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Productivity of solid and intercropped soybean with corn under low irrigation water levels

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ABSTRACT

A three-year study was carried out at Giza Agricultural Experiments and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt during the summer seasons of 2018, 2019, and 2020 to evaluate the effect of low irrigation water levels on the productivity of corn and soybean under different solid and intercropping systems. This study included 18 treatments. Three levels of irrigation water (7140, 5712, and 4284 m^3/ha) were expressed as 100 "I_{Sa}", 80 "I_{Sb}" and 60%"I_{Sc}", respectively. Six cropping systems that included alternating ridges 2:2 (A_a), mixed (B_b), solid corn ridges (Soc_a), solid corn beds (Soc_b), solid soybean ridges (Sos_a), and solid soybean beds (Sos_b). Corn cultivar S.C.132 (white grains) and soybean cultivar Giza 111 were used in this study. A split plot design in randomized complete blocks arrangement with three replications was used. All soybean and corn traits were negatively affected when received I_{Sc}. However, there were no significant differences between I_{Sa} and I_{Sb} for all soybean traits in all seasons. A significantly higher seed yield per hectare for soybean was recorded for solid plantings than for intercropping systems. Intercropping system Bb had high kernel weight and grain yield per hectare. Irrigation water use efficiency (IWUE) was increased by decreasing the applied irrigation water level from 7140 to 4284 m3/ha. The intercropping system Bb recorded high values of IWUE. Land equivalent ratio (LER) was not significantly affected by applied irrigation water levels, while intercropping system Bb recorded high LER in all seasons. Most interactions were significant throughout the seasons of the study. It can be concluded that intercropped soybean cultivar Giza 111 with corn in raised beds that received irrigation water of 5712 m3/ha recorded higher productivity values (IWUE and LER), as well as total and net returns, than the other treatments.

Keywords: Intercropping, Soybean, Corn, IWUE, Competitive relationship, farmer's benefit

INTRODUCTION

In Egypt, the per capita share of water has dropped dramatically to less than 1000 m^3, which is classified as "Water poverty limit". It is projected that the value decreases to 500 m^3 per capita in the year 2025 (Abdel-Wahaab, 2003). There is a modern trend for growing some field crops on beds (100 – 140 cm width) according to their densities to save irrigation water by about 15% compared by traditional practice on ridges 60-70 cm in width (Abouelenein *et al*., 2009; Ahmad *et al*., 2009). Although availability of water can limit crop production (Genc *et al*., 2013), but improving water use efficiency (IWUE) is necessary for securing environmental sustainability of food production in semiarid areas (Medrano *et al*., 2015). In the limited water resources, a choice suitable intercropping system is essential. The current population of Egypt is 104988276 as of Thursday, November 18, 2021, based on Worldometer elaboration of the latest United Nations data (Worldometers population, 2021). Egypt imported around eight million tons of corn (*Zea mays* L.) grains and two million tons of soybean (*Glycine max* L.) seeds and meals every year in the last five years. It is known that there is a decline in area under soybean in the Nile Valley and Delta, where it reached to about 7812 ha in 2019, while, under corn to about 861137 ha in 2019 (Bulletin of Statistical Cost Production and Net Return, 2019).

Consequently, the cropping system adopted by the farmer should be physically viable, sustainable, less exhaustive, acceptable to the farming community, and most importantly, economical. Since corn is a cash crop with a quick profit during the summer season, most farmers grow corn in their fields due to higher economic returns and lower financial costs, as well as being a social crop. On the other hand, soybean seeds contain an average of 36 to 38% protein and about 19% oil on a dry weight basis (Gandhi, 2009). Soybean as an oil seed rather than pulse crop as approximately 85% of the world's soybean crop is processed into soybean meal and vegetable oil (Fatih *et al*., 2015). The Egyptian farmer tended to grow soybean with corn in order to achieve additional profit for a long time, especially the Egyptian soybean breeders produced high-yielding soybean varieties under different environmental conditions. In recognition of the economic importance of soybean as seed legume and corn as important cereal crop, intercropping soybean with corn is more profitable than corn solid culture (Metwally *et al*., 2005, 2009 and 2017a).

Land equivalent ratio (LER) helps to quantify whether or not an intercropping system is advantageous over sole cropping, and if so, by how much. Although intercropping can reduce the yield of component crops due to adverse competitive effects (Willey *et al*., 1980), some knowledge is not yet available about the effect of water deficiency under intercropping. Particularly, Alizadeh (2001) showed that intercropping is one of the agricultural strategies for increasing water productivity to make maximum use of soil moisture. Consequently, the ratio of water used in plant metabolism to water lost by the plant through transpiration under different cropping systems should be considered. Soybean can grew with corn in alternating ridges without more irrigation water than that of solid corn plantings (Metwally *et al*., 2019a). So, it is important to address our efforts to address this fundamental issue by increasing the water use efficiency (IWUE) of intercropping soybean with corn in the Nile Valley and Delta areas. Therefore, the objective of this investigation was to evaluate the effect of low irrigation water levels on the productivity of corn and soybeans under different solid and intercropping systems.

MATERIALS AND METHODS

A three-year study was carried out at Giza Agricultural Experiments and Research Station (Latitude 30°00'30" N, Longitude 31°12'43" E, 26 m a.s.l), Faculty of Agriculture, Cairo University, Giza, Egypt during the summer seasons of 2018, 2019, and 2020 to evaluate the effect of low irrigation water levels on the productivity of corn and soybean under solid and intercropping systems. The factors included three levels of flood irrigation water applied as 7140, 5712 and 4284 m^3/ha expressed as 100% "I_{Sa}", 80% "I_{Sb}" and 60%"I_{Sc}", respectively, of that recommended, and six cropping systems (alternating ridges 2:2 "A_a", mixed "B_b" and solid plantings of corn "ridges Soc_a and beds Soc_b" and soybean "ridges Sos_a and beds Sos_b"). Irrigation levels were distributed through 8 times.

- Cropping systems (intercropping and solid plantings) were shown in Fig (1) as follows:
  1) Intercropping ridges (A_a): Two corn ridges alternating with two of soybean, 70 cm width of each ridge, by growing two corn plants/hill distanced at 25 cm apart, meanwhile two rows of soybean were grown in each of the other two ridges with leaving two plants/hill distanced at 20 cm apart. This system was expressed as 100% corn plants +50% soybean plants per ha (A_a) as compared to recommended solid plantings of both crops.
  2) Intercropping mixed system (B_b): Corn plants were grown in both sides of raised beds 140 cm width by growing two plants/hill distanced at 50 cm apart, meanwhile three rows of soybean were grown in the middle of the beds and leaving two plants/hill distanced at 20 cm apart. This system (B_b) was expressed as 100% corn plants + 75% soybean plants per ha as compared to solid plantings of both crops.
  3) Recommended solid corn (Soc_a): It was conducted by growing one corn plant/hill distanced at 25 cm apart in ridges 70 cm width resulted in 57120 plants/ha.
  4) Solid corn (Soc_b): It was conducted by growing two corn plants/hill distanced at 50 cm on both sides of beds 140 cm width resulted in 57120 plants/ha. Corn plant density was 100% of recommended solid planting of corn (Soc_a).
  5) Recommended solid soybean (Sos_a): It was conducted by growing two rows of soybean in ridges 70 cm width with leaving two plants/hill distanced at 20 cm apart resulted in 285600 plants/ha.
  6) Solid soybean (Sos_b): It was conducted by growing four rows of soybean in raised beds 140 cm width with leaving two plants/hill distanced at 20 cm apart. Soybean plant density was 100% of recommended solid planting of soybean (Sos_a) apart resulted in 286000 plants/ha.

