Research Article

Evaluation of Different Production Systems in Combination with Foliar Sulphur Application for Sunflower (*Helianthus annuus* L.) under Arid Climatic Conditions of Pakistan

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Abstract | Sunflower is a new emerging oilseed crop in Pakistan. Its oil is recommended for use across the globe including Pakistan. Due to lower production of indigenous edible oil, a huge quantity is imported which has a negative effect on the economy. To reduce the import expenses and meet country's demand, there is a need to increase area under oilseed crops without disturbing the cropping systems. Climate variability is another emerging threat for current production and cropping systems especially in south regions of Pakistan having high arid climatic conditions. A study was conducted in South Punjab (30°1575 N, 71°5249 E) to evaluate the performance of sunflower production systems (nursery transplanted and direct seeded) and sulphur foliar spray (0, 50, 100 and 150 ppm) on sunflower in a randomized complete block, with split plots arrangement. Results revealed that tallest plant (175 cm) with maximum number of leaves (32.7) recorded with the application of foliar sulphur spray (150 ppm). Similarly, sunflower produced maximum head diameter (18.0 cm), number of achenes per head (1510), 1000-achene weight (55.7 g) resulted in higher achene yield (2225 kg ha^{-1}) including oil contents (38.7%) with foliar sulphur spray of 150 ppm. The nursery transplanted production system, however, produced the highest number of achenes per head (1466), head diameter (17.4 cm), 1000-achene weight (54.4 g), achene yield (2305 kg ha^{-1}), biological yield (9183 kg ha^{-1}) and oil contents (37.4%) in comparison to direct seeded sunflower. Interaction of sunflower production systems and foliar sulphur levels indicated that nursery transplanted sunflower produced highest number of achenes per head (1567), head diameter (18.3 cm), 1000-achene weight (57.6 g), achene yield (2495 kg ha^{-1}) and biological yield (9454 kg ha^{-1}) in comparison to direct seeded sunflower with foliar sulphur spray of 150 ppm. The nursery transplanted sunflower showed higher net benefits and benefit to cost ratio and 16 days early maturity than direct seeded sunflower, which ultimately provide optimum time for cotton crop sowing in cotton-sunflower cropping system. It is concluded that sunflower has to be shifted through nursery transplanted production system in field to achieve the highest achene yield with achene oil content which also ensures timely sowing of cotton crop for effective use of field under cotton-sunflower cropping system.

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Links Researchers

Introduction

Sunflower is considered as the major and 4th largest oilseed crop across the world which is attributed to its high protein and oil contents (Rodriguez *et al*., 2002; Canavar *et al*., 2010). It is cultivated on 25.98 million hectares area worldwide with 47.40 million tons annual production (USDA, 2018). Among oilseed crops, sunflower ranked at 3rd position after cotton seed and mustard in Pakistan (USDA, 2018). The concentrations of oil and protein contents are 36-52% and 28-32% respectively into the sunflower seeds (Rosa *et al*., 2009). Estimated production of cooking oil is 0.503 million tons and the consumption of cooking oil is 2.447 million tons in Pakistan. Due to higher demands and lower production the country has purchased 1.944 million tons of cooking oil and paid Rs.155.278 billion during 2017-18 (GOP, 2017-18). Therefore, sunflower is a feasible crop which can overcome the gap present between production and consumption (Badar *et al*., 2002). Sunflower yield and productivity per unit area (1.13 tons ha^{-1}) is lower compared to other countries on the globe (USDA, 2018). There are various factors associated with low yield of sunflower crop while the most important ones are delay in sowing time, inadequate planting techniques, drought and heat stress (Nezami *et al*., 2008; Ahmad *et al*., 2009; Moriondo *et al*., 2011; Tahir *et al*., 2013; Ahmad *et al*., 2019). There are four main constraints for the successful production of sunflower in Pakistan. Firstly, sowing of cotton crop is delayed which is attributed to overlapping of sunflower maturity duration with cotton sowing time (Ali *et al*., 2018). Thus, growers hesitate to grow sunflower crop because of considerable yield losses of delayed planted cotton (Bozbek *et al*., 2006; Bilal *et al*., 2019). On the other hand, there are more chances of infestation of insect pests and diseases on late sown cotton crop (Ullah *et al*., 2019). Secondly, sunflower faces the problem of seed dormancy which reduces the germination percentage and crop stand due to climatic variability which ultimately results in low production (Nasreen *et al*., 2015; Bodrone *et al*., 2017; Rahman *et al*., 2018). Thirdly, sunflower faces the problem of heat stress which hastens the phenological stages especially reproductive stages and ultimately reduced total growth period, biomass, seed size and seed quality (Moriondo and Bindi, 2007; Moriondo *et al*., 2011). Hence, sustainable sunflower production is under threat because of heat stress induced by climate variability (Kalyar *et al*., 2013; Tariq *et al*., 2018). Fourthly, non-adoption of improved modern technology and imbalanced nutrition is also main constraint to sunflower production (Aulack, 2003; Farokhi *et al*., 2015). Among macronutrients, sulphur is considered as 4th most important nutrient for crop production after N, P and K (Tendon and Messick, 2002; Jamal *et al*., 2010). Oilseed crops have higher sulphur nutrient demand as compared to other crops which is attributed to its fundamental function in the synthesis of oil (Ahmad *et al*., 2007). Sulphur and phosphorus are required in equal amounts by the plants (DeKok *et al*., 2002). Sustainable crop production is under threat because of sulphur deficiency in Asian countries including Pakistan (Biswas *et al*., 2004; Khalid *et al*., 2009; Scherer, 2009; Isitekhale *et al*., 2013). Sulphur is considered a fundamental nutrient for oilseed crops which is attributed to its imperative functions in the synthesis of protein, carbohydrate metabolism, production of chlorophyll content, synthesis of vitamins (B, biotin and thiamine) and oil containing amino acids (cystine, methionine and cystein) (Tiwari and Gupta, 2006; Havlin *et al*., 2004; Najar *et al*., 2011). It improves the chemical composition as well as oil content into the seeds of oilseed crops which also makes sulphur as fundamental plant nutrient for oilseed crops (Hassan *et al*., 2007). Sulphur has also synergistic effect with other essential plant nutrients (N, P, K and Zn) and hence it increases the uptake of these plant nutrients (Nasreen and Huq, 2002).

