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Soil boron application accelerates mobilization of pre-anthesis reserves in sunflower (*Helianthus annuus* L.)

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Abstract

Insufficient mobilization of pre-anthesis photosynthates from vegetative sources to reproductive sinks during achene growth and development plays a key role in reduced productivity of sunflower. Among different essential plant nutrients, a micronutrient boron (B) is known to have a prominent role in the mobilization of pre-anthesis reserves. A field experiment was carried out to investigate the role of soil applied boron in the mobilization and partitioning of pre-anthesis photoassimilates in early and late sown sunflower hybrid. Treatments were comprised of sowing dates (S) randomized in main plots and different rates of boron (B) randomized in sub plots. Treatments were S_1= Normal sowing (Mid-February); S_2= Late sowing (1st week of March) and B_1= Control; B_2= Water spray; B_3= 1.5 kg B ha^{-1} at button stage; B_4= 2 kg B ha^{-1} at button stage; B_5= 2.5 kg B ha^{-1} at button stage; B_6= 1.5 kg B ha^{-1} at ray floret stage; B_7= 2 kg B ha^{-1} at ray floret stage; B_8= 2.5 kg B ha^{-1} at ray floret stage. Soil applied boron significantly improved the dry matter accumulation (fresh and dry weight of leaf, stem, head and whole plant) and mobilization of photosynthates, capitulum diameter, number of achenes per head, 1000-achene weight, achene and biological yield. Moreover, achene oil and protein contents also increased by the soil application of boron. Normal sowing date was more effective for mobilization of reserves. However, application of B (2-2.5 kg ha^{-1}) mitigated the adverse effects of late sowing to a considerable extent.

Keywords: Sunflower, soil application, sowing date, dry matter accumulation, mobilization of pre-anthesis reserves

Introduction

Plant growth, development and productivity are affected by various biotic and abiotic factors (Jaleel *et al.*, 2009). Late planting, imbalanced use of fertilizers and sowing of exhaustive crops continuously in the same field, have been proved to be the major constraints for low yield of sunflower in Pakistan.

Sowing of short duration crops i.e., sunflower at the optimum sowing time is crucial for improved performance of yield contributing parameters and ultimate production (Hussain *et al.*, 2014) because delay in sowing date results in poor economic yield due to poor fertilization, abortion of embryo and poor filling of achenes (Killi and Altunbay, 2005). Yield and yield contributing components of sunflower get decreased in case of delayed sowing in both of temperate (Abelardo *et al.*, 2002) and subtropical environments (Manzoor *et al.*, 2016). Due to delay in sowing, the crop faces higher temperature during its vegetative growth period which hastens the growth of the crop resulting in reduced growth cycle which results in reduced amount of intercepted radiation and ultimately total dry matter production (Barros *et al.*, 2004). Overall longer growth period of a crop could be due to longer period of time available to different vegetative stages of the crop. Such situation is possible only when the crop is sown at optimum time with respect to specific agro-ecology.

The poor mobilization of photosynthates during achene growth and development is still a problem of economic concern in sunflower cultivation (Reddy *et al.*, 2003) because a large amount of photo-assimilates remain locked up in different vegetative sinks of sunflower and their reduced translocation towards reproductive head may result in lower economic productivity of sunflower (Naik, 1991). Out of various important functions performed by boron in the growth and development of plant, role of boron in cell wall development and inhibition or stimulation of different metabolic pathways are considered to be the most important ones (Ahmad *et al.*., 2009). Insufficient supply of boron has been reported to decrease the release of sucrose and amino acids with an ultimate reduction of dry matter accumulation and achene yield (Cakmak *et al.*, 1995) and poor seed setting because of malformed capitulum (Blamey *et al.*, 1987).

