. The highest values of the rice yield components were found for irrigation every 6 days and 25% maize planting densities intercropped with rice. Whereas, the lowest values of the studied rice components were found for irrigation every 12 days and 50% maize planting densities intercropped with rice (Table 4).

Application of irrigation every 12 days to upland rice induced water stress and negatively affected the studied yield attributes (Table 4). In this context, Bassiouni (2018) indicated that increasing irrigation interval from 6 days to 9 days reduce paddy rice plant height by 20%. Furthermore, El-Sayed and Abd El-Monem (2017) stated that 85% soil moisture depletion from the available water reduced number of grains/panicle in paddy rice by 19%, compared to 30% soil moisture depletion from the available water. Darwesh et al. (2016) reported that plant height was reduced by 5% and 1000-grain weight of paddy rice was reduced by 24% when irrigation interval was increased from 6 to 12 days.

Table 5 showed that all upland rice yield and its components were significantly affected by irrigation intervals ($P \leq 0.05$) in both seasons, except amylose content in the first season. Furthermore, rice yield and its components were significantly affected by intercropping systems between maize and upland rice ($P \leq 0.05$) and the interaction between them ($P \leq 0.05$), except amylose content in both season. The means of rice yield and its components resulted from irrigation intervals, intercropping systems between maize and upland rice and the interaction between them were mostly significantly different, which were true in both seasons.

Lower values of rice yield and its components were found in table 5 as a results of increasing irrigation intervals from 6 days to 12 days. Similar results were obtained by Darwesh et al. (2016), where they stated that sterility percentage was increased by 264% in paddy rice and its grain yield was reduced by 29% under irrigation every 12 days, compared to irrigation every 6 days. Bassiouni (2018) indicated that increasing irrigation interval from 6 days to 9 days reduce the yield of paddy rice by 55%. Furthermore, El-Sayed and Abd El-Monem (2017) stated that 85% soil moisture depletion from the available water reduced paddy rice yield by 64%, compared to 30% soil moisture depletion from the available water.

The highest values of rice yield and its components were found for irrigation every 6 days and 25% maize planting density intercropped with rice, namely 10.6 and 10.0 ton/ha where rice yield was higher by 113 and 71% in the first and second seasons, respectively, compared to the values obtained under irrigation every 12 days and 50% maize planting density intercropped with rice. The lowest values of rice yield and its components were found for irrigation every 12 days and 50% maize planting density intercropped with rice, where rice yield was reduced by 34 and 31% in the first and second seasons, respectively, compared to the yield obtained under irrigation every 6 days and 25% maize planting density intercropped with rice (Table 5).

It is worth noting that rice planting density under intercropping was 80% of its recommended density, whereas the planting density of sole rice was 100% and its yield was 10.8 and 10.3 ton/ha in the first and second season, respectively. Thus, the highest value of intercropped rice yield was lower by 2 and 3% than its value under solid cultivation (Table 5).

The high yield of rice under its intercropping system with maize is attributed to several factors. The superiority of rice yield under intercropping with maize over the solid cultivated rice yield can be attributed to reduction in disease severity index under intercropping as stated by Iwuagwu et al. (2019). Furthermore, Riyanto et al. (2021) indicated that intercropping maize with upland rice resulted in an increase in soil organic carbon content, available P, and available K, compared to sole rice or maize cultivation. The increase in soil organic carbon can be attributed to crops residues or roots in soil after harvest, which indirectly increase soil organic matter content (Huang, 2003). Both P and K affect the growth and development of rice through different physiological and metabolic processes. P participates in the formation of cellular membranes and in various metabolic processes, and promotes rice growth and physiological metabolism (Plaxton and Tran, 2011). Bi et al. (2014) indicated that application of P fertilizer not only increased the rice yield, but also improved yield stability. Furthermore, Fageria et al. (2003) reported that P is responsible for the development of root, early flowering and tolerance to specific biotic and abiotic stresses in rice, whereas its deficiency delays maturity and increase vulnerability to diseases.

Furthermore, K is an activator of various enzymes and involves in the intracellular osmotic regulation and membrane protein transport. Consequently, it plays an important role in carbohydrate transport in rice and is beneficial for the plant metabolism and stress resistance (Nieves-Cordones et al., 2019). Rice plants absorb K in larger quantities than nitrogen for proper function of various activities (Sharma et al., 2013).

Maize crop

The results in table 6 indicated that all the studied maize yield components were significantly affected by irrigation intervals ($P \leq 0.05$), except plant height in the second season. Furthermore, both intercropping systems between maize and upland rice ($P \leq 0.05$) and the interaction between them significantly ($P \leq 0.05$) affected the studied maize yield components. Additionally, the means of maize yield components resulted from irrigation intervals, intercropping systems between maize and upland rice and the interaction between them were significantly different. These results were true in both studied seasons.

