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RESISTANCE OF PEANUT TO HEAT STRESS THROUGH SUBSURFACE IRRIGATION AND INTERCROPPING WITH SORGHUM UNDER NEW VALLEY CONDITION

Shoman, Hosam A.
Department of Plant Production, Desert Research Center, El-Matareya, Cairo, Egypt
E-mail: h.shoman@gmail.com

Field trials had carried out at the Agricultural Experiment Station of the Desert Research Center at El-Kharga Oasis, New Valley Governorate, Egypt, during 2021 and 2022 summer seasons. The effect of intercropping sorghum on peanut and using subsurface irrigation system under heat stress conditions on peanut productivity in New Valley Governorate was evaluated. Results indicated that all studied peanut parameters were increased due to application of subsurface irrigation and intercropping systems. The highest values of peanut production were obtained when applying subsurface irrigation at a depth of 30 cm. Whereas, the percentages increased when percolation lines was buried at a depth of 30 cm, surface irrigation of seed yield were 56.8 and 54.65% and water use efficiency (WUE) were 77.36 and 74.93% in the first and second seasons, respectively. The maximum values of peanut parameters regarding intercropping systems were obtained by intercropping peanut with sorghum at the rate of 2 peanut plants: 1 sorghum plant, the percentages of increase in seed yield were 40.6 and 39.54% and WUE were 40.42 and 37.35% as compared to planting peanut alone without intercropping (control) in both seasons, respectively.

Key words: peanut, heat stress, intercropping, subsurface irrigation, yield, sorghum

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is among the major leguminous crops grown in the world and it is the third largest oilseed crop after soybean and seed cotton globally, about two-thirds of world production used for oil extraction and it is an essential source of vegetable protein and oil (Marfo et al., 2020). Peanut seed contains about 44–56% oil, 22–30% protein, 20% carbohydrates, 2.5% minerals and 5% fiber on dry seed basis and is a rich source of minerals (phosphorus, calcium, magnesium, and potassium) and vitamins (Savage and Keenan, 1994). One of the most important factors affecting the growth and productivity of peanuts in desert areas during growth stage, especially filling pods, is high temperatures (heat stress).

In arid and semi-arid regions such as New Valley Governorate, where rainfall is scarce, limited water resources, which is, confined to groundwater that represents all life pattern. Therefore, heat stress causes alterations in plant growth, development, physiological processes and yield. One of the major consequences of heat stress is the excess generation of reactive oxygen species (ROS), which leads to oxidative stress (Hasanuzzaman et al. 2013). The peanut crop when undergo high temperature stress, may face several problems like reduction in germination, growth and development, photosynthesis, oxidative stress in consequence of high temperature and finally decrease in quantity and quality of groundnut production (Singh et al. 2016). Dreyer et al. (2019) reported that both air and soil temperatures are important factors to determine the yield of peanut as peanut flowers develop aerially and pods in the soil. Where, the optimum soil temperature for pod formation and development ranged between 31 and 33ºC and soil temperatures above 33ºC significantly reduced the number of mature pod and seed yields. Ketring (1984) indicated that the optimum mean air temperature for vegetative growth of peanut seemed to range between 25 and 30ºC while that for reproductive processes ranged between 20 and 25ºC. Singh et al. (2016) indicated that day temperatures above 35ºC during the reproductive phase reduce seed-set and consequently the number of pods and ultimately reduce seed yield by 55%. Prasad et al. (2021) reported that the seed yield of peanut decreases progressively by 14, 59 and 90% as temperature increased from 32 to 36, 40 and 44ºC, respectively.

One of the best simple agricultural methods to mitigate the negative impact of high temperature on peanut is the application of intercropping system (IS) and subsurface irrigation system (SIS). High temperatures in summer, especially at noon lead to an increase in the percentage of irrigation water lost through evaporation, which reduces the efficiency of the irrigation process and reduces plant growth because of its exposure to thirst quickly, which exposes these plants to damage due to drying of rhizosphere quickly. In this case, the use of SISs with peanut expected to provide adequate moisture around roots and thus reduce soil temperature, allowing the completion of all physiological processes inside plant by high efficiency. Subsurface irrigation (SI) is application of water below the soil surface though burying of percolation lines at a certain depth. Sorensen et al. (2015) found that SI results in 38% more pod yield for peanut compared to surface irrigated treatment. Pods yield of peanut increases by 45% due to using SI compared to the surface irrigation, furthermore water use efficiency was higher when using SI by 46% compared to surface irrigation. Lamm and Trooien (2012) indicated that SIS may increase water use efficiency due to reduced soil and plant surface evaporation and because only the root zone has irrigated as opposed to other irrigation systems, where the entire field area is wetted. Several benefits of SI are reported by Gunarathna et al. (2017) such as; (a) decreasing the rate of evapotranspiration, (b) increasing water use efficiency, (c) improving crop yields and quality, (d) elimination of irrigation run off from sloping fields or hillsides, (f) reducing deep percolation, and (e) improving fertilizer and other chemical applications with minimized leaching and run off the chemicals.