Soil application of boron is reported to improve harvest index (HI) and high oil percentage in sunflower (Oyinlola, 2007). Inhibition of overall growth, developing vascular bundles, death of meristems and reduction of photosynthesis are common observations of boron

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deficiency during vegetative growth phase of crop (Brown *et al.*, 2002) while in case of boron deficiency during reproductive phase resulted in inhibited flower development, decreased fruit as well as seed setting, seed abortion, impaired embryogenesis and male sterility (Garcia and Lopez, 2005). Boron requirement of most of the crops is higher during reproductive growth stage of the crops where the applied boron improved the fruit set and total grain yield (Dordas, 2006; Zahoor *et al.*, 2011).

Keeping in view the reduced mobilization of pre-anthesis reserves in sunflower, it is crucial to investigate the possible solution of reduced productivity of sunflower. It is hypothesized that soil application of boron may improve the assimilate mobilization and translocation towards the reproductive organs leading to improved productivity. The objective of the study was to investigate the most appropriate dose of soil applied boron with respect to growth stage and sowing time of sunflower.

Materials and Methods

Description of experimental site and design

The field experiment was conducted at the Agronomic Research Farm, University of Agriculture, Faisalabad (73.09° East longitude and 31.25° North latitude and 135 meters above the sea level) during spring 2011. Soil of experimental area (belonging to Lyallpur soil series according to USDA) was well drained clay loam with pH 7.9 (Thomas, 1996), EC 1.12 dSm^{-1} (Rhoades, 1996) total N 0.028% (Bremner and Mulvaney, 1982; Buresh *et al*., 1982) available P_2O_5 7.76 ppm (Olsen and Sommers, 1982) available K_2O 160 ppm (Richards, 1954) and boron 0.37 ppm (pre-sowing) and 0.36 ppm (after harvest) (Parker and Gardner, 1981). Sunflower hybrid HYSUN-33 was used as experimental material. The experiment was laid out in RCBD with split plot arrangement, using three replications. The net plot size was 6.0 m × 3.75 m. The experiment comprised of two sowing dates (mid February as optimum sowing date and first week of March as late sowing) in main plots and seven levels of soil applied boron (0, 1.5, 2 and 2.5 kg ha^{-1} at button and the same doses at ray floret stage) in sub-plots. One foliar spray of water was also applied to one experimental unit per replication. Seedbed was prepared in advance. After soaking irrigation, the field was cultivated at proper moisture level with tractor-mounted cultivator up to the depth of 10-12 cm, each followed by planking. Crop was sown on the 15th of February 2011, in case of first sowing date and on the 5th of March for second sowing date. Sowing was done with the help of dibbler keeping row to row distance of 75 cm and plant to plant distance of 22 cm. Recommended NPK (150:100:60 kg ha^{-1}) was applied in such a way that full dose of P, K and half nitrogen was applied at the time of seedbed preparation and remaining half N at the time of first irrigation. Boron was spread uniformly at button and ray floret stage by mixing with sand just before the irrigation. First irrigation was applied at 30 DAS (days after sowing) and then according to the crop requirements. There was no considerable attack of insect pests and diseases, hence no pesticide was used. While to keep the crop free of weeds, manual weeding was done at the time of thinning (18 DAE) and at button stage (45 DAE) prior to ray floret stage. All other agronomic practices, except the treatments under study, were kept uniform for all the treatments. Early and late sown crops were harvested on the 14th and 29th of June, 2011, respectively; sun-dried for 3 days and then threshed manually.

Collection and analysis of data:

Each experimental unit was divided into two major parts; central two rows were arranged for final harvest while the other surrounding rows were set for destructive sampling. Observations regarding dry matter accumulation were recorded periodically starting at 30 DAE and then with an interval of 15 days until maturity. For dry matter (DM) accumulation fresh and dry weights of whole plants, leaves, stems and heads of randomly selected five plants were weighed separately with digital balance. Fresh weights were taken immediately after harvesting while for dry weights, the plant materials were chopped thoroughly mixed and subsamples were placed in oven at 70 °C ± 5 °C till constant weight. After that the dried plant samples were again weighed.

