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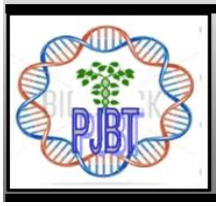

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EFFECT OF AGRONOMIC AMENDMENTS ON GROWTH AND YIELD OF SUNFLOWER

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ABSTRACT

Proper planting geometry helps in obtaining optimum plant population and crop yield, whereas irrigation at adequate time intervals result in improved crop yields and quality of the produce. Considering the same, two years field experiments were conducted during 2019 and 2020 at Tandojam to examine the effect of sowing methods (Raised bed, Ridge, Drilling and Broadcasting), planting densities (recommended, high density and ultra-high density) and nutrient management (90+60+60+0, 90+60+60+10 and 90+60+ 60+20 kg ha^{-1} N±P±K+$FeSO_4$) on growth and yield parameters of sunflower. The experimental design was a randomized complete block design with three replications. Best result in all parameters on average factors including drilling method, high density planting (66,666 plants ha^{-1}), NPK+FeSO4 =90+60+60+20 kg ha^{-1} and their interaction resulted in economically superior overall sunflower performance in relation to its growth, seed yield and quality attributes. The drilling method was highly effective to improve seed yield apart from the lower biological yield due to greater harvest index as compared to rest of the sowing methods. Although, recommended plant spacing (55,555 plants ha^{-1}) produced better individual plant based results, but due to lesser plant population, the overall seed yield was greater under high density planting (66,666 plants ha^{-1}). Ultra-high density plantation (83,333 plants ha^{-1}) did not prove beneficial due to crowded plant population where harvest index became poor despite an increased biological yield. Higher $FeSO_4$ improved the grain quality and no effect on foliage; hence 20 kg $FeSO_4$ remained economically most beneficial to achieve desired seed production.

Keywords: Plant density, fertilizer, Sowing Methods, Growth, Yield

Introduction

Pakistan's yearly import bill of crude edible oils is approximately US$ 3.4 billion metric tons, apart from the agrarian national economy. In 2020-21, palm and soybean oil up 5% from the previous year. Palm oil remains the major imported oil, while oilseed imports are projected at 3.3 MMT, up 6%. The import bill of edible oils and oilseeds shows a diminishing trend in 2019-20 in the first half of 2020-21 probably due to soft international prices and increased local output of oilseeds as well as improved efficiency of the domestic edible refining industry. However, the increase in cooking oil and vegetable ghee production is entirely associated with a rise in local oilseeds production, particularly at a time when policies of the government are causing a contraction in imports (Rana *et al.*, 2022). The major sunflower-growing countries are Russia, Ukraine, Argentina and European nations. Only Russia and Ukraine produce half of the total world sunflower production (FAO, 2019). According to the FAO (2019), globally, the sunflower was cultivated on 26 million hectares, and 45 million metric tons of sunflower seed was produced worldwide in the year 2019, while the seed yield produced in Pakistan is only 1274.7 kgs. According to the Pakistan Economic Survey, 2019-20 during July-March, 2.748 million tons of edible oils were imported spending US$ 2.046 billion, while during this period the local edible oil production remained 0.507 million tons. During 2019-20 in Pakistan, the sunflower was cultivated on an area of 219 thousand acres, receiving seed production of 105 thousand tons and oil production of 40 thousand tons (GoP, 2020).

Sunflower (*Helianthus annuus* L.) is a potential oilseed crop that can bridge the gap between consumption and supply of edible oil in Pakistan (Nezami *et al.*, 2008). However, there is still a huge gap between the achieved and potential yields of sunflower, and this happens only because of the non-adoption of recommended agronomic practices including application of nutrients without considering the optimum rate of these inputs, low or no use of micronutrients, traditional methods of growing crop; non-adoption of new sunflower varieties possessing high yielding characteristics that have resistance against various biotic and abiotic factors (Ullah &

Hussain, 2010). Among the factors associated with successful crop cultivation, the sowing of crops using appropriate methods is of great importance to achieve desired crop yields as the sowing method has a significant impact on crop growth and subsequent yields (Zhangzhong *et al.,* 2018). The growers with small land holdings generally adopt traditional methods of sowing, while the progressive growers use relatively improved production practices, because they have easy access to awareness of the advanced crop production technologies (Ahmad *et al.*,2000; Cucci *et al.,* 2017). Traditional sowing methods include broadcasting manually, opening furrows by a local plough dropping seeds by hand and dropping seeds in the furrow through a bamboo/metal funnel attached to a plough. For sowing in small areas dibbling is practiced. Multi-row traditional seeding devices with manual metering of seeds are quite popular with experienced farmers (Hussain *et al.,* 2000; Vijayakumar & Ramesh, 2005). Traditional sowing methods have various limitations. In manual seeding, it is not possible to achieve uniformity in the distribution of seeds. A farmer may sow at the desired seed rate but the inter-row and intra-row distribution of seeds is likely to be uneven resulting in bunching and gaps in the field; poor control over the depth of seed placement; it is necessary to sow at high seeding rates and bring the plant population to desired level by thinning (Shariti & Amin, 2003; Pereira & Hall, 2019). The main aim of this study was to evaluate the influence of different sowing methods, planting density, and fertilizers on the growth, yield and oil content of sunflower.

MATERIAL AND METHODS

Field experiments were conducted for consecutive two years at the Oil Seeds Research Institute, Agriculture Research Centre Tandojam during 2018 and 2019. Various growth and yield performances (quantitative and qualitative traits) of sunflowers were investigated under the influence of different sowing methods, planting density and fertilization ($NPK+FeSO_4$). The experiment was arranged in a randomized complete block design with three-factor combinations replicated thrice. The area of each replicated experiment combination plot was 30 m^2 (6 m x 5 m). The analysis of soil was performed before sowing and after harvesting. The research study consisted of four different sowing methods (Raised bed, Ridge, Drilling, Broadcasting), four planting density [Recommended density =30 cm or 55,555 plants ha^{-1} or 5.56 plants m^{-2}), High density = 25 cm or 66,666 plants ha^{-1} or 6.67 plants m^{-2}), Ultra density = 20 cm or 83,333 plants ha^{-1} or 8.33 plants m^{-2})], and three fertilizer levels (NPK at 90+60+60 kg ha^{-1}, $NPK+FeSO_4$ at 90+60+60+10 kg ha^{-1}, $NPK+FeSO_4$ at 90+60+60+20 kg ha^{-1}), using HO-1 sunflower variety. Sowing was done through hand drill in ridges and drilling methods while broad casting was done in raised bed and broad casting methods. Thinning was done to maintain optimum plant distance. A total of five irrigations were applied at 15 days interval. The N, P, and K were applied at 90, 60 and 60 (kg ha^{-1}) and $FeSO_4$ (10+20 kg ha^{-1}) from Urea, SSP and SOP sources, respectively. The application of N was in three equal splits; i.e. 1st at planting time, 2nd at 1st irrigation (15 DAS) and 3rd at 3rd irrigation (45 DAS). All phosphorus and potassium were applied at the time of land preparation. Inter-culturing was done for controlling weeds before 1st, 2nd, and 3rd irrigations, respectively.

Statistical analysis: The collected data was subjected to Analysis of Variance (ANOVA) using STATISTIX ver. 8.1 computer software (Statistix, 2006) where P values less than 0.05 were considered statistically significant. The Least Significant Difference (LSD) test was applied to compare treatments superiority.

