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Effect of Phosphorus, Zinc and Their Interactions on Vegetative Growth Characters, Yield and Fruit Quality of Strawberry

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Abstract: This work was carried out in the two successive summer seasons of 2007/2008 and 2008/2009 on strawberry cv. Sweet Charlie at south Tahrir district, newly reclaimed sandy soils at the Experimental Station Farm, Horticultural Research Station, Behiera Governorate, to study the influence of phosphorus (0, 60, 80, 100 Kg P_2O_5/fed.) and zinc (0, 5, 15, 25 Kg Zn/fed.) on vegetative growth, yield and fruit quality of strawberry plants.The results indicated that, vegetative growth characters (number of leaves, number of runners, number of secondary crowns, leaf area, foliage fresh mass and dry mass/ plant) and flowering traits (number of flower clusters / plant and earliness) were significantly increased with the high rates of P and Zn, in both growing seasons. Early yield, marketable yield, total yield and yield/plant, generally seemed to be increased with the high rates of P and Zn, in both growing seasons. On the other hand, culls (non-marketable yield) exhibited significant decrease due to the high rates of P and Zn. The highest mean values of average fruit weight, fruit length, fruit diameter, fruit juice content, TSS and vitamin C% were figured out for plants supplied with P and Zn at the highest levels, in both growing seasons. On the other hand, the lowest mean values of fruit moisture content and titratable acidity were traced for plants that fertilized with the high rates of P and Zn. Results revealed the antagonistic effects between P and Zn on leaf contents of P and Zn, particularly, with the high rates of P and Zn. The interaction between P and Zn reflected positive effects on all studied quantitative and qualitative characters of strawberry plants.

Key words: Strawberry · Phosphorus · Zinc · Vegetative Growth · Yield · Fruit Quality

INTRODUCTION

Strawberry (*Fragaria x ananassa* Dush.) is a perennial cool season crop, which is popular as a fresh fruit. In Egypt, it occupies an important position among the untraditional vegetable crops due to its multifarious use as local fresh consumption, food processing and exportation [1]. Strawberries are an ideal model for nutrient interaction studies in perennial crops. First, they are relatively precocious, producing their first crop with months of planting. Second, the plants are small, so that many plots can be established within uniform soils. Third, they can be easily excavated and divided into vegetative and reproductive components, allowing for detailed evolution of observed growth or yield responses. Forth, when compared to other perennial fruit crops, cropping history has little influence on flower bud initiation and fruiting [2]. The nutrition status of strawberry plant plays a fundamental importance in determining growth, yield and quality, since it is a very sensitive plant to nutritional balance. This might be due to its shallow root system and high productivity in relation to plant size, beside it is a perennial crop with a long season. Optimal fertilization is conductive to obtaining high yield of good quality and high biological value [3]. Mineral fertilization as well as cultivar, weather conditions, agronomic practices and water supply affected directly the quality of strawberry fruit [4]. Phosphorus is essential for the general health and vigor of all plants. Some specific growth factors that have been associated with phosphorus nutrition are: stimulated root development, increased stalk and stem strength, improved flower formation and seed production, more uniform and earlier crop maturity, increased nitrogen N-fixing capacity of legumes, improved crop quality and increased resistance to plant diseases [5]. In this respect, Geoffrey and Pritts [2] found that, applied P nutrient had significant effects on yield components of strawberry plants. A balanced fertilization program with macro and micro-nutrients in plant nutrition is very important in the production of high yield with high quality products [6].

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Zinc has also shown to have an important role in photosynthesis and related enzymes, resulting in increasing sugar and decreasing acidity [7]. Among nutrient elements, zinc and boron have important role on pollination, fruit set and total yield [8]. Zinc induces pollen tube growth resulted from its role on tryptophan synthesis as an auxin precursor biosynthesis [9]. Moreover, Dixi and Gamdagin [10] claimed that a foliar spray application of $ZnSO_4$ on March and April increased size, T.S.S. and juice of oranges. On the other hand, zinc as a $ZnSO_4$ source had positive effect on leaf area, length and diameter of petiole, fresh and dry shoot ratio, yield, total soluble solid, acidity and vitamin C of strawberry plants [11]. Continuous use of phosphoric fertilizers and intensive cultivation of high yield crop varieties have resulted in widespread deficiency of Zn and decrease in the growth of many field crops on most soil types. This may be due to interaction between Zn and P and, also, due to the variability of other growth factors, i.e., pH, moisture, zinc and phosphorus sources, organic matter, temperature, soil salinity, etc. [12, 13].

The objective of this research was to study the effects of P, Zn and their interactions on vegetative growth, yield and fruit quality of Sweet Charlie strawberry cultivar.