Data regarding the yield and quality attributes were recorded from the two central rows at the harvest of crop. Capitulum diameter was recorded manually with the help of measuring tape, number of achenes per head by manual counting and 1000-achene weight with the help of digital balance at constant moisture contents. For achene yield, the heads of plants in central rows were removed with the help of sickle, air dried and threshed manually. The achene yield was adjusted to 10 % moisture contents and recorded in kg ha^{-1}. The biological yield was calculated on plot basis and converted to kg ha^{-1}. Achene oil contents (%) were determined by the Soxhlet Fat Extraction method (AOAC, 1990). Data collected were statistically analyzed applying Fisher's analysis of variance technique (Steel *et al*.., 1997).

Results and discussion

Biomass mobilization and translocation

Increased amount of assimilated biomass is not necessarily valuable to improve the final economic yield of sunflower because a considerable amount of photosynthates in sunflower remain locked up in different vegetative organs. Out of different vegetative organs which are supposed to be involved in the storage of essential biomass, stem is found to be the most prominent.

Percentage change of stem dry weight

Percentage change of stem dry weight between different sampling intervals as shown in table 2, indicates that stem dry matter accumulation started increasing and reached to peak (Table 1) after that the stem dry weight started decreasing and even became negative indicating that the rate of translocation of dry matter is higher than that of dry matter accumulation. Out of different sampling intervals, stem dry matter continue to increase from 14th of April to 14th of June in case of B_1 (control, no boron application) and up to 29th of May in B_2 (water spray) however, the percentage of accumulated dry matter started decreasing from 14th of May to 14th of June without becoming negative in control and became negative in case of B_2 (water spray) during 29th of May to 14th of June. In case of experimental units treated with boron at the time of button stage, maximum dry matter addition was observed during 14th of April to 29th of April and the amount of dry matter addition decreased during 29th of April to 14th of May. Onward from 14th of May percentage stem dry matter became negative in all of experimental units treated with boron at button stage, indicating that the amount of biomass translocation was higher than dry matter accumulation. In contrast, stem dry matter accumulation started increasing from 14th of April and reached to peak during 14th of May in plots treated with boron at ray floret stage. After that the stem dry matter accumulation become negative, indicating that the amount of biomass accumulated is lower than that of translocated. More the negative value of stem dry matter percentage, more will be the amount of translocated biomass from vegetative organ (i.e., stem) to reproductive sink (i.e., head). Out of different experimental units treated with boron at button and ray floret stages, highest negative value of stem dry matter was recorded in case of B_7S_1 (2 kg B ha^{-1} applied at ray floret stage in sunflower sown at optimum sowing time) followed by B_8S_1 (2.5 kg B ha^{-1} applied at ray floret stage sown at same time) when compared with control which showed no negative value during the whole sampling interval.

Soil applied boron especially at ray floret stage of sunflower resulted in increased amount of photosynthates translocation from vegetative organs to reproductive organs. These results are in accordance to those of Reddy *et al.* (2003) that translocation of assimilates from vegetative to reproductive organs is enhanced by the application of boron because of important role played by boron in the transport of sugars, which are reported to have stimulatory effect on different metabolic activities. Out of various important functions performed by boron in the growth and development of plant, role of boron in cell wall development and inhibition or stimulation of different metabolic pathways are considered to be the most important ones (Ahmad *et al*., 2009).

Percentage change of whole plant dry weight

Percentage change in whole plant dry weight as showed in table 2, indicates that whole plant dry matter accumulation started decreasing after reaching the peak value (Table 1). In both of sowing dates, maximum accumulation of dry matter occurred from 14th of April to 29th of April in experimental units treated with boron at button stage. After that the amount of dry matter accumulation started decreasing and reached to the minimum level at the time of 14th of June. However, in case of experimental units treated with boron at ray floret stage, maximum value of dry matter accumulation was observed during 29th of April to 14th of May. After that a sharp decline in total dry matter accumulation was recorded, reaching to a minimum value at the time of 14th of June. In all of the experimental units minimum value of dry matter accumulation recorded at the 14th of June was comparatively higher in case of late sown sunflower as compared to normal sown sunflower.