The applied irrigation amount every 6 days to maize intercropped with upland rice was relatively high to negatively affect the studied maize yield attributes. Irrigating maize every 6 days increased available soil moisture in the rhizosphere in a way to cause waterlogging. Tian et al. (2019) indicated that this condition resulted in decrease of stomatal conductance and intercellular CO2 concentration, which caused a decrease in photosynthesis and dry matter accumulation in the plants and consequently yield. Furthermore, waterlogging causes oxygen deficiency in the soil, which inhibits root respiration, that also negatively affected the rate of photosynthesis and CO2 assimilation (Arbona et al., 2008).

Whereas, the highest values of the studied maize attributes under its intercropping system with upland rice were found when irrigation was applied every 9 days (Table 6), which implied that maize is relatively responsive to application of higher irrigation amounts than every 6 days. This assumption was supported with the findings of Meleha (2006) and Megyes et al. (2005) where they indicated that maize is considered one of the most efficient field crops in producing higher dry matter per unit of applied irrigation water, without causing waterlogging. El-Sobky and Desoky (2017) reported that maize growth was increased by the application of adequate water irrigation every 10 days, compared to irrigation every 16 days. Furthermore, these high values of maize yield components could be attributed to increasing the availability and the uptake of N, P and K under higher soil moisture content. Ibrahim and Kandil (2007) indicated that maize growth was increased as a result of increasing solubility and mobility of these elements.

Similar results were obtained by Rekaby et al. (2017) and Hammad and Ali (2014), who reported that application of the required irrigation to maize increased plant height by 5% than its value under application of deficit irrigation. Abu-Grab et al. (2019) indicated that increasing available soil moisture content increased plant height, ear height and ear length by 2, 6 and 2%, compared to its value under lower soil moisture content.

Moreover, the results in Table 7 indicated that all the studied maize yield and its components were significantly affected by irrigation intervals ($P \leq 0.05$), except grain weight per ear in the second season. Furthermore, maize intercropped with upland rice systems, as well as interaction between irrigation intervals and maize intercropping systems with upland rice significantly affected all the studied maize yield and its components ($P \leq 0.05$).

The lowest values of maize yield and its components were found under irrigation every 6 days. Tian et al. (2019) indicated that increasing soil moisture in the rhizosphere causes waterlogging and that resulted in high yield reduction in maize. The highest maize yield components were obtained under irrigation every 9 days and 50% of maize planting density intercropped with upland rice, namely 8.07 and 7.78 ton/ha in the first and second season, respectively, which was lower than maize solid yield (100% planting density) by 16 and 19% in the first and second season, respectively as a result of 50% planting density of maize under its intercropping system with upland rice (Table 7).

Abu-Grab et al. (2019) indicated that increasing available soil moisture content increased number of grain per ear, 100-grain weight and maize yield by 10, 15 and 29%, respectively, compared to application of deficit irrigation. Ali and Abdelaal (2020) reported that number of maize grain per ear, grain weight per ear, 100-grain weight and maize yield was reduced by 22, 26, 11, 29%, respectively when irrigation intervals was increased from 12 days to 22 days. Abo El-Ezz and Haffez (2019) indicated that the productivity of maize was increased by the application of adequate water irrigation every 10 days.

Although both maize and rice are cereal crops, which are soil exhausting crops contributes in depleting soil nutrients, our results showed high values of both crops relative to its population density. This result could be attributed to the fact that intercropping a C3 crop (rice) with a C4 crop (maize) can attain several advantages. Collins et al. (2017) reported that in an intercropping system, sometimes, the total plant population exceeds the population of the base crop in the pure stand, which facilitate more plants exploit the available resources. Thus, it allows more biomass to be produced due to more assimilated production by the intercrops together. Additionally, intercropping a C3 crop with a C4 crop will have different type of CO2 acquisition and fixation. Li et al. (2012) indicated that C4 have more efficient use of solar energy, cause an increase in its biomass with higher light intensity. Furthermore, the increase of both biomass and CO2 fixation with higher CO2 concentration in C4 are faster than that in C3, which reflect more efficient use of CO2 in C4 plants (Wang et al., 2012). Thus, in this way, more quantity of greenhouse gas (CO2) is used in photosynthesis and biomass production under intercropping of C3 and C4 plants could increase. In addition, Wu et al. (2012) stated that the taller species in an intercropping system, such as maize, could change the light and heat environment of a shorter shade-tolerant species. Wang et al. (2015) stated that rice plants are characterize by having high shading tolerance ability related to high light using efficiency reflected by high grain filling rate during grain filling period.