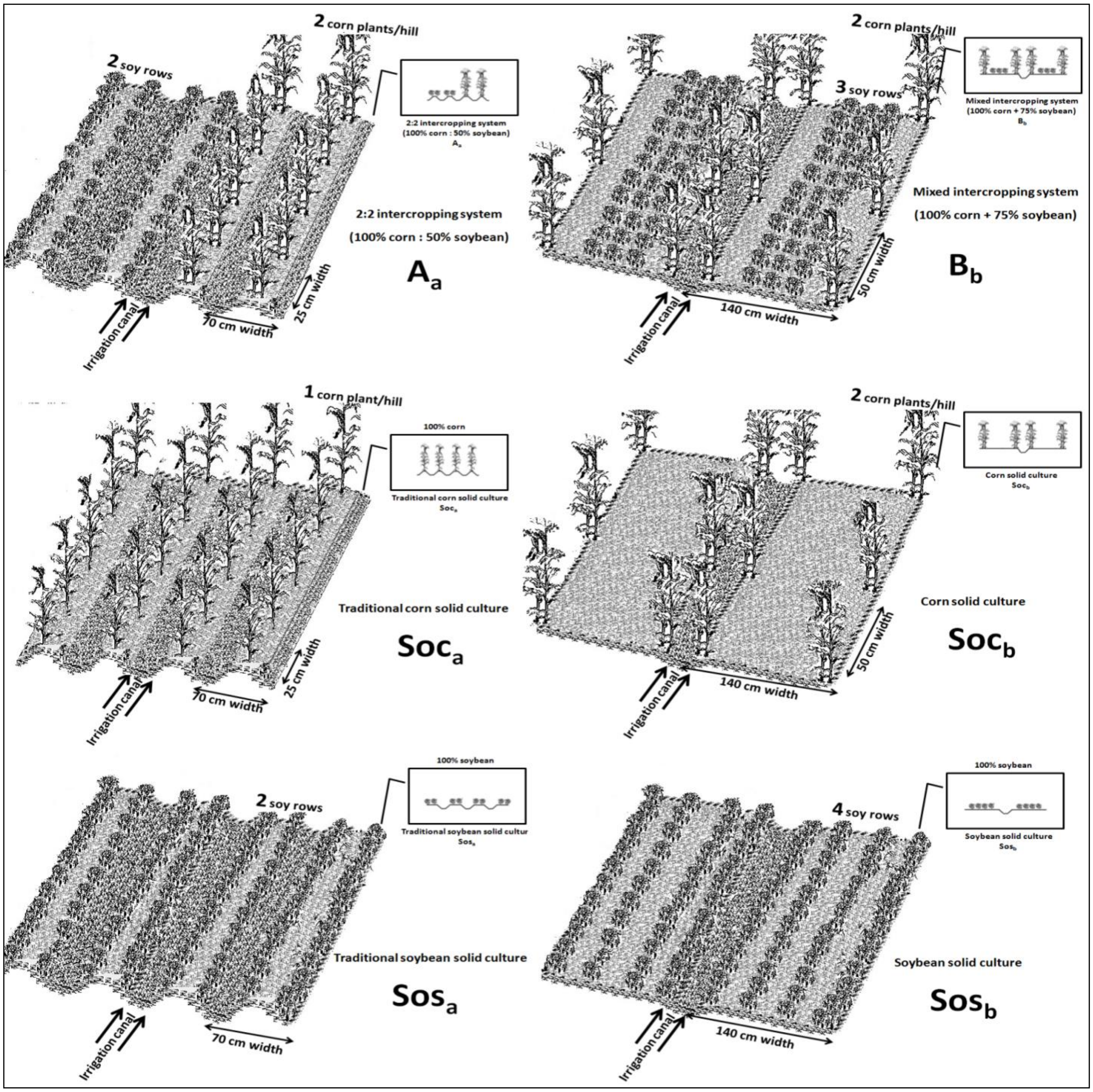

Figure 1. Intercropping systems of corn and soybean and solid plantings of both crops

The soil texture was clay loam and the preceding winter crops were wheat, Egyptian clover and faba bean for successive seasons (2018, 2019 and 2020, respectively). Corn cultivar S.C.132 (white grains) was sown on 15^{th}, 14^{th} and 17^{th} May in 2018, 2019 and 2020 seasons, respectively, while soybean cultivar Giza 111 was sown five days later than corn. A split plot design in randomized complete blocks arrangement with three replications was used. Applied irrigation water levels were randomly assigned to the main plots, and cropping systems were allocated in sub plots. Sub plot area was 28.0 m^2. Each plot consisted of four raised beds 5.0 m long and 1.4 m wide for each bed (in case of ridges, each plot consisted of eight ridges 5.0 m long and 0.7 m wide for each ridge).

Data recorded:

a) Soybean traits

Ten guarded plants at harvest were taken at random from each sub plot to determine: Number of pods per plant "at least one seed for each pod", seed yield per plant (g), seed index [100-seed weight] (g), and seed yield per ha (ton). Seed yield per ha was determined from seed weight of each sub plot and converted to ton per ha.

b) Corn traits

Ten guarded plants at harvest were taken at random from each sub plot to determine: Grain yield per plant (g), 100 – kernel weight (g), and grain yield per ha (ton). Grain yield per ha was determined from grain weight of each sub plot and converted to ton per ha.

c) Irrigation water use efficiency (IWUE)

IWUE, defined as the ratio of grain yield per hectare to the amount of irrigation water. IWUE values were calculated according to Tanner and Sinclair (1983) as follows: IWUE = (yield/ seasonal irrigation water quantity). Where IWUE is irrigation water use efficiency (kg/m^3), yield is the economical yield (kg/ha) and seasonal irrigation water quantity is the sum of the irrigation water quantity throughout the season (mm).

d) Land equivalent ratio (LER)

LER defines as 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). It is calculated as follows: LER = (Y_{ab} / Y_{aa}) + (Y_{ba}/ Y_{bb}); where Y_{aa} = Pure stand yield of crop a (corn), Y_{bb} = Pure stand yield of crop b (soybean), Y_{ab} = Intercrop yield of crop a (corn) and Y_{ba} = Intercrop yield of crop b (soybean).

e) Farmer's benefit

It was calculated by determining the total costs and net return of intercropping cultures as compared to recommended sole culture as follows:

1) Total return of intercropping cultures = Price of soybean yield + price of corn yield (USD), to calculate the total return, the average of soybean and corn prices were 545 USD for one ton of soybean seeds and 274 USD for one ton of corn grains according to Bulletin of Statistical Cost Production and Net Return (2021).
2) Net return = Total return – (fixed costs + variable costs according to cropping systems and irrigation water requirements. Financial costs were obtained from Bulletin of Statistical Cost Production and Net Return (2019).

Statistical analysis:

Analysis of variance of the recorded data of each season was performed. The measured variables were analyzed by ANOVA using MSTATC statistical package (Freed, 1991). Mean comparisons were done using least significant differences (L.S.D.) method at 5 per cent level of probability to compare differences between the means (Gomez and Gomez, 1984).