Increased value of dry matter accumulation is associated with increased productivity of the crop. Out of different experimental units treated with boron at button and ray floret stages, maximum value of whole plant dry matter accumulation was recorded from 29th of April to 14th of May in case of B_8S_1 (2.5 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) followed by B_8S_2 (2.5 kg B applied at ray floret stage of late sown sunflower) and then by B_7S_1 (2 kg B ha^{-1} applied at ray floret stage in normal sown sunflower)). Oyinlola (2007) reported increased amount of dry matter accumulation by the application of boron. In another experiment, Zahoor *et al.* (2011) reported increased total plant dry weight by the application of boron at ray floret stage of normal sown sunflower. Similarly Renukadevi and Savithri (2003) and Castro *et al.* (2006) found that B nutrition increased dry matter production of crop plants. Reddy *et al.* (2002) reported that leaf, stalk, head and total dry matter production increased with increased level of soil applied boron. Increased biomass production by the application of boron is thought due to boron role in cell elongation, photosynthesis and transpiration (Brown and Hu, 1996). Increased total fresh and dry weight in case of normal sown sunflower is due to the exposure of crop to more growing degree days as compared to that of late sown. Similar observations have been reported by Ahmad *et al.* (2005).

Table 1: Biomass accumulation in sunflower under different sowing times and boron levels

Boron Levels	Sampling date	Stem fresh weight (g/plant) ± % change		Stem dry weight (g/plant) ± % change	
		S_1(15-02-2011)	S_2(05-03-2011)	S_1(15-02-2011)	S_2(05-03-2011)
B_1 (Control)	14th April	195.40 ----	159.91 ----	45.17 ----	39.32 ----
	29th April	474.00 ----	367.19 ----	51.80 ----	43.26 ----
	14th May	548.00 ----	472.22 ----	69.57 ----	62.81 ----
	29th May	558.00 ----	458.00 ----	79.84 ----	67.21 ----
	14th June	537.00 ----	443.00 ----	80.76 ----	69.56 ----
B_2 (Water spray)	14th April	195.80 + 0.20	156.42 – 2.23	45.36 + 0.42	39.81 + 1.23
	29th April	481.50 + 1.56	365.12 – 0.57	50.83 – 1.91	44.58 + 2.96
	14th May	553.33 + 0.96	474.21 + 0.42	70.33 + 1.08	63.34 + 0.84
	29th May	589.15 + 5.29	448.27 – 2.17	87.21 + 8.45	68.14 + 1.36