RESULTS AND DISCUSSIONS

Seed Germination (m^{-2}): The data pertaining to seed germination of sunflower under the influence of various treatment combinations are provided in Table 1. The statistical analysis described that the germination percentage of sunflower was significantly ($P<0.05$) influenced by different sowing methods, planting densities, and fertilizer levels. The germination would have little or no response to the treatments, because the planting densities were dependent on seed rates; and high or ultra-high densities correspond to high seed rates were used to get more seedlings. Ahmad *et al.* (2000) argued that although the final crop stand has significant association with nutrient and crop management, but at germination, only soil and climatic conditions play vital role including seed viability. Similar results have been reported by Ahmed *et al.* (2011) who also found improved crop presence and absence of $FeSO_4$ had a vital impact on germination and this impact was proportional to the dose of application in addition to NPK recommendation. Drilling proved to be more advantageous sowing method as compared to raised bed, ridge sowing or broadcast method. However, germination is a typical parameter and little is associated with the sowing patterns; but factors that affect aerial and soil environment could be more influential to germination. Akbari *et al.* (1999) and Ali (2008) experienced that seed germination is significant association with the soil type, soil available nutrients and climatic conditions, and in the present study, only basal fertilizer dose could influence this crop characteristics. Ahmed *et al.* (2011) Moreover the entire plots in the experiment were supplied with similar NPK combination, but difference was the application of $FeSO_4$ and this nutrient may have apparent effect after seedling development, growth, and crop yield production levels, but the data did not show a linear impact of cropping patterns or nutrient management including iron sulphate application on germination level of sunflower

Table 1. Seed germination (m^{-2}) of sunflowers as affected by sowing methods, density, and fertilization.

Sowing methods	Planting density	Fertilizer levels (kg ha^{-1})			Mean
		NPK: 90+60+60	NPK+FeSO4: 90+60+60+10	NPK+FeSO4: 90+60+60+20	
Raised bed	Recommended density	20.00jk	22.00hi	24.00g	22.00G
	High density	19.00kl	21.00ij	22.00hi	20.67H
	Ultra density	22.00hi	24.00g	22.00hi	22.67F
	Mean	20.00H	22.00G	22.67FG	*21.78D*
Ridge	Recommended density	24.00g	22.00hi	20.00jk	22.00G
	High density	23.00gh	25.00f	24.00g	24.11E
	Ultra density	23.00gh	21.00ij	18.00l	20.66H
	Mean	23.33E	22.78EFG	20.67H	*22.26C*
Drilling	Recommended density	23.00gh	21.00ij	23.00gh	22.33FG
	High density	25.00f	26.00ef	24.00g	25.22D
	Ultra density	24.00g	25.33f	22.00hi	23.77E
	Mean	24.11D	24.22D	23.00EF	*23.78B*
Broadcasting	Recommended density	29.33bc	26.33ef	25.33f	27.00C
	High density	27.33de	30.33ab	27.33de	28.33B
	Ultra density	31.00a	28.33cd	29.33bc	29.55A
	Mean	29.22A	28.33B	27.34C	*28.30A*
Averages	Recommended density	24.08DE	22.83F	23.08F	23.33B
	High density	23.67F	25.75A	24.33CD	24.58A
	Ultra density	25.00B	24.67BC	22.83F	24.17A
	Mean	24.25A	24.42A	23.42B	--

Variables	SE	P-value	LSD 5%
Methods (M)	0.1709	0.0000	0.3409
Densities (D)	0.1480	0.0000	0.2952
Fertilizers (F)	0.1480	0.0000	0.2952
M × D	0.2961	0.0000	0.5905
M × F	0.2961	0.0000	0.5905
D × F	0.2564	0.0000	0.5114
M × D × F	0.5128	0.0000	1.0227

Plant height (cm): The plant height remained superior in drilling sowing method with high planting density (25 cm plant spacing) and when the crop supplied with N+P+K+$FeSO_4$ @90+60+60+20 kg ha^{-1} (181.30 cm). Ali *et al.* (2011) found that taller plants (178 cm) were observed in Hysun-33 with optimum row spacing of 75cm followed by the same hybrid (177.5 cm) with narrow row spacing of 55 cm (Khan *et al.*, 2011). The use of secondary nutrients ($FeSO_4$) showed high economic results suggesting growing soil deficiency for this element. Drilling method proved to be far better than raised bed, ridge sowing or broadcast methods as evident from the results. Hussain *et al*. (2000); Vijayakumar and Ramesh (2005) found that plant growth was significantly affected by sowing patterns and seed drilling showed its superiority and tallness of the plants were greater in drilling method as compared to other sowing techniques. The results of the present study are further confirmed by Badiyala and Chopra (2011) who have reported that nutrients availability in soil as per the crop requirement is of prime significance and secondary elements including iron and zinc deficiency in soil may sometimes constrain the crop from potential growth. Bameri *et al.* (2012) found that application of micronutrients improves crop growth optimally.

Table: 2. Plant height (cm) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	Planting density	Fertilizer levels (kg ha^{-1})			Mean
		NPK: 90+60+60	NPK+FeSO4: 90+60+60+10	NPK+FeSO4: 90+60+60+20	
Raised bed	Recommended density	165.59 x	168.24 u	172.05 k	168.63 k
	High density	171.39 n	174.12 h	178.08 c	175.20 c
	Ultra density	168.90 s	171.60 m	175.49 f	171.32 h
	Mean	168.62 k	171.32 h	175.20 c	*171.72 C*
Ridge	Recommended density	166.92 w	169.59 q	173.43 i	169.98 j
	High density	172.76 j	175.52 f	179.50 b	176.61 b
	Ultra density	170.26 o	172.98 j	176.90 e	172.70 f
	Mean	169.98 i	172.70 f	176.61 b	*173.10 B*

Drilling	Recommended density	168.59 t	171.29 n	175.17 f	171.69 h
	High density	174.50 h	177.29 d	181.30 a	178.38 a
	Ultra density	171.97 l	174.72 h	178.67 c	174.43 d
	Mean	171.69 g	174.43 d	178.38 a	*174.83 A*
Broadcasting	Recommended density	163.59 y	166.20 v	169.96 p	166.59 l
	High density	169.31 r	172.02 k	175.92 g	173.08 e
	Ultra density	166.86 w	169.53 q	173.36 i	169.25 j
	Mean	166.59 l	169.25 j	173.08 e	*169.64 D*
Averages	Recommended density	166.17 i	168.83 h	172.65 d	169.22 C
	High density	171.99 f	174.74 c	178.70 a	175.14 A
	Ultra density	169.50 g	172.21 e	176.11 b	172.60 B
	Mean	169.23 C	171.93 B	175.82 A	--

Variables	**SE**	**P-value**	**LSD 5%**
Methods (M)	0.0174	0.0000	0.0347
Densities (D)	0.0151	0.0000	0.0300
Fertilizers (F)	0.0151	0.0000	0.0300
M × D	0.0301	0.0083	0.0600
M × F	0.0301	0.0018	0.0600
D × F	0.0261	0.0000	0.0520
M × D × F	0.0521	1.0000^{NS}	0.1040

Stem girth (cm): Sunflower stem girth was greater in drilling method (6.53 cm), followed by ridge method (6.47 cm) and raised bed method (6.41 cm); while in broadcast method, the produced plants had least stem girth (6.33 cm). This greater stem thickness under drilling method of sowing was mainly associated with better ventilation and adequate availability of nutrients due to proper and uniform spacing between rows. In broadcast method, the plants could not intercept sunlight, resulting the reduced development of the stems. The studies carried out by Shariti and Amin (2003) and Pereira, & Hall (2019) concluded that in drilling sown sunflowers, the stems of plants were found stronger and thicker as compared to broadcast method or any other sowing technique. In case of increased planting density beyond the recommendations, the plant population was increased substantially, and hence with increasing plants competition for attaining natural resources and applied inputs more sharing of inputs caused to decrease stems' girth. Thus, 30 cm plant spacing which is already recommended by the agriculture scientists for sunflower was found to be better than rest of the planting densities, however, examination of such impacts on yield traits should be carefully considered. Moreover, addition of $FeSO_4$ at the higher rates of 20 kg ha^{-1} remained quite beneficial for sunflower when added to NPK at recommended rate. So treatment interaction of drilling sowing method, 30 cm plant spacing and N+P+K+$FeSO_4$ @90+60+60+20 kg ha^{-1} remained superior treatments for stem girth (7.05 cm). Similar results have also been reported by Bansal and Chahal (1990) and Pereira & Hall (2019) reported that Fe application in addition to NPK recommended fertilizers results in stronger crop stems to optimize crop performance from yield point of view. Ballare and Casal (2000) described that due to wider spacing and less plant population in recommended density, the average share of plants for inputs and natural resources increased and hence better ventilation caused positive impact to grow vigorous plants. Shariti and Amin (2003) found that with increasing planting density, the allocated share of the average plant for nutrients, other inputs and natural resources. Johnson *et al.* (2010) and Pereira, & Hall (2019) reported that the thicker stems in sunflower ensure the plants to establish bigger seed head to produce more seed rows. Similarly, $FeSO_4$ application resulted in encouraging results in regards to stem thickness, because there is interrelationship of stem thickness with the yield contributing traits. In sowing methods, drilling showed more encouraging results in regards to stem girth as compared to rest of the methods tested Boorboori *et al.* (2012).

