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Response of weeds and maize (*Zea mays* L.) to some weed control treatment under different plant density

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A R T I C L E I N F O

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A B S T R A C T

Plant density and weed control treatments for annual weeds and their influences on yield traits in maize plants were studied during 2020 and 2021 seasons at the farm of Agriculture College, Demo, Fayoum Governorate, Egypt. Plant densities exhibited significant differences in dry annual weeds weight. Plant density 23333 plant feddan^{-1} produced the heaviest dry weight of total annual weeds (641.16 and 582.76 g m^{-2}). Regarding weed control efficiency (WCE %), 23333 plant feddan^{-1} was the maximum and produced values reached to (20.14 and 5.15 %). Weed control treatments had a highly significant effect on dry weight of weeds and WCE %. Hand hoeing gave the lowest dry weight of total annual weed (224.62 and 130.06 g m^{-2}) and produced the maximum WCE% (74.60 and 84.83 %). Plant densities and weed control treatments had significant effect on leaf area index (LAI), plant and ear height, ear dimensions, number of rows and grains row^{-1}, 100-grain weight, ear weight and grain and biological yield on both seasons. 35000 plant feddan^{-1} gave the maximum in grain yield 1.80 and 2.05 ton feddan^{-1} and biological yield 4.66 and 4.46 tons feddan^{-1}. For grain yield, hand hoeing produced 2.16 and 2.24 tons feddan^{-1}, Active herbicides produced 1.73 and 1.90 tons feddan^{-1} and Equip herbicides produced 1.67 and 1.72 tons feddan^{-1}. The maximum value of grain yield (2.28 and 2.54 tons feddan^{-1}) was produced by 35000 plant feddan^{-1} with hand hoeing.

1. Introduction

Maize (*Zea mays* L.) is considered one of the world's most important cereal crops, ranks 3rd after wheat and rice and plays an essential role in the economy [1]. Maize is namely as Queen of cereals because it has plants of its highest genetic yield potential. Maize plants are the only cereal crop that can be grown in different ecologies and seasons. Maize considers a C4 plant because it can use solar radiation more efficiently even at higher radiation intensity. Maize is considered a multipurpose crop, used as food for man and feed for animals and poultry and in raw materials for fructose, starch, maize oil, dextrin, and glucose.

In Egypt, maize is the only crop that covers all the cultivated areas with hybrids. The cultivated area is about 1.8 million hectares, with single and triple hybrid varieties, whether white or yellow. Egypt ranks 14th among the top 20 countries in the production of maize in the world and fourth in Africa, after South Africa, Nigeria, and Ethiopia.

Plant density plays a major role in the competition between weeds and maize plants. The competition for growth factors (water, light, and nutrients) in maize by weeds may include technique systems such as increased planting density and reduced row spacing that clearly show weeds suppressive potential. The high plant density reduces weed growth and increases crop production [2]. Higher plant density leads to increase plant competition for growth factors. Despite this, lower plant density reduces the plant population, but leads to improve vegetative growth. Finally, it provides suitable conditions for the weed's growth, thereby decreasing production. Youngerman *et al.* [3] at different experimental sites, found a negative relationship between weed biomass and maize plants densities when weed biomass would minimize as maize density increased. Acciares and Zuluaga [4] found that the higher plant density registered a lower dry matter of weeds and maize yield was maximum.

Weeds plants are considered as an important limiting element for crop production [5]. Weed plants spread and grow more quickly then it reproduce in high numbers and produce super quantities of seeds that make them able to start a kingdom with a short period [6]. Among the biotic stress factors, weeds plants are one of the major factors causing reduce the yield because of the competition between weeds and maize plants for

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nutrients, water and light. Weed control must be done at the earlier periods of growth. The main challenge in yielding higher maize productivity is linked with control of weed growth [7]. Weed mechanical control is not suitable control in maize plants plantations, that it requires a high amount of labor and is high costs, for the aforementioned reason of labor and costs in maize areas, weed chemical control methods are preferred because of their easy application, low cost and fast results [8]. Weeds plants not only decrease crop production but also harbor pests, diseases and insects [9]. Weed must be managed to avoid yield losses. Although, in Egypt the high yield of maize cultivation areas, the yield is still very low compared with advanced countries. In spite of, many high yielding of maize varieties have been developed, the required yield still cannot be done. Therefore, the aim of the research work was to study the effect of plant density, weed control and their interaction on yield and yield components of maize and its associated weeds.

2. Materials and Methods

Two successive field trials were conducted for the 2020 and 2021 summer seasons at the farm of Agriculture College, Demo (29 ∘ 170 N, 30 ∘ 530 E), Fayoum Governorate, Egypt, to assess the effect of plant densities and weed control treatments on weeds and their influences on yield and yield components for maize crop under Fayoum conditions.