	14th June	533.42 – 0.67	403.94 – 9.67	84.34 + 4.24	67.56 – 2.96
B_3 (1.5 kg B ha^{-1} at button stage)	14th April	193.00 – 1.24	155.15 – 3.07	44.62 – 1.23	39.56 + 0.61
	29th April	509.23 + 6.92	401.11 + 8.46	99.12 + 47.74	76.72 + 43.61
	14th May	577.25 + 5.07	511.21 +7.63	108.23 + 35.72	96.14 + 34.67
	29th May	611.20 + 8.70	483.37 + 5.25	107.42 + 25.67	91.33 + 26.41
	14th June	538.12 + 0.21	431.72 – 2.61	96.10 + 15.96	86.72 + 19.79
B_4 (2 kg B ha^{-1} at button stage)	14th April	194.50 – 0.46	157.02 – 1.84	45.17 + 0.00	39.77 + 1.13
	29th April	531.24 + 10.77	441.45 + 16.82	106.00 + 51.13	87.91 + 50.79
	14th May	583.15 + 6.03	549.63 + 14.08	110.00 + 36.75	101.00 + 37.81
	29th May	641.00 + 12.95	517.57 + 11.51	103.00 + 22.49	95.44 + 29.58
	14th June	551.00 + 2.54	481.21 + 7.94	99.47 + 18.81	89.62 + 22.38
B_5 (2.5 kg B ha^{-1} at button stage)	14th April	194.86 – 0.28	158.14 – 1.12	45.34 + 0.37	40.02 + 1.75
	29th April	578.14 + 18.01	451.00 + 18.58	109.48 + 52.69	89.29 + 51.55
	14th May	601.26 + 8.86	563.00 + 16.12	114.62 + 39.30	103.44 + 39.28
	29th May	663.25 + 15.87	521.00 + 12.09	109.73 + 27.24	95.21 + 29.41
	14th June	558.45 + 3.84	485.00 + 8.66	101.85 + 20.71	90.44 + 23.09
B_6 (1.5 kg B ha^{-1} at ray floret stage)	14th April	195.00 – 0.21	157.14 – 1.76	46.51 + 2.88	39.87 + 1.38
	29th April	476.00 + 0.42	369.46 + 0.61	52.30 + 0.96	43.18 - 0.19
	14th May	592.00 + 7.43	549.92 + 14.13	104.00 + 33.11	93.64 + 32.92
	29th May	619.00 + 9.85	507.51 + 9.76	98.00 + 18.53	85.76 + 21.63
	14th June	531.00 – 1.13	449.92 + 1.54	95.70 + 15.61	82.13 + 15.31
B_7 (2 kg B ha^{-1} at ray floret stage)	14th April	197.00 + 0.81	154.42 – 3.56	46.82 + 3.52	39.21 – 0.28
	29th April	474.00 + 0.00	374.58 + 1.97	51.73 – 0.14	44.11 + 1.93
	14th May	642.33 + 14.69	604.28 + 21.85	118.54 + 41.31	102.92 + 38.97
	29th May	673.00 + 17.09	581.67 + 21.26	112.00 + 28.71	94.16 + 28.62
	14th June	592.00 + 9.29	521.11 + 14.99	97.82 + 17.44	89.96 + 22.68
B_8 (2.5 kg B ha^{-1} at ray floret stage)	14th April	195.90 + 0.26	155.17 – 3.05	46.74 + 3.36	39.63 + 0.78
	29th April	475.00 + 0.21	362.26 – 1.36	51.26 – 1.05	42.32 – 2.22
	14th May	639.85 + 14.35	619.72 + 23.80	120.11 + 42.08	105.13 + 40.25
	29th May	681.00 + 18.06	593.18 + 22.79	111.67 + 28.50	98.67 + 31.88
	14th June	596.00 + 9.90	525.22 + 15.65	99.17 + 18.56	93.52 + 25.62