Table: 3. Stem girth (cm) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	**Planting density**	**Fertilizer levels (kg ha^{-1})**			**Mean**
		NPK: 90+60+60	**NPK+FeSO4: 90+60+60+10**	**NPK+FeSO4: 90+60+60+20**	
Raised bed	Recommended density	6.59 j	6.80e	6.92 c	6.77 C
	High density	6.27 p	6.46 n	6.58 k	6.44 G
	Ultra density	5.87 y	6.05 v	6.17 s	6.03 K
	Mean	6.25 I	6.43 F	6.56 C	*6.41 C*

Ridge	Recommended density	6.65 h	6.85 d	6.98 b	6.83 B
	High density	6.32 p	6.51 l	6.64 i	6.49 F
	Ultra density	5.92 w	6.10 u	6.22 q	6.08 J
	Mean	6.30 H	6.49 D	6.61 B	*6.47 B*
Drilling	Recommended density	6.72 f	6.92 c	7.05 a	6.90 A
	High density	6.38 o	6.57 k	6.70 g	6.55 E
	Ultra density	5.98 w	6.16 t	6.28 q	6.14 I
	Mean	6.36 G	6.55 C	6.68 A	*6.53 A*
Broadcasting	Recommended density	6.52 k	6.71 f	6.84 d	6.69 D
	High density	6.19 r	6.38 o	6.50 l	6.35 H
	Ultra density	5.80 z	5.98 w	6.10 u	5.95 L
	Mean	6.17 J	6.36 G	6.47 E	*6.33 D*
Averages	Recommended density	6.62 C	6.82 B	6.95 A	6.80 A
	High density	6.29 F	6.48 E	6.61 D	6.46 B
	Ultra density	5.89 I	6.07 H	6.19 G	6.05 C
	Mean	6.26 C	6.46 B	6.58 A	--

Variables	**SE**	**P-value**	**LSD 5%**
Methods (M)	0.0018	0.0000	0.0036
Densities (D)	0.0016	0.0000	0.0031
Fertilizers (F)	0.0016	0.0000	0.0031
M × D	0.0032	0.0000	0.0063
M × F	0.0032	0.4369	0.0063
D × F	0.0027	0.0000	0.0054
M × D × F	0.0054	0.9988	0.0109

Head diameter (cm): The head diameter was desirable under drilling method (24.81 cm), followed by ridge method and raised bed method, while in broadcast method the head size was found to be the least. Drilling method proved to be more effective produce seed heads with bigger size than rest of the sowing methods. Probably, aeration due to proper line sowing, easy interception of light and adequate reception of soil moisture and nutrients was the major advantage to the plants sown through drilling method over other seedling techniques. These results are in agreement with those of Johnson *et al.* (2010) who concluded that drilling sown sunflowers resulted in greater head size and under this sowing technique the plants get optimally greater share of nutrients from the soil and utilize natural resources from the environment. The increasing planting density caused increased plant population, more competition among plants to grow vigorously, while under 30 cm plant spacing due to lowest plant population, the plants experienced better utilization of applied inputs and natural resources. In case of nutrients management, NPK+$FeSO_4$ @90+60+60+20 kg ha^{-1} resulted in maximum head size (25.01 cm) and addition of $FeSO_4$ at the higher rates of 20 kg ha^{-1} remained effective to improve head size when added to NPK at recommended rate. These results contrast with those of Diepenbrock *et al.* (2001), who achieved better crop growth and head size. However, the ecology of the research might differ from the location of the present research. Thus, treatment interaction of drilling method sown with NPK+$FeSO_4$ @ 90+60+60+20 resulted in biggest sunflower head size. Boorboori *et al.* (2012) reported that application of Fe in addition to NPK fertilizers resulted in improved seed heads. Bybordi and Malakouti (2003) found that the seeds number increased markedly when the crop received iron and other minerals used to fortify the applied macronutrients. There was a great impact of row direction on sunflower head size; probably North-South row direction improved the crop ventilation to intercept more soil and environmental natural resources over the East-west row orientation. The test of secondary element ($FeSO_4$) on head size remained quite encouraging and head diameter considerably improved over the control. It could be concluded that for achieving a desirable head size in sunflower, the crop needs to be sown with North-south row orientation; the straight fertilizers should be fortified with secondary elements; and better to use drilling method for sowing the crop in lines.

Table: 4. Head diameter (cm) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	**Planting density**	**Fertilizer levels (kg ha^{-1})**			**Mean**
		NPK: 90+60+60	**NPK+FeSO4: 90+60+60+10**	**NPK+FeSO4: 90+60+60+20**	
Raised bed	Recommended density	25.07 j	25.82 e	26.33 c	25.74 C
	High density	23.82 r	24.53 n	25.01 k	24.45 G
	Ultra density	22.32 y	22.99 w	23.43 t	22.91 K

	Mean	23.74 J	24.45 G	24.92 C	*24.37 C*
Ridge	Recommended density	25.27 h	26.03 d	26.54 b	25.95 B
	High density	24.01 p	24.73 m	25.21 i	24.65 F
	Ultra density	22.49 y	23.17 v	23.62 r	23.09 J
	Mean	23.93 I	24.64 E	25.12 B	*24.56 B*
Drilling	Recommended density	25.53 f	26.29 c	26.80 a	26.21 A
	High density	24.25 o	24.98 k	25.46 g	24.90 E
	Ultra density	22.72 x	23.40 u	23.85 q	23.32 I
	Mean	24.17 H	24.89 D	25.37 A	*24.81 A*
Broadcasting	Recommended density	24.77 l	25.51 f	26.01 d	25.43 D
	High density	23.53 t	24.24 o	24.71 m	24.16 H
	Ultra density	22.04 z	22.70 x	23.15 v	22.63 L
	Mean	23.45 K	24.15 H	24.62 F	*24.07 D*
Averages	Recommended density	25.17 c	25.91 b	26.42 a	25.83 A
	High density	23.90 f	24.62 e	25.10 d	24.54 B
	Ultra density	22.39 i	23.06 h	23.51 g	22.99 C
	Mean	23.82 C	24.53 B	25.01 A	--

Variables	**SE**	**P-value**	**LSD 5%**
Methods (M)	0.0586	0.0000	0.0117
Densities (D)	0.0507	0.0000	0.0101
Fertilizers (F)	0.0507	0.0000	0.0101
M × D	0.0101	0.0000	0.0202
M × F	0.0101	0.4573	0.0202
D × F	0.0878	0.0000	0.0175
M × D × F	0.0176	1.0000	0.0350

Seed weight head^{-1}(g): The drilling sown crop maximized seed weight head^{-1}, followed by ridge method (g), and raised bed method (g), while in broadcast method the seed weight head^{-1} was minimum (g). The treatments based on nutrients management suggested that NPK+$FeSO_4$ @90+60+60+20 kg ha^{-1} maximized seed weight head^{-1} (80.35 g) and treatment interaction of drilling method with 30 cm planting density supplied with N+P+K+$FeSO_4$ @90+60+60+20 kg ha^{-1} maximized seed weight head^{-1}upto 86.12 g. Kurilcik *et al.* (2008) reported that the drilling sown crop grew more vigorously probably due to optimum aeration and adequate moisture and nutrients consumption because of allocated space between the lines. The research findings reported by Ahuja *et al.* (2003) and Shariti and Amin (2003) from India found that sunflower sowing by drilling and maintaining plant stand after thinning showed significantly better results in relation to growth and yield parameters. Similarly, the wider plant spacing decrease planting density which facilitated plants to obtain increased share from soil and atmosphere, while in decreased plant spacing plant population was increased and the available resources were depleted for individual plants. Another addition of $FeSO_4$ (20 kg ha^{-1}) proved beneficial for achieving greater seed weight head^{-1} that necessitates the research to assess the soil availability of other nutrients apart from the commonly used soil fertilizers. The above results are in concurrence to those of Duraisamy and Mani (2001); Ebrahimian and Bybordi (2011) and Gaffar *et al.* (2011) who reported that application of micronutrients including Fe as fortification of recommended macronutrients proved to be beneficial for crop production and produce quality. The soil organic matter was also found improved after soil applied micro nutrients. This higher seed weight head^{-1} under this treatment combination was chiefly linked with improved head size and more seeds head^{-1} that in the end produced healthier seeds and hence greater seed weight head was achieved. Ebrahimian and Bybordi (2011) and Gaffar *et al.* (2011) found that the drilling sown crop intercept the natural resources from the soil and environment and grew vigorously as compared to other methods of sowing and generally that not only optimize aeration to the plants, but adverse effect of natural hazards is also minimized.