2.1. Treatments

In the current study, the treatments were designed in two factors (plant density and weed control treatments). The plant densities (D) were desined in three levels i.e., D_1; 23333 plants feddan^{-1} (planting on one side of ridges, 60 cm width and 30 cm between hills), D_2; 28000 plants feddan^{-1} (planting on one side of ridges, 60 cm width and 25 cm between hills), and D_3; 35000 plants feddan^{-1} (planting on one side of ridges, 60 cm width and 20 cm between hills). While, weed control treatments (W) were desined in four levels i.e., W_1; Weedy check (un-weeded), W_2; Equip 2.25% OD, (Foramsulfuron), Benzamide, 2-[[[[(4, 6-dimethoxy-2-pyrimidinyl] amino] carbonyl] amino] sulfonyl] -4- (formylamino)-N, N-dimethyl, W_3; Active 6% SC, (Nicosulfuron), 2-[[[[(4, 6-Dimethoxy-2-pyrimidinyl) amino] carbonyl] amino] sulfonyl]- A, A-dimethyl-3-pyridinecarboxamide, and W_4; Hand hoeing was practiced two times at 21 and 42 days after planting (DAP). In addition Equip 2.25% and Active 6% herbicides were sprayed on the maize plants as post-emergence application, at 750 and 400 cm^3 feddan^{-1} rates, respectively.

2.2. Analysis of the Soil characteristics

The current study was carried out in a Sandy loam soil. The Physical and chemical analyses of the used soil before planting at the experimental site in both successive seasons are presented in the Table 1.

Table 1: Physical and chemical analysis of soil (0- 40 cm depth) before planting at the experimental site in both successive seasons of study.

Physical analysis			Chemical analysis		
	2020	2021		2020	2021
Coarse sand (%)	59.5	58.3	Ece (dS m^{-1})	6.12	6.61
Fine sand (%)	15.6	14.8	PH	7.54	7.51
Loam (%)	13.8	15.2	Organic matter (%)	1.09	1.11
Clay (%)	11.1	11.7	Available N (ppm)	527	546
Texture class	Sandy loam	Sandy loam	Available P (ppm)	5.19	5.39
			Available K (ppm)	141	145

2.3. Cultural practices

The *Zea mays* variety "cv. Single-cross 2055" was used as a planting material in the both seasons. Planting took place on 11th of May in both seasons. Completely Randomized Block Design (split plot) with three replications was used, plant densities were arranged randomly in the main plots and weed control treatments in the subplots. The sub plot area was 10.5 m^2 and consisted of five ridges of 3.5 m in length and 60 cm in width. The field experimental was irrigated immediately after planting. Seedlings were thinned on one plant per hill before the first irrigation. The first irrigation was applied after three weeks from planting and the following irrigation were applied at two weeks intervals during the growing seasons. Nitrogen fertilizer was applied in the form of ammonium nitrate (33.5% N) at the rate of 120 kg N feddan^{-1}, splatted into four equal doses, the first was applied after thinning), the second, third and fourth doses were applied before the following irrigation. Single Calcium super phosphate (15.5% P_2O_5) was applied at the rate of 200 kg feddan^{-1} before ridging. Potassium fertilizer was applied in the form potassium sulphate (48% K_2O) at the rate of 24 kg K_2O feddan^{-1}., applied during the field experimental preparation. In both seasons, the preceding crop was (*Trifolium alexandrinum* L.). The normal cultural practical of growing maize plants was practiced as recommended by the Ministry of Agriculture for maize crop.

2.4. Data recorded for weeds:

To measure the dry weight of weeds biomass (broad and narrow leaves and total annual weeds) in g m^{-2} in each subplot, weeds were manually removed from an area of one square meter at 65 days after planting. Then, they were categorized into annual broad and narrow weeds. The total weeds were air-dried for 5 days, then, dried in the oven at 105 ∘C for 48 h until they reached a constant weight. The dry weight of total weeds (g m^{-2}) was registered for each weed group. The family, common, and scientific names of weeds (broad and narrow leaves) registered in the maize field during the 2020 and 2021 summer seasons are showed in Table 2.

Weed control efficiency % (WCE %) was determined as following formula:

$$(\text{WCE \%}) = \left(\frac{(\text{WDC} - \text{WDT})}{\text{WDC}}\right) x\ 100$$

Where, WDC= weed dry weight in weedy check, WDT= weed dry weight in treated plots.