Table 1: Biomass accumulation in sunflower under different sowing times and boron levels (Continue….)

Boron Levels	Sampling date	Whole plant fresh weight (g/plant) ± % change		Whole plant dry weight (g/plant) ± % change	
		S_1(15-02-2011)	S_2(05-03-2011)	S_1(15-02-2011)	S_2(05-03-2011)
B_1 (Control)	14th April	401.06 ----	322.70 ----	84.25 ----	71.58 ----
	29th April	752.66 ----	613.67 ----	92.02 ----	78.74 ----
	14th May	932.30 ----	793.59 ----	128.05 ----	114.38 ----
	29th May	983.69 ----	792.29 ----	160.29 ----	133.65 ----
	14th June	915.00 ----	777.61 ----	169.66 ----	147.55 ----
B_2 (Water spray)	14th April	402.81 + 0.43	318.24 – 1.40	84.70 + 0.53	71.89 + 0.43
	29th April	765.51 + 1.68	581.94 – 5.45	94.02 + 2.13	80.68 + 2.40
	14th May	945.50 + 1.40	807.49 + 1.72	132.15 + 3.10	119.15 + 4.00
	29th May	1038.8 + 5.31	775.35 – 2.18	170.36 + 5.91	136.98 + 2.43
	14th June	927.43 + 1.34	748.94 – 3.83	177.65 + 4.50	149.62 + 1.38
B_3 (1.5 kg B ha^{-1} at button stage)	14th April	397.00 – 1.02	319.34 – 1.05	83.50 – 0.90	71.84 + 0.36
	29th April	821.22 + 8.35	652.50 + 5.95	146.38 + 37.14	115.40 + 31.77
	14th May	1024.60 +9.01	887.67 + 10.60	181.36 + 29.39	157.53 + 27.39
	29th May	1124.18 + 12.50	912.59 + 13.18	193.93 + 17.35	172.17 + 22.37
	14th June	1016.60 + 9.99	841.36 + 7.58	200.16 + 15.24	182.30 + 19.06
B_4 (2 kg B ha^{-1} at button stage)	14th April	400.52 - 0.13	322.17 – 0.16	84.30 + 0.06	72.18 + 0.83
	29th April	870.24 + 13.51	738.83 + 16.94	157.33 + 41.51	133.13 + 40.85
	14th May	1080.15 + 13.69	985.76 + 19.49	191.24 + 33.04	171.83 + 33.43
	29th May	1225.50 + 19.73	997.00 + 20.53	215.24 + 25.53	190.95 + 30.01
	14th June	1087.00 + 15.82	917.32 + 15.23	221.37 + 23.36	201.02 + 26.60
B_5 (2.5 kg B ha^{-1} at button stage)	14th April	398.86 – 0.55	322.95 + 0.08	84.30 + 0.06	72.65 + 1.47
	29th April	959.14 + 21.53	758.00 + 19.04	170.72 + 46.10	135.79 + 42.01
	14th May	1149.86 + 18.92	1009.90 + 21.42	213.01 + 39.89	175.97 + 35.00
	29th May	1237.26 + 20.49	1009.63 + 21.53	228.45 + 29.84	191.25 + 30.12
	14th June	1141.45 + 19.84	957.00 + 18.75	241.09 + 29.63	208.86 + 29.35
B_6 (1.5 kg B ha^{-1} at ray floret stage)	14th April	402.00 + 0.23	322.66 – 0.01	86.06 + 2.10	72.92 + 1.84
	29th April	757.00 + 0.57	581.02 – 5.62	92.54 + 0.56	78.95 + 0.27
	14th May	1068.40 + 12.74	983.20 + 19.28	185.63 + 31.02	163.90 + 30.21
	29th May	1179.90 + 16.63	984.22 + 19.50	201.55 + 20.47	178.00 + 24.92
	14th June	1054.00 + 13.19	909.09 + 14.46	209.77 + 19.12	191.02 + 22.76
B_7 (2 kg B ha^{-1} at ray floret stage)	14th April	402.50 + 0.36	318.00 – 1.48	85.76 + 1.76	71.72 + 0.20
	29th April	757.00 + 0.57	593.81– 3.34	92.24 + 0.24	80.92 + 2.69
	14th May	1245.96 + 25.17	1133.89 + 30.01	224.34 + 42.92	186.54 + 38.68
	29th May	1342.90 + 26.75	1131.47 + 29.98	238.41 + 32.77	203.55 + 34.34
	14th June	1231.17 + 25.68	1067.29 + 27.14	246.94 + 31.30	228.08 + 35.31
B_8 (2.5 kg B ha^{-1} at ray floret stage)	14th April	402.88 + 0.45	319.27 – 1.07	83.55 – 0.84	72.35 + 1.06
	29th April	755.00 + 0.31	578.17 – 6.14	91.40 – 0.68	78.53 – 0.27
	14th May	1253.85 + 25.65	1179.15 + 32.70	228.88 + 44.05	191.62 + 40.31
	29th May	1370.48 + 28.22	1176.90 + 32.68	243.04 + 34.05	217.49 + 38.55
	14th June	1245.73 + 26.55	1056.15 + 26.37	247.09 + 31.34	230.72 + 36.05

Table 2: Effect of soil applied boron and sowing date on percentage change of stem and whole plant dry weight (g/plant) of sunflower at different sampling intervals