Table: 6. Seed weight head^{-1} (g) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	**Planting density**	**Fertilizer levels (kg ha^{-1})**			**Mean**
		NPK: 90+60+60	**NPK+FeSO4: 90+60+60+10**	**NPK+FeSO4: 90+60+60+20**	
Raised bed	Recommended density	80.55 j	82.97 e	84.58 c	82.70 C
	High density	76.53 r	78.82 n	80.35 k	78.57 G
	Ultra density	71.69 z	73.85 w	75.28 u	73.61 K
	Mean	76.26 J	78.55 G	80.07 C	*78.29 C*
Ridge	Recommended density	81.20 h	83.64 d	85.26 b	83.37 B
	High density	77.14 p	79.46 m	81.00 i	79.20 F

	Ultra density	72.27 y	74.44 v	75.88 s	74.20 J
	Mean	76.87 I	79.18 E	80.71 B	*78.92 B*
Drilling	Recommended density	82.02 f	84.48 c	86.12 a	84.20 A
	High density	77.92 o	80.25 k	81.81 g	79.99 E
	Ultra density	73.00 v	75.18 u	76.64 q	74.94 I
	Mean	77.64 H	79.97 D	81.52 A	*79.71 A*
Broadcasting	Recommended density	79.58 l	81.97 f	83.56 d	81.70 D
	High density	75.60 t	77.87 o	79.38 m	77.62 H
	Ultra density	70.83 z	72.95 x	74.37 v	72.71 L
	Mean	75.37 K	77.60 H	79.10 F	*77.35 D*
Averages	Recommended density	80.84 b	83.26 b	84.88 a	82.99 A
	High density	76.98 f	79.10 e	80.64 d	78.85 B
	Ultra density	71.95 i	74.10 h	75.54 g	73.87 C
	Mean	76.53 C	78.82 B	80.35 A	--

Variables	**SE**	**P-value**	**LSD 5%**
Methods (M)	0.0190	0.0000	0.0379
Densities (D)	0.0165	0.0000	0.0329
Fertilizers (F)	0.0165	0.0000	0.0329
M × D	0.0330	0.0000	0.0657
M × F	0.0330	0.3895	0.0657
D × F	0.0285	0.0000	0.0569
M × D × F	0.0571	1.0000	0.1138

Seed index (1000-seed weight, g): Sunflower sown by drilling produced higher seed index value (64.57 g) than rest of the methods, and 30 cm planting density maximized seed index (67.23 g), while NPK+$FeSO_4$ @90+60+60+20 kg ha^{-1} produced highest seed index value (65.09 g). Similar results have also been reported by Anwar *et al.* (2010) who were of the opinion that except broadcast seeding, all sowing methods produced satisfactory results regarding the seed index, but drilling method was more effective than other methods of sowing to produce quality seed. Usman and Perveen (2004) revealed that hybrid 65A24 showed high and stable yields among the hybrids under drilling method sowing as compared to broadcast. Siddiqui *et al.* (2009) reported that sunflower cultivars under drilling method had better growth compared to other sowing methods. Soomro *et al.* (2005) and Soleymani (2017) also reported that sunflower cultivars under the drilling method recorded better growth and heavier seeds compared to other sowing methods. In case of planting density regardless of other parameters that contribute yield ha^{-1}, 30 cm spacing resulted in heavier seeds than the seed obtained from plots sown with rest of the planting densities. The addition of $FeSO_4$ at higher rate (20 kg ha^{-1}) showed more positive results on this trait as compared to its lower rate (10 kg ha^{-1}) in addition to NPK fertilizers, which suggested that apart from the macronutrients, the soil may also be amended with micronutrients and other secondary elements to achieve the desired crop yields and seed quality in sunflower. Gangadhar *et al.* (1992) recorded higher seed quality of sunflower when supplied with Fe in addition to recommended nitrogen. Pathak *et al.* (2012) found improvement in seed quality after iron and zinc fortification to NPK fertilizers. Guruprasad *et al.* (2009) reported improved seed index value of sunflower after application of Fe in combination with other fertilizers. It was concluded that all sowing methods produced good results regarding the seed index, but drilling method was more effective than other methods of sowing to produce quality seed

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Table: 7. Seed index (1000-seed weight, g) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	**Planting density**	**Fertilizer levels (kg ha^{-1})**			**Mean**
		NPK: 90+60+60	**NPK+FeSO4: 90+60+60+10**	**NPK+FeSO4: 90+60+60+20**	
Raised bed	Recommended density	65.25 j	67.21 e	68.51 c	66.99 C
	High density	61.99 r	63.85 n	65.09 k	63.64 G
	Ultra density	58.07 y	59.81 w	60.97 u	59.62 K
	Mean	61.77 j	63.62 g	64.86 c	*63.42 C*
Ridge	Recommended density	65.78 h	67.75 d	69.06 b	67.53 B
	High density	62.49 p	64.36 m	65.61 i	64.15 F
	Ultra density	58.54 x	60.30 v	61.47 r	60.10 J
	Mean	62.27 i	64.14 e	65.38 b	*63.93 B*

Drilling	Recommended density	66.43 f	68.43 c	69.76 a	68.21 A
	High density	63.11 o	65.00 k	66.27 g	64.79 E
	Ultra density	59.12 x	60.90 u	62.08 q	60.70 I
	Mean	62.89 h	64.77 d	66.03 a	*64.57 A*
Broadcasting	Recommended density	64.46 l	66.39 f	67.68 d	66.18 D
	High density	61.24 t	63.07 o	64.30 m	62.87 H
	Ultra density	57.37 z	59.09 x	60.24 v	58.99 L
	Mean	61.02 k	62.85 h	64.07f	*62.65 D*
Averages	Recommended density	65.48 c	67.44 b	68.75 a	67.23 A
	High density	62.21 f	64.07 e	65.32 d	63.86 B
	Ultra density	58.27 i	60.03 h	61.19 g	59.83 C
	Mean	61.99 C	63.85 B	65.09 A	--

Variables	**SE**	**P-value**	**LSD 5%**
Methods (M)	0.0154	0.0000	0.0307
Densities (D)	0.0133	0.0000	0.0266
Fertilizers (F)	0.0133	0.0000	0.0266
M × D	0.0267	0.0000	0.0532
M × F	0.0267	0.3514	0.0532
D × F	0.0231	0.0000	0.0461
M × D × F	0.0462	1.0000	0.0922

Biological yield (kg ha^{-1}): The biological yield in broadcast method resulted in more biological yield (11513 kg) than rest of the methods; while NPK+$FeSO_4$ @90+60+60+20 kg ha^{-1} resulted in highest biological yield ha^{-1} (11705 kg). The results of this study are in similarity with those of Pandey *et al*. (2013) who concluded that sowing method plays a vital role in production of field crops, It was further observed that broadcast sown crop produced more foliage as compared to systematic line sowing methods, while drilling sowing method produced least foliage. The dense plant population caused remarkably more foliage than the low-density plantation. The addition of $FeSO_4$ at higher rate of 20 kg ha^{-1} did not produce higher foliage but $FeSO_4$ at 10 kg ha^{-1} produced more foliage and hence increased biological yield ha^{-1} was occurred. The validity of these results could only be recognized if the harvest index simultaneously follows this trend of effectiveness. The application of Iron sulphate (20 kg ha^{-1}) did enough to improve foliage but $FeSO_4$ at 10 kg ha^{-1} produced relatively lower amount of foliage and hence decreased biological yield ha^{-1} over higher $FeSO_4$ level. Similar results have also been reported by Habib (2012) and reported that supplementary nutrition with Fe and Zn showed marked positive impact growth and foliage of the crop. Khan *et al.* (2009) supplied sunflower with zinc and iron under irrigated conditions and found increased total biomass yield over control. Kumar *et al.* (1993) from India reported positive impact of iron on total crop biomass yield. In another study, Kumawat (1999) found that iron supplementation resulted in improved crop biomass yield; while Khushwaha (1999) found soil deficiency of Fe and suggested its soil amendment to achieve potential crop yields.