The following data were recorded for weeds; dry weight of annual broad leaves weeds (g m^{-2}), dry weight of annual narrow leaves weeds (g m^{-2}), dry weight of total annual weeds (g m^{-2}), and weed control efficiency (WCE %). At harvest stage (after 125 planting days) a random sample of five guarded maize plants was taken from each sub plot to determine yield and yield traits as the following; leaf area index (LAI) using the formula of

LAI = leaf area per plant (cm^2)/plant ground area (cm^2), plant height (cm), ear height (cm), ear length (cm), ear diameter (cm), number of rows ear^{-1}, number grains row^{-1}, 100- grain weight (g), ear weight (g), grain yield (ton $feddan^{-1}$), and biological yield (ton $feddan^{-1}$).

Table 2. Family, common, and scientific names of weeds registered in the maize field during the 2020 and 2021summer seasons.

No	Type of weeds	Family	Scientific Name	Common Name
1	Annual broad leaves	Asteraceae	*Xanthium brasilicum*	Common cocklebur
2		Portulacaceae	*Portulaca oleraceae*	common purslane
3		Malvaceae	*Hibiscus trionum*	Venice mallow
1	Annual Narrow leaves	Poaceae	*Echinochloa colonum*	Jungle rice
2			*Digitaria sanguinalis*	Large crabgrass

2.5. Statistical Analysis

All obtained parameters were statistically analyzed by the analysis of variance (ANOVA) technique for the study in a completely randomized block design (spilt-plot) by using M-STAT-C (Michigan, USA). The comparisons between means were performed by using least significance difference test at a ($p \leq 0.05$) probability level.

3. Results and discussion

3.1. Effect of plant densities (D) on weeds:

The data in Table (3) showed that plant densities (D) exhibited significant differences in *Xanthium brasilicum*, *Portulaca oleraceae* and *Hibiscus trionum* as an annual broad leaf weed, *Echinochloa colonum* and *Digitaria sanguinalis* as an annual narrow leaf weed in both seasons. According to List Significant Differences (LSD 5%) test, the lowest plant density (D_1) produced significantly the heaviest dry weight of broad (413.14 and 413.67 g m^{-2}), narrow-leaves (228.02 and 169.08 g m^{-2}) and total annual weeds (641.16 and 582.76 g m^{-2}) in both seasons than the other plant densities. Regarding weed control efficiency (WCE %) as affected due to the plant densities, D_1 was the maximum and produced values reached to (20.14 and 5.15 %) higher than 35000 plant $feddan^{-1}$ in both seasons.

The heaviest dry weight of weeds under low plant densities may be due to planting at wide distances between maize plants, which allows for wide intervening distances between maize plants that encourage the growth of weeds. The dry total annual weeds are reduced probably of the improved competitiveness of the maize plants and increased the intensity of the shading. The variation among dry weight of broad and narrow-leaves, and total annual weeds in plant densities was noted by many studies among them, noted that the weed dry weight usually decreases as maize crop density increase [10, 11].

Table 3: Effect of plant density (D) and weed control treatments (W) on dry weight of broad, narrow-leaved, and total annual weeds (g) and weed control efficiency % (WCE %) and that accompaniment to maize (*Zea mays* L.) in 2020 and 2021 seasons.

Treatments		2020 Season				2021 Season			
Plant Density (D)	Weed control treatments (W)	Broad leaves weeds	Narrow leaves weeds (g m^{-2})	Total annual weeds	WCE %	Broad leaves weeds	Narrow leaves weeds (g m^{-2})	Total annual weeds	WCE %
(D_1)	(W_1)	744.22	341.00	1085.22	0.00	783.95	320.81	1104.75	0.00
	(W_2)	462.53	225.34	687.87	36.12	439.82	174.76	614.58	44.22
	(W_3)	243.20	248.77	491.97	54.21	283.50	130.79	414.29	62.41
	(W_4)	202.60	96.98	299.58	72.39	147.43	49.98	197.41	82.10
	Mean	413.14	228.02	641.16	40.68	413.67	169.08	582.76	47.18
(D_2)	(W_1)	590.34	265.01	855.34	0.00	581.76	251.13	832.89	0.00
	(W_2)	375.55	252.20	627.75	26.64	273.74	125.70	399.44	51.83
	(W_3)	235.27	236.54	471.80	44.78	322.04	163.32	485.36	42.06
	(W_4)	179.68	46.96	226.63	73.52	40.29	10.88	51.17	93.90
	Mean	345.21	200.18	545.38	36.23	304.46	137.76	442.21	46.95
(D_3)	(W_1)	446.79	220.92	667.71	0.00	443.99	214.64	658.63	0.00
	(W_2)	242.33	233.67	476.00	28.74	215.25	96.38	311.63	52.91
	(W_3)	279.46	194.19	473.65	28.80	279.46	62.52	341.98	48.07
	(W_4)	114.46	33.18	147.63	77.90	121.67	19.92	141.59	78.48
	Mean	270.76	170.49	441.25	33.86	265.09	98.36	363.46	44.87
Means of W	(W_1)	593.78	275.64	869.42	0.00	603.23	262.19	865.42	0.00
	(W_2)	360.14	237.07	597.21	30.50	309.60	132.28	441.88	49.65
	(W_3)	252.64	226.50	479.14	42.60	295.00	118.87	413.87	50.85
	(W_4)	165.58	59.04	224.62	74.60	103.13	26.92	130.06	84.83
LSD (5 %) For:	D	55.07**	39.85**	63.67**	2.47*	164.54*	90.46*	188.09**	2.19*
	W	68.81**	22.10**	76.86**	8.64**	79.57**	44.35**	80.00**	8.68**
	D× W	48.66**	15.63**	54.35**	6.11**	56.27**	ns	56.58**	6.14**
CV%		14.17	7.82	10.01	15.52	16.15	14.75	12.21	13.24