Intercropping is a cropping system, which integrates crop production with soil conservation. Intercropping, the cultivation of two or more crops at the same time in the same field is a common practice, especially in the warm regions. Benefits of intercropping can be brief as; (a) reduction of biotic and abiotic risks by increasing diversity and suppression of weed infestation, (b) improvement of soil fertility by legume components of the system, (c) soil preservation through covering the bare land between the plants which reduces the rate of evapotranspiration, (d) increasing productivity per unit land area, and (e) optimal utilization of natural resources (Emam, 2020). According to Kheroar et al. (2021), the idea of intercropping peanut and sorghum is to boost productivity per unit area of soil, time despite the judicious use of growing resources and reducing various environmental stresses. Gebru (2015) showed that intercropping provides soil cover for the whole year or longer than monoculture farming, this cover protects the soil against drying and erosion under heat stress conditions. Jones (2021) found that intercrop sorghum on peanut led to the protection of peanut from heat stress, as it gave a percentage of shading that led to an increase in the productivity of the land unit of both crops by 40%. Therefore, the objective of the present study is to evaluate the influence of intercropping sorghum with peanut and using SIS under heat stress conditions as one of the factors that mitigate the harmful effect of high temperature on the peanut crop.

MATERIALS AND METHODS

1. Experiment Site

Two field experiments were conducted in Desert Research Center, Agricultural Experiment Station at El-Kharga Oasis, New Valley Governorate, Egypt (27°47.7\ 42\\ N and 30°24.7\ 63\\ E), during the two summer growing seasons of 2021 and 2022, to study the effect of some practices that mitigate the negative impact of heat stress on peanut yield. The physical and chemical soil characteristics of the studied site were determined according to Klute (1986), as recorded in Table (1). As well as the chemical analysis of irrigation water was carried out using the standard method of Page et al. (1982) and is presented in Table (2). The meteorological data of the studied site are presented in Table (3).

Table (1). Physical and chemical properties of the experimental soil.

Season	Particles (%)			Texture	EC (ppm)	pH	P (ppm)	Available ions (meq/l)						
	Sand	Silt	Clay					K	Na	Ca	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$
2021	26.2	39.6	34.2	**Clay loamy**	769	8.8	0.51	2.27	112.3	3.03	2.14	4.65	62.3	1.41
2022	24.5	36.7	38.8		781	8.5	0.57	2.75	96.4	2.84	1.83	4.32	55.7	1.60

Table (2). Analysis of irrigation water.

Season	pH	EC (ds/m)	S.A.R.	Soluble cations (meq/l)				Soluble anions (meq/l)			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	$SO4^{=}$	Cl^{-}
2021	7.84	1.17	4.32	13.68	2.74	14.82	0.41	-	5.43	4.37	9.47
2022	7.79	1.12	3.64	15.32	2.93	14.51	0.45	-	5.69	4.76	10.24

2. Treatments

The experiment included 20 treatments, which were the combinations between the three depths of percolation lines beside control treatment (normal surface irrigation) as SIS and five types of intercropping system (IS) of intercrop peanut with sorghum.

2.1. Subsurface irrigation system (SIS)

In this study, three depths of percolation lines were compared with control and explained as follows:

a. Normal surface irrigation (control)
b. Percolation lines at a depth of 10 cm below the soil surface
c. Percolation lines at a depth of 20 cm below the soil surface
d. Percolation lines at a depth of 30 cm below the soil surface

The used irrigation lines were made of fabric so that water had allowed escaping from the pores in the form of filtration.

2.2. Intercropping system (IS)

Peanut were intercropped with sorghum through five types of ISs as follows:

a. 1 peanut plant: 1 sorghum plant
b. 2 peanut plant: 2 sorghum plant
c. 1 peanut plant: 2 sorghum plant
d. 2 peanut plant: 1 sorghum plant
e. Sole peanut (control)

Therefore, the distances between rows and plants were constant (60 and 25 cm, respectively). Given that, flow meters installed in all irrigation treatments to compute water consumption rates.

Table (3). Meteorological data of the experimental region.