Table: 8. Biological yield (kg ha^{-1}) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	**Planting density**	**Fertilizer levels (kg ha^{-1})**			**Mean**
		NPK: 90+60+60	**NPK+FeSO4: 90+60+60+10**	**NPK+FeSO4: 90+60+60+20**	
Raised bed	Recommended density	11344 w	11537 t	11457 u	11446 I
	High density	11491 u	11687 q	11606 r	11595 H
	Ultra density	11571 r	11767 p	11686 q	11675 G
	Mean	11469 I	11664 G	11583 H	*11572 C*
Ridge	Recommended density	11673 q	11872 m	11790 o	11779 F
	High density	11825 n	12026 i	11944 k	11932 E
	Ultra density	11907 l	12109 h	12026 i	12014 D
	Mean	11802 F	12002 D	11920 E	*11908 B*
Drilling	Recommended density	10903 z	11089 z	11012 z	11001 L
	High density	11045 y	11233 w	11155 y	11144 K
	Ultra density	11121 x	11310 w	11233 x	11221 J

	Mean	11023 L	11210 J	11133 K	*11122 D*
Broadcasting	Recommended density	12005 j	12209 e	12125 g	12113 C
	High density	12161 f	12368 b	12282 c	12270 B
	Ultra density	12245 d	12453 a	12368 b	12355 A
	Mean	12137 C	12343 A	12258 B	*12246 A*
Averages	Recommended density	11481 H	11677 E	11596 G	11585 C
	High density	11631 F	11828 B	11747 C	11735 B
	Ultra density	11711 D	11910 A	11828 B	11816 A
	Mean	11608 C	11805 A	11724 B	--

Variables	**SE**	**P-value**	**LSD 5%**
Methods (M)	2.4515	0.0000	4.8893
Densities (D)	2.1230	0.0000	4.2343
Fertilizers (F)	2.1230	0.0000	4.2343
M × D	4.2461	0.0251	8.4685
M × F	4.2461	0.1056	8.4685
D × F	3.6772	0.9737	7.3340
M × D × F	7.3544	1.0000	14.668

Seed yield (kg ha^{-1}): The treatment interaction of drilling method of sowing × 25 cm planting density × N+P+K+$FeSO_4$ @ 90+60+60+20 kg ha^{-1} maximized seed yield upto 3058 kg ha^{-1}, while in row orientation interaction. This suggested that drilling method was found to be highly effective to produce higher seed yield apart from the lowest biological yield due to greater harvest index as compared to rest of the sowing methods. Hingoro (2008) reported that sunflower sown on ridges resulted in greater seed under value (15.50, g), seed yield (2311.26 kg per ha) and oil content (40.01%). The studies of Rahimzadeh and Mirak (2009) concluded that sunflower crop under drilling method showed better overall yield performance. Ali *et al.* (2011) also found that taller plants (178 cm) were observed in Hysun-33 with optimum row spacing of 75cm followed by the same hybrid (177.5 cm) with narrow row spacing of 55 cm (Khan *et al.*,2011). Baghdadi *et al.* (2014) reported highest seed yield (2489 kg ha^{-1}) from the early planting date at the 75 cm ×20 cm plant spacing. In a recent investigation, maximum crop yield was obtained under drilling method of planting with thinning space. Therefore, it was suggested to the farmers to go for adoption of drilling planting only if labor was available for the thinning (Sharma *et al.,* 2017). Phuhong *et al.* (2005) found superiority of broadcast seeding in terms of yield; while in the present study, drilling sowing method proved to be better than any other method. This indicates that the above researcher must have different ecology and wind direction or wind velocity as compared to the location of the present study. On the other hand, broadcast method of sowing produced more dry mass than seeds yield. Results of raised bed and ridge sowing were also encouraging and better than broadcast method so far, the grain yield was concerned. Khan *et al.,* (2011) described that the 30 cm plant spacing (55,555 plants ha^{-1}) produced better individual plant-based results, but due to lesser plant population, the overall seed yield was higher when high density planting was done, where 25 cm plant spacing was maintained with a population of 66,666 plants ha^{-1}. However, ultra high density plantation at 20 cm plant spacing (83,333 plants ha^{-1}) did not prove beneficial due to crowded plant population where harvest index became poor but biological yield increased. (Sharma *et al.,* 2017) described that the addition of $FeSO_4$ at higher rate of 20 kg ha^{-1} remained highly beneficial to improve seed yield, against biological yield trait where $FeSO_4$ at 10 kg ha^{-1} produced more foliage. Hence, higher $FeSO_4$ improved the grain quality and no effect on foliage, hence under greater harvest index, 20 kg $FeSO_4$ remained economical and highly for sunflower seed production. It was concluded that drilling surpassed all rest of the sowing methods in seed yield while biological yield was highest under broadcast method. $FeSO_4$ addition at 20 kg ha^{-1} to recommended NPK encouragingly improved seed yield as compared to control. Mahriya (1997) reported beneficial effect of iron on the crop yields and mixed with soil applied phosphorus. Majumdar and Singh (2000) analyzed soil deficiency of iron and recommended Fe based fertilizers application in addition to NPK for obtaining higher crop yields. In another investigation, Meena *et al.* (2006) used a combination of iron, zinc and Sulphur in addition to NPK fertilizers on oilseeds and reported increased yield and benefit cost ratio over control. Muhammed *et al.* (2006) achieved greater crop production when the crop supplied with iron in addition to common fertilizers over control. Moussavi-Nik *et al.* (2012) reported from Iran that micronutrient application has shown positive impact on crop seed quality and resulted in higher crop yields when given in addition to regular NPK fertilizers. Qing *et al.* (2011) investigated the effect of combined application of iron and zinc and achieved improved yield and quality of the crop produce.

Table: 9. Seed yield (kg ha^{-1}) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	Planting density	Fertilizer levels (kg ha^{-1})			Mean
		NPK: 90+60+60	NPK+FeSO4: 90+60+60+10	NPK+FeSO4: 90+60+60+20	
Raised bed	Recommended density	2422.7 v	2519.7 l	2555.7 p	2499.3 G
	High density	2543.7 q	2645.3 k	2683.7 i	2624.3 E
	Ultra density	2253.0 y	2343.3 x	2377.3 w	2324.6 J
	Mean	2406.4 I	2502.8 G	2538.9 F	*2482.7 C*
Ridge	Recommended density	2483.0 r	2582.3 n	2619.7 l	2561.7 F
	High density	2607.3 m	2711.7 h	2751.0 g	2690.0 C
	Ultra density	2309.0 x	2401.7 u	2436.3 t	2382.3 I
	Mean	2466.4 H	2565.2 E	2602.3 D	*2544.7 B*
Drilling	Recommended density	2760.3 f	2871.0 e	2912.0 c	2847.8 B
	High density	2898.3 d	3014.0 b	3058.0 a	2990.1 A
	Ultra density	2567.0 o	2669.7 j	2708.3 h	2648.3 D
	Mean	2741.9 C	2851.6 B	2892.8 A	*2828.7 A*
Broadcasting	Recommended density	2228.3 xy	2317.0 x	2351.0 xy	2298.8 K
	High density	2339.7 x	2433.3 o	2468.0 t	2413.7 H
	Ultra density	2072.3 yz	2155.0 z	2186.0 z	2137.8 L
	Mean	2213.4 L	2301.8 K	2335.0 J	*2283.4 D*
Averages	Recommended density	2473.6 f	2572.5 e	2609.6 c	2551.9 B
	High density	2597.2d	2701.1 b	2740.2 a	2679.5 A
	Ultra density	2300.3 i	2392.4 h	2427.0 g	2373.2 C
	Mean	2457.1 C	2555.3 B	2592.2 A	--