The efficiency of soil application of sulphur is not appreciable because plants cannot directly use elemental form of sulphur and has to be transformed into sulphate form in soil. The transformation of elemental sulphur to sulphate depends upon several factors i.e. size and activity of the microbes population, soil moisture, soil temperature and degree of sulphur crumbling (Wen *et al*., 2001; Eriksen, 2009). Foliar spray of nutrients is considered a best technique because nutrients can contact the actual position of activity quickly (Kołota and Osinska, 2000). Similarly, foliar spray of nutrients is considered more economical and effective method because it provides rapid utilization of nutrients and permits the correction of observed deficiencies in less time as compared to soil application (Fageria *et al*., 2009; Geetha, 2019).

It has been observed that there is need to evaluate different production systems for sunflower to overcome the problem of adjustment of sunflower before cotton sowing (Rahman *et al*., 2016; Rahman *et al*., 2019) and limited research work has been done on different production systems for sunflower. Nursery transplanted sunflower production system may reduce the crop period in the field through early maturity which is necessary for the adjustment of cotton-sunflower cropping system. On the other hand, efficiency of soil application of sulphur is not appreciable. Thus, there is need to evaluate the response of sunflower to various levels of sulphur foliar spray as it may be a sustainable approach towards increasing fertilizer use efficiency and ultimately higher sunflower productivity.

Materials and Methods

Study site and environmental conditions

The experiment was conducted in arid climatic conditions of South-Punjab (30°1575 N, 71°5249E) Pakistan under irrigated conditions during the spring season of 2019. The experimental site has soil belong to Entisols having soil pH 8.10 and electrical conductivity 4.0 dS m^{-1} and nutritional composition of soil profile is given in Table 1. Climate is totally arid of the region, there is only lower rainfall which did not meet the crop requirements and even did not coincide with the production technology and crop irrigation requirement stage of the sunflower. Summer months especially May and June are too hot while currently climatic variability is the serious threat for the sustainable production of crops and cropping system. Weather data during the experimental period are presented in the Figure 1.

Table 1: *Fertility status of soil profile (0-30 cm).*

Treat-ment	N (mg kg^{-1})		P (mg kg^{-1})		K (mg kg^{-1})		S(mg kg^{-1})	
Soil depth (cm)								
	0-15	15-30	15-30	15-30	0-15	15-30	0-15	15-30
NTS+S_0	77.5	78.1	7.20	7.41	230	220	4.59	4.62
NTS+S_1	77.4	77.5	7.15	8.40	220	240	4.57	4.67
NTS+S_2	77.4	77.8	7.20	8.18	240	230	4.57	4.66
NTS+S_3	77.3	78.0	7.40	7.42	230	220	4.57	4.64
DSS+S_0	77.5	77.9	7.50	7.80	230	230	4.61	4.65
DSS+S_1	77.1	77.6	7.40	7.75	220	220	4.63	4.67
DSS+S_2	77.1	77.5	7.10	8.00	230	230	4.65	4.72
DSS+S_3	77.0	77.3	7.40	7.90	220	240	4.65	4.69

N: Available nitrogen; P: Available phosphorus; K: Available potassium; S: Available Sulphur; NTS: Sunflower grown by nursery transplanted sunflower production system; DSS: Sunflower grown by direct seeded sunflower production system; S_0: Control; S_1: 50 ppm Sulphur; S_2: 100 ppm Sulphur; S_3: 150 ppm Sulphur.