MATERIALS AND METHODS

A field experiment was carried out during the two summer seasons of 2007/2008 and 2008/2009 at South Tahrir, newly reclaimed sandy soils, under a drip irrigation system at the Experimental Station Farm, Horticultural Research Station, Behiera Governorate, Egypt.

Preceding the initiation of each experiment, soil samples at 25 cm depth were collected from each experimental site and analyzed, according to Black [14]. The results of the analyses are given in Table (1)

Frigo transplants of strawberry Sweet Charlie cultivar were obtained from local nurseries under the supervision of Horticulture Research Institute, Agricultural Research Center. Transplants were treated with fungicides (1ml/l Brificour N + 1 g/l Ridomil gold cupper) for 30 minutes. The transplanting took place in row 0.75 m apart in the two sides of the row at 0.25 m inter row spacing.

The experimental layout was a split-plot system in a randomized complete blocks design with four replications. Phosphorus fertilizer levels were arranged as the main plots and the Zn rates were considered as the sub-plot. Each sub-plot was two rows of 8.25 m long and 1.4 m width (2 rows), having an area of 11.55 square meters. Planting dates were carried out on September 15 and 20 in the two seasons of 2007/2008 and 2008/2009, respectively. Each experiment contained 16 treatments representing the combinations of four phosphorous levels (0, 60, 80 and 100 kg P_2O_5/fed.) and four zinc levels (0, 5, 15 and 25 kg Zn/fed.). The respective P source was phosphoric acid (80% P_2O_5). Zinc sulphate was the respective Zn source. Both P and Zn were added through the drip irrigation system (fertigation, during the growing season). Phosphorus was added three times per week. However zinc were applied through drip irrigation system one times per week at rate of 0, 5, 15 and 25 kg Zn /fed.

Calcium super phosphate (15.5% P_2O_5) at the rate of 46.5 Kg P_2O_5 /fed. and potassium sulphate (48% K_2O) at the rate of 72 Kg K_2O /fed. were applied once during soil preparation. During the entire growing season, nitrogen and potassium fertilizers were also added through the drip irrigation system four times per week, at the rates of 200 Kg N/ fed., in the form of ammonium nitrate (20.5% N) and 120 Kg K_2O /fed. as soluble potassium sulphate (48% K_2O).

Harvesting started on the 25th of March and extended to the 29th of May in the first season; whereas, in the second season, it started on 5th of March and extended to the 21th of May.

The other agricultural practices were applied according to the Ministry of Agricultural recommendations.

Data Recorded

Vegetative Growth Characters: Ten randomly selected plants were taken from each sub-plot at blooming stage.The following vegetative characters were measured: number of crowns, number of runners, number of leaves, leaf area (cm^2), foliage fresh mass (g) and foliage dry mass / plant (g).

Table 1: Some physical and chemical properties of the experimental soil during 2008 and 2009 seasons

								Available Nutrients (ppm)					
Properties	Sand%	Silt%	Clay%	Texture	O.M.%	$CaCO_3$	pH	N	P	K	Fe	Zn	Mn
2008	94.5	3.8	2.9	Sandy	0.06	1.13	7.9	0.05	3.79	9.75	3.12	1.7	1.4
2009	93.7	3.5	2.8	Sandy	0.05	1.15	8.1	0.04	3.85	10.14	3.10	1.5	1.7

Flowering Traits: Ten randomly chosen plants, from each sub-plot, were labeled to record the earliness of flowering as the number of days from transplanting till flowering of 25% of the plants and to count the number of flower clusters / plant.

Yield and its Components: Early yield (ton/ fed.) was calculated as fresh weight of harvested fruits from the first four pickings.

Total yield (ton/fed.) was calculated as the fresh weight of all harvested fruits all over the growing season. It included marketable and non marketable fruit yield (included spitted, malformed, green shouldered, water damaged and rotted fruits). Fruit yield/plant (g/ plant); weight of all fruits harvested all over the season/ plant (g).

Fruit Quality Characteristics: Random samples of ten fresh fruits were taken from each sub-plot at the peak of harvesting period to determine average fruit weight (g), fruit length (cm) and fruit diameter (cm). Moisture and juice contents of fruits were determined according to A.O.A.C. [15].

Chemical Contents: Random samples of ten fresh fruits were taken from each sub-plot at the peak of harvesting period to determine total soluble solids (TSS%) by refractometer. Vitamin C (ascorbic acid) content was determined using 2.6-dichlorophenol indophenol as indicator for titration as outlined in A.O.A.C. [15]. Total soluble sugars of each sample were extracted in a 0.3 gm ground dried material by distilled water and then determined by the Nelsson arsenate – molybdate colorimetric method[16]. Total titratable acidity percentage as g of citric acid/100 g fruits extract was determined according to A.O.A.C. [15]. Phosphorous and zinc contents in leaves were determined in the youngest expanded mature 6^{th} leaf from the plant top before the first picking. Phosphorus was calorimetrically according to the method described by Bould [17] and Zn was measured as outlined in Jackson [18] by Atomic Absorption technique [19].