Year	Month	Temp.		Rrelative humidity (%)	Wind speed (meter s^{-1})	Average sunshine (h)	Average solar radiation (MJ/m^2)	Total rain (mm)	Evapotranspiration (mm)
		Max. (°C)	Min. (°C)						
2021	**May**	39.1	23.5	22.0	140.3	12.2	27.3	-	10.1
	June	41.2	25.9	22.6	152.4	13.4	29.7	-	11.6
	July	41.0	24.8	24.7	128.7	13.0	29.4	-	10.7
	August	40.6	23.7	27.3	120.6	12.7	28.1	-	9.5
	September	37.4	22.0	29.5	112.2	11.6	24.6	-	9.2
2022	**May**	39.6	23.1	21.5	143.2	12.0	28.0	-	10.1
	June	41.8	26.5	21.3	155.0	13.3	29.9	-	11.8
	July	41.7	25.4	25.4	124.5	13.1	29.6	-	10.8
	August	40.3	23.9	28.7	118.7	12.6	28.2	-	9.7
	September	38.5	22.4	30.1	106.3	11.4	24.8	-	9.1

Source: Central Laboratory of Agricultural Climate, Cairo, Egypt (2021 and 2022)

3. Experimental Design

A split plot design was used with three replications. Where, main plots were arranged by SIS and the sub plots allotted with ISs treatments. Each experimental unit area in the two seasons was 10.5 m^2 (1/400 fed), consisting of five lines with a width of 60 cm, a length of 3 meters and the distance between plants were 25 cm. All the obtained data for each treatment were subject to analysis of variance according to the method described by Gomez and Gomez (1985). The least significant difference (LSD) was at 5% level of significance.

4. Inoculants Preparation and Inoculation

Rhizobium (Okadeen) were mixed well with 10% sugar solution and were added to peanut seeds which were spread on a clean plastic sheet under shading. Seeds of peanut were soaked in liquid inoculate after being diluted 1: 1 with well water for 30 minutes before sowing.

5. Agricultural Practices

Giza 6 cultivar of peanut (*Arachis hypogaea* L.) was sowing on 1st May, while Dorado cultivar of sorghum was sowing after complete germination of peanut. The previous crop was faba bean in both seasons. During soil preparation, poultry manure was thoroughly mixed with 0-30 cm of the soil surface, two weeks before planting (5 m^3 fed^{-1}), 37.5 kg P_2O_5 were applied, and 100 kg fed^{-1} of mineral sulphur were used. Potassium sulfate (K_2SO_4 48%) was applied after 45 days of sowing at the rate of 50 kg fed^{-1}. Nitrogen fertilizer was added at the rate of 60 kg fed^{-1} that were divided in doses through irrigation, after completion of germination in the form of ammonium sulfate (20.5%). Other cultural practices applied as per the recommendations. Peanut plants were harvested after 146 and 149 days of planting, while sorghum after 137 and 131 days in both seasons, respectively.

6. Measurements

At 50% flowering stage, five random plants were random taken from each plot to estimate the net photosynthesis rate (NPR), transpiration rate (TR), SPAD values determination and leaf area index (LAI). Whereas the third leaf from top was selected to measure each of NPR and TR by using a portable photosynthesis system (LI-6400, LI-COR, Lincoln, NE, USA) and SPAD values by using a SPAD chlorophyll meter (SPAD-502 Chlorophyll Meter Model SPAD-502, Konica Minolta Holding. Japan). The leaf area was recorded using leaf area meter (Li-COR model LI 3000) and expressed as cm^2 $plant^{-1}$. Leaf area index (LAI) was calculated by dividing the total leaf area with the corresponding ground area (Watson, 1952).

At harvest, samples of 5 plants/ plot were taken randomly after 146 and 149 days from sowing in 2020 and 2021 growing seasons, respectively from the middle of plot for every treatment to determine the following characters: 100-seed weight (g), shelling (%), seed yield (kg fed^{-1}), water use efficiency (WUE) as kg m^{-3}, oil seed yield (kg fed^{-1}) and seed protein (%). Whereas shelling percentage was worked out by using the formula as suggested by Beadle (1987), via dividing weight of seeds/ weight of pods x 100. WUE was calculated by using the equation of Vites (1965) as follows: Seed yield (kg fed^{-1})/actual consumptive use (m^3 fed^{-1}). Oil seed yield as kg fed^{-1} was calculated by multiplying oil percentage in the seeds by seed yield as kg fed^{-1}. Lastly, seed protein (%) were determined by using the Kjeldahl method (N%) as described by Peach and Tracey (1956) with a conversion factor of 6.25.

7. Statistical Analysis

All data subjected to statistical analysis according to procedure outlined by Snedecor and Cochran (1990). Means of the different treatments were compared using the least significant difference (LSD) test at $P<0.05$.