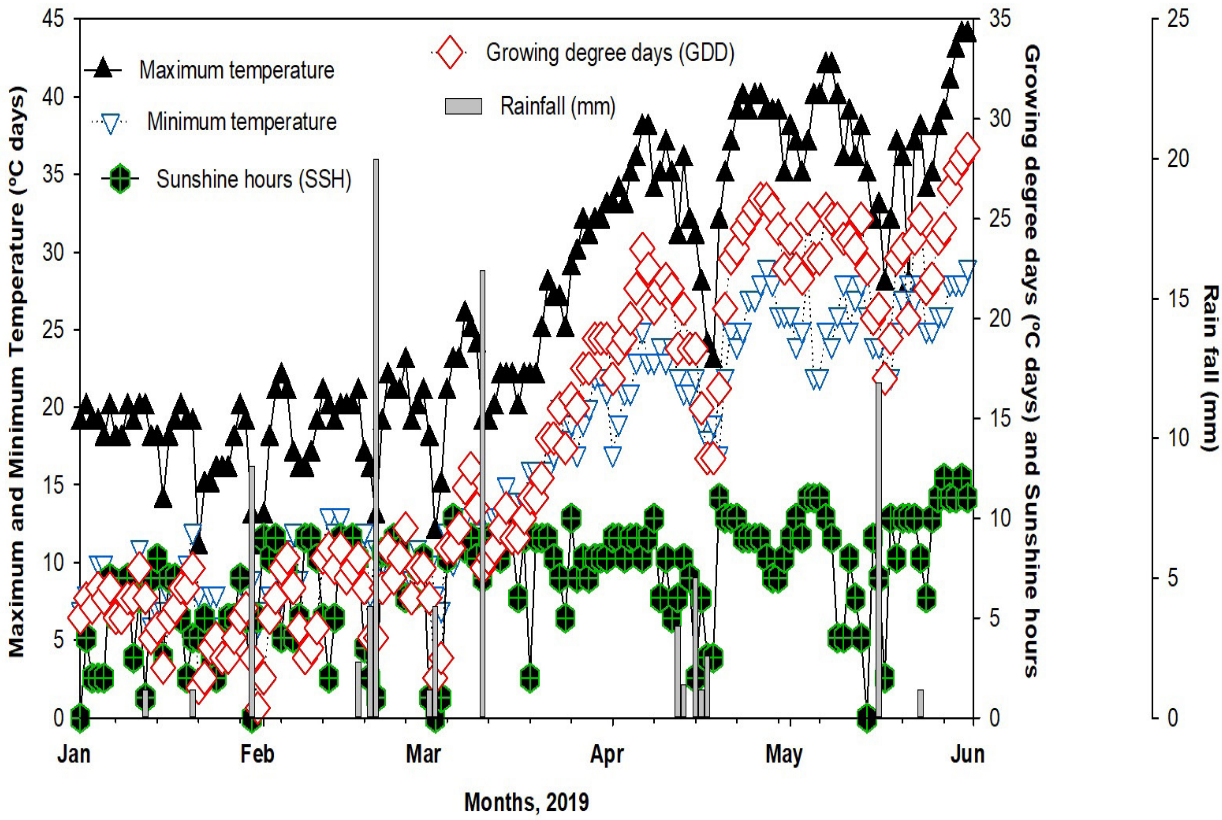

Figure 1: *Weather data during experimental period.*

Experimental treatments and design

The experiment was consisted of two sunflower production systems (nursery transplanted and direct seeded) and four foliar sulphur levels (0, 50, 100 and 150 ppm). The experiment was laid out in a split plot arrangement under RCBD having three replications, keeping net plot size of 4.80 m × 4.50 m. Different sunflower production systems and foliar sulphur levels were arranged in main plots and sub plots, respectively.

Crop husbandry

Nursery of sunflower was grown using plastic trays and coco-peat 30 days before transplanting (January 02, 2019). The direct seeded sunflower was sown on February 01, 2019 and transplanting of sunflower nursery of about 30 days in age was also carried out on the same day under field conditions. The sunflower genotype Hybrid Hysun-33 was sown as it is the one being cultivated on major of the area at farmer field in the region. Before sowing, the soil was ploughed twice followed by planking. With the help of tractor mounted ridger, ridges were made (75 cm apart) and seeds were sown (20 cm apart) through dibbler. Similarly, nursery was transplanted with same spacing into the ridges with the help of dibbler. At the time of sowing, whole of the P (90 kg ha^{-1}), K (60 kg ha^{-1}) and half of the N (65kg ha^{-1}) were applied using diammonium phosphate (DAP), urea and sulphate of potash as a fertilizer source. While, remaining N was applied in two equal splits with 1st (February 01, 2019) and 2nd (February 22, 2019) irrigation. Two foliar sprays of sulphur were applied according to the treatments. First foliar sulphur spray was applied at the initiation of flowering (March, 03, 2019 in nursery transplanted sunflower and March, 23, 2019 in direct seeded sunflower) and second spray was applied after 10 days of first spray (March, 13, 2019 in nursery transplanted sunflower and April, 02, 2019 in direct seeded sunflower). In total, 5 irrigations were applied at 20 days interval, while irrigation schedule comprised of 1st (February 01, 2019), 2nd (February 22, 2019), 3rd (March 14, 2019), 4th (April 04, 2019) and 5th (April 25, 2019) irrigations during crop growing season. After one month (March 01, 2019), thinning was carried out to maintain the plant population. Weeds were controlled manually by hoeing. There was no insect-pest or disease attack on the crop during entire growth cycle. The nursery transplanted sunflower was harvested on May 06, 2019 and direct seeded sunflower was harvested on May 22, 2019.