Statistical analysis: Data were statistically analyzed according to Co-stat Software [20] and the Revised L.S.D test was used to compare the differences among the treatments as outlined by Smith [21].

RESULTS AND DISCUSSION

Vegetative Growth Characters: Data presented in Tables 2 and 3 indicated that, the vegetative growth characters of strawberry, i.e., number of leaves, number of runners, number of secondary crowns, leaf area, foliage fresh and dry masses / plant were significantly affected by the phosphorous treatments, in both seasons. It was, also, clear that the application of 100 Kg P_2O_5/ fed., gave the highest significant mean values of all the studied vegetative characters as compared to the unfertilized control or those of the other application rates (60, 80 Kg P_2O_5 /fed.). Such a positive effect of phosphorus could be explained on the ground that phosphorus plays an important role in functions of enzymes required for the vital processes and growth [22, 5].

Data in Table 2 showed that, increasing the application of zinc fertilizer from 0 to 5 or 15 and fatherly to 25 kg Zn/fed. resulted in corresponding and significant increases in all studied vegetative growth characters, i.e. number of runners, leaf area and foliage fresh and dry masses per plant, in both seasons. The exception was in 2007/ 2008 season, where the differences between 15 and

Table 2: Vegetative growth characters of strawberry plants as affected by phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

	2007/2008 season						2008/2009 season					
Treatments	Number of leaves/ plant	Number of runners/ plant	Number of secondary crowns/ plan	Leaf area (cm^2/ plant)	Foliage fresh mass/ plant	Foliage dry mass/ plant	Number of leaves/ plant	Number of runners/ plant	Number of sec ondary crowns/ plant	Leaf area (cm^2/ plant)	Foliage fresh mass/ plant	Foliage dry mass/ plant
Phosphorus (Kg P_2O_5/ fed.)												
0	28.03	6.62	2.90	420.50	44.07	11.80	30.58	6.08	2.52	426.22	41.19	10.73
60	31.82	8.91	3.87	436.03	49.18	13.34	32.96	8.16	3.26	440.86	46.11	12.32
80	34.11	10.40	4.77	457.23	52.25	14.88	34.93	9.39	4.19	462.09	49.38	13.90
100	37.02	12.01	4.76	489.34	54.13	16.00	36.73	11.16	4.77	495.23	51.18	15.15
R.$LSD_{0.05}$	0.29	0.16	0.09	5.06	0.21	0.26	0.23	0.26	0.16	3.19	0.23	0.25
Zinc (Kg Zn/ fed.)												
0	31.68	8.99	3.95	445.66	48.86	13.35	33.08	8.30	3.38	450.07	45.83	12.36
5	32.62	9.35	3.88	447.04	49.79	13.92	33.70	8.51	3.49	453.29	46.72	12.95
15	33.30	9.72	4.17	452.78	50.36	14.32	34.10	8.87	3.71	457.79	47.37	13.29
25	33.39	9.89	4.30	457.61	50.62	14.43	34.33	9.10	4.16	463.24	47.95	13.49
R.$LSD_{0.05}$	0.22	0.23	0.09	2.97	0.25	0.16	0.18	0.29	0.14	2.73	0.29	0.14

Table 3: Vegetative growth characters of strawberry plants as affected by the interaction between phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009.