RESULTS AND DISCUSSION

1. Effect of Subsurface Irrigation Systems (SISs)

1.1. Growth of peanut

The results tabulated in Table (4) show that all depths taken for SI in peanut had a significant effect on all the studied growth parameters as compared to surface irrigation in both seasons. The lowest values were obtained under surface irrigation, while the highest values occurred when percolation lines were buried at a depth of 30 cm below the soil surface in both seasons. The percentage of increase when percolation lines were buried at a depth of 30 cm on peanut as compared to surface irrigation in NPR were 20.50 and 19.93%, SPAD were 57.82 and 55.34%, LAI were 62.28 and 53.33% in the first and second seasons, respectively. While TR decreased as percentage of 28.99 and 28.20% when percolation lines had buried at a depth of 30 cm below the soil surface as compared to surface irrigation in the first and second seasons, respectively. The highest value of all traits when using SI lines at a depth of 30 cm gave an abundance of irrigation water in a way that included wetting the soil that increased the efficiency of the photosynthesis process and thus increased the net output from the process. The decreasing in TR values causative by this depth of percolation lines may be due to that peanut plants when irrigated by surface irrigation, may be exposed to thirst, and with high temperatures at noon, the rate of transpiration increased.

These results are in harmony with those obtained by Abdel-Wahed (2020), who found that SI at 30 cm enables the direct provision of water to the thin functional absorbing area of the root zone, evaporation and TR decrease therefore, the physiological processes inside the plant improved

Table (4). Effect of subsurface irrigation systems on peanut (*Arachis hypogaea* L.) productivity during 2021 and 2022 growing seasons under heat stress conditions.

Measurements	Growth				Yield and quality						Sorghum
Character / SIS	NPR ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	TR ($mmol\ H_2O\ m^{-2}\ s^{-1}$)	Grain yield ($kg\ fed^{-1}$)	LAI	100 Seeds weight (g)	Shelling %	Seed (yield $kg\ fed^{-1}$)	WUE ($m^3\ fed^{-1}$)	Seed oil %	Seed protein %	Grain yield ($kg\ fed^{-1}$)
2021											
Control	22.34	8.235	31.25	7 1.6	40.36	42.31	801	170.3	40.32	23.13	1104
10 cm	23.56	7.542	38.64	1.95	47.76	51.22	974	0.474	43.26	25.18	1286
20 cm	25.67	6.120	46.21	92.5	50.36	59.43	1108	0.581	49.48	27.65	1425
30 cm	26.92	6.384	49.32	2.71	55.20	63.31	1256	800.6	50.69	28.45	1391
LSD at 5%	**0.78**	**0.184**	**3.25**	**0.14**	**2.01**	**3.25**	**56**	**0.047**	**2.01**	**1.87**	**41**
2022											
Control	22.12	8.114	31.10	.651	39.84	8.941	697	760.3	39.94	22.76	1082
10 cm	23.29	7.451	38.24	1.82	46.25	50.17	962	0.456	41.21	25.00	1273
20 cm	25.45	6.032	45.97	2.44	49.20	58.49	1093	0.571	48.45	27.13	1409
30 cm	26.75	6.329	48.31	2.53	54.34	6.262	1312	0.642	49.07	27.74	1385
LSD at 5%	**0.89**	**0.163**	**2.66**	**30.1**	**2.17**	**2.81**	**62**	**0.042**	**1.16**	**1.31**	**27**

SIS: Subsurface irrigation systems, control: Normal surface irrigation, 10, 20, 30 cm: depths of percolation lines, NPR: Net photosynthetic rate, TR: Transpiration rate, SPAD: Leaves chlorophyll level, LAI: Leaf area index, WUE: Water use efficiency, and LSD: Least significant difference under heat stress conditions. In this respect, Douh et al. (2019) found that SI leads to a greater growth traits making significant water saving of 23.2% rather than surface irrigation. SI makes the plant capable of applying small amounts of water directly to the plant root zone where the water is needed and can be applied frequently to maintain favorable moisture of root zone conditions. Douh and Boujelben (2020) reported that SI could reduce evaporation loss, precise placement, management of water, nutrients and pesticides leading to more efficient water use, greater water application uniformity and enhancing plant growth of many crops under heat stress conditions.

1.2. Yield and quality of peanut

Data illustrated in Table (4) reveal that all the studied traits (100-seed weight, shelling percentage, seed yield, WUE, seed oil and protein percentages) were affected significantly by the depths of SI used in both seasons. The lowest values for these traits were obtained when irrigating peanut with surface irrigation, while the highest ones were obtained when using SI at a depth of 30 cm in both seasons. However, the differences between the depths of 30 and 20 cm were not significant for the percentages oil and protein of seeds in both seasons. The percentages increased when percolation lines were buried at a depth of 30 cm as compared to surface irrigation in 100-seed weight which were 36.77 and 36.40%, shelling percentages were 49.63 and 48.30%, seed yield were 56.80 and 54.65%, WUE were 77.36 and 74.93%, seed oil percentage were 25.72 and 22.86% and seed protein percentage were 23.00 and 21.88% in the first and second seasons, respectively. Improving the productivity of peanuts resulting from the application of the SIS at 30 cm may be due to increasing the WUE, reducing the soil temperature and thus the roots, which leads to improving the physiological processes of plants, thus improving productivity. In this context, Sorensen et al. (2015) found that SI is purported to maximize WUE by reducing soil evaporation, percolation, and runoff and decrease soil surface evaporative losses while decreasing soil surface temperatures. Lamm and Trooien (2012) indicated that SIS may increase WUE due to reduced soil and plant surface evaporation and because only the root zone has irrigated as opposed to other irrigation systems, where the entire area is wetted. Gunarathna et al. (2017) reported that productivity of peanut increases by 45% due to using SI compared to the surface irrigation, furthermore WUE was higher when using SI by 46% compared to surface irrigation and reduced runoff and erosion. This system has the capability of frequently supplying water to the root zone thereby reducing the risk of increasing yield.