RESULTS

a) Soybean traits:

1) Applied irrigation water levels:

Number of pods per plant was decreased significantly by decreasing applied irrigation water levels in the second season only; meanwhile it was not affected in the first and third seasons (Table 1). However, seed yield per plant, seed index and seed yield per ha were affected significantly by applied irrigation water levels in all seasons. The full – irrigated (I_{Sa}) treatment had seed yield per plant (18.3, 15.4 and 17.7 g in the first, second and third seasons, respectively), seed index (15.5, 12.4 and 14.7 g in the first, second and third seasons, respectively), and seed yield per ha (2.33, 1.97 and 2.26 ton in the first, second and third seasons, respectively). The deficient – irrigated (I_{Sb}) treatment came in the second rank for the studied soybean traits. The severe deficient – irrigated (I_{Sc}) treatment had the lowest values of pods per plant (21.9 in the second season), seed yield per plant (13.6, 13.0 and 14.3 g in the first, second and third seasons, respectively), seed index (12.1, 9.5 and 11.3 g in the first, second and third seasons, respectively), and seed yield per ha (1.35, 1.35 and 1.42 ton in the first, second and third seasons, respectively) compared to the others. In other words, number of pods per plant was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 2.19 and 19.78% in the second season only. Also, yield of soybean plant was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 6.55 and 25.68% in the first season, the corresponding values were 5.84 and 15.58% in the second season, but it reached 6.21 and 19.20% in the third season. Moreover, seed index was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 13.54 and 21.93% in the first season, the corresponding values were 15.32 and 23.38% in the second season, but it reached 14.28 and 23.12% in the third season. Finally, yield of soybean seeds per ha was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 16.30 and 42.06% in the first season, the corresponding values were 14.72 and 31.47% in the second season, but it reached 15.92 and 37.16% in the third season.

Table 1. Effect of applied irrigation water levels, cropping systems, and their interactions onthe studied soybean traits in 2018, 2019 and 2020 seasons

Applied irrigation water level	Cropping system		Pods/plant (no.)			Seed yield/plant (g)			Seed index (g)			Seed yield/ha (ton)		
			2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
I_{Sa} (7140 m³/ha)	Inter	A_a	27.0	26.3	28.1	17.6	14.3	16.8	14.9	12.2	14.3	1.33	1.11	1.30
		B_b	25.0	27.9	27.9	17.0	16.3	17.6	14.5	12.6	14.3	1.85	1.99	2.02
	Solid	Sos_a	30.6	32.0	32.9	19.1	14.9	17.9	15.9	12.6	15.0	3.07	2.26	2.80
		Sos_b	30.7	30.0	31.9	19.3	16.1	18.6	16.6	12.1	15.0	3.09	2.49	2.95
	Mean		**28.3**	**27.3**	**30.2**	**18.3**	**15.4**	**17.7**	**15.5**	**12.4**	**14.7**	**2.33**	**1.97**	**2.26**
I_{Sb} (5712 m³/ha)	Inter	A_a	33.8	28.0	27.5	15.9	12.5	14.9	12.3	8.4	10.9	1.19	1.07	1.19
		B_b	33.2	24.5	30.4	16.9	14.6	16.6	13.4	10.2	12.4	1.80	1.40	1.68
	Solid	Sos_a	33.0	27.1	31.6	18.2	15.4	17.7	14.2	11.4	13.6	2.30	2.21	2.38
		Sos_b	29.0	26.8	29.3	17.0	15.5	17.1	13.5	12.0	13.5	2.61	2.07	2.38
	Mean		**32.3**	**26.7**	**29.7**	**17.1**	**14.5**	**16.6**	**13.4**	**10.5**	**12.6**	**1.95**	**1.68**	**1.90**
I_{Sc} (4284 m³/ha)	Inter	A_a	26.0	24.1	26.4	13.2	12.9	13.8	11.3	8.5	10.4	0.78	0.92	0.88
		B_b	25.9	23.0	25.8	13.9	13.5	14.4	11.7	9.5	11.2	1.33	1.42	1.45
	Solid	Sos_a	27.4	27.0	28.6	13.0	12.2	14.3	12.9	9.8	12.0	1.54	1.42	1.57
		Sos_b	26.3	22.3	26.7	14.2	13.5	14.6	12.3	9.9	11.7	1.73	1.61	1.76
	Mean		**26.5**	**21.9**	**26.9**	**13.6**	**13.0**	**14.3**	**12.1**	**9.5**	**11.3**	**1.35**	**1.35**	**1.42**
Average of cropping systems	Inter	A_a	**28.9**	**26.1**	**27.3**	**15.6**	**13.2**	**15.2**	**12.8**	**9.7**	**11.9**	**1.09**	**1.04**	**1.11**
		B_b	**28.0**	**25.1**	**28.0**	**15.9**	**14.8**	**16.2**	**13.2**	**10.8**	**12.6**	**1.66**	**1.61**	**1.71**
	Solid	Sos_a	**30.3**	**28.7**	**31.0**	**16.8**	**14.2**	**16.6**	**14.3**	**11.3**	**13.5**	**2.30**	**1.97**	**2.23**
		Sos_b	**28.7**	**26.4**	**29.3**	**16.8**	**15.0**	**16.8**	**14.1**	**11.3**	**13.4**	**2.45**	**2.07**	**2.38**
L.S.D. 0.05 Applied irrigation level			**N.S.**	**1.3**	**N.S.**	**1.9**	**1.6**	**1.7**	**1.4**	**2.1**	**2.2**	**0.48**	**0.36**	**0.43**
L.S.D. 0.05 Cropping system			**N.S.**	**N.S.**	**2.1**	**N.S.**	**1.5**	**1.5**	**1.2**	**1.0**	**1.1**	**0.38**	**0.30**	**0.35**
L.S.D. 0.05 Interaction			**N.S.**	**2.5**	**2.5**	**N.S.**	**N.S.**	**N.S.**	**1.8**	**2.5**	**2.5**	**0.46**	**0.41**	**0.53**

I_{Sa}: 100% of flood irrigation water applied I_{Sb}: 80% of flood irrigation water applied I_{Sc}: 60% of flood irrigation water applied
A_a: Intercropping ridges B_b: Intercropping mixed system
Soc_a: Recommended solid corn Soc_b: Solid corn
Sos_a: Recommended solid soybean Sos_b: Solid soybean

However, it is important to mention that there were no significant differences between the full – irrigated (I_{Sa}) treatment and the deficient – irrigated (I_{Sb}) treatment for the studied soybean traits in all seasons.

2) Cropping systems

Number of pods per plant was affected significantly by the cropping systems in the third season only; seed yield per plant was affected significantly by the cropping systems in the second and third seasons; meanwhile seed index and seed yield per ha were affected significantly by the cropping systems in all seasons (Table 1). Significantly higher number of pods per plant was recorded in solid plantings than in intercropping systems. The recommended solid planting Sos_a recorded higher number of pods per plant (31.0), followed by solid planting Sos_b (29.3) without significant differences between them in one season. Number of pods per plant under intercropping system A_a(27.3) had a similar response to the intercropping system B_b (28.0). Significantly higher seed yield per plant and seed index were recorded in solid plantings and intercropping system (B_b) than in intercropping system (A_a). Significantly higher seed yield per ha were recorded in solid plantings than in intercropping systems. Solid planting of soybean (Sos_b) recorded higher seed yield (2.45, 2.07 and 2.38 ton/ha in the first, second and third seasons, respectively), followed by recommended solid planting of soybean (Sos_a) without significant differences between them than the others. The intercropping system (B_b) came in the third rank (1.66, 1.61 and 1.71 ton/ha in the first, second and third seasons, respectively), followed by the intercropping system A_a (1.09, 1.04 and 1.11 ton/ha in the first, second and third seasons, respectively).