Treatments		2007/2008 season						2008/2009 season					
Phos-phorus (Kg P2O5 fed.)	Zinc (Kg Zn/ fed.)	Number of leaves /plant	Number of runners/ plant	Number of secondary crowns/ plant	Leaf area (cm2 /plant)	Foliage fresh mass/ plant	Foliage dry mass/ plant	Number of leaves/ plant	Number of runners/ plant	Number of secondary crowns/ plant	Leaf area (cm2 /plant)	Foliage fresh mass/ plant	Foliage dry mass/ plant
0	0	27.79	6.09	2.89	409.42	43.34	11.26	30.86	5.86	2.10	414.74	40.51	10.17
	5	27.56	6.29	2.43	417.31	43.69	11.72	30.68	5.76	2.28	424.68	40.50	10.49
	15	28.40	6.96	3.15	428.29	44.62	11.95	30.46	6.06	2.76	433.28	41.76	10.87
	25	28.36	7.16	3.12	426.96	44.62	12.28	30.34	6.66	2.93	432.18	42.01	11.39
60	0	30.82	8.54	3.63	433.81	47.16	12.46	32.34	7.74	2.74	438.47	43.89	11.44
	5	31.70	8.68	3.86	432.93	49.72	13.29	32.67	7.71	3.24	438.34	46.41	12.22
	15	32.19	9.14	3.89	432.86	49.69	13.63	33.20	8.53	3.15	437.68	46.72	12.64
	25	32.58	9.29	4.11	444.52	50.14	13.98	33.62	8.67	3.90	448.97	47.44	12.99
80	0	32.95	9.90	4.67	454.62	51.39	14.28	33.74	9.07	4.04	458.79	48.44	13.30
	5	34.01	10.43	4.75	456.50	51.80	14.82	35.01	9.40	4.17	461.72	48.97	13.78
	15	34.44	10.67	4.80	457.76	52.63	15.23	35.25	9.56	4.01	463.38	49.51	14.29
	25	35.05	10.61	4.89	460.04	53.19	15.17	35.72	9.51	4.54	464.47	50.61	14.23
100	0	35.16	11.44	4.61	484.79	53.54	15.38	35.37	10.55	4.63	488.31	50.48	14.56
	5	37.20	12.01	4.48	481.41	53.95	15.84	36.43	11.20	4.28	488.43	51.01	15.31
	15	38.17	12.11	4.85	492.21	54.49	16.48	37.49	11.33	4.93	496.83	51.49	15.38
	25	37.57	12.49	5.11	498.94	54.54	16.29	37.65	11.56	5.26	507.34	51.76	15.33
R.LSD$_{0.05}$	0.48	0.42	0.17	7.21	0.48	0.38	0.38	0.57	0.29	5.70	0.56	0.35	

25 kg Zn/fed. for number of leaves and runners as well as foliage fresh mass/plant were not significant. The difference between 15 and 25 kg Zn with respect to number of runners/plant, in the second season, was, also, not significant. The enhancing effect of applied Zn on plant growth may be attributed to its beneficial effects on stimulating the meristimic activity for producing more tissues and organs via its role in activation of cell division and cell elongation. The obtained results are in general agreement with those reported by Chaplin and Westwood [9]; Archbold and Dennis [23]; Treder [3] and Motesharezade *et al.* [8].

Concerning the interaction effects between phosphorus and zinc treatment on the studied vegetative growth characters of strawberry plants, the obtained results in Table 3 reflected significant differences for all vegetative growth characters. The application of 100 Kg P_2O_5 /fed. combined with 15 Kg Zn/ fed. can be considered the best choice as it attained the best results for most vegetative growth characters, in both seasons. On the other hand, it was noticed that the combined treatment including 100 Kg P_2O_5 /fed. plus 25 kg Zn/fed. gave the highest significant mean value for number of secondary crowns/plant, in both seasons. Similar results were obtained by Geoffrey and Pritts [2].

Flowering Traits: The effect of phosphorus rates on flowering time (earliness) and number of flower clusters/plant were found significant, in both studied experiments (Table 4). The addition of phosphorus at the rate of 100 kg P_2O_5 /fed reflected more earliness and higher number of clusters than the control. Such a result indicated that the application of 100 Kg P_2O_5 /fed. is a better choice for earliness than the other levels of phosphorus.

Fertilizing strawberry plants with Zn at the rates of 5, 15 and 25 kg/fed., significantly, resulted in earlier flowering and a pronounced increase for number of flower clusters relative to the unfertilized control. The promoting effects of zinc on flowering traits might be attributed to its stimulating effects on vegetative growth characters (Table, 2) and its activation of pollination, fruit set and production of auxin, which in turn, were positively reflected on flowering traits [9]. The obtained results seemed to be in general agreements with those reported by Geoffrey and Pritts [2]; Sawan *et al.* [6] and Mahnaz *et al.* [11].

Data in Table 4 showed that, the interaction effects between phosphorus and zinc rates on earliness of flowering and number of flower cluster/plant were significant, in both seasons. The treatment combination of 100 Kg P_2O_5/ fed. and 25 Kg Zn/ fed. gave the least number of days from transplanting to flowering and recorded the highest number of clusters /plant. The obtained results seemed to be in general agreements with those reported by Geoffrey and Pritts [2] Sawan *et al.* [6] and Mahnaz *et al.* [11].