1.3. Grain yield of sorghum

Data presented in Table (4) refer that grain yield of sorghum was significantly affected by the depths of SI. Where the depth of 20 cm gave the highest yield, but the difference between this depth and 30 cm was not significant in both seasons. The results indicate that percentage of increase in sorghum yield because of using SI at a depth of 20 cm compared to surface irrigation was 29.08 and 30.22% in first and second season, respectively. The high yield of sorghum with the application of SI at a depth of 20 cm may be due to the important role of SI in supplying the necessary amount of water to sorghum plants. Subsurface drip irrigation method supplies the whole amount of water directly to the effective plant root zone, resulting in a more efficient use of it and avoiding water evaporative losses. Hence, plants more efficiently use the supplied water. Similar results were obtained by Efthimios et al. (2009) and Colaizzi et al. (2016).

2. Effect of Intercropping Systems (ISs)

2.1. Growth of peanut

The obtained data in Table (5) confirm that there are significant differences in the growth parameters of peanut due to intercropping treatments with sorghum. The highest NPR and LAI in peanut were obtained when two peanut plants had grown with one sorghum plant in the two seasons. While the highest content of chlorophyll in the leaves (SPAD) were obtained when growing peanut alone without intercropping, and the lowest content was obtained when growing one peanut plant with two sorghum plants, but the difference between them was not significant in the two seasons. As for the TR, sowing of peanut alone gave the highest rate of transpiration, while the lowest rate was obtained when planting 1 peanut plant: 2 sorghum plants in both seasons. The lowest values of NPR, SPAD and LAI were obtained when sowing peanut alone without intercropping with sorghum while lowest values of TR were when sowing two peanut plants: one plant sorghum in both seasons. NPR, SPAD and LAI values were the highest when two plants of peanut intercropped with one plant of sorghum. However, TR was higher when peanut was planted alone without intercropping with sorghum in both seasons.

The percentages of increase in NPR were 22.86 and 22.54% and LAI were 36.36 and 34.59% when planting 2 peanut plants: 1 sorghum plant compared to planting peanut alone without intercropping (control). As for the percentage of increase in SPAD. because of growing peanut alone without intercropping, it was 27.26 and 25.53% compared to planting it at the rate of one plant: two sorghum plants in the two consecutive seasons. On the other hand, the percentages of decrease in the rate of transpiration in peanut when cultivated with a ratio of 1 plant peanut: 2 sorghum plants were 39.43 and 38.65%. The increase of peanut growth because of intercropping with sorghum might be due to that, plants can obtain effective solar radiation so that the highest possible photosynthesis rate occurs; at the same time, sorghum plant achieved appropriate shading for peanut plants to reduce the temperature, TR and increasing the exchange of CO_2. At the same time, the

Table (5). Effect of intercropping peanut with sorghum on peanut (*Arachis hypogaea* L.) productivity during 2021 and 2022 growing seasons under heat stress conditions.

Measurements	Growth of peanut				Yield and quality of peanut						Sorghum
Character / Intercropping system	NPR (µmol CO_2 m^{-2} s^{-1})	TR (mmol H_2O m^{-2} s^{-1})	SPAD	LAI	100 Seeds weight (g)	Shelling (%)	Seed yield (kg fed^{-1})	WUE (m^3 fed^{-1})	Seed oil (%)	Seed protein (%)	Grain yield (kg fed^{-1})
2021											
1: 1	23.05	7.954	45.68	1.52	46.10	54.18	1014	0.516	47.52	26.42	852
2: 2	26.16	6.741	41.25	1.74	51.72	57.29	1160	0.590	50.74	27.64	997
1: 2	23.87	6.066	39.54	1.59	47.74	51.36	1050	0.535	45.61	24.76	1029
2: 1	26.98	7.471	49.36	1.80	53.66	60.49	1181	0.601	54.38	28.49	824
Control	21.96	8.458	50.32	1.32	42.72	48.15	408	0.428	42.24	23.47	0
LSD at 5%	0.73	0.362	1.20	0.06	0.64	2.02	02	0.015	1.01	0.74	18
2022											
1: 1	22.88	7.938	44.74	1.51	45.76	54.09	1007	0.507	47.11	26.10	844
2: 2	26.03	6.697	40.46	1.74	51.66	56.84	1159	0.574	50.42	27.51	986
1: 2	23.76	6.031	39.76	1.58	47.52	50.76	1045	0.529	44.93	24.14	1012
2: 1	26.80	7.324	48.20	1.79	53.01	59.80	1177	0.581	53.67	27.71	816
Control	21.87	8.362	9149.	1.33	42.64	7847.	368	0.423	42.13	23.22	0
LSD at 5%	**0.81**	**0.321**	**0.84**	**0.06**	**0.51**	**1.75**	**17**	**0.014**	**1.24**	**1.17**	**19**