The high yield of both maize and upland rice under intercropping system could be also a result of uncompetitive underground relationship, where the average rooting depth of maize can reach 1.58 m, whereas for the average rooting depth of upland rice can reach 1.15 m (Araki et al., 2000). Machado (2009) indicated that deeper roots can penetrate far into the soil and use moisture and nutrients from deeper soil layers. Lynch (2011) stated that maize plants have shallow root growth angles of axial roots, which enhance topsoil foraging and thereby P acquisition. Grant et al. (2001) reported that early-season P nutrition in maize results in increasing dry matter partitioning to the grain at later development stages. Additionally, the increase in both yields of maize and rice may be also a result of increase in the content of iron (Fe) in the rhizosphere by maize plants as it was reported by Xiong et al. (2013) in peanut–maize intercropping system, where Fe enhanced the carbon and nitrogen metabolism and photosynthetic efficiency of the peanut crop as well as the resistance of both crops against various environmental stresses.

Competitive relations

The results in table 8 indicated that the highest land equivalent ratio (LER), area time equivalent ratio (ATER) and land equivalent coefficient (LEC) were obtained under 9 days irrigation interval and 50% of maize planting density intercropped with upland rice, namely 1.52, 1.32 and 0.58 for LER, ATER and LEC, respectively averaged over the two growing seasons. This result can be attributed to the highest value of maize yield under this system. Similar results were obtained by Abou-Elela (2013) who stated that irrigation every 10 days and 75% maize population intercropped with upland rice gave the highest LER value.

Furthermore, percentage of saved land as a result of the studied intercropping systems was the highest under 9 days irrigation interval and 50% of maize planting density intercropped with upland rice, namely 34% averaged over the two seasons.

The results in table 9 indicated that the highest value of competitive ratio (CR) was found for maize under 9 days irrigation interval and 50% of maize planting density intercropped with upland rice. The results also showed that maize have higher aggressivity (A) than upland rice under its intercropping systems, where it had a positive values. Furthermore, the highest value of relative crowding coefficient (RCC) was found under 6 days irrigation interval and 25% of maize planting density intercropped with rice. Similar results were obtained by Abou-Elela (2013) under irrigation every 6 days and 75% maize population intercropped with upland rice.

Economic evaluation

The results in table 10 indicated that the highest value of total income (TI) was obtained when irrigation was done every 6 days and 25% of maize population intercropped with upland rice, namely 3835 USD/ha averaged over the two growing seasons. Furthermore, the highest values of monetary advantage index (MAI) were found under 9 days irrigation interval and 50% of maize planting density intercropped with rice, namely 1320 averaged over the two growing seasons. Similar results were obtained by Abou-Elela (2013) for maize intercropped with rice.

Water equivalent ratio (WER)

The highest values of WERtotal were obtained under irrigation every 9 days for 50% maize intercropped with rice, namely 1.53 and 1.49 in the first and second season, respectively. These results showed that the water utilization of this intercropping system was higher than the value of the other studied intercropping systems. In this case, the values of WERtotal were increased by 53 and 49% in the first and second growing seasons, respectively. Similar results were obtained by Zohry and Ouda (2019) when onion was intercropped with sugar beet and by El-Mehy et al. (2020) when faba bean was intercropped with sugar beet.

Conclusion

The above results proved that intercropping 50% maize planting density with 80% planting density of upland rice and irrigation every 9 days contributed in producing maize yield lower than the sole maize yield (100% planting density) by an average of 18% only. Furthermore, this system also obtained the highest land and water equivalent ratios, area time equivalent ratio, and land equivalent coefficient. In addition, 35% of lands can be saved under this system. Furthermore, there are savings in the applied water to upland rice through saving the applied water to the nursery, increasing irrigation interval from 6 to 9 days, and producing two crops (maize and upland rice) with the amount of water applied to upland rice. The results also showed that this system is profitable to the farmers. These results implied that intercropping maize with upland rice can solve part of the maize production-consumption gap through increasing its production without using additional lands or water, thus attained both yield and water advantages.

Thus, it is recommended to intercrop 50% maize planting density with 80% upland rice of its planting density, where upland rice is cultivated in sunken seed beds (2.0 m width and 5.0 m length). Each seed bed was separated by ridges (0.7 m width, 5.0 m length and 0.3 m height) for maize cultivation, with 25 cm distance between hills (one plant/hill in both sides) (Sheha sowing method) under irrigation application every 9 days.

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