Parameter	Sampling date	Boron levels (kg B ha^{-1}) B$_1$ (Control) ± % change		B$_2$ (Water spray) ± % change		B$_3$ (1.5 kg B ha^{-1} at button stage) ± % change		B$_4$ (2 kg B ha^{-1} at button stage) ± % change	
		S$_1$	S$_2$	S$_1$	S$_2$	S$_1$	S$_2$	S$_1$	S$_2$
Stem dry weight change (%)	14th April – 29th April	12.80	9.11	10.76	10.70	54.98	48.44	57.39	54.76
	29th April – 14th May	25.54	31.13	27.73	29.62	8.42	20.20	3.64	12.96
	14th May – 29th May	12.86	6.55	19.36	7.04	-0.75	-5.27	-6.80	-5.83
	29th May – 14th June	1.14	3.38	-3.40	-0.86	$^{-1}$1.78	-5.32	-3.55	-6.49
Whole plant dry weight change (%)	14th April – 29th April	8.44	9.09	9.91	10.89	42.96	37.75	46.42	45.78
	29th April – 14th May	28.14	31.16	28.85	32.29	19.29	26.74	17.73	22.52
	14th May – 29th May	20.11	14.42	22.43	13.02	6.48	8.50	11.15	10.01
	29th May – 14th June	5.52	9.42	4.10	8.45	3.11	5.56	2.77	5.01

Parameter	Sampling date	B$_5$ (2.5 kg B ha^{-1} at button stage) ± % change		B$_6$ (1.5 kg B ha^{-1} at ray floret stage) ± % change		B$_7$ (2 kg B ha^{-1} at ray floret stage) ± % change		B$_8$ (2.5 kg B ha^{-1} at ray floret stage) ± % change	
Stem dry weight change (%)	14th April – 29th April	58.59	55.18	11.07	7.67	9.49	11.11	8.82	6.36
	29th April – 14th May	4.48	13.68	49.71	53.89	56.36	57.14	57.32	59.75
	14th May – 29th May	-4.46	-8.64	-6.12	-9.19	-5.84	-9.30	-7.56	-6.55
	29th May – 14th June	-7.74	-5.27	-2.40	-4.42	$^{-1}$4.50	-4.67	$^{-1}$2.60	-5.51
Whole plant dry weight change (%)	14th April – 29th April	50.62	46.50	7.00	7.64	7.03	11.37	8.59	7.87
	29th April – 14th May	19.85	22.83	50.15	51.83	58.88	56.62	60.07	59.02
	14th May – 29th May	6.76	7.99	7.90	7.92	5.90	8.36	5.83	11.89
	29th May – 14th June	5.24	8.43	3.92	6.82	3.45	10.75	1.64	5.73

(S$_1$ = optimum sowing date, S$_2$ = late sowing date)

Yield contributing attributes

Different levels of soil applied boron and sowing date significantly affected the different yield contributing characteristics of sunflower.

Capitulum diameter

Soil applied boron and normal sowing of sunflower resulted in improved value of capitulum diameter. Mean maximum capitulum diameter was observed in B$_8$ (2.5 kg B ha^{-1} at ray floret stage) which was 25.68 % higher than that of control followed by B$_7$ (2 kg B ha^{-1} at ray floret stage) (25.37 % higher than control) and then by B$_5$ (2.5 kg B ha^{-1} at button stage) (Table 4). All three (B$_8$, B$_7$ and B$_5$) shared the same letter indicating that they differed non-significantly with each other however, differed significantly from all other treatments. Similar to that of boron levels, sowing date also significantly affected the capitulum diameter with higher value of capitulum diameter in case of normal sowing date. Interactive influence of sowing date and boron levels on capitulum diameter was also found to be significant with maximum capitulum diameter (20.66 cm) in case of B$_8$S$_1$ (2.5 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) followed by B$_7$S$_1$ (2 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) which differed non-significantly with S$_1$B$_8$ (Table 3).

Soil application of boron at ray floret stage of normal sown sunflower resulted in significantly improved value of capitulum diameter. These results are in accordance to those of Zahoor *et al.* (2011) who found that boron application at the rate of 2 kg B ha^{-1}at ray floret stage of earlier sown sunflower resulted in increased value of head diameter. Oyinlola (2007) reported that exogenously applied boron resulted in increased head diameter and achene yield.