Table 4: Earliness of flowering and number of flower clusters/ plant as affected by phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

Treatments		2007/2008 season earliness of flowering (days)	2007/2008 season number of flower clusters/ plant	2008/2009 season earliness of flowering (days)	2008/2009 season Number of flower clusters/ plant
Phosphorus (Kg P_2O_5/ fed.)					
0		135.29	7.61	136.16	6.93
60		130.34	11.76	131.39	10.91
80		124.43	13.25	125.98	12.30
100		120.30	13.67	121.82	13.04
R.LSD$_{0.05}$		0.37	0.27	0.66	0.24
Zinc (Kg Zn/ fed.)					
0		128.34	11.09	129.68	10.31
5		128.00	11.44	128.85	10.61
15		127.33	11.63	128.43	10.78
25		126.69	12.13	128.39	11.47
R.LSD$_{0.05}$		0.29	0.21	0.78	0.18
Phosphorous (Kg P_2O_5/ fed.)	Zinc (Kg Zn/ fed.)				
0	0	135.46	7.17	136.35	6.77
	5	135.67	7.43	136.29	6.42
	15	135.45	7.48	136.24	6.78
	25	134.59	8.37	135.76	7.75
60	0	132.34	11.19	133.27	10.35
	5	130.29	11.42	131.49	10.69
	15	129.39	11.65	130.48	10.69
	25	129.35	12.79	130.31	11.92
80	0	125.16	12.89	126.61	11.83
	5	125.20	13.28	126.02	12.30
	15	123.97	13.54	125.20	12.48
	25	123.40	13.29	126.08	12.58
100	0	120.42	13.10	122.50	12.30
	5	120.84	13.66	121.58	13.04
	15	120.52	13.85	121.81	13.19
	25	119.42	14.09	121.40	13.65
R.LSD$_{0.05}$	0.63	0.45	1.50	0.39	

Table 5: Fruit yield and its components of strawberry plants as affected by phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

Treatments	2007/2008 season Early yield (ton/ fed.)	Marketable yield (ton/ fed.)	Culls (ton/ fed.)	Total yield (ton/ fed.)	Yield / plant (g)	2008/2009 season Early yield (ton/ fed.)	Marketable yield (ton/ fed.)	Culls (ton/ fed.)	Total yield (ton/ fed.)	Yield / plant (g)
Phosphorus (Kg P_2O_5/ fed.)										
0	1.41	18.07	0.454	18.50	462.56	1.45	18.30	0.479	18.78	470.37
60	1.65	20.12	0.348	20.47	511.84	1.68	19.16	0.378	19.55	488.79
80	1.81	21.64	0.218	21.82	545.69	1.84	20.61	0.248	20.83	520.66
100	1.77	21.67	0.178	21.85	546.23	1.87	20.84	0.208	20.96	523.43
R.LSD$_{0.05}$	0.04	0.18	0.013	0.21	5.29	0.04	0.13	0.013	0.07	3.31
Zinc (Kg Zn/ fed.)										
0	1.64	20.04	0.317	20.36	509.14	1.67	19.43	0.346	19.78	494.53
5	1.65	20.19	0.300	20.49	512.33	1.70	19.62	0.330	19.95	497.85
15	1.66	20.57	0.295	20.81	520.30	1.72	19.87	0.323	20.14	504.80
25	1.70	20.70	0.286	20.98	524.54	1.76	20.00	0.314	20.25	506.08
R.LSD$_{0.05}$	0.03	0.09	0.009	0.10	2.66	0.03	0.12	0.009	0.08	3.79

Table 6: Fruit yield and its components as affected by the interaction between phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

		2007/2008 season					2008/2009 season				
Treatments		Early yield (ton/ fed)	Marketable yield (ton/ fed.)	Culls yield (ton/ fed.)	Total yield (ton/ fed.)	Yield / plant (g)	Early yield (ton/ fed.)	Marketable yield (ton/ fed.)	Culls yield (ton/ fed.)	Total yield (ton/ fed.)	Yield/ plant (g)
Phosphorus (Kg P_2O_5/ fed.)	Zinc (Kg Zn/ fed.)										
0	0	1.37	17.70	0.178	18.15	453.89	1.41	18.08	0.510	18.59	464.66
	5	1.38	17.56	0.483	18.02	450.50	1.42	18.18	0.483	18.66	466.59
	15	1.43	18.35	0.453	18.72	468.35	1.46	18.37	0.475	18.85	474.08
	25	1.47	18.67	0.428	19.10	477.50	1.51	18.58	0.450	19.04	476.14
60	0	1.65	19.55	0.370	19.94	498.55	1.68	18.67	0.400	19.07	476.80
	5	1.66	19.90	0.338	20.24	506.24	1.69	18.94	0.368	19.30	482.61
	15	1.62	20.39	0.355	20.75	518.72	1.64	19.41	0.385	19.79	494.90
	25	1.69	20.63	0.328	20.96	523.83	1.72	19.65	0.358	20.03	500.87
80	0	1.78	21.37	0.233	21.61	540.46	1.80	20.38	0.263	20.65	516.37
	5	1.79	21.53	0.225	21.76	543.84	1.82	20.53	0.255	20.78	519.47
	15	1.84	21.81	0.203	21.86	546.63	1.87	20.84	0.233	20.96	523.77
	25	1.84	21.86	0.213	22.07	551.85	1.87	20.69	0.243	20.93	523.05
100	0	1.75	21.56	0.183	21.74	543.65	1.78	20.59	0.213	20.80	520.27
	5	1.77	21.76	0.185	21.94	548.73	1.85	20.84	0.215	21.06	522.75
	15	1.77	21.73	0.170	21.90	547.53	1.91	20.87	0.200	20.96	526.45
	25	1.81	21.63	0.175	21.80	544.99	1.94	21.06	0.205	21.02	524.27
R.LSD$_{0.05}$	0.07	0.24	0.02	0.28	7.02	0.06	0.24	0.02	0.16	7.35	