3) The interaction between applied irrigation water levels and cropping systems

Number of pods per plant was affected significantly by applied irrigation water levels x cropping systems in the second and third seasons, seed index and seed yield per ha were affected significantly by applied irrigation water levels x cropping systems in all seasons, meanwhile seed yield per plant was not affected significantly in all seasons (Table 1). Recommended solid planting Sos_a and solid planting Sos_b that received the full – irrigated (I_{Sa}) treatment recorded higher number of pods per plant and seed index than the others. Meanwhile, the lowest number of pods per plant and seed index were obtained by intercropping soybean with corn (A_a or B_b) that received the severe deficient – irrigated (I_{Sc}) treatment in all seasons.

b) Corn traits

1) Applied irrigation water levels

All the studied corn traits were affected significantly by applied irrigation water levels in the three seasons (Table 2). Yield of corn grains per plant was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 8.60 and 30.37% in the first season, the corresponding values were 21.97 and 27.07% in the second season, but it reached 15.42 and 28.27% in the third season. Moreover, 100 – kernel weight was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 7.40 and 16.72% in the first season, the corresponding values were 7.36 and 12.10% in the second season, but it reached 7.22 and 14.82% in the third season. Finally, yield of corn grains per ha was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 9.91 and 30.73% in the first season, the corresponding values were 20.21 and 27.90% in the second season, but it reached 12.40 and 24.36% in the third season.

2) Cropping systems

All the studied corn traits were affected significantly by the cropping systems in the three seasons (Table 2). Solid planting of corn (Soc_b) had high grain yield per plant while it recorded 194.3 and 177.3 g in the first and third seasons, respectively. Meanwhile, the intercropping system I_b recorded high grain yield per plant (182.1 g) in the first one. With respect to 100-kernel weight, solid planting of corn (Soc_b) recorded 28.8, 18.0 and 24.6 g in the first, second and third seasons, respectively. Also, intercropping system I_b gave 29.6, 17.9 and 25.0 g of 100-kernel weight in the first, second and third seasons, respectively. Moreover, the recommended solid planting of corn Soc_a had 27.7, 17.3 and 23.7 g in the first, second and third seasons, respectively. With respect to grain yield per ha, solid planting of corn (Soc_b) recorded 6.46, 5.16 and 5.99 ton/ha in the first, second and third seasons, respectively. Meanwhile, the intercropping system I_b gave 6.06, 4.89 and 6.19 ton/ha in the first, second and third seasons, respectively. Moreover, the recommended solid planting of corn (Soc_a) had 6.33, 4.63 and 5.49 ton/ha in the first, second and third seasons, respectively. It is worthy to note that solid planting of corn (Soc_b) was statistically similar to intercropping system B_b and recommended solid planting of corn (Soc_a) for grain yield per plant and per ha. Also, the solid planting of corn (Soc_b) was statistically similar to intercropping system B_b for grain yield per plant, 100-kernel weight and grain yield per ha.

Table 2. Effect of applied irrigation water levels, cropping systems, and their interactions on the studied corn traits in 2018, 2019 and 2020 seasons

Applied irrigation water level	Cropping system		Grain yield/plant (g)			100-kernel weight (g)				Grain yield/ha (ton)	
			2018	2019	2020	2018	2019	2020	2018	2019	2020
I_{Sa} (7140 m^3/ha)	**Inter**	**A_a**	199.3	153.1	185.0	30.1	18.9	25.8	6.76	5.13	6.53
		B_b	210.0	167.2	198.0	32.1	19.3	27.0	7.06	5.63	7.09
	Solid	**Soc_a**	220.0	159.9	200.0	30.1	18.9	25.8	7.39	5.53	6.49
		Soc_b	212.0	169.9	195.0	31.8	18.7	26.6	7.06	6.03	6.66
	Mean		**210.4**	**162.9**	**194.5**	**31.1**	**19.0**	**26.3**	**7.06**	**5.59**	**6.69**
I_{Sb} (5712 m^3/ha)	**Inter**	**A_a**	181.0	122.0	146.0	27.9	18.1	24.2	5.80	3.93	5.49
		B_b	189.2	142.1	174.0	30.1	18.4	25.5	6.39	4.59	6.33
	Solid	**Soc_a**	189.0	112.8	159.0	27.1	16.9	23.1	6.43	4.53	5.49
		Soc_b	210.0	131.1	179.0	30.1	16.6	24.6	6.83	4.83	6.06
	Mean		**192.3**	**127.1**	**164.5**	**28.8**	**17.6**	**24.4**	**6.36**	**4.46**	**5.86**
I_{Sc} (4284 m^3/ha)	**Inter**	**A_a**	127.6	92.9	116.0	26.1	16.0	22.2	4.19	3.43	4.29
		B_b	147.2	127.0	144.0	26.7	16.0	22.5	4.76	4.43	5.19
	Solid	**Soc_a**	150.0	116.0	140.0	26.0	16.2	22.2	5.13	3.49	4.49
		Soc_b	161.0	139.0	158.0	24.6	18.6	22.7	5.43	4.66	5.23
	Mean		**146.5**	**118.8**	**139.5**	**25.9**	**16.7**	**22.4**	**4.89**	**4.03**	**5.06**
Average of cropping systems	**Inter**	**A_a**	**169.3**	**122.7**	**149.0**	**28.0**	**17.7**	**24.1**	**5.59**	**4.16**	**5.43**
		B_b	**182.1**	**145.4**	**172.0**	**29.6**	**17.9**	**25.0**	**6.06**	**4.89**	**6.19**
	Solid	**Soc_a**	**186.3**	**129.6**	**166.3**	**27.7**	**17.3**	**23.7**	**6.33**	**4.63**	**5.49**
		Soc_b	**194.3**	**146.7**	**177.3**	**28.8**	**18.0**	**24.6**	**6.46**	**5.16**	**5.99**
L.S.D. 0.05 Applied irrigation level			**26.0**	**19.5**	**22.8**	**2.5**	**1.5**	**2.6**	**0.69**	**0.83**	**0.76**
L.S.D. 0.05 Cropping system			**15.0**	**17.1**	**15.0**	**1.4**	**1.0**	**1.0**	**0.69**	**0.58**	**0.72**
L.S.D. 0.05 Interaction			**21.2**	**21.1**	**21.2**	**N.S.**	**N.S.**	**N.S.**	**0.83**	**N.S.**	**0.81**

I_{Sa}: 100% of flood irrigation water applied I_{Sb}: 80% of flood irrigation water applied I_{Sc}: 60% of flood irrigation water applied
A_a: Intercropping ridges B_b: Intercropping mixed system
Sos_a: Recommended solid soybean Soc_b: Solid corn
Soc_a: Recommended solid corn Sos_b: Solid soybean

Intercropping system Bb and solid planting of corn (Soc_b) recorded higher 100-kernel weight than others in the three seasons. Conversely, intercropping system (A_a) and recommended solid planting of corn (Soc_a) recorded lower 100-kernel weight than others in the three seasons.

3) The interaction between applied irrigation water levels and cropping systems

Grain yield per plant was affected significantly by applied irrigation water levels x cropping systems in all seasons; also grain yield per ha was affected significantly by applied irrigation water levels x cropping systems in the first and third seasons only (Table 2). All cropping systems that received the full – irrigated (I_{Sa}) treatment had higher grain yields per plant and per ha.

c) Irrigation water use efficiency (IWUE)

1) Applied irrigation water levels

IWUE was affected significantly by applied irrigation water levels in the three seasons (Table 3). IWUE was increased gradually by decreasing irrigation water levels to 80 and 60%, where these increments were 11.36 and 10.22% in the first season, the corresponding values were 2.81 and 18.30% in the second season, but it reached 8.33 and 15.47% in the third season. In other words, IWUE increased gradually by decreasing applied irrigation water level from 7140 to 4284 m^3/ha. The differences between 100% applied irrigation water and 60% levels were significant through the first and third seasons. However, it is important to mention that IWUE of the full – irrigated (I_{Sa}) treatment and the deficient – irrigated (I_{Sb}) treatment were not significantly different from each other in all seasons.