Intercropping system, 1: 1: 1 peanut plant: 1 sorghum plant and so on, control: Peanut only, NPR: Net photosynthetic rate, TR: Transpiration rate, SPAD: Leaves chlorophyll level, LAI: Leaf area index, WUE: Water use efficiency, and LSD: Least significant difference presence of sorghum plant next to peanut can cause a decrease in the temperature of the plant and soil, so the rate of transpiration decreases, and thus LAI, SPAD and all other physiological processes are improved. These results were supported by Begum et al. (2016), Langat et al. (2006), Molla and Getachew (2018) and El-Aref et al. (2019).

2.2. Yield and quality of peanut

The performance of peanut under intercropping treatments with sorghum in respect to yield and its components are given in Table (5). Results show that all studied traits were significantly affected by the intercropping treatments in both seasons. The highest values were obtained when planting 2 peanut plants: 1 sorghum plant, while the lowest was when planting peanut alone without intercropping (control) in both seasons. The percentage of increase in 100-seeds weight was 25.61 and 24.32%, shelling percentages was 25.63 and 24.92%, seed yield was 40.6 and 39.54%, WUE was 40.42 and 37.35%, seed oil was 28.74 and 27.39% and protein percentage was 21.39 and 19.34% when planting 2 peanut plants: 1 sorghum plant compared to planting peanut alone without intercropping (control) in both seasons, respectively. This means intercropping of peanut with sorghum at the rate of 1: 2 plants had a higher yield and hence competition for soil moisture and nutrients could have been high yields of peanut than the other intercropping treatments. Many research workers reported about the effectiveness of intercropping peanut and sorghum in increasing yield, among them are El-Naggar et al. (2012), Zohary and Abd El-All (2016) and El-Aref et al. (2019) recorded significant effects of different intercropping systems on yield of many crops. Langat et al. (2020) reported that the highest peanut seed yield (1352 kg fed^{-1}) was obtained due to intercropping two peanut rows alternated with one sorghum row, which considered the best combination (pattern) to use.

2.3. Grain yield of sorghum

Data illustrated in Table (5) indicate that grain yield of sorghum was significantly affected by treatments of intercropping. Where the intercropping of peanut at the rate of 1 plant: 2 sorghum plants gave the highest grain yield (1029 and 1012 kg fed^{-1}). The lowest grain yield (824 and 816 kg fed^{-1}) was obtained when sowing 2 plants of peanut: 1 plant of sorghum in the first and second seasons, respectively. Increasing of sorghum yield may be due to that peanut root nodules can fix high amount of atmospheric nitrogen and enhances the growth of sorghum plants. El-Aref et al. (2019) found that cultivation of peanut in two rows and one raw of sorghum gave 66% increasing than cultivation of one plant alone.

3. Effect of the Interaction Between the Two Studied Factors (SIS and TR)

3.1. Growth of peanut

Results in Table (6 a and b) indicate that the interaction between SI and IS systems had a significant effect on all the studied growth characters. The highest values of the studied traits were obtained when irrigation of peanut was applied by SI at a depth of 30 cm and intercropped with sorghum at the rate of 2: 1 plant for NPR and LAI, while the lower values were obtained by the two control treatments in both seasons. Furthermore, the highest values of SPAD were performed under SI at 30 cm depth and growing peanut alone without intercropping with sorghum (control), the lower at surface irrigation (control) and sowing of peanut intercropped on sorghum in the ratio of 1 peanut plant: 2 sorghum plants in the two seasons. Whereas the highest values of TR were achieved in control treatments of the two studied factors and the lowest values when peanut was irrigated by SI at a depth of 30 cm and intercropped with sorghum at the rate of 2: 1 plants in both seasons.

3.2. Yield and quality of peanut

Results in Table (6 a and b) show that the interaction between SI and IS systems had a significant effect on all the studied parameters of yield and quality of peanut in the two growing seasons. The lowest values of all studied traits resulted from the two control treatments for the two study factors. Whilst the highest values were obtained when using SI at a depth of 30 cm and intercropping at the rate of 2 peanut plants: 1 sorghum plant in both seasons.