Variables	SE	P-value	LSD 5%
Methods (M)	1.5125	0.0000	3.0165
Densities (D)	1.3098	0.0000	2.6124
Fertilizers (F)	1.3098	0.0000	2.6124
M × D	2.6196	0.0000	5.2247
M × F	2.6196	0.0000	5.2247
D × F	2.2687	0.0001	4.5247
M × D × F	4.5374	1.0000	9.0495

Harvest index (%): The treatment interaction based on of drilling method of sowing, high density planting (25 cm plant spacing, 66,666 plants ha^{-1}) and N+P+K+$FeSO_4$ @ 90+60+60+20 kg ha^{-1} maximized harvest index upto 27.41 percent. Baghdadi *et al.* (2014) reported highest seed yield (2489 kg ha^{-1}) and harvest index (18.93%) from 75 cm ×20 cm plant spacing under drilling method of sowing. It is evident from the results that drilling sown crop remained highly economical to produce higher harvest index as compared to rest of the sowing methods, while broadcast method was found to be the least productive. Under high density planting, the harvest index was greater than planting densities of 83,333 (ultra-high density) or 55,555 plants ha^{-1} (recommended density) urging to increase plant population upto 66,666 plants ha^{-1} over 55,555 plants ha^{-1} planting density. The $FeSO_4$ addition at 20 kg ha^{-1} proved to be effective with significant improvement in harvest index indicating that $FeSO_4$ had direct impact on seed rather than to effect crop foliage. Similarly, the interaction of NPK+$FeSO_4$ @ 90+60+60+0 and drilling sowing method resulted in harvest index of 27.28 percent. (Jaya *et al.,* 2001). Higher temperature within-canopy due to more direct penetration of radiation. Rise in temperatures reduces period from visible bud to flower development (Yu *et al.,* 2002). The above results did not support the trend of results in the present research. Such differences in findings might be associated with the harvest index is calculated on the basis of seed yield as percentage of the biological yield, and in this regard, the treatment variables interrelate differently. So, only on the basis of harvest index, the treatment superiority cannot be examined but critically examined the seed yield response to these treatments. However, probably soil inadequacy in secondary elements such as $FeSO_4$ needs to be rectified along with other elements. Naga (2005) applied zinc and iron under irrigated agriculture conditions and reported better growth and harvest index over control. Ravi *et al.* (2008) also have reported similar results that are clearly in line with the findings of the present study. Shahrokhi *et al.* (2012) used foliar spray of iron sulphate and reported improved harvest index due to heavier crop seeds. Sharma (2006) reported improved crop seed quality and harvest index due to application of iron sulphate. However, it is doubtless that north-south row orientation is more effective than anyone else; while would be pertinent if drilling method is adopted on normal irrigated soils to facilitate the inter culturing practices and for achieving quality seeds Shahrokhi *et al.* (2012).

Table: 10. Harvest index (%) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	Planting density	Fertilizer levels (kg ha^{-1})			Mean
		NPK: 90+60+60	NPK+FeSO4: 90+60+60+10	NPK+FeSO4: 90+60+60+20	
Raised bed	Recommended density	21.36s	21.84s	22.31m	21.83F
	High density	22.14o	22.64k	23.12h	22.63D
	Ultra density	19.47w	19.91vw	20.34uv	19.91H
	Mean	20.99H	21.46F	20.90I	*21.46B*
Ridge	Recommended density	21.27s	21.75s	22.22m	21.75G
	High density	22.05m	22.55m	23.03h	22.54E
	Ultra density	19.39w	19.83vw	20.26uv	19.83I
	Mean	20.90I	21.37G	21.83E	*21.37C*
Drilling	Recommended density	25.31f	25.89e	26.44c	25.88B
	High density	26.24d	26.83b	27.41a	26.82A
	Ultra density	23.08j	23.60h	24.11g	23.60C
	Mean	24.88C	25.44B	25.99A	*25.44A*
Broadcasting	Recommended density	18.56x	18.98xy	19.39w	18.98K
	High density	19.24w	19.67w	20.10v	19.67J
	Ultra density	16.92z	17.31y	17.68x	17.30L
	Mean	18.24L	18.65K	19.05J	*18.65D*
Averages	Recommended density	21.63F	22.11E	22.59G	22.11B
	High density	22.42D	22.92B	23.41A	22.92A
	Ultra density	19.72I	20.16H	20.60G	20.16C
	Mean	21.25C	21.73B	22.20A	--

Variables	SE	P-value	LSD 5%
Methods (M)	0.0039	0.0000	0.0079
Densities (D)	0.0034	0.0000	0.0068
Fertilizers (F)	0.0034	0.0000	0.0068
M × D	0.0068	0.0000	0.0136
M × F	0.0068	0.0000	0.0136
D × F	0.0059	0.0000	0.0118
M × D × F	0.0118	0.9932	0.0236

Oil content (%): The interactive effect of drilling sowing method, high density planting (25 cm, 66,666 plants ha^{-1}) and N+P+K+$FeSO_4$ @ 90+60+60+20 kg ha^{-1} maximized oil content (41.39 %). The results highlighted that the differences in oil content between drilling, ridge and raised bed methods were marginal, but these differences were wider when compared with broadcast method. Hingoro (2008) reported that sunflower sown on ridges resulted in heavier seeds (15.50 g) and seed yield (2311.26 kg ha^{-1}) and oil content (40.01%). Due to wider spacing in low density planting, the oil content in sunflower seed was relatively higher under 30 cm spacing (55,555 plants ha^{-1}) and the oil content followed a certain decline with increased planting density. The $FeSO_4$ addition at 20 kg ha^{-1} showed great positive impact on oil content of sunflower and with decrease in $FeSO_4$ or in its absence the oil content in seed followed a certain decrease. Similarly, interaction based on NPK+$FeSO_4$ @90+60+60+20 and drilling method resulted in higher oil content in sunflower. Working on the similar aspects, Singh *et al.* (1995) applied iron in addition to zinc and potassium to fortify existing nutrients and reported that iron supplemented improved crop seed quality, while Singh (2008) reported worldwide micronutrient deficiency of soils. Singh *et al.* (1993) also reported that ferrous sulphate application improved crop nutrient content. Some other studies such as Singhal and Rattan (1999), White and Broadley (2005), Yadav (2002), and Zareie *et al.* (2011) concluded that in oilseed crops, the application of micronutrients including iron resulted in significant improvement in seed quality and oil contents. The oil content being a most crucial sunflower trait was markedly influenced by different treatments including nutrient management and sowing methods. The seed obtained from the crop sown by drilling remained superior in oil content. Besides, crop response to $FeSO_4$ reflected the need to rectify inadequacy of secondary elements in the soil.

Table: 11. Oil content (%) of sunflower as affected by sowing methods, density and fertilization

Sowing methods	Planting density	Fertilizer levels (kg ha^{-1})			Mean
		NPK: 90+60+60	NPK+FeSO4: 90+60+60+10	NPK+FeSO4: 90+60+60+20	
Raised bed	Recommended density	40.27 k	40.59 h	40.95 d	40.61 D
	High density	40.05 m	40.37 j	40.73 f	40.39 F
	Ultra density	38.26 v	38.56 u	38.91 r	38.58 I
	Mean	39.53 H	39.84 G	40.20 D	39.86 C
Ridge	Recommended density	40.69 g	41.02 c	41.38 a	41.03 B
	High density	40.37 j	40.69 g	41.06 b	40.71 C
	Ultra density	38.66 t	38.97 q	39.31 o	38.98 H
	Mean	39.91 E	40.23 C	40.58 A	40.24 A
Drilling	Recommended density	40.70 g	41.02 c	41.39 a	41.04 A
	High density	40.25 l	40.57 i	40.93 e	40.59 E
	Ultra density	38.67 t	38.98 q	39.32 o	38.99 H
	Mean	39.87 F	40.19 D	40.55 B	40.21 B
Broadcasting	Recommended density	38.26 v	38.56 u	38.91 r	38.58 I
	High density	38.69 s	39.00 p	39.35 n	39.01 G
	Ultra density	36.35 y	36.64 x	36.96 w	36.65 J
	Mean	37.76 K	38.07 J	38.41 I	38.08 D
Averages	Recommended density	39.98 E	40.30 C	40.66 A	40.31 A
	High density	39.84 F	40.16 D	40.52 B	40.17 B
	Ultra density	37.98 I	38.29 H	38.63 G	38.30 C
	Mean	39.27 C	39.58 B	39.94 A	--