2) Cropping systems

IWUE was affected significantly by the cropping systems in the three seasons (Table 3). Intercropping system (B_b) recorded higher values of IWUE (1.37, 1.18 and 1.41 kg/m^3 in the first, second and third seasons, respectively) than the others, meanwhile, the intercropping system (A_a) came in the second rank in the three seasons.

3) The interaction between applied irrigation water levels and cropping systems

IWUE was affected significantly by applied irrigation water levels x cropping systems in the three seasons (Table 3). The intercropping system (B_b) that received the deficient – irrigated (I_{Sb}) treatment recorded higher IWUE than others in the first season. Meanwhile, the intercropping system (B_b) that received the severe deficient – irrigated (I_{Sc}) treatment recorded higher IWUE than others in the second and the third seasons.

d) Land equivalent ratio (LER)

1) Applied irrigation water levels

LER was not affected significantly by applied irrigation water levels in the three seasons (Table 4). These data indicate that there were no effects of applied irrigation water levels on LER in the three seasons.

2) Cropping systems

LER was affected significantly by the cropping systems in the three seasons (Table 4). With respect to intercropping systems, intercropping system (B_b) recorded higher LERs (1.62 in the 1st season, 1.73 in the 2nd season and 1.77 in the 3rd season) than others. Meanwhile, intercropping system (A_a) came in the second ranking (1.34 in the 1st season, 1.47 in the 2nd season and 1.50 in the 3rd season). This system (B_b) has the same plant density of solid corn (100%) and around 75% of solid soybean.

3) The interaction between applied irrigation water levels and cropping systems

LER was affected significantly by applied irrigation water levels x cropping systems in the three seasons (Table 4). Growing soybean with corn in raised beds Ib that received all applied irrigation water gave higher LER than intercropping system Ia or corn solid plantings.

e) Farmer's benefit

The economic return of intercropped soybean with corn plants as compared with solid plantings of both crops is shown in Table (5).The intercropping system (Bb) under the full – irrigated (I_{Sa}) treatment had higher total return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 14.24, 45.41, 52.27, 76.13 and 74.78% in the first season, 30.60, 73.70, 59.30, 113.63 and 93.28% in the second season and 21.74, 71.16, 66.88, 99.08 and 89.45% in the third season. Meanwhile, the intercropping system (B_b) under the deficient – irrigated (ISb) treatment had higher total return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 21.92, 56.23, 55.43, 117.66 and 91.94% in the first season, 21.92, 60.74, 63.11, 67.88 and 79.46% in the second season and 23.23, 53.09, 76.28, 104.73 and 104.73% in the third season. Furthermore, the intercropping system (B_b) under the severe deficient – irrigated (I_{Sc}) treatment had higher total return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 28.73, 55.63, 44.52, 141.00 and 114.59% in the first season, 37.77, 64.09, 107.85, 156.02 and 125.90% in the second season and 33.65, 55.55, 79.75, 158.78 and 130.81% in the third season.

Table 3. Effect of applied irrigation water levels, cropping systems, and their interactions on IWUE* in 2018, 2019 and 2020 seasons

Applied irrigation water level	Cropping system		IWUE (kg/m³)		
			2018	2019	2020
I_{Sa} (7140 m³/ha)	Inter	A_a	1.13	0.88	1.10
		B_b	1.25	1.07	1.28
	Solid corn	Soc_a	1.04	0.77	0.91
		Soc_b	0.99	0.84	0.93
	Solid soybean	Sos_a	0.43	0.32	0.39
		Sos_b	0.43	0.35	0.41
	Mean		**0.88**	**0.71**	**0.84**
I_{Sb} (5712 m³/ha)	Inter	A_a	1.23	0.88	1.17
		B_b	1.44	1.10	1.40
	Solid corn	Soc_a	1.13	0.79	0.96
		Soc_b	1.20	0.85	1.06
	Solid soybean	Sos_a	0.40	0.39	0.42
		Sos_b	0.46	0.36	0.42
	Mean		**0.98**	**0.73**	**0.91**
I_{Sc} (4284 m³/ha)	Inter	A_a	1.16	1.02	1.21
		B_b	1.42	1.37	1.55
	Solid corn	Soc_a	1.20	0.82	1.05
		Soc_b	1.27	1.10	1.22
	Solid soybean	Sos_a	0.36	0.33	0.37
		Sos_b	0.41	0.38	0.41
	Mean		**0.97**	**0.84**	**0.97**
Average of cropping systems	Inter	A_a	**1.17**	**0.93**	**1.16**
		B_b	**1.37**	**1.18**	**1.41**
	Solid corn	Soc_a	**1.12**	**0.79**	**0.97**
		Soc_b	**1.15**	**0.93**	**1.07**
	Solid soybean	Sos_a	**0.40**	**0.35**	**0.39**
		Sos_b	**0.43**	**0.35**	**0.41**
L.S.D. 0.05 Applied irrigation level			**0.11**	**0.08**	**0.12**
L.S.D. 0.05 Cropping system			**0.16**	**0.18**	**0.21**
L.S.D. 0.05 Interaction			**0.10**	**0.09**	**0.15**

* IWUE: Irrigation water use efficiency
I_{Sa}: 100% of flood irrigation water applied I_{Sb}: 80% of flood irrigation water applied I_{Sc}: 60% of flood irrigation water applied
A_a: Intercropping ridges B_b: Intercropping mixed system
Soc_a: Recommended solid corn Soc_b: Solid corn
Sos_a: Recommended solid soybean Sos_b: Solid soybean

Table 4. Effect of applied irrigation water levels, cropping systems, and their interactions on LER* in 2018, 2019 and 2020 seasons

Applied irrigation water level	Cropping system		LER 2018	LER 2019	LER 2020
I_{Sa} (7140 m^3/ha)	Inter	A_a	1.35	1.42	1.47
		B_b	1.60	1.73	1.75
	Mean		**1.48**	**1.58**	**1.61**
I_{Sb} (5712 m^3/ha)	Inter	A_a	1.42	1.35	1.50
		B_b	1.63	1.63	1.75
	Mean		**1.52**	**1.49**	**1.63**
I_{Sc} (4284 m^3/ha)	Inter	A_a	1.33	1.63	1.52
		B_b	1.64	1.83	1.82
	Mean		**1.49**	**1.73**	**1.67**
Average of cropping systems	Inter	A_a	**1.34**	**1.47**	**1.50**
		B_b	**1.62**	**1.73**	**1.77**
Solid plantings (corn, soybean)			**1.00**	**1.00**	**1.00**
L.S.D. 0.05 Applied irrigation level			**N.S.**	**N.S.**	**N.S.**
L.S.D. 0.05 Cropping system			**0.16**	**0.21**	**0.25**
L.S.D. 0.05 Interaction			**0.15**	**0.22**	**0.25**

*LER: Land equivalent ratio

I_{Sa}: 100% of flood irrigation water applied I_{Sb}: 80% of flood irrigation water applied I_{Sc}: 60% of flood irrigation water applied
A_a: Intercropping ridges B_b: Intercropping mixed system

Table 5. Economic return of corn grains and soybean seeds under applied irrigation water levels and cropping systems in 2018, 2019 and 2020 seasons