Data recording protocols

Data was collected for phenology (number of days to 50% buds formation (March 20-21, 2019 in nursery transplanted sunflower and April 12-13, 2019 in direct seeded sunflower) , number of days to 50% flower formation (April 4-5, 2019 in nursery transplanted sunflower and April 27-28 2019 in direct seeded sunflower), number of days to 50% initiation of achene formation (April 7-8, 2019 in nursery transplanted sunflower and April 30, 2019 in direct seeded sunflower), number of days to physiological maturity (May 3-4, 2019 in nursery transplanted sunflower and May 19-20, 2019 in direct seeded sunflower), and number of days to harvesting maturity (April 5-6, 2019 in nursery transplanted sunflower and April 21-22, 2019 in direct seeded sunflower).. While growth parameters (plant height, number of leaves per plant) were recorded on May 22, 2019, physiological parameters (stomatal conductance, net photosynthesis rate, transpiration rate) on April 17, 2019, yield parameters (number of achenes per head, head diameter, 1000-achene weight, achene yield, biological yield and harvest index) on May 06, 2019 in nursery transplanted sunflower and May 22, 2019 in direct seeded sunflower, and quality parameters (oil contents, linoleic acid, oleic acid, palmatic acid and stearic acid) on June, 15, 2019. Number of days taken to 50 percent of the plant formed buds, plant flowered, plant formed achenes, physiological maturity and harvesting maturity from the date of sowing in each plot was recorded and expressed in number of days after sowing (DAS) in both nursery transplanted and direct seeded sunflower. At maturity, the plant height of randomly selected 10 plants was measured with the help of a meter rod from the plant base to the tip of the ear and their mean was calculated. Number of leaves was counted by selecting 10 plants randomly from each plot and their mean was calculated. Stomatal conductance, net photosynthesis rate and transpiration rate were estimated using CIRAS-3 Portable Photosynthesis System (https://ppsystems.com/ciras3-portable-photosynthesis-system/) for the selected tagged plants in each treatment at full canopy development stage. Head diameter was measured with the help of vernier caliper. The crop was harvested and threshed manually. After threshing, the achene yield (kg ha^{-1}) of each treatment was recorded with the help of an electric balance. Similarly, five samples were taken from seed lot of each plot and 1000-achenes were counted and weighed on an electric balance and recorded as 1000-achene weight. Five heads from each plot were taken and number of achenes counted and their mean was calculated. Oil contents were determined by the Soxhlet apparatus (Kelrich, 1990). In this method, achenes were dried at 105°C in an oven for about 8 hours. Diethyl ether of low boiling point (40-60 °C) was used for extraction of fat from dry powdered material. Two grams of achenes per thimble was ground by grinding. The concentration of linoleic acid, oleic acid, palmitic acid, stearic acid was determined by Near Infrared Reflectance Spectroscopy System (Sato, 2002). Soil samples from each plot were collected and their analysis was conducted at initial conditions of the soil and after the harvesting of crop during experiment. Collected soil samples from 0-15 cm and 15-30 cm depth were sieved (2-mm mesh) after air drying. In these soil samples, available nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) were estimated through alkaline potassium permanganate (Subbiah and Asija, 1956), sodium bicarbonate (Olsen *et al*., 1954), ammonium acetate (Nelson and Heidel, 1956) and acid digestion method (Tabatabai, 1982) respectively.

Daily Tmax and Tmin air temperatures were used to compute thermal time (growing degree days) requirements above a threshold temperature (TT) in terms of degrees days (DD). Thermal time was calculated with the formula equation that calculates DD as the difference between the daily mean temperature and the threshold temperature (TT).

$$\sum_{i=dh}^{i=ds} \left[\left\{\frac{Tmax + Tmin}{2}\right\} - TT\right]$$

Where;
DD (°C days) accretion is the accumulative degrees days for specific phenophase, "ds" is date of sowing, "dh" date of harvest, TT is threshold temperature which was considered as 8°C for sunflower crop to compute the thermal time (FAO, 1978). In this case, if [(Tmax + Tmin)/2] < TT, or [(Tmax + Tmin)/2] = TT then DD was considered equal to zero.

Economic analysis
The economic analysis was performed to check the comparative net benefits and benefit to cost ratio using standard protocols and procedures of CIMMYT (1988). Total cost was calculated by adding the total fixed cost and total variable cost. The fixed cost included the cost of fertilizer, seeds, weeding, and harvesting. The variable cost included the cost used on land preparation, plastic trays, coco-peat, sowing operations and labor cost. The gross income was calculated by multiplying the achene yield by the market rate of sunflower seed. The net benefits were calculated by subtracting the gross income from the total cost. The benefit to cost ratio was calculated by dividing the gross income by the total cost.

Statistical analysis
Data collected for all parameters was analyzed statistically by using fisher's analysis of variance technique using the computer software "Statistix 8.1" and all the treatment means were separated through applying HSD Tuckeys test at 5% probability level (Steel *et al*., 1997).

Results and Discussion

This study indicated that different sunflower production systems significantly affected phenological parameters (Figure 2), and yields related parameters, quality parameters excluding plant height, number of leaves per plant (Figure 3) linoleic acid, stearic acid (Table 4) and physiological parameters (Table 5) of sunflower crop. However, different foliar sulphur levels significantly affected growth parameters (Figure 3), yield related parameters (Tables 2, 3), oil contents, oleic acid, palmatic acid (Table 4) and physiological parameters (Table 5) of sunflower crop. However, results were being non-significant for the phenological parameters of sunflower crop due to foliar application of different sulphur levels (Figure 2). Similarly, two-way interaction of different sunflower production systems with foliar sulphur levels was also significant for number of days to harvest maturity, yield related and physiological parameters of sunflower crop. However, results of two-way interaction of different sunflower production systems with foliar sulphur levels were being non-significant for growth (Figure 3), phenological (Figure 2) and quality parameters of sunflower crop (Table 4).