D_1 = 23333 plants fed^{-1}, D_2 = 28000 plants fed^{-1}, D_3 = 35000 plants fed^{-1} , W_1=Weedy check, W_2 = Equip, W_3 = Active, and W_4 = Hand hoeing.

3.2. Effect of weed control treatments (W) on weeds

Weed control treatments (W) had a highly significant effect on dry weight of broad and narrow-leaves, and total annual weeds as well as weed control efficiency % (WCE %) in both seasons. LSD 5% test reported that hand hoeing (W_1) gave significantly the lightest broad leaves weed (165.58 and 103.13 g m^{-2}), narrow leaves weed (59.04 and 26.92 g m^{-2}), total annual weed (224.62 and 130.06 g m^{-2}) and weed control efficiency (74.60 and 84.83 %) in both seasons. In 2020 and 2021 seasons, the tested weed control treatments exhibited reduced weed dry weight values, where the reduction reached to (39.35 and 48.68 %) for broad leaves weed, (13.99 and 49.55 %) for narrow leaves weed and (31.31 and 48.94 %) for total annual weed, respectively, with Equip 2.25 % OD Foramsulfuron herbicides (W_2), comparable with weedy check treatment. The reduction reached to (57.45 and 51.07 %) for broad leaves weed, (17.83 and 54.66 %) for narrow leaves weed and (44.89 and 52.18 %) for total annual weed, respectively, with Active 6 % SC Nicosulfuron herbicides (W_3), comparable with weedy check treatment. The reduction reached to (72.11 and 82.90 %) for broad leaves weed, (78.58 and 89.73 %) for narrow leaves weed and (74.16 and 84.97 %) for total annual weed, respectively, with hand hoeing comparable with weedy check treatment. Similar results have been noted that herbicides have significantly reduced the dry annual weed biomass in maize plant [12-15].

The lightest weed dry weight and the maximum weed control efficiency (WCE %), might be due to the effective controls of weeds. Also, dense maize plants canopy might have reduced weed growth and finally less weed dry weight. The weedy check treatment produced significantly highest weed dry weight and minimum control efficiency owing to untreated condition favored maximum weed growth.

3.3. Effect of interactions (D x W) on weeds

The interaction between D x W was a highly significant with respect to broad leaves weed, total annual weed and WCE % in the 1st and 2nd seasons. The same interaction was a highly significant with respect to narrow weed leaves in the 2020 season only. Results in Table (3) indicated that the maximum values of broad leaves weed (744.22 and 783.95 g m^{-2}) and total annual weed (1085.22 and 1104.75 g m^{-2}) in both seasons respectively, as well as narrow leaves weed (341.00 g m^{-2}) in the 2020 season were produced by D_1 and W_1 of weed control treatments. Regarding WCE data in Table (3) indicated that the maximum value (77.90 %) was produced by D_3 and W_4 of weed control treatments in the first season but the maximum value (93.90 %) was produced by D_2 and W_4 in the second one. Maize annual weed control by hand hoeing or herbicides as controls treatments was improved in the higher plant density compared to lowest one. Similar observation was agreed with Abouziena *et al.* [11] who noted that the weed biomass usually decrease as maize crop density increase with applied of the weed control treatments.

3.4. Effect of plant densities (D) on yield and yield components

Data presented in Tables (4 and 5), plant densities (D) had a significant effect on leaf area index (LAI), plant height, ear height, ear length, ear diameter, number of rows ear^{-1}, number of grains row^{-1}, 100-grain weight, ear weight and grain and biological yield on both seasons of the experimental.