Applied irrigation water level	Cropping system		Economic return (USD*/ha) 2018 Corn	2018 Soybean	2019 Corn	2019 Soybean	2020 Corn	2020 Soybean
I_{Sa} (7140 m^3/ha)	Inter	A_a	1853.32	726.37	1405.97	609.63	1789.41	713.40
		B_b	1935.49	1011.73	1542.91	1089.56	1944.62	1102.53
	Solid corn	Soc_a	2026.78	---	1515.52	---	1780.28	---
		Soc_b	1935.49	---	1652.47	---	1825.93	---
	Solid soybean	Sos_a	---	1673.25	---	1232.24	---	1530.57
		Sos_b	---	1686.23	---	1361.95	---	1608.40
I_{Sb} (5712 m^3/ha)	Inter	A_a	1597.69	648.55	1077.30	583.69	1506.39	648.55
		B_b	1752.89	985.79	1259.89	765.28	1734.63	920.94
	Solid corn	Soc_a	1762.02	---	1241.63	---	1506.39	---
		Soc_b	1871.58	---	1323.80	---	1661.60	---
	Solid soybean	Sos_a	---	1258.18	---	1206.30	---	1297.1
		Sos_b	---	1426.81	---	1128.47	---	1297.1
I_{Sc} (4284 m^3/ha)	Inter	A_a	1150.34	428.04	940.35	505.86	1177.72	479.92
		B_b	1305.54	726.37	1214.24	778.26	1424.23	791.23
	Solid corn	Soc_a	1405.97	---	958.61	---	1232.50	---
		Soc_b	1488.13	---	1278.15	---	1433.36	---
	Solid soybean	Sos_a	---	843.11	---	778.26	---	856.08
		Sos_b	---	946.88	---	882.02	---	959.85

Table 5. Continuad

Applied irrigation water level	Cropping system		Economic return (USD*/ha)					
			2018		2019		2020	
			Total	Net	Total	Net	Total	Net
I_{Sa} (7140 m³/ha)	**Inter**	**A_a**	2579.70	1762.82	2015.60	1198.73	2502.82	1685.94
		B_b	2947.23	2095.45	2632.48	1780.70	3047.15	2195.38
	Solid corn	**Soc_a**	2026.78	1279.70	1515.52	768.44	1780.28	1033.20
		Soc_b	1935.49	1188.41	1652.47	905.39	1825.93	1078.85
	Solid soybean	**Sos_a**	1673.25	1126.21	1232.24	685.20	1530.57	983.53
		Sos_b	1686.23	1139.18	1361.95	814.91	1608.40	1061.36
Mean			**2141.45**	**1431.96**	**1735.04**	**1025.56**	**2049.19**	**1339.71**
I_{Sb} (5712 m³/ha)	**Inter**	**A_a**	2246.24	1440.17	1660.99	854.92	2154.94	1348.87
		B_b	2738.69	1897.72	2025.18	1184.21	2655.58	1814.61
	Solid corn	**Soc_a**	1752.89	1138.69	1259.89	645.68	1734.63	1120.43
		Soc_b	1762.02	1147.82	1241.63	627.42	1506.39	892.19
	Solid soybean	**Sos_a**	1258.18	721.16	1206.30	669.27	1297.10	760.07
		Sos_b	1426.81	889.78	1128.47	591.45	1297.10	760.07
Mean			**1864.14**	**1205.89**	**1420.41**	**762.16**	**1774.29**	**1116.04**
I_{Sc} (4284 m³/ha)	**Inter**	**A_a**	1578.38	783.11	1446.22	650.96	1657.65	862.39
		B_b	2031.92	1201.75	1992.50	1162.34	2215.46	1385.29
	Solid corn	**Soc_a**	1305.54	580.07	1214.24	488.77	1424.23	698.75
		Soc_b	1405.97	680.49	958.61	233.14	1232.50	507.03
	Solid soybean	**Sos_a**	843.115	316.11	778.26	251.25	856.08	329.08
		Sos_b	946.883	419.87	882.02	355.02	959.85	432.85
Mean			**1351.96**	**663.57**	**1211.98**	**523.58**	**1390.96**	**702.56**
Average of cropping systems		**A_a**	**2134.77**	**1328.70**	**1707.61**	**901.54**	**2105.14**	**1299.07**
		B_b	**2572.61**	**1731.64**	**2216.72**	**1375.75**	**2639.39**	**1798.43**
		Soc_a	**1695.07**	**999.49**	**1329.89**	**634.30**	**1646.38**	**950.79**
		Soc_b	**1701.16**	**1005.57**	**1284.24**	**588.65**	**1521.61**	**826.02**
		Sos_a	**1258.18**	**721.16**	**1072.26**	**535.24**	**1227.92**	**690.89**
		Sos_b	**1353.30**	**816.28**	**1124.15**	**587.13**	**1288.45**	**751.42**

*USD: US Dollars

I_{Sa}: 100% of flood irrigation water applied I_{Sb}: 80% of flood irrigation water applied I_{Sc}: 60% of flood irrigation water applied

A_a: Intercropping ridges B_b: Intercropping mixed system

Soc_a: Recommended solid corn Soc_b: Solid corn

Sos_a: Recommended solid soybean Sos_b: Solid soybean

With respect to net return, the intercropping system (B_b) under the full – irrigated (I_{Sa}) treatment had higher net return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 18.86, 63.74, 76.32, 86.06 and 83.94% in the first season, 48.54, 131.72, 96.67, 159.88 and 118.51% in the second season and 30.21, 112.48, 103.49, 123.21 and 106.84% in the third season. Meanwhile, the intercropping system (B_b) under the deficient – irrigated (I_{Sb}) treatment had higher net return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 31.77, 66.65, 65.33, 163.14 and 113.27% in the first season, 38.51, 83.40, 88.74, 76.94 and 100.22% in the second season and 34.54, 61.96, 103.38, 138.74 and 138.74% in the third season. Furthermore, the intercropping system (B_b) under the severe deficient – irrigated (I_{Sc}) treatment had higher net return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 53.45, 107.17, 76.60, 280.16 and 186.21% in the first season, 78.55, 137.81, 398.74, 362.61 and 227.39% in the second season and 60.63, 98.25, 173.21, 320.95 and 220.04% in the third season.

With respect to total return, intercropping soybean with corn was decreased gradually by decreasing irrigation water levels to 80 and 60%, where these reductions were 12.95 and 36.87% in the first season, the corresponding values were 18.13 and 30.15% in the second season, but it reached 13.42 and 32.12% in the third season. With respect to net return, intercropping soybean with corn was decreased gradually by decreasing irrigation water levels to 80% and 60%, where these reductions were 15.79 and 53.66% in the first season, the corresponding values were 25.68 and 48.95% in the second season, but it reached 16.70 and 47.56% in the third season.

With respect to average of cropping systems, intercropping soybean with corn under the intercropping system B_b had higher total and net returns than the others where it recorded 2572.61 and 1731.64 USD/ha in the first season, 2216.72 and 1375.75 USD/ha in the second season, and 2639.39 and 1798.43 USD/ha in the third seasons, respectively. In other words, intercropping soybean with corn under system B_b had higher total return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 20.50, 51.77, 51.22, 104.47 and 90.09% in the first season, 29.81, 66.68, 72.61, 106.73 and 97.19% in the second season, and 25.37, 60.31, 73.46, 114.94 and 104.85% in the third seasons, respectively. With respect to net return, intercropping soybean with corn under system B_b had higher net return than A_a, Soc_a, Soc_b, Sos_a and Sos_b by 30.32, 73.25, 72.20, 140.11 and 112.13% in the first season, 52.60, 116.89, 133.71, 157.03 and 134.31% in the second season, and 38.43, 89.15, 117.72, 160.30 and 139.33% in the third seasons, respectively.