Sunflower produced highest plant height and number of leaves per plant with the 150 ppm foliar application of sulphur which was at par with 100 ppm foliar sulphur application in case of plant height (Figure 3). Higher plant height and number of leaves per plant with foliar application of 150 ppm sulphur level were due to imperative role of sulphur in enhanced nutrient availability (N, P and K), chlorophyll content and carbohydrate metabolism (Nasreen and Huq, 2002; Dhage and Patil, 2008; Kalaiyarasan *et al*., 2016). Sunflower grown by nursery transplanted sunflower production system took minimum days to achieve 50% buds formation, 50% flower formation, 50%

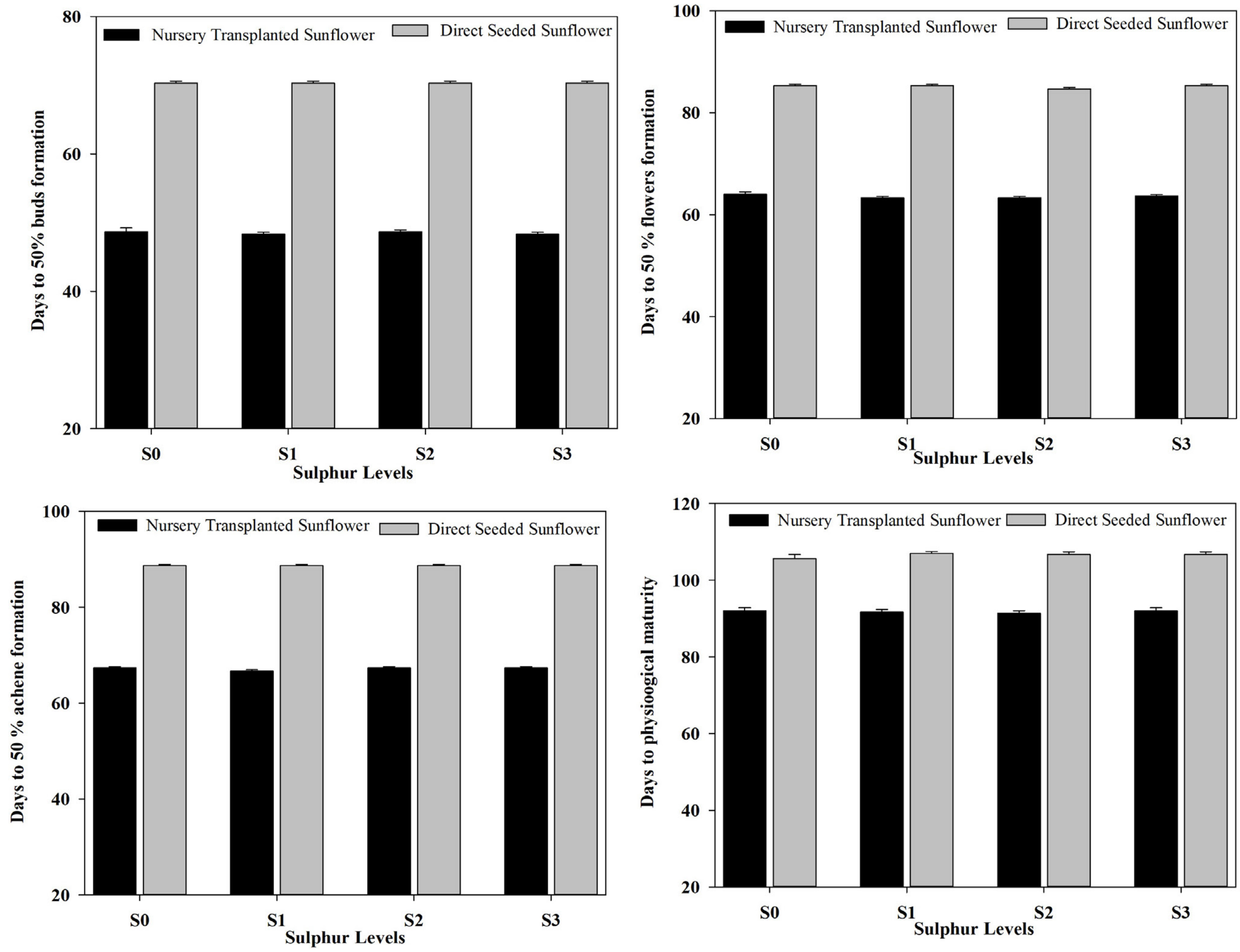

Figure 2: *Influence of different production systems and foliar sulphur application on phonological parameters of both nursery transplanted and direct seeded sunflower.*