According to least significant differences (LSD) test indicated that 35000 plant $feddan^{-1}$ (D_3) produced the maximum LAI (6.40 and 5.38), higher plant height (206.01 and 208.23 cm) with increase (12.35 and 14.51 %), higher ear height (85.08 and 88.03 cm) with increase (24.01 and 15.18 %), enhanced grain yield from 1.60 to 1.80 tons $feddan^{-1}$ and from 1.45 to 2.05 tons $feddan^{-1}$ with increase 12.5 and 41.38 %, improved biological yield from 3.92 and 3.59 tons $feddan^{-1}$ to 4.66 and 4.46 tons $feddan^{-1}$ compared with 23333 plant $feddan^{-1}$ (D_1) in the 1st and 2nd seasons respectively.

On the contrary, the data indicated that decrease plant density from 35000 (D_3) to 23333 (D_1) plant $feddan^{-1}$ tended to increase ear length with 7.24 to 11.70 %, improved ear diameter (4.06 and 4.10 cm), produced the higher number of rows ear^{-1} (15.66 and 15.55), showed the highest number grains row^{-1} from (36.28 and 36.64) with increase 57.74 and 44.76, produced the heaviest 100-grain weight (23.42 and 25.13 g) with increase (20.10 and 27.82 %), gave the highest ear weight 166.13 and 168.44 in both seasons respectively. The increase in grain yield may be due to an increase in the ear length and diameter, number of rows ear^{-1}, number of grains row^{-1}, 100-grain weight and ear weight which produced by highest plant density. Similar results were illustrated [16-21].

3.5. Effect of weed control treatments (W) on yield and yield components

The results regarding LAI, plant height, ear height, ear length, ear diameter, number rows ear^{-1}, Number of grains row^{-1}, 100-grain weight, ear weight, grain and biological yield of maize crop as affected by weed control treatments were noted a highly statistically a significant difference in both seasons (Tables 4 and 5). The maximum leaf area index was observed with hand hoeing (W_4) gave (6.52 and 6.32), Active herbicides (W_3) gave (5.96 and 5.16), Equip herbicides (W_2) gave (4.98 and 4.08), the highest plant height was obtained from hand hoeing (W_4) with an average of 237.83 and 231.88 cm, Active herbicides (W_3) with an average of 207.91 and 212.36 cm, Equip herbicides (W_2) with an average of 193.11 and 197.41 cm, the highest ear height was obtained from hand hoeing (W_4) with an average of 90.99 and 96.99 cm, Active herbicides (W_3) with an average of 81.49 and 92.60 cm, Equip herbicides (W_2) with an average of 77.89 and 85.86 cm, the highest ear length was obtained from hand hoeing (W_4) with an average of 22.54 and 23.18 cm, Active herbicides (W_3) with an average of 20.51 and 20.64 cm, Equip herbicides (W_2) with an average of 19.78 and 19.40 cm, the thickest values of ear diameter were produced by hand hoeing (W_4) gave 4.17 and 4.18 cm with increase 33.23 and 31.86 %, Active herbicides (W_3) gave 3.87 and 3.88 cm with increase 23.64 and 22.40, Equip herbicides (W_2) gave 3.58 and 3.65 cm with increase 14.38 and 15.14 % increase in comparison with the weedy check (W_1) in both seasons respectively.

Our results show (Table 5) the significant increase of number rows ear-1 in the hand hoeing (W_4) with 36.08 and 35.17 %, Active herbicides (W_3) with 21.84 and 25.37 %, Equip herbicides (W_2) with 11.25 and 13.10 % increase in comparison with the weedy check (W_1) in both seasons respectively. Hand hoeing (W_4), Active herbicides (W_3) and Equip herbicides (W_2) gave significantly the highest number of grains row^{-1} 39.23 and 41.00, 30.70 and 33.11, 28.67 and 30.93 grains row^{-1}, while weedy check (W_1) gave significantly the lowest one 20.22 and 20.81 grains row^{-1} in the 2020 and 2021 seasons respectively. The heaviest 100-grain weight was produced by hand hoeing (W_4) with an average of 24.83 and 25.45 g, Active herbicides (W_3) with an average of 22.04 and 22.90 g, Equip herbicides (W_2) with an average of 20.71 and 21.36 g, the heaviest ear weight was obtained from hand hoeing (W_4) with an average of 200.86 and 215.03 g, Active herbicides (W_3) with an average of 156.52 and 164.69 g, Equip herbicides (W_2) with an average of 132.05 and 131.04 g, the maximum grain yield was obtained from hand hoeing (W_4) with an average of 2.16 and 2.24 tons $feddan^{-1}$, Active herbicides (W_3) with an average of 1.73 and 1.90 tons $feddan^{-1}$, Equip herbicides (W_2) with an average of 1.67 and 1.72 tons $feddan^{-1}$, the maximum biological yield was obtained from hand hoeing (W_4) with an average of 5.54 and 5.14 tons $feddan^{-1}$, Active herbicides (W_3) with an average of 4.69 and 4.26 tons $feddan^{-1}$, Equip herbicides (W_2) with an average of 4.21 and 3.85 tons $feddan^{-1}$, and the minimum values of the aforementioned characteristics produced by weedy check (W_1) in 2020 and 2021 seasons, respectively.