DISCUSSION

a) Soybean traits

1) Applied irrigation water levels

It is likely that soybean water requirements fluctuated throughout the season depending on climatic conditions and crop growth stage. Accordingly, soybean plants could be tolerating water deficiency up to 20% of the recommended irrigation water. It is known that the critical periods in terms of water requirements occur during flowering and seed maturation stages (Thuzar *et al*., 2010). Our findings are in agreement with the results reported by Metwally *et al*. (2017a and b and 2021b).It seems that the severe deficient – irrigated (I_{Sc}) treatment reduced light intensity within soybean canopy that resulted in the photosynthetic activity of soybean plants. This leads to reduction in photosynthates required by the sink, so there were fewer pods per plant. Increased soil water deficit is correlated with reduced dry-matter development (Lopez *et al*., 1996) which explains the low seed yield under severe water shortage conditions (I_{Sc}). Such a reduction in seed yield per ha resulted from a reduction in photosynthesis of soybean plants which affected negatively translocation of assimilates from source to sink. Thus, it is expected that stomata will be closed affecting CO_2 assimilation and transpiration under the severe deficient – irrigated (I_{Sc}) treatment according to Taiz and Zeiger (2010).

2) Cropping systems

These results indicate that number of pods per plant was found to be significantly lower under intercropping conditions as compared with solid plantings of soybean. Maximum number of pods per plant was recorded in soybean alone and minimum pods per plant were recorded in intercropping treatments (Panhwar *et al.*, 2004). Similar results were obtained by Metwally *et al*. (2012, 2017 a and b, 2018, 2019 a, b, c and d, and 2021 a and b).

It seems that the inter-specific competition between the two species (corn & soybean) and the intra-specific competition between plants of one species (soybean & soybean) had similar effects on seed yield per plant and seed index under the three cropping systems (Sos_a, Sos_b and B_b).In regard to intercropping system (A_a), the adverse effects of intercropping system (A_a) led to increase in inter-specific competition between corn and soybean plants for basic growth resources (Olufajo, 1992) as compared with soybean solid culture. These data indicate that intercropping system (A_a) formed unfavorable conditions for soybean plant which reflected on the severe decrease in seed yield per plant and seed index as compared with those grown under solid culture. These results are in the same context with Metwally *et al*. (2019, a, b, c and d).

The plant density of soybean plants per unit area played a major role in increasing seed yield per unit area where plant density of intercropped reached 50% (A_a) and 75% (B_b) of solid soybean plant density, however, soybean of raised beds was a higher productive system than those of ridges under intercropping. These results are in accordance with Metwally *et al*. (2019 b and c), who showed that intercropping systems had lower seed yields per plant and per ha than solid planting.

3) The interaction between applied irrigation water levels and cropping systems

Pod formation and seed filling are benefited from availability in environmental conditions including soil water (ISa) probably due to higher total dry matter and leaf area index compared with the other treatments. Meanwhile, it seems that ISc has interfered with the physiological maturing process of soybean which reflected in negative effects on pod enlargement and seed-filling. These results are in the same context with Metwally *et al*. (2017a and b). With respect to seed yield per ha, the rate of reductions in solid soybean yield by decreasing water levels were more than those of intercropping systems through years (for example) 49.8 and 44.0% of solid ridges and beds as compared with 41.3 and 28.1% in intercropping plantings, respectively, in first season, this may be due to shading effect of adjacent corn plants.

Under solid culture, solid planting (Sos_b) and recommended solid planting (Sos_a) that received the full – irrigated (I_{Sa}) treatment recorded higher soybean seed yield per ha than others. It is worthy to note that soybean of ridges (Sos_a) that received the full – irrigated (I_{Sa}) treatment produced seed yield per ha statistically similar to those of raised beds (Sos_b) that received the deficient – irrigated (I_{Sb}) treatment in 2018 season. Meanwhile, solid planting (Sos_b) that received the full – irrigated (I_{Sa}) treatment, and recommended solid planting (Sos_a) and solid planting (Sos_b) that received the deficient – irrigated (I_{Sb}) treatment recorded higher soybean seed yield per ha than others in the second season.

For intercropping, the intercropping system B_b that received the full – irrigated (I_{Sa}) treatment gave the highest seed yield per ha, meanwhile, the intercropping system (A_a) that received the severe deficient – irrigated (I_{Sc}) treatment had the lowest value in all seasons. It is likely that plant arrangements of intercropping system (B_b) have intercepted radiation by most leaves per unit area than A_a. With regard to intercropping, soybean of raised beds that received the full – irrigated (I_{Sa}) treatment produced seed yield per ha statistically similar to those of raised beds by decreasing irrigation water levels from 100 to 80% of the recommended irrigation water in the first season. Soybean plants under Solid planting (Sos_b) were not tolerate water deficiency up to 20% by decreasing irrigation water level from 7140 to 5712 m^3/ha as compared to those intercropped with corn in mixed intercropping system (B_b). These results could be due to the competition between soybean plants for irrigation water under high summer temperatures, especially when water levels are lower than recommended. While the corn plants were shaded on the soybean plants from the high temperatures, which led to the soybean plants tolerating the irrigation water deficiency by 20% of the recommended one.

b) Corn traits

1) Applied irrigation water levels

It is expected that corn plants have different transpiration rates in their leaves among the first, second, and third seasons. It seems that the full – irrigated (ISa) treatment increased the efficiency of the photosynthetic process of corn plant that needs high water requirements (Igbadun *et al*., 2008).

Consequently, more assimilates were accumulated in the different organs of the corn plant as a result of increased leaf expansion and efficiency of the photosynthetic process. However, it is important to mention that 100-kernel weight and grain yields of the full – irrigated (I_{Sa}) treatment and the deficient – irrigated (I_{Sb}) treatment were not significantly different from each other. The reasons are likely that the deficient – irrigated (I_{Sb}) treatment provides sufficient soil water conditions for proper root development to obtain water and nutrients. It also ensured that the water requirements of corn plants were met, and the efficient use of irrigation water and nutrients for proper growth and development, which undoubtedly was reflected on dry matter accumulation during growth and development. These results are in accordance with those abstained by Abd El-Halim and Abd El-Razek (2014). In this concern, Kebede *et al*. (2014) revealed that reducing soil moisture from 100% field capacity (fully irrigated) to 75% field capacity of a silt loam soil starting at the R1 growth stage (fourteen leaf stage) in corn did not reduce yield significantly compared to yield from the 100% field capacity, while saving a significant quantity of water. Meanwhile, grain yields of the deficient – irrigated (I_{Sb}) treatment and the severe deficient – irrigated (I_{Sc}) treatment were significantly different from each other. Grain yield considerably decreased at the application of deficit irrigation up to 40% of the full – irrigated (I_{Sa}) treatment probably due to the total leaf area which had become smaller that resulted from negative effects on cell division and expansion (Avramova *et al*., 2015). Such reduction in leaf area could be reflected on a root system that is not able to compensate for irrigation water, as well as, grain filling and seed index. These results are in harmony with Metwally *et al*. (2017a) who indicated that grain yield per ha was affected by applied irrigation water treatments.

2) Cropping systems

It is observed that the plant density of corn plants per unit area of intercropping system (A_a) reached 100% of the recommended plant density of corn (Soc_a) which leads to stability in grain yield per unit area between them. In contrast, the same plant density of intercropping system (B_b) gave a higher grain yield per ha than intercropping system (A_a). These results are probably due to differences in the spatial arrangement of corn plants that correlated with differences in their plant densities which played a major role in the intra-specific competition between plants for available agricultural resources. These results are in accordance with Abdel-Wahab *et al*. (2016), who indicated that there was an increase in grain yield of intercropped corn than solid ones under the same plant density. Moreover, Metwally *et al.* (2019b) found that grain yield per ha was affected significantly by the cropping systems, recommended and solid planting had higher grain yield per ha than the others.