Fruit Yield and its Components: Data presented in Table 5 showed that, early yield, marketable yield, non- marketable yield (culls), total yield and yield/ plant were significantly affected by different phosphorus treatments. The plants were received 100 Kg P_2O_5 /fed. gave the highest mean values of all studied characters of yield and its components, in both seasons. The only favorable exception was non- marketable yield (culls), where application of 100 Kg P_2O_5 /fed. was statistically responsible for the reduction of non- marketable yield/fed. (Culls); It was, also, noticed that the differences between 80 and 100 kg P_2O_5 /fed. were not found to be significant in most cases, in both seasons. These positive results of P could be attributed to the potentiality of P- fertilization; particularly, the medium P level (80 kg P_2O_5 /fed.) to secure the P requirements, which were resulted in better vegetative growth and flowering potential (Table 2, 3) and in term yielding capacity of strawberry. These findings are in agreement with those reported by Chaplin and Westwood [9]; Archbold and Dennis [23]; Abedy [7] and Mahnaz *et al.* [11].

Respecting the effect of Zn application, data shown in Table 5 indicated that, addition of Zn at the rates of 15 and 25 kg Zn/fed., significantly, increased most studied fruit yield and its components as compared to the unfertilized control or the lower Zn level (5 kg Zn/fed.), in both seasons. However, a negative relationship was detected between culls and Zn fertilization.

According to the results in Table 6, some significant differences were observed due to the interaction effects between the different phosphorus and zinc treatments on yield and its components, in both seasons. The addition of the highest rate of 100 Kg P_2O_5 /fed., coupled by 25 Kg Zn /fed. gave the highest mean values for yield and its components except for culls/fed. in the first season. However, in the second season, application of 100 kg P_2O_5 /fed., together with 25 kg Zn/fed., appeared to achieve the best result for fruit yield and its components. The only exception was for non- marketable yield (culls), where the lowest mean value of culls was obtained from the interaction between 100 Kg P_2O_5 /fed. coupled with 15 kg Zn/fed. in both seasons. Such findings could be Interpreted on the basis that the sufficient application and the efficient absorption of P and Zn addition were coupled together to promote the production of more photosynthesis required for good fruit yield and its components. Similar results were also recorded by Mahnaz *et al.* [11].

Fruit Quality Characteristics: Results presented in Table 7 indicated that, average fruit weight, fruit length, fruit diameter, fruit moisture juice contents of strawberry fruits were significantly affected by the various rates of phosphorus, in both seasons. The highest mean values of average fruit weight, fruit length, fruit diameter, fruit juice content were obtained from the application of the highest P rate(100 Kg P_2O_5 /fed.). However, the lowest mean values of fruit moisture content seemed to be associated with the highest P rate, in both seasons. On the other hand, no significant effects were detected with respect to average fruit weight and fruit moisture content, in both seasons.

Table 7: Fruit quality characteristics of strawberry plants as affected by phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

	2007/2008 season					2008/2009 season				
Treatments	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit moisture (%)	Fruit juice (%)	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit moisture (%)	Fruit Juice (%)
Phosphorus (Kg P_2O_5/fed.)										
0	19.59	2.28	1.31	95.34	5.40	18.49	2.14	1.25	94.71	6.39
60	21.22	2.89	1.70	93.28	5.60	21.90	2.60	1.57	92.44	6.59
80	24.68	3.48	1.97	90.18	6.81	25.60	3.24	1.87	90.98	7.82
100	26.29	3.61	2.38	89.60	8.73	27.61	3.75	2.33	89.24	9.73
R.$LSD_{0.05}$	0.35	0.07	0.02	0.19	0.09	0.32	0.04	0.01	0.25	0.10
Zinc (Kg Zn/ fed.)										
0	22.89	2.99	1.66	92.23	6.22	22.97	2.78	1.59	92.28	7.23
5	22.83	3.03	1.82	92.03	6.46	23.44	2.88	1.73	91.80	7.44
15	23.00	3.07	1.90	92.18	6.76	23.66	3.01	1.81	91.63	7.74
25	23.08	3.16	1.97	91.95	7.11	23.54	3.07	1.89	91.65	8.12
R.$LSD_{0.05}$	0.27	0.05	0.02	0.31	0.07	0.23	0.04	0.02	0.30	0.07