The strong weed competition in weedy check decreases the leaf surface area and its index as well as photosynthesis which caused a noticeable shortage in the grain yield compared with weeds free maize crops, in addition to weed control treatments (Hand hoeing or/and herbicides applied) enhanced grain yield compared with the weedy check. The increase in grain yield may be due to an increase in the ear length and diameter, number of rows ear^{-1}, number of grains row^{-1}, 100-grain weight and ear weight which produced by weed control systems. These results are in agreement with the previous findings [15, 17, 22-25].

Table 4: Effect of plant densities (D), weed control treatments and their interactions (D x W) on leaf area index, plant height, ear height, ear length and ear diameter in 2020 and 2021 seasons.

Treatments		2020 Season					2021 Season				
Plant Density (D)	Weed management regimes (W)	Leaf area index	plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Leaf area index	plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)
(D_1)	(W_1)	2.27	128.91	56.22	19.72	3.85	2.57	123.89	52.56	19.50	3.75
	(W_2)	3.75	185.67	68.00	20.17	3.73	3.66	180.77	78.06	21.09	3.96
	(W_3)	5.18	196.75	72.11	20.72	4.10	4.30	201.18	87.71	21.88	4.11
	(W_4)	5.64	222.12	78.10	23.94	4.54	5.54	221.56	87.40	23.99	4.60
	Mean	4.21	183.36	68.61	21.14	4.06	4.02	181.85	76.43	21.62	4.10
(D_2)	(W_1)	3.42	163.74	64.11	18.06	3.25	3.51	143.67	58.11	17.61	3.25
	(W_2)	5.25	188.34	80.68	20.00	3.73	4.23	195.33	85.40	18.56	3.69
	(W_3)	5.95	209.34	78.17	20.64	3.92	5.24	213.7	93.30	19.98	3.98
	(W_4)	6.16	231.45	94.06	21.74	4.16	5.81	225.74	99.56	24.00	4.12
	Mean	5.20	198.22	79.25	20.11	3.76	4.70	194.61	84.09	20.04	3.76
(D_3)	(W_1)	5.16	141.17	60.33	17.17	2.29	3.57	146.22	57.22	16.17	2.51
	(W_2)	5.95	205.33	84.98	19.17	3.29	4.37	216.11	94.11	18.57	3.30
	(W_3)	6.73	217.64	94.19	20.17	3.60	5.94	222.21	96.78	20.05	3.54
	(W_4)	7.76	259.9	100.83	21.94	3.80	7.63	248.36	104.00	21.56	3.83
	Mean	6.40	206.01	85.08	19.61	3.25	5.38	208.23	88.03	19.09	3.30
Means of W	(W_1)	3.62	144.6	60.22	18.31	3.13	3.22	137.93	55.96	17.76	3.17
	(W_2)	4.98	193.11	77.89	19.78	3.58	4.08	197.41	85.86	19.40	3.65
	(W_3)	5.96	207.91	81.49	20.51	3.87	5.16	212.36	92.60	20.64	3.88
	(W_4)	6.52	237.83	90.99	22.54	4.17	6.32	231.88	96.99	23.18	4.18
LSD (5 %) For:	D	2.35*	14.77**	12.55**	1.51*	0.30**	0.74**	13.03**	11.99*	1.98**	0.73*
	W	0.84**	9.50**	9.20**	1.31**	0.20**	0.53**	10.12**	11.28**	1.93**	0.25**
	D× W	ns	6.72**	ns	ns	0.14**	0.37**	ns	ns	ns	ns
CV%		11.22	3.42	8.37	4.58	3.74	7.99	3.67	9.62	4.17	4.83

D_1 = 23333 plants fed^{-1}, D_2 = 28000 plants fed^{-1}, D_3 = 35000 plants fed^{-1} , W_1=Weedy check, W_2 = Equip, W_3 = Active, and W_4 = Hand hoeing.