3) The interaction between applied irrigation water levels and cropping systems

There were no significant differences between cropping systems in their productivity under high level of irrigation water, but the intercropping system B_b gave more tolerant to drought of lower levels of irrigation water than the intercropping system A_a. This is probably due to the close relationship between the bed width and the evaporation rate from the soil surface.

c) Irrigation water use efficiency (IWUE)

1) Applied irrigation water levels

IWUE was increased by decreasing irrigation water levels to 60% probably due to the difference in climatic conditions and other environmental factors among the first, second and third seasons. In this concern, Metwally *et al.* (2017a and 2021b) showed that decreasing of irrigation water levels from 125 to 75% of the recommended irrigation water (8092 m^3/ha) increased water use efficiency.

2) Cropping systems

The results could be due to the plant densities of corn and soybean plants per unit area. These results indicate that the intercropping system (B_b) had a good performance of soybean production systems. Also, the results show that intercropping systems maximize IWUE than solid plantings, especially solid soybean plantings. These results are in accordance with those obtained by Metwally *et al*. (2021b).

3) The interaction between applied irrigation water levels and cropping systems

The intercropping system B_b gave more tolerant to drought of lower levels of irrigation water than the intercropping system A_a, and this may be due to wider raised beds than that of ridges and evaporation from soil surface. Similar results were obtained by Metwally *et al*. (2021b).

d) Land equivalent ratio (LER)

1) Applied irrigation water levels

Reduction of irrigation water levels did not has the same trend of reduction of LERs.

2) Cropping systems

The system (B_b) has the same plant density of solid corn (100%) and around 75% of solid soybean. The results could be attributed to the spatial arrangement of corn plants per unit area of the intercropping system B_b (100% of the plant density of the recommended solid planting of corn Soc_a and solid planting of corn Soc_b) interacted positively with spatial arrangement of soybean plants per unit area to decrease intra and inter-specific competition between plants on available agricultural resources than the intercropping system (A_a). Also, it is clear from the data that intercropping systems have higher values of LER as compared with solid plantings of corn and soybean. These data are in agreement with earlier ones obtained in Egypt by many researchers (Metwally, 1999; Metwally *et al*., 2012, 2017a, b and 2021b).

3) The interaction between applied irrigation water levels and cropping systems

The results show that applied irrigation water levels responded differently to cropping systems in the three seasons. LER values of intercropping systems increased more under low levels of irrigation water levels 60 and 80% as compared with 100% (Metwally *et al*., 2021b).

e) Farmer's benefit

It is noticed that decreasing applied irrigation water level from 7140 to 4284 m^3/ha decreased total and net returns in all seasons. That is, the deficient – irrigated (I_{Sb}) treatment produced no reduction in total and net returns of the full – irrigated (I_{Sa}) treatment in the first, second and third seasons. The results suggest that intercropping soybean cultivar Giza 111 with corn under B_b that received the deficient – irrigated (I_{Sb}) treatment recorded high economic return than solid plantings of both crops and it should be recommended to Egyptian farmers. With respect to solid plantings, Soc_b or Sos_b had higher total and net returns than Soc_a or Sos_a, respectively showing that increasing the ridge width from 70 to 140 cm increased the total, and net returns whether under intercropping or solid plantings. These findings are parallel with those obtained by Ouda *et al*. (2007) and Metwally *et al.* (2017a) who found that intercropping soybean with corn is more profitable than solid corn culture under limited applied irrigation water.

CONCLUSION

It can be recommended that mixed intercropping system (beds, 140 cm width) gave higher productivity of corn and soybean and higher net return than alternating two ridges (2:2; 70 cm width) in addition to higher values of IWUE and LER especially under low irrigation levels (5712 and 4284 m^3/ha).

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إنتاجية فول الصويا المنفرد والمحمل مع الذرة الشامية تحت مستويات منخفضة من مياه الرى

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أجريت هذه الدراسة بمحطة البحوث الزراعية بكلية الزراعة بجامعة القاهرة خلال مواسم النمو 2018م و2019م و2020م لتقييم تأثير مستويات مياه الرى المنخفضة على إنتاجية نباتات الذرة الشامية وفول الصويا تحت نظم مختلفة من الزراعة المنفردة والمحملة. تضمنت الدراسة ثمانية عشر معاملة عبارة عن ثلاثة مستويات من مياه الرى المضافة (7140، 5712، 4284 م3/هكتار تم التعبير عنها بـ 100% "مستوى مياه الرى الكامل"، 80% "مستوى مياه الرى المنخفض"، 60% "مستوى مياه الرى المنخفض جدا"، على الترتيب) وستة نظم زراعية (خطوط متبادلة بعرض 70 سم "خطين من الذرة الشامية بالتبادل مع خطين من فول الصويا بحيث يمثل 100% ذرة شامية : 50% فول الصويا"، الزراعة المختلطة على مصاطب بعرض 140 سم "نباتات الذرة الشامية على جانبى المصطبة ونباتات فول الصويا بوسط المصطبة بحيث يمثل 100% ذرة شامية + 75% فول صويا"، الزراعة المنفردة الموصى بها للذرة الشامية على خطوط بعرض 70 سم، الزراعة المنفردة للذرة الشامية على مصاطب بعرض 140 سم، الزراعة المنفردة الموصى بها لفول الصويا على خطوط بعرض 70 سم، الزراعة المنفردة لفول الصويا على مصاطب بعرض 140 سم). تم إستخدام صنف الذرة الشامية البيضاء الهجين الفردى 132 بينما كان صنف فول الصويا هو جيزة 111. كان التصميم التجريبى المستخدم فى هذه الدراسة هو تصميم القطع المنشقة مرة واحدة موزعة فى القطاعات الكاملة العشوائية فى ثلاثة مكررات.

إنخفضت جميع صفات فول الصويا بنقص مستوى مياه الري حتى 60٪. ومع ذلك ، من المهم الإشارة إلى عدم وجود فروق معنوية بين مستوى مياه الرى الكامل و مستوى مياه الرى المنخفض لجميع صفات فول الصويا لجميع مواسم الدراسة. تم تسجيل أعلى محصول بذور فول صويا للهكتار في الزراعات المنفردة مقارنة بالزراعات المحملة. أعطى نظام التحميل المختلط أعلى وزن للمائة حبة ولمحصول حبوب الهكتار للذرة الشامية. زادت كفاءة إستخدام مياه الرى بنقص مستوى مياه الرى من 7140 م 3 / فدان إلى 4284 م 3 / هكتار. سجل التحميل المختلط أعلى القيم لكفاءة إستخدام مياه الرى. لم يتأثر معدل كفاءة إستخدام الأرض معنويا بمستويات مياه الري المضافة، بينما سجل التحميل المختلط أعلى معدل لكفاءة إستخدام الأرض لجميع مواسم الدراسة. كانت معظم التفاعلات بين عوامل الدراسة معنوية خلال مواسم الدراسة. توصى الدراسة بتحميل صنف فول الصويا جيزة 111 مع نباتات الذرة الشامية فى مصاطب التى إستقبلت مستوى مياه الرى المنخفض (5712 م 3 / هكتار) حيث أعطت أعلى إنتاجية وأعلى كفاءة لإستخدام مياه الرى والأرض وكذلك أعلى عائد إجمالى وعائد صافى مقارنة بالمعاملات الأخرى.

الكلمات الدالة: التحميل، فول الصويا، الذرة الشامية، كفاءة إستخدام مياه الرى، العلاقات التنافسية، فائدة المزارع