Variables	SE	P-value	LSD 5%
Methods (M)	0.0027	0.0000	0.0053
Densities (D)	0.0023	0.0000	0.0046
Fertilizers (F)	0.0023	0.0000	0.0046
M × D	0.0046	0.0000	0.0092
M × F	0.0046	0.0000	0.0092
D × F	0.0031	0.0000	0.0079
M × D × F	0.0080	1.0000	0.0159

CONCLUSION AND RECOMMENDATIONS

The results suggested that Drilling method of sowing sunflower may preferably be employed. High density planting based on 25 cm plant spacing, 60 cm row spacing (66,666 plants ha^{-1}, 6.67 plants m^{-2}) proved to be better than recommended density of 30 cm plant spacing (55,555 plants ha^{-1}, 5.56 plants m^{-2}) in relation to yield attributes, and farmers may adopt high density plantation to achieve better returns from sunflower crop.

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REFERENCES

Ahmad, G., Quresh, Z. & Hafeezullah. (2000). Effect of different sowing methods on the performance of sunflower. *Pakistan Journal of Biological Sciences*, **3**(1), 1829-1830.

Ahmed, F., Abid, Mahmood, M.M., Ali, C.N., Anwar, M. & Sandhu, N.A. (2011). Effect of potassium in different proportions with nitrogen and phosphorus on growth, yield and oil contents of sunflower (*Helianthus annuus* L.). *Journal of Agricultural Research*, **30**(3), 353-357.

Ahuja, S.S., H.S. Dhingra & Bhatia, B.S. (2003). Comparison of various sunflower planting methods in Punjab. *Journal of Agriculture Research*, **40**(1), 64-70.

Akbari, K.N., Karan, F., Qureshi, F.M. & Pandya, H.R. (1999). Effect of micronutrient, sulphur and gypsum on yield of wheat and post-harvest soil fertility in red loam soils of Mewar (Rajasthan). *Indian Journal of Agricultural Research*, 33, 80-86.

Ali, A., Afzal, M., Rasool, I. J., Hussain, S. & Ahmad, M. (2011). Sunflower (*Helianthus annuus* L.) hybrids performance at different plant spacing under agro-ecological conditions of Sargodha, Pakistan. *International Conference on Food Engineering and Biotechnology Singapore*, **9**(1), 317-322.

Ali, S.A. (2008). Assessment of different crop nutrient management practices for yield improvement. *Australian Journal of Crop Science*, **12**(3),150-159.

Anwar, H., Rashid, A., Butt, M.A., Akhter, M.A., Aslam, M. & Saeed, A. (2010). Evaluation of sunflower (*Helianthus annuus* L.) hybrids for yield and yield components in central Punjab. *Journal of Agricultural Research*, **44**, 277-285.

Baghdadi, R., Halim, R.A., Nasiri, A., Ahmad, I. & Aslani, F. (2014). Influence of plant spacing and sowing time on yield of sunflower. *Journal of Food, Agriculture and Environment*, **12**(2), 688-691.

Badiyala, D., & Chopra, P. (2011). Effect of zinc and FYM on productivity and nutrient availability in maize (Zea mays)–linseed (Linum usitatissimum) cropping sequence. *Indian Journal of Agronomy*, **56**(2), 88-91.

Ballare, C.L. & Casal, J.J. (2000). Light signals perceived by crop and weed plants. *Journal of Field Crop Research*, **67**, 149-160.

Bameri, M., Abdolshahi, R., Mohammadi-Nejad, G., Yousefi, K., & Tabatabaie, S. M. (2012). Effect of different microelement treatment on wheat (Triticum aestivum) growth and yield. *International Research Journal of Applied and Basic Sciences*, **3**(1), 219-223.

Bansal, R.L. & Chahal, D. S. (1990). Effect of iron-manganese interaction on the yield and content of Fe and Mn in sunflower. *Acta Agronomica Hungarica*, **47** (1), 19–25.

Boorboori, M.R., Asli, E. & Tehrani, M.M. (2012). Effect of micronutrient application by different methods on yield, morphological traits and grain protein percentage of sunflower in greenhouse conditions. *RevistaCientífica UDO Agrícola*, **12**(1), 128-135.

Bybordi, A. & Malakouti, M.J. (2003). Effects of Iron, Manganese, Zinc and Copper on sunflower Yield and Quality under Saline Condition. *Olom-eAbVaKhak*, **17**(2), 48-59.

Cucci, G.G. Lacolla & Caranfa, G. (2017). Spatial distribution of roots and cracks in soils cultivated with sunflower. *Journal of Agronomy Soil Sciences*, **64**, 13-24.

Diepenbrock, W., Lang, M. & Feil, B. (2001). Yield and quality of sunflower as affected by row orientation, row spacing, and plant density. *Journal of Plant Research*, **52**(1), 29-36.

Duraisamy, V. P. and Mani,A. K. (2001). Effects of zinc and iron on yield and content uptake and soil fertility under samai in red loamy sandy soil. *Mysore Journal of Agriculture Science*, **35**(3), 297-301.

Ebrahimian, E. & Bybordi, A. (2013). Growth, yield and quality components of canola fertilized with urea and zeolite. *Communication Journal of soil Science and Plant Analysis*, **44**(1), 2896-2915.

FAO, (2019). List of countries by sunflower production. Food and Agriculture Organization of the United Nations. https://www.atlasbig.com/en-gb/countries-by-sunflower-production.

Gangadhar, G.A., Manjunathaih, H.M. & Satyanarayana, J. (1992). Effect of micronutrients on the yield and uptake of sunflower. *Journal of Indian Society of Soil Science*, **40**(3), 591-593.

Ghaffar, A., Ehsanullah, T., Nadeem, A. & Sultan, H. K. (2011). Influence of zinc and iron on yield and quality of sunflower planted under various trench spacings. *Pakistan Journal of Agriculture Science*, **48**(1), 25-33; 2011.

GOP, (2020). Economic Survey of Pakistan. Government of Pakistan, Ministry of Food, Agriculture and Livestock, Agriculture & Livestock Division (Economic Wing), Islamabad.

Guruprasad, F., Hiremath, T. & Hajisaheb, A. L. (2009). Assessment of stay green genotypes of sunflower for root traits under different soil moisture regime. *International Journal of Current Microbiology and Applied Sciences*, **11**(4), 156-166.

Habib, M. (2012). Effect of supplementary nutrition with Fe, Zn chelates and urea on wheat quality and quantity. *African Journal of Biotechnology*, **11**(2), 2661-2665.

Hingoro, M.I. (2008). Response of sunflower varieties to various sowing methods. M.Sc. Thesis, Sindh Agriculture University, Tandojam, Pp. 67.

Hussain, M. K., Rasul, E. & Ali, S. K. (2000). Growth analysis of sunflower under drought conditions. *International Journal of Agriculture and Biology*, **2**, 136-140.

Khan, M., Syed, S. & Shaukat, A. (2009). Growth, yield and nutrient content of sunflower using treated wastewater from waste stabilization ponds. *Pakistan Journal of Botany*, **41**(3),1391-1399.

Johnson, B.L., M.E. Zarnstorff & J.F. Miller. (2010). Effect of Row Spacing and Plant Population on Oil Seed Sunflower. Proc. 21st Sunflower Res. Workshop Dgs, Pp. 183-192.

Jaya, K.D., C.J. Bell & P.W. Sale. (2001). Modification of within-canopy microclimate in maize for intercropping in the lowland Tropics. In: Proc. 10th Aust. Agron. Conf., Hobart, Australia.

Khan, M.M., Khilji, A.R., & Taran, S.A. (2011). Effects of Row Spacing on the Growth and Yield of Sunflower Varieties. LAP Lambert Academic Publishing Co. Pp. 88.

Khushwaha, B.L. (1999). Studies on response of sunflower to zinc, boron and molybdenum application. *Indian Journal of Pulses Research*, **12**(3), 44-48.