Table 5: Effect of plant densities (D), weed control treatments and their interactions (D x W) on No. of rows ear^{-1}, No. of grain ear^{-1}, 100-grains weight, grain yield and biological yield in 2020 and 2021 seasons:

Treatments		2020 Season						2021 Season					
Plant Density (D)	Weed control (W)	No. of rows ear^{-1}	No. of grains row^{-1}	100-grains weight	Ear weight (g)	Grain yield (t fed^{-1})	Biological yield (t fed^{-1})	No. of rows ear^{-1}	No. of grains row^{-1}	100-grains weight	Ear weight (g)	Grain yield (t fed^{-1})	Biological yield (t fed^{-1})
(D_1)	(W_1)	13.18	27.55	19.23	140.47	1.23	2.38	12.56	25.11	20.30	114.09	0.93	2.40
	(W_2)	14.17	35.00	22.42	143.31	1.48	3.93	14.56	36.33	23.91	137.46	1.26	3.62
	(W_3)	16.10	36.56	23.83	176.32	1.64	4.04	16.64	37.56	25.59	185.53	1.57	3.86
	(W_4)	19.21	46.00	28.20	204.41	2.05	5.34	18.45	47.56	30.72	236.66	2.06	4.48
	Mean	15.66	36.28	23.42	166.13	1.60	3.92	15.55	36.64	25.13	168.44	1.45	3.59
(D_2)	(W_1)	12.59	19.22	18.70	98.47	1.22	2.54	12.15	18.89	19.27	101.41	1.26	2.78
	(W_2)	14.00	28.78	21.08	141.10	1.69	3.95	13.74	33.00	21.34	128.58	1.80	3.58
	(W_3)	14.59	31.11	22.12	161.88	1.64	4.62	14.96	35.22	22.94	174.00	1.89	4.34
	(W_4)	15.93	40.22	24.21	208.18	2.15	5.27	15.66	42.67	23.38	230.14	2.10	5.31
	Mean	14.28	29.83	21.53	152.41	1.68	4.09	14.13	32.44	21.73	158.53	1.76	4.00
(D_3)	(W_1)	11.29	13.89	17.10	63.82	1.18	2.47	11.70	18.44	17.44	83.77	1.32	3.27
	(W_2)	13.07	22.22	18.63	111.73	1.84	4.74	12.89	23.45	18.82	127.08	2.09	4.37
	(W_3)	14.48	24.44	20.17	131.36	1.90	5.41	14.07	26.56	20.16	134.54	2.25	4.58
	(W_4)	15.33	31.46	22.08	190.00	2.28	6.01	15.11	32.78	22.23	178.29	2.56	5.63
	Mean	13.54	23.00	19.50	124.23	1.80	4.66	13.44	25.31	19.66	130.92	2.05	4.46
Means of W	(W_1)	12.36	20.22	18.34	100.92	1.21	2.46	12.14	20.81	19.00	99.76	1.17	2.82
	(W_2)	13.75	28.67	20.71	132.05	1.67	4.21	13.73	30.93	21.36	131.04	1.72	3.85
	(W_3)	15.06	30.70	22.04	156.52	1.73	4.69	15.22	33.11	22.90	164.69	1.90	4.26
	(W_4)	16.82	39.23	24.83	200.86	2.16	5.54	16.41	41.00	25.45	215.03	2.24	5.14
LSD (5 %) For:	D	2.32*	14.17*	2.54**	21.41*	0.43**	0.48*	2.67*	6.28**	1.67**	13.74*	0.32*	0.67**
	W	0.87**	3.12**	1.09**	30.82**	0.01**	0.42**	0.93**	2.59**	0.75**	20.70**	0.01**	0.28**
	D× W	0.62**	ns	0.77**	ns	0.01**	0.05*	0.65*	1.83**	0.53**	ns	0.01*	ns
CV%		4.24	7.43	3.56	14.74	5.39	7.28	4.58	5.81	2.37	9.58	5.89	5.16

D_1 = 23333 plants fed^{-1}, D_2 = 28000 plants fed^{-1}, D_3 = 35000 plants fed^{-1} , W_1=Weedy check, W_2 = Equip, W_3 = Active, and W_4 = Hand hoeing.

3.6. Effect of interactions (D x W) on yield and yield components

The interaction between D and W was a highly significant with respect to 100-grain weight and grain yield in the 2020 and 2021 season. The interaction was significant with respect to plant height, ear diameter, number of rows ear^{-1} and biological yield in only the 1st season as well as LAI and number of grains row^{-1} in only the 2nd season. The interaction was insignificant with respect to ear height and weight in both seasons of the experiential.