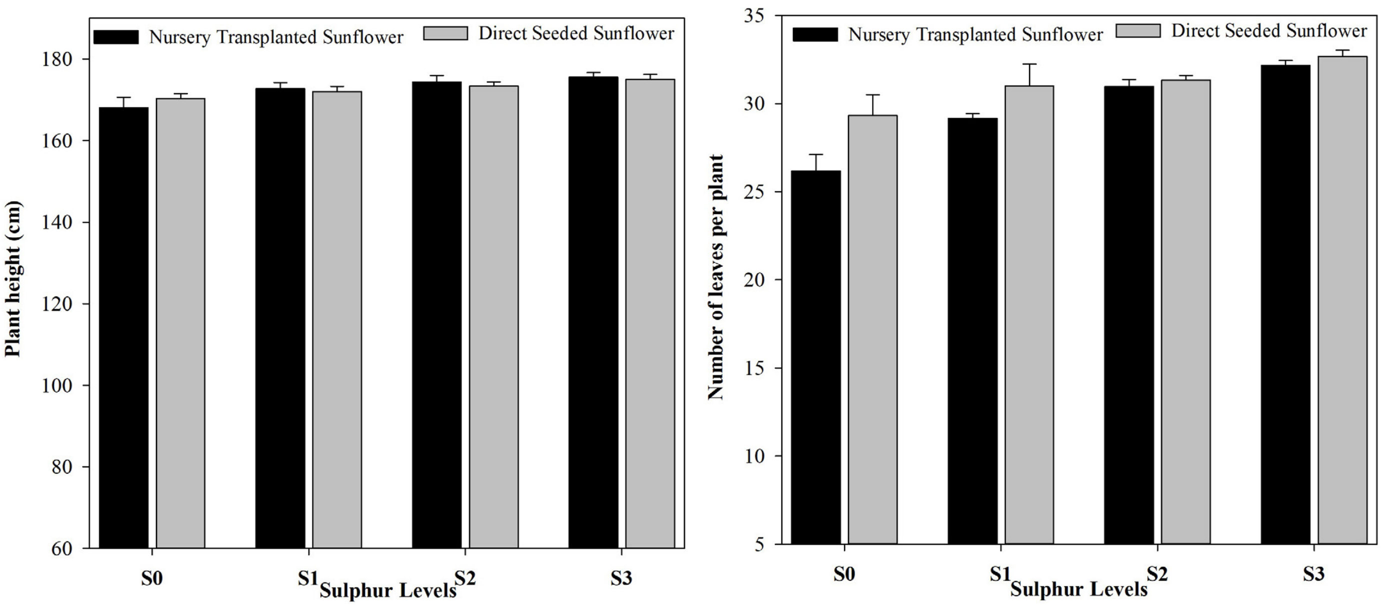

Figure 3: *Influence of different production systems and foliar sulphur application on plant height and number of leaves per plant of both nursery transplanted and direct seeded sunflower.*

Table 2: *Influence of different production systems and sulphur application on head diameter, number of achenes per head and 1000-achene weight of sunflower crop.*

Treatments	Head diameter (cm)	Number of achenes per head	1000-achene weight (g)
Production Systems (PS)			
Nursery Transplanted	17.4 a	1466 a	54.1a
Direct Seeded	16.9 b	1320 b	51.7 b
HSD (p≤0.05)	0.27	62.2	1.62
Foliar Sulphur (ppm)			
S_0	16.2 d	1273 d	49.5 d
S_1	16.9 c	1343 c	52.4 c
S_2	17.4 b	1449 b	54.1 b
S_3	18.0 a	1510 a	55.7 a
HSD (p≤0.05)	0.21	13.6	
Interaction of Production Systems × Foliar Sulphur (ppm)			
NTS+S_0	16.3 c	1352 d	49.8 d
NTS+S_1	17.3 ab	1435 c	53.8 c
NTS+S_2	17.7 a	1511 b	55.3 b
NTS+S_3	18.3 a	1567 a	57.6 a
DSS+ S_0	16.2 c	1194 f	49.2 d
DSS+ S_1	16.5 c	1250 e	51.0 d
DSS+ S_2	17.2 ab	1387 d	52.9 c
DSS+ S_3	17.7 a	1452 c	53.7 c
HSD (p≤0.05)	0.62	23.5	1.22
PS	**	*	**
FS	**	**	**
PS × FS	**	**	**

*Means of main effects and interaction sharing the same case letters for a parameter do not differ significantly at p≤0.05; NS = non-significant; * = Significant at p≤0.05 ** = Significant at p≤0.01; NTS= Sunflower grown by nursery transplanted sunflower production system; DSS=Sunflower grown by direct seeded sunflower production system; S_0=Control; S_1= 50 ppm Sulphur; S_2= 100 ppm Sulphur; S_3= 150 ppm Sulphur*

Table 3: *Influence of different production systems and sulphur application on achene yield, biological yield and harvest index of sunflower crop.*

Treatments	Achene yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Production Systems (PS)			
Nursery Transplanted	2305 a	9183 a	25.1 a
Direct Seeded	1932 b	8775 b	22.0 b
HSD (p≤0.05)	57.2	3.24	0.66
Foliar Sulphur (ppm)			
S_0	1979 d	8704 d	22.7 d
S_1	2067 c	8909 c	23.2 c
S_2	2153 b	9060 b	23.7 b
S_3	2275 a	9244 a	24.6 a
HSD (p≤0.05)	13.6	52.5	0.19
Interaction of Production Systems × Foliar Sulphur (ppm)			
NTS +S_0	2125 d	8902 d	23.9 d
NTS +S_1	2241 c	9112 c	24.6 c
NTS +S_2	2359 b	9266 b	25.5 b
NTS +S_3	2495 a	9454 a	26.4 a
DSS +S_0	1833 g	8506 f	22.7 d
DSS +S_1	1893 f	8707 e	22.0 e
DSS +S_2	1947 e	8854 d	21.7 ef
DSS +S_3	2055 d	9034 c	21.6 f
HSD (p≤0.05)	23.5	90.4	0.32
PS	**	*	**
FS	**	**	**
PS × FS	**	**	**

*Means of main effects and interaction sharing the same case letters for a parameter do not differ significantly at p≤0.05; NS = non-significant; * = Significant at p≤0.05 ** = Significant at p≤0.01; NTS= Sunflower grown by nursery transplanted sunflower production system; DSS=Sunflower grown by direct seeded sunflower production system; S_0=Control; S_1= 50 ppm Sulphur; S_2= 100 ppm Sulphur; S_3= 150 ppm Sulphur.*

initiation of achene formation, physiological maturity, harvesting maturity in comparison to sunflower grown by direct seeded sunflower production system (Figure 2). In this field experiment, nursery of sunflower was about 30 days at the time of transplanting while both transplantation of nursery and direct seeding was done at the same day in the field. Hence, sunflower grown by nursery transplanted sunflower production system might took an advantage of less days to achieve 50% buds formation, 50% flower formation, 50% initiation of achene formation, physiological maturity and harvesting maturity in comparison to sunflower grown by direct seeded sunflower production system.