Table 8: Fruit quality characteristics of strawberry plants as affected by the interaction between phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

		2007/2008 season					2008/2009 season				
Treatments		Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit moisture (%)	Fruit Juice (%)	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit moisture (%)	Fruit Juice (%)
Phosphorus (Kg P_2O_5/ fed.)	Zinc (Kg Zn /fed.)										
0	0	19.61	2.26	1.25	95.38	5.12	17.88	2.07	1.13	94.38	6.12
	5	19.45	2.28	1.30	95.46	5.17	18.57	2.08	1.26	94.63	6.16
	15	19.51	2.28	1.32	95.54	5.57	18.75	2.15	1.29	95.03	6.54
	25	19.81	2.31	1.37	94.97	5.74	18.78	2.29	1.32	94.81	6.75
60	0	21.18	2.76	1.49	93.17	5.40	21.12	2.48	1.39	93.63	6.41
	5	21.26	2.82	1.65	93.33	5.59	21.85	2.51	1.52	92.94	6.55
	15	21.22	2.90	1.79	93.49	5.64	22.47	2.68	1.66	91.62	6.63
	25	21.25	3.07	1.86	93.13	5.76	22.18	2.74	1.72	91.55	6.76
80	0	24.71	3.48	1.88	90.46	6.51	25.49	3.06	1.76	91.28	7.53
	5	24.43	3.38	1.95	90.09	6.49	25.72	3.26	1.84	90.85	7.49
	15	24.68	3.49	1.99	90.11	6.92	25.62	3.33	1.88	90.90	7.90
	25	24.92	3.56	2.05	90.04	7.33	25.59	3.32	2.00	90.88	8.37
100	0	26.06	3.46	2.01	89.89	7.82	27.40	3.51	2.07	89.84	8.86
	5	26.20	3.65	2.39	89.26	8.58	27.63	3.69	2.32	88.80	9.57
	15	26.58	3.64	2.50	89.60	8.90	27.80	3.87	2.43	88.97	9.89
	25	26.33	3.68	2.61	89.66	9.61	27.62	3.92	2.53	89.36	10.59
R.$LSD_{0.05}$		0.59	0.10	0.03	0.57	0.16	0.51	0.08	0.03	0.58	0.16

Table 9: Chemical contents of strawberry fruits and leaves as affected by phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

	2007/2008 season						2008/2009 season					
Treatments	Total sugars (%)	T.S.S (%)	V.C. (%)	Titratable acidity (%)	Leaf's P (%)	Leaf's Zn (ppm)	Total sugars (%)	T.S.S (%)	V.C. (%)	Titratable acidity (%)	Leaf's P (%)	Leaf's Zn (ppm)
Phosphorus (Kg P_2O_5/ fed.)												
0	17.90	8.00	28.53	0.527	0.96	26.54	18.84	8.43	29.59	0.539	0.92	27.12
60	18.59	9.16	29.20	0.476	1.30	25.90	19.48	9.19	30.18	0.490	1.38	25.65
80	20.24	10.20	30.97	0.426	2.61	23.53	20.68	10.24	32.04	0.439	2.44	23.39
100	21.13	11.52	31.85	0.383	3.47	23.74	21.82	11.84	33.27	0.378	3.49	22.61
R.$LSD_{0.05}$	0.06	0.05	0.08	0.005	0.11	0.31	0.04	0.03	0.04	0.003	0.03	0.10
Zinc (Kg Zn/ fed.)												
0	18.83	8.77	29.00	0.484	2.11	19.48	19.51	9.13	30.30	0.491	2.29	19.41
5	19.43	9.42	29.88	0.469	2.13	24.35	19.94	9.45	30.93	0.475	2.14	24.15
15	19.56	10.19	30.56	0.437	2.06	26.36	20.33	10.51	31.53	0.452	1.99	26.21
25	20.03	10.49	31.11	0.422	2.04	29.52	21.05	10.61	32.31	0.429	1.82	28.99
R.$LSD_{0.05}$	0.07	0.05	0.07	0.004	0.07	0.21	0.05	0.03	0.04	0.004	0.04	0.06

Table 10: Chemical contents of strawberry fruits and leaves as affected by the interaction between phosphorus and zinc rates during the seasons of 2007/2008 and 2008/2009