3.3. Grain yield of sorghum

Obtained data in Table (6 a and b) show that sorghum grain yield was significantly affected by the interaction between SI and ISs. The highest grain yield was produced when applying SI at a depth of 20 cm and intercropping peanut with sorghum at the rate of 1 peanut plant: 2 sorghum plants in the two seasons. By contrast, the lowest values were produced at control treatment (surface irrigation) for the first factor and the control treatment (peanut cultivation alone) for the second factor in each of the two seasons.

CONCLUSION

The results recommend applying a SIS for peanuts at a depth of 30 cm, as the seed yield increased by 56.8 and 54.65% and the WUE increased by 77.36 and 74.93% compared to surface irrigation (control) in the first and second seasons, respectively. The results also recommend intercropping peanuts with sorghum at a ratio of 2 peanut plants: 1 sorghum plant, where the percentages of increase in seed yield were 40.60 and 39.54%, and WUE

Table (6 a). Effect of the interaction between subsurface irrigation systems and intercropping peanut with sorghum on peanut (*Arachis hypogaea* L.) productivity during 2021 growing season under heat stress conditions.

Measurements		Growth				Yield and quality						Sorghum
SIS x IS	Character	NPR (μmol CO_2 m^{-2} s^{-1})	TR (mmol H_2O m^{-2} s^{-1})	SPAD	LAI	100 Seeds weight (g)	Shelling %	Seed yield (kg fed^{-1})	WUE %	Seed oil %	Seed protein %	Grain yield (kg fed^{-1})
SIS	Intercropping					2021						
Control	1: 1	22.70	8.095	38.47	1.41	43.23	48.25	908	0.419	43.92	23.98	978
	2: 2	24.25	7.488	36.25	1.51	46.54	49.80	981	0.456	45.53	24.44	1051
	1: 2	23.11	7.151	35.40	1.43	44.05	46.84	926	0.428	42.97	23.00	1067
	2: 1	24.66	7.853	40.31	1.54	47.01	51.40	991	0.461	47.35	25.36	964
	Control	21.85	8.347	40.79	1.30	41.54	45.23	821	0.375	41.28	21.85	552
10 cm	1: 1	23.31	7.748	42.16	1.75	46.93	52.70	994	0.495	47.39	25.95	1069
	2: 2	24.86	7.142	39.95	1.85	50.24	54.26	1067	0.532	49.00	26.41	1142
	1: 2	23.72	6.804	39.09	1.77	47.75	51.29	1012	0.505	46.44	24.97	1158
	2: 1	25.27	7.507	44.00	1.88	50.71	55.86	1078	0.538	50.82	27.34	1055
	Control	22.46	8.000	44.48	1.64	45.24	49.69	907	0.451	44.75	23.83	643
20 cm	1: 1	24.36	7.037	45.95	2.07	48.23	56.81	1061	0.549	50.50	28.19	1139
	2: 2	25.92	6.431	43.73	2.17	51.54	58.36	1134	0.586	52.11	28.65	1211
	1: 2	24.77	6.093	42.88	2.09	49.05	55.40	1079	0.558	49.55	27.21	1227
	2: 1	26.33	6.796	47.79	2.20	52.01	59.96	1145	0.591	53.93	29.57	1125
	Control	23.52	7.289	48.27	1.96	46.54	53.79	974	0.505	47.86	26.06	713
30 cm	1: 1	24.99	7.169	47.50	2.13	50.65	58.75	1135	0.587	52.06	29.10	1122
	2: 2	26.54	6.563	45.29	2.23	53.96	60.30	1208	0.624	53.67	29.56	1194
	1: 2	25.40	6.225	44.43	2.15	51.47	57.34	1153	0.597	51.10	28.12	1210
	2: 1	26.95	5.928	49.64	2.26	54.43	61.90	1219	0.630	55.49	30.49	1108
	Control	24.14	7.421	49.82	2.02	48.96	55.73	1048	0.543	49.42	26.98	696
LSD at 5%		**0.14**	**0.024**	**0.36**	**0.02**	**0.41**	**0.62**	**9**	**0.012**	**0.55**	**0.14**	**10**

SIS: Subsurface irrigation systems, IS: intercropping system, control of TSS: Normal surface irrigation, 10, 20, 30 cm: depths of percolation lines, 1: 1: 1 peanut plant: 1 sorghum plant and so on, control of intercropping: peanut only, NPR: Net photosynthesis rate, TR: Transpiration rate, SPAD: Leaves chlorophyll level, LAI: Leaf area index, WUE: Water use efficiency, and LSD: Least significant difference

Table (6 b). Effect of the interaction between subsurface irrigation systems and intercropping peanut with sorghum on peanut (*Arachis hypogaea* L.) productivity during 2022 growing season under heat stress conditions.