Sunflower grown by nursery transplanted sunflower production systems produced highest head diameter, number of achenes per head, 1000-achene weight, achene yield, biological yield and harvest index in comparison to sunflower grown by direct seeded sunflower production system when foliar spray of 150 ppm was sprayed (Tables 2 and 3). Moreover, higher values of yield related parameters of both sunflower grown by nursery transplanted and direct seeded sunflower production system recorded with 150 ppm foliar application of sulphur were attributed to imperative functions of sulphur in the synthesis of protein, carbohydrate metabolism, production of chlorophyll content and improving availability of essential plant nutrients (Tiwari and Gupta, 2006; Havlin *et al*., 2004; Heydamezhad *et al*., 2012; Ravikumar *et al*., 2016). Many studies have reported improvement in the yield related parameters with the application of sulphur (Rani *et al*., 2009; Geetha *et al*., 2010; Bharose *et al*., 2011; Ullah *et al*., 2019).

Table 4: *Influence of different production systems and sulphur application on oil contents and fatty acid composition of sunflower crop.*

Treatments	Oil contents (%)	Linoleic acid (%)	Oleic acid (%)	Palmatic acid (%)	Stearic acid (%)
Production Systems (PS)					
Nursery Trans-planted	37.4 a	75.4	14.3 b	3.52 b	5.38
Direct Seeded	35.0 b	74.7	14.8 a	3.78 a	4.68
HSD (p≤0.05)	0.69	1.08	0.62	0.15	0.72
Foliar Sulphur (ppm)					
S_0	33.9 d	74.8 b	14.4	3.60	4.91
S_1	35.3 c	74.9 ab	14.5	3.71	4.92
S_2	36.7 b	75.2 a	14.5	3.66	5.16
S_3	38.7 a	75.2 a	14.7	3.62	5.12
HSD (p≤0.05)	0.60	0.39	0.55	0.13	0.53
PS	**	NS	**	**	NS
FS	**	**	NS	NS	NS
PS × FS	NS	NS	NS	NS	NS

*Means of main effects and interaction sharing the same case letters for a parameter do not differ significantly at p≤0.05; NS = Non-significant; * = Significant at p≤0.05 ** = Significant at p≤0.01; S_0=Control; S_1= 50 ppm Sulphur; S_2= 100 ppm Sulphur; S_3= 150 ppm Sulphur.*

Sunflower grown by nursery transplanted sunflower production system produced highest concentration of oil contents in comparison to sunflower grown by direct seeded sunflower production system (Table 4). Higher temperature during reproductive stages of sunflower reduces the oil content in the sunflower seed (Grompone, 2005; Regitano *et al*., 2016). Under direct seeded sunflower production system, there was high temperature during reproductive stages which reduced achene size as well as both quantity and quality of oil contents (Moriondo *et al*., 2011; Kalyar *et al*., 2013). Sunflower grown by direct seeded sunflower production system produced highest concentration of oleic acid and palmatic acid in comparison to sunflower grown by nursery transplanted sunflower production system (Table 4). Higher concentration of oleic acid and palmatic acid were attributed to higher temperature during reproductive stages which increased oleic acid and palmatic acid concentration in sunflower seeds (Vander Merwe *et al*., 2015; Regitano *et al*., 2016). Among different foliar sulphur levels, highest concentration of oil contents was recorded with 150 ppm foliar sulphur application (Table 4). Among different foliar sulphur levels, highest concentration of oil contents recorded with 150 ppm foliar sulphur application was attributed to its imperative functions in the synthesis of oil containing amino acids i.e.

Table 5: *Influence of different production systems and sulphur application on leaf photosynthesis rate, stomatal conductance and leaf transpiration rate of sunflower crop.*

Treatments	Leaf photo-synthesis rate (μmol $m^{-2}s^{-1}$)	Stomatal conductance (molm$^{-2}s^{-1}$)	Leaf transpi-ration rate (m mols^{-1})
Production Systems (PS)			
Nursery Trans-planted	17.8 a	874 a	9.22 a
Direct Seeded	16.2 b	781 b	8.82 b
HSD (p≤0.05)	0.05	1.57	0.02
Foliar Sulphur (ppm)			
S_0	15.0 d	691 d	7.68 d
S_1	16.2 c	727 c	8.54 c
S_2	17.8 b	922 b	9.59 b
S_3	19.0 a	968 a	10.3 a
HSD (p≤0.05)	0.04	6.65	0.04
Interaction of Production Systems × Foliar Sulphur (ppm)			
NTS+S_0	15.5 f	748 f	7.96 g
NTS+S_1	17.2 d	770 e	8.63 e
NTS+S_2	18.6 b	972 b	9.70 c
NTS+S_3	19.8 a	1004 a	10.6 a
DSS+ S_0	14.6 h	633 h	7.39 h
DSS+ S_1	15.1 g	684 g	8.45 f
DSS+ S_2	16.0 e	872 d	9.47 d
DSS+ S_3	18.1 c	933 c	9.95 b
HSD (p≤0.05)	0.06	11.5	0.07
PS	**	**	**
FS	**	**	**
PS × FS	**	**	**