Treatments		2007/2008 season						2008/2009 season					
		Total sugars (%)	T.S.S (%)	V.C. (%)	Titratable acidity (%)	Leaf's P (%)	Leaf's Zn (ppm)	Total sugars (%)	T.S.S (%)	V.C. (%)	Titratable acidity (%)	Leaf's P (%)	Leaf's Zn (ppm)
Phosphorus ($Kg P_2O_5$/ fed.)	Zinc (Kg Zn/ fed.)												
0	0	17.53	7.17	28.14	0.556	0.90	20.27	18.41	7.98	29.40	0.568	0.89	20.37
	5	17.69	7.69	28.44	0.538	0.93	25.26	18.43	7.79	29.37	0.549	0.85	25.90
	15	18.02	8.21	28.55	0.517	0.93	28.33	19.12	8.94	29.45	0.532	0.96	28.82
	25	18.35	8.92	28.99	0.497	1.07	32.31	19.40	9.02	30.12	0.510	0.97	33.38
60	0	18.02	7.94	28.30	0.511	1.35	20.10	19.11	8.17	29.42	0.524	1.63	20.37
	5	18.43	8.89	29.17	0.496	1.18	25.22	19.27	8.62	30.23	0.499	1.53	25.80
	15	18.68	9.83	29.57	0.467	1.27	28.05	19.71	9.98	30.58	0.488	1.30	27.18
	25	19.22	9.96	29.76	0.430	1.42	30.23	19.84	9.98	30.49	0.450	1.06	29.25
80	0	18.92	9.82	29.33	0.464	2.47	18.94	19.38	9.77	30.49	0.480	2.74	19.44
	5	19.85	9.95	30.21	0.455	2.58	22.64	19.58	9.89	31.37	0.467	2.52	22.40
	15	20.63	10.41	31.54	0.391	2.79	24.34	21.16	10.58	32.48	0.411	2.34	24.60
	25	21.54	10.64	32.79	0.394	2.59	28.21	22.59	10.71	33.83	0.398	2.16	27.12
100	0	20.84	10.16	30.22	0.406	3.71	18.62	21.13	10.60	31.89	0.391	3.90	17.44
	5	21.74	11.15	31.69	0.387	3.82	24.29	22.47	11.49	32.73	0.385	3.65	22.51
	15	20.90	12.33	32.59	0.373	3.28	24.73	21.33	12.55	33.63	0.380	3.35	24.25
	25	21.03	12.45	32.91	0.366	3.07	27.32	22.37	12.72	34.81	0.358	3.07	26.23
$R.LSD_{0.05}$		0.13	0.10	0.15	0.01	0.17	0.48	0.10	0.06	0.09	0.01	0.08	0.14

It was noticed that the highest mean values for most physical fruit quality characters were obtained with the high rates of zinc. Similar results were reported by Van den Driessche [13] and Alam and Shereen [24].

With respect to the interaction effects between phosphorus and zinc rates, it appeared from the results in Table 8 that, there were significant differences among the means of average fruit weight, fruit length, fruit diameter, fruit moisture content and fruit juice, in both seasons. It was, also, noticed that the highest mean values of all characters were obtained by 100 Kg P_2O_5 /fed. and 25 Kg Zn/ fed., in both seasons. Similar results were obtained by Alam and Shereen [24].

Chemical Contents: It was evident from Table 9 that, application of phosphorus rates at 60, 80 and 100 kg P_2O_5 /fed., significantly, had positive effects on total sugars, TSS, V.C, leaf P content, in both seasons. Fruits titratable acidity and leaf's Zn content, however, showed a reversal trend as the P rate increased.

Application of Zinc at the used levels, significantly, enhanced the fruit contents of total sugars, TSS, V.C and leaf's Zn content, in both seasons. Titratable acidity and leafs Zn content exhibited a remarkable decrease as Zn rate increased.

With respect to the combination effects between phosphorus and zinc rates (Table 10), results reflected significant effects on total sugars, TSS, V.C, fruit acidity and leaf P and Zn contents, in both seasons. The treatment combination100 kg P_2O_5 /fed. and 25 Kg Zn/ fed., in most cases or 80 kg P_2O_5 /fed. and 25 Kg Zn/ fed., in some cases recorded the highest significant magnitudes for most chemical content, in both seasons. Similar results were obtained by Shuman [12] and Van den Driessche [13]. On the other hand, increasing levels of phosphorus induced remarkable decrease of zinc content in leaves, in both seasons. This antagonistic effect between P and Zn may be due to: (a) dilution of zinc in plants by the increase in growth induced by phosphorus fertilizers, (b) inhibition of zinc uptake by the cations (Ca^{2+} in particular) added with phosphorus fertilizers, (c) phosphorus-induced zinc adsorption in the soil to hydroxides and oxides of iron and aluminum and to $CaCO_3$ and (d) inhibition of zinc translocation from roots to the shoot [22].

The aforementioned results of the present study indicated clearly that the application of phosphorus and zinc at the highest rates (100 kg P_2O_5 /fed. and 25 Kg Zn/ fed.) favored the production of high yield of strawberry plants with good quality, under the conditions of this experiment.

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