Measurements		Growth				Yield and quality						Sorghum
SIS x IS	Character	NPR (µmol CO_2 m^{-2} s^{-1})	TR (mmol H_2O m^{-2} s^{-1})	SPAD	LAI	100 Seeds weight (g)	Shelling %	Seed yield (kg fed^{-1})	WUE %	Seed oil %	Seed protein %	Grain yield (kg fed^{-1})
SIS	**Intercropping**					**2022**						
	1: 1	22.50	8.056	37.92	1.36	42.80	47.84	897	0.412	43.115	23.58	963
	2: 2	24.08	7.436	35.78	1.47	46.25	49.21	973	0.446	44.770	24.14	1034
Control	**1: 2**	22.94	7.103	34.63	1.39	43.68	46.17	916	0.423	42.025	22.45	1047
	2: 1	24.46	7.749	39.65	1.49	46.67	50.84	982	0.454	46.495	24.94	949
	Control	21.70	8.268	40.46	1.24	41.19	44.63	811	0.365	40.575	21.44	541
	1: 1	23.09	7.695	41.49	1.68	46.01	52.13	985	0.482	46.160	25.70	1059
	2: 2	24.66	7.074	39.35	1.78	49.46	53.51	1061	0.515	47.815	26.26	1130
10 cm	**1: 2**	23.53	6.741	38.20	1.70	46.89	50.47	1004	0.493	45.070	24.57	1143
	2: 1	25.05	7.388	43.22	1.81	49.88	55.14	1070	0.524	49.540	27.06	1045
	Control	22.28	7.907	44.03	1.55	44.40	48.92	899	0.435	43.620	23.56	637
	1: 1	24.17	6.985	45.36	1.99	47.48	56.29	1050	0.539	49.780	27.77	1126
20 cm	**2: 2**	25.74	6.365	43.22	2.09	50.93	57.67	1126	0.573	51.435	28.32	1197
	1: 2	24.61	6.032	42.07	2.01	48.36	54.63	1069	0.550	48.690	26.64	1210
	2: 1	26.13	6.678	47.09	2.12	51.35	59.30	1135	0.581	53.160	29.12	1112
	Control	23.36	7.197	47.90	1.86	45.87	53.08	965	0.492	47.240	25.63	704
	1: 1	24.82	7.096	46.53	2.08	50.05	58.53	1124	0.575	51.190	28.43	1115
	2: 2	26.39	6.476	44.39	2.19	53.50	59.90	1200	0.608	52.845	28.99	1186
30 cm	**1: 2**	25.26	6.143	43.24	2.11	50.93	56.86	1143	0.586	50.100	27.30	1199
	2: 1	26.78	6.789	48.26	2.21	53.92	61.53	1209	0.617	54.570	29.79	1101
	Control	24.01	7.308	49.07	1.96	48.44	55.32	1039	0.528	48.650	26.29	693
LSD at 5%		**0.11**	**0.033**	**0.29**	**0.02**	**0.38**	**0.84**	**8**	**0.010**	**0.38**	**0.12**	**9**

were 40.42 and 37.35% compared to sowing peanuts alone without intercropping (control) in both seasons, respectively.

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مقاومة الفول السوداني للإجهاد الحراري من خلال الري تحت السطحي والتحميل مع السورجم تحت ظروف الوادي الجديد

حسام الدين أحمد شومان
قسم الإنتاج النباتي، مركز بحوث الصحراء، المطرية، القاهرة، مصر

أقيمت تجربتان حقليتان بالمزرعة البحثية بالخارجة التابعة لمركز بحوث الصحراء بمحافظة الوادي الجديد خلال موسمي ٢٠٢١ و٢٠٢٢ لدراسة تأثير تحميل السورجم على الفول السوداني واستخدام الري تحت السطحي تحت ظروف الإجهاد الحراري على إنتاجية وجودة الفول السوداني بالوادي الجديد .أشارت النتائج إلى أن جميع قياسات الفول السوداني المدروسة قد زادت نتيجة تطبيق نظام الري تحت السطحي وأنظمة الزراعة البينية (التحميل) في كلا الموسمين. توصي النتائج بتطبيق نظام الري تحت السطحي للفول السوداني على عمق ٣٠ سم, حيث زادت كمية محصول البذور بنسبة ٥٦.٨ و٥٤.٦٥٪ وكفاءة استخدام الماء بنسبة٧٧.٣٦ و٧٤.٩٣٪ في الموسمين الأول والثاني على التوالي نتيجة تطبيق هذه المعاملة مقارنة بالري السطحي (كنترول). كما توصى النتائج بتحميل الفول السوداني مع السورجم بمعدل ٢ نبات فول سوداني: ١ نبات سوجم، حيث كانت نسب الزيادة في محصول البذور ٤٠.٦ و٣٩.٥٤٪ وWUE كانت ٤٠.٤٢ و٣٧.٣٥٪ مقارنة بزراعة الفول السوداني بمفرده بدون تحميل (كنترول) في كلا الموسمين على التوالي.