Kumar, A., Baburai, N., Bhat, S.N. & Shanwad, U. K. (1993). Effect of micronutrients on growth and yield in sunflower. *Journal of Crop Research*, **70**(4), 128-141.

Kumawat, R. N. (1999). Effect of iron on enzymatic activity and chlorophyll content of sunflower. *Journal of Plant Nutrition*, **29**(3), 111-117.

Kurilcik, A., Dapkuniene, S., Kurilcik, G., Zilinskaite, S., Zukauskas, A. & Duchovskis, P. (2008). Effect of the photoperiod duration on the growth of chrysanthemum plantlets *in vitro*. Scientific Works of the Lithuanian Institute of Horticulture and Lithuanian University of Agriculture. *Journal of Plan Science*, **27**(2), 246-252.

Majumdar, T. & Singh, A. (2000. Effect of tillage and crop establishment, residue management and K fertilization on yield, K use efficiency and apparent K balance under rice-maize system in north-western India. *Journal of Field Crops Research*, **22**(4), 411-425.

Meena, H., Sharma, R. & Rawat, U. (2006). Status of macro-and micronutrients in some soils of tonk district of Rajasthan. *Journal of Indian Society of Soil Science*, **54**(4), 508-519.

Moussavi-Nik, M., Rengel, Z., Pearson, J.N. & Hollamby, G. (2012). Dynamics of nutrient remobilization from seed of sunflower genotypes during imbibition, germination and early seedling growth. *Journal of Plant and Soil*, **19**(4), 271–280.

Muhammad, S., Bakht, J., Yousaf, M., & Khan, M. A. (2006). Effects of fertilizer on growth and seed yield of sunflower. *Journal of Botany*, **45**(6), 1995-2000.

Naga, A.N. (2005). Influence of zinc and iron on biochemical and yield characteristics of sunflower. *Indian Journal of Plant Physiology*, **10**(3), 400-403.

Nezami, H., Khazaei, R. Z., Rezazadeh, B. & Hosseini, A. (2008). Effect of drought stress and defoliation on sunflower (*Helianthus annuus*L.) in controlled conditions. *Asian Journal of Agriculture*, **12,** 99-104.

Phuhong L.T., Denich, M., Vlek, P.L.G. & Balasubramanian, V. (2005). Suppressing weeds in direct seeded lowland rice: effects of methods and rates of seeding. *Journal of Agronomy and Crop Science*, **191**(2), 185-194.

Pandey, B.P., Basnet, K.B., Bhatta, M.R., Sah, S., Thapa, R.B. & Kandel, T.P. (2013). Effect of rows spacing and direction of sowing on yield and yield attributing characters of wheat cultivated in Western Chitwan Nepal. *Journal of Agricultural Sciences*, **4**(7), 309-316.

Pathak, G. C., Gupta, B., & Pandey, N. (2012). Improving reproductive efficiency of chickpea by foliar application of zinc. *Brazilian Journal of Plant Physiology*, *24*, 173-180.

Pereira, M.L & Hall, A.J. (2019). Sunflower oil yield responses to plant population and row spacing: Vegetative and reproductive plasticity. *Journal of Field Crop Research*, **23**(1), 17-30.

Qing, Z., Qiong. B., Xiao, T., Xin, L. & Gale, W. J. (2011). Combined effect of iron and zinc on micronutrient levels in sunflower. *Journal of Environmental Science*, **32**(3), 235-239.

Rana, A. W., Gill, S., & Akram, I. (2022). Promoting oil seed crops in Pakistan: Prospects and constraints. International Food Policy Research Institute.

Ravi, S.D., Papakosta, D.K. & Doitsinis, A. (2008). iron utilization efficiency of safflower hybrids and open-pollinated varieties under Mediterranean Conditions. *Journal of Field Crops Re*search, **10**(1),56-61.

Rahimzadeh, R. & Mirak,T.N. (2009). Effect of planting methods and plant density on grain yield and agronomic characteristics of sunflower (*Helianthus annuus* L.) under rainfed conditions. *Iranian Journal of Crop* Sciences, **11**(2), 123-135.

Shariti, A. & Amin, R. (2003). The effect of sowing methods on sunflower seed yield in dry land area. Agri. Sci. Info. Doc. Centre, Agri. Res. &Edu.Org. (Iran Islamic Republic), Pp 24.

Sharma, B.M., Manan, J. & Singh, G. (2017). Evaluation of different methods of sowing of sunflower at farmers' field in central plain zone of Punjab India. *International Journal of Current Microbiology and Applied Science*, **6**(10), 691-697.

Soomro, F.M., Sheikh, S.A., Jamro, G.H. & Leghari, M.H. (2005). Performance of sunflower under different water stress levels and sowing methods. *Indus Journal of Plant Science*, **4**(1), 93-96.

Soleymani, A. (2017). Light response of sunflower and canola as affected by plant density, plant genotype and N fertilization. *Journal of Photochem and Photobiology*, **17**(3), 580-588.

Siddiqui, F.C., M.H., Oad, Abbasi, M.K. & Gandahi, A.W. (2009). Zinc and boron fertility to optimize physiological parameters, nutrient uptake and seed yield of sunflower. *Sarhad Journal of Agriculture Science*, **25**(1), 286-292.

Shahrokhi, N., Ali, K., Nasrollahi, H. & Shirani, A.H. (2012). The effect of iron sulfate spraying on yield and some qualitative characteristics in three sunflower cultivars. *Annals of Biological Research*, **11**(3), 5205-5210.

Sharma, A. (2006). Iron–An indispensable micronutrient. *Journal of Physiology and Molecular Biology of Plants*, **19**(1), 11-20.

Singh, I., Levy, Y. & Sharma, T. (1993). Response of iron-deficient citrus trees to foliar iron sprays with; low-surface-tension surfactant. *Journal of Horticultural Science*, **15**(2), 227–233.

Singh, J.P., Karamanose, R.E., & Stewart, J.W.B. (1995). The mechanisms of iron-zinc deficiency in sunflower. *Canadian Journal of Soil Science*, **68**(4), 345-358.

Singh, M. V. (2008). Micronutrient deficiencies in crops and soils in India. *Journal of Micronutrient Deficiencies in Global Crop Production*, pp 93-125.

Singhal, S.K. & Rattan, R.K. (1999). Zinc nutrition of soybean and mustard in relation to source of zinc. *Annals of Agricultural Research*, **20**(1), 4-8.

Statistix. (2006). Statistix user manual, version 8.

Ullah, A., & Hussain, J. (2010). Response of growth and yield of sunflower to NPK fertilizer. *Journal of Agriculture Science*, **2**(3), 15-25.

Usman, M. & Perveen, L. (2004). Evaluation of sunflower hybrids for seed and oil yield for commercial cultivation in NWFP. *Indus Journal of Biology Science*, **1**(3), 248-252.

Vijayakumar, M. & Ramesh, S. (2005). Effect of crop geometry and nitrogen management on growth analysis and yield of rain-fed sunflower (*Helianthus annuus*L.). *Journal of Ecotoxicology and Environment Monitoring*, **15**(4), 371-376.

White, P.G. & Broadley, M.R. (2005). Biofortifying crops with essential mineral elements. *Trends Journal of Plant Science*, **10**(3), 586-593.

Yadav, P.S. (2002). Response of phosphorus and iron to mungbean to loamy sand soil. M.Sc. (Agriculture) Thesis, Rajasthan Agricultural University, Bikaner, India.

Yu, H., Y. Xu, Tan, E.L. & Kumar, P.P. (2002). Agamous-Like 24, a dosage-dependent mediator of the flowering signals. *Journal of Soil and Applied Science*, **55**(2), 55-61.

Zareie, S., Golkar, P. & Mohamadi-Nejad, G. (2011). Effect of nitrogen and iron fertilizers on seed yield and yield components of safflower genotypes. *African Journal of Agricultural Research*, **6**(3), 3924-3929.

Zhangzhong, L., Yang, P., Zheng, C. Wang, C. Zhang, K. & Niu, M. (2018). Effects of drip irrigation models on chemical clogging under saline water use in Hetao District, China. *Journal of Irrigation Science*, **10**(3), 345.