*Means of main effects and interaction sharing the same case letters for a parameter do not differ significantly at p≤0.05; NS = non-significant; * = Significant at p≤0.05 ** = Significant at p≤0.01; NTS= Sunflower grown by nursery transplanted sunflower production system; DSS=Sunflower grown by direct seeded sunflower production system; S_0=Control; S_1= 50 ppm Sulphur; S_2= 100 ppm Sulphur; S_3= 150 ppm Sulphur.*

Table 6: *Economics of influence of different production systems and sulphur application on sunflower crop.*

Treatments	AY (kg ha^{-1})	IAY (Rs.)	IS (Rs.)	GI (Rs.)	CTPS (Rs.)	LC (Rs.)	FC (Rs.)	TFC (Rs.)	NR (Rs.)	BCR
NTS+S_0	2125	14,0803	14,820	155,623	10,796	5187	82,065	98,048	57,575	0.59
NTS+S_1	2241	14,8444	14,820	163,264	10,946	5187	82,065	98,198	65,066	0.66
NTS+S_2	2359	15,6306	14,820	171,126	11,096	5187	82,065	98,348	72,778	0.74
NTS+S_3	2495	16,5294	14,820	180,114	11,246	5187	82,065	98,498	81,616	0.83
DSS+S_0	1833	12,1436	14,820	136,256	0	2594	82,065	84,659	51,598	0.61
DSS+S_1	1893	12,5411	14,820	140,231	150	2594	82,065	84,809	55,423	0.65
DSS+S_2	1947	12,8967	14,820	143,787	300	2594	82,065	84,959	58,829	0.69
DSS+S_3	2055	13,6122	14,820	150,942	450	2594	82,065	85,109	65,834	0.77

NTS= Nursery transplanted sunflower; DSS= Direct seeded sunflower; S_0=Control; S_1= 50 ppm Sulphur; S_2= 100 ppm Sulphur; S_3= 150 ppm Sulphur; AY= Achene yield; IAY= Income from achene yield; IS= Income from straw; GI=Gross income; CTPS= Cost of trays, peat moss and sulphur; LC= Labor cost; TFC= Total fixed cost; NR= Net returns; BCR= Benefit cost ratio.

cystein, cystine and methionine (Kumar *et al*., 2010; Najar *et al*., 2011). Many studies have reported the improvement in oil contents and linoleic acid of sunflower with the application of sulphur (Bhagat *et al*., 2005; Kabade *et al*., 2006; Kumar *et al*., 2011; Ullah *et al*., 2019). Sunflower grown by nursery transplanted sunflower production system showed highest stomatal conductance, net leaf photosynthesis rate, leaf transpiration rate in comparison to sunflower grown by direct seeded sunflower production system with 150 ppm foliar sulphur application (Table 5). Increased stomatal conductance, net leaf photosynthesis rate and leaf transpiration rate were due to optimum growth conditions (optimum temperature) which prevented from the drastic impact of higher temperature under nursery transplanted sunflower production system due to faster growth of nursery transplanted sunflower as phenological stages are presented in Figure 2 (Kalyar *et al*., 2013; Dekov *et al*., 2001; Hassan, 2006). Moreover, highest physiological parameters of sunflower grown by nursery transplanted production system with 150 ppm foliar application of sulphur were attributed to imperative functions of sulphur in the synthesis of protein, carbohydrate metabolism, production of chlorophyll content (Tiwari and Gupta, 2006; Havlin *et al*., 2004). The economic analysis revealed that the cost of production was the highest in sunflower grown by nursery transplanted sunflower production system than sunflower grown by direct seeded sunflower production system due to additional cost of tray and peat moss in nursery transplanted sunflower production system. The highest net benefits and benefit to cost ratio were achieved from nursery transplanted sunflower production system with foliar application of 150 ppm sulphur (Table 6). The economic analysis indicated that the sunflower grown by nursery transplanted sunflower production system with foliar application of 150 ppm sulphur showed highest net benefits and benefit to cost ratio. The highest profitability in this treatment combination was due to more achene yield which results in more net returns.

Conclusions and Recommendations

This study indicated that different production systems and foliar sulphur application significantly affected growth, phenology, yield related parameters and quality parameters of sunflower crop. Sunflower grown by nursery transplanted sunflower production system took 16 days less to achieve maturity and produced highest achene yield and oil contents in comparison to sunflower grown by direct seeded sunflower production system. Among foliar sulphur levels, highest achene yield and oil contents were recorded with foliar application of 150 ppm sulphur level. The highest net benefits and BCR was recorded in sunflower grown by nursery transplanted sunflower production system with foliar application of 150 ppm sulphur level. In crux, it is recommended that sunflower would be grown through nursery transplanted production system to achieve early maturity that is necessary for the adjustment of sunflower in cotton-sunflower cropping system for the timely sowing of cotton and foliar sulphur application of 150 ppm would be done to achieve the highest achene yield, oil contents and net profitability under the arid climatic conditions of South Punjab-Pakistan. Future studies are needed to evaluate the response of various sowing nursery dates on transplanted production system of sunflower in cotton-sunflower cropping system under diverse environmental conditions under the current and future climate change scenarios for the adaptability of these production system.

Novelty Statement

Nursery transplanted production system with the application of foliar sulphur produced more sunflower yield in less time than direct seeded, and ensure early sowing of cotton crop and high profitability of cotton sunflower cropping system

Author's Contribution

AG, TH and MHR: Conceptualization.
SA and MAK: Methodology.
SA: Formal analysis.
SA and MHR: Data curation.
SA: Writing original draft preparation.
MHR, AG and AM: Writing review and editing.
AG: Supervision and project administration.

Conflict of interest
The authors have declared no conflict of interest.

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