Results in Tables (4 and 5) indicated that the maximum value of ear diameter (4.54 cm), number of rows ear^{-1} (19.21 and 18.45), number of grains row^{-1} (47.56) and 100-grain weight (28.20 and 30.72 g) were produced by 23333 plant feddan^{-1} (D_1) and hand hoeing (W_4). On the other hand, the maximum value of LAI (7.63), plant height (259.90 cm), grain yield (2.28 and 2.54 tons feddan^{-1}) and biological yield (6.01 tons feddan^{-1}) were produced by 35000 plant feddan^{-1} (D_3) and hand hoeing (W_4) compared with 23333 plant feddan^{-1} (D_1) and weedy check (W_1). Similar results were previously illustrated [11, 17, 19, 26, 27].

3.7. The direct and indirect analyses.

The data in Table 6 show that, the direct (underlined and bolded values) and indirect effects of nine specified grain yield are related traits to grain yield. The data show that the plant height, ear weight, ear length and diameter, and 100-grain weight had positive direct effects with 0.33 and 0.28, 0.26 and 0.29, 0.18 and 0.04, 0.07 and 0.12 and 0.04 and 0.02 path coefficients in 2020 and 2021 seasons, respectively, on grain yield. Plant height and ear weight traits had the highest indirect positive effects on grain yield through number of grain weight by 0.17 and 0.16 and 0.22 and 0.25 in the first and second seasons, respectively. Furthermore, plant height and ear weight traits had the indirect positive effects on grain yield through 100-grain weight by 0.19 and 0.12 and 0.20 and 0.23 in 2020 and 2021 seasons, respectively.

Table 6: Direct (underlined diagonals) and indirect effects of grain yield (ton feddan^{-1}) components and their correlations with grain yield (ton feddan^{-1}) in 2020 and 2021 seasons.

Character	1		2		3		4		5		6		7		8		9	
Season	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
1 Total dry weed (g m^{-2})	-0.48	-0.05	0.43	0.05	0.43	0.05	0.25	0.03	0.28	0.03	0.17	0.02	0.29	0.03	0.23	0.03	0.24	0.02
2 Weed control efficiency %	0.37	-0.34	-0.41	0.37	-0.35	0.33	-0.30	0.30	-0.30	0.29	-0.28	0.24	-0.33	0.28	-0.31	0.29	-0.32	0.23
3 plant height (cm)	-0.30	-0.25	0.29	0.25	0.33	0.28	0.19	0.18	0.20	0.16	0.17	0.13	0.20	0.17	0.17	0.16	0.19	0.12
4 Ear weight (g)	-0.14	-0.19	0.19	0.23	0.15	0.18	0.26	0.29	0.23	0.23	0.22	0.23	0.20	0.24	0.22	0.25	0.20	0.23
5 Ear length (cm)	-0.10	-0.02	0.13	0.03	0.11	0.02	0.15	0.03	0.18	0.04	0.14	0.03	0.14	0.03	0.15	0.03	0.14	0.03
6 Ear diameter (cm)	-0.02	-0.05	0.05	0.08	0.03	0.06	0.06	0.09	0.06	0.10	0.07	0.12	0.05	0.10	0.06	0.11	0.06	0.10
7 No of rows ear^{-1}	-0.17	0.14	0.23	-0.18	0.17	-0.15	0.22	-0.20	0.24	-0.21	0.23	-0.20	0.29	-0.24	0.25	-0.21	0.26	-0.22
8 No of grain ear^{-1}	0.29	0.10	-0.46	-0.14	-0.31	-0.10	-0.52	-0.15	-0.53	0.15	-0.54	-0.15	-0.53	-0.15	-0.61	-0.17	-0.56	-0.15
9 100-grain weight (g)	-0.02	-0.01	0.03	0.01	0.02	0.01	0.03	0.01	0.03	0.01	0.03	0.02	0.04	0.02	0.04	0.02	0.04	0.02
Total *r*	-0.88**	-0.89**	0.71**	0.90**	0.89**	0.90**	0.45*	0.73**	0.50*	0.65**	0.30ns	0.54**	0.49*	0.60**	0.29ns	0.62**	0.36ns	0.46*

*, ** and, ns refer to $p \le 0.05$, $p \le 0.01$ and not significant.

4. Conclusions

It can be concluded that the maximum grain yield of maize was a significantly recorded at highest plant density (35000 plant population feddan^{-1}) and/or all weed control treatments (hand hoeing, Equip 2.25% OD and Active 6% SC herbicides) under the environmental conditions of Fayoum Governorate.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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