Table 3: Effect of soil applied boron and sowing date on different yield and quality attributes of early and late sown sunflower

Boron levels (kg B ha^{-1})	Sowing date	Capitulum diameter (cm)	Achenes per capitulum	1000- achene weight (g)	Achene yield (kg ha^{-1})	Achene oil contents (%)
B_1	S_1	14.31 e	516.06 fg	36.76 d	1160.35 ijk	37.72 def
(Control)	S_2	13.92 e	475.03 g	33.69 e	974.48 k	33.81 g
B_2	S_1	14.63 de	542 fg	37.11 d	1230.52 ij	37.83 de
(Water spray)	S_2	14.26 e	482 g	33.79 e	992.02 jk	34.07 g
B_3	S_1	17.06 c	665.33 de	43.39 b	1764.10 def	42.91 b
(1.5 kg B ha^{-1} at button stage)	S_2	13.72 e	578 f	35.73 de	1256.72 hi	36.25 f
B_4	S_1	17.92 bc	723.29 cd	44.62 b	1975.79 cd	45.14 a
(2 kg B ha^{-1}at button stage)	S_2	14.81 de	646 e	37.51 d	1477.47 gh	38.87 cd
B_5	S_1	19.53 ab	828.96 b	48.61 a	2453.79 b	45.29 a
(2.5 kg B ha^{-1} at button stage)	S_2	16.53 c	738 c	37.46 d	1682.59 efg	39.03 cd
B_6	S_1	17.83 c	754.42 c	45.02 b	2078.95 c	43.53 b
(1.5 kg B ha^{-1} at ray floret stage)	S_2	16.29 cd	719 cd	36.62 d	1604.38 fg	37.22 ef
B_7	S_1	20.63 a	925.09 a	49.99 a	2828.60 a	46.39 a
(2 kg B ha^{-1}at ray floret stage)	S_2	17.21 c	766 bc	40.87 c	1905.60 cde	39.96 c
B_8	S_1	20.66 a	931.04 a	50.01 a	2847.58 a	46.47 a
(2.5 kg B ha^{-1} at ray floret stage)	S_2	17.33 c	778 bc	41.14 c	1945.26 cd	40.07 c
LSD		1.6692	61.177	2.1107	231.62	1.5431

Number of achenes per head

Different levels of soil applied boron and normal sowing of sunflower resulted in improved value of number of achenes per head. Mean maximum number of achenes per head (854.52) was observed in B_8 (2.5 kg B ha^{-1} at ray floret stage) which was 42.01% higher than that of control followed by B_7 (2 kg B ha^{-1} at ray floret stage) with 845.55 achenes per head (41.39% higher than control) (Table 4). Similar to that of boron levels, sowing date also significantly affected the number of achenes per head with higher value of number of achenes per head in case of normal sowing date. Interaction of sowing date and boron levels was also found to be significant with maximum number of achenes per head (931.04) in case of B_8S_1 (2.5 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) followed by B_7S_1 (2 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) which differed non-significantly with S_1B_8 (Table 3). Similar observations have been recorded by Reddy *et al.* (2003) who suggested that increased number of achenes per head may be due to increased translocation of assimilates from source to sink as boron was found to have an important role in translocation of sugars. Parkash and Mehra (2006) found that boron application significantly increased the number of achenes per head. Zahoor *et al.* (2011) found that number of achenes per head significantly increased by boron application especially at ray floret stage and sowing of sunflower on normal sowing date. Results regarding significantly higher number of achenes per head in case of normal sowing date are supported by Qadir *et al.* (2007) who reported that under agro-ecology of Pakistan, February sown sunflower results in significantly higher values of all yield contributing components as compared to that of late sown.

and sunflower was sown at normal time. Increased 1000-achene weight with respect to normal sowing date is in accordance of Qadir *et al.* (2007) who reported that under agro-ecology of Pakistan, February sown sunflower results in significantly higher values of all yield contributing components as compared to that of late sown. Delayed sowing results in poor fertilization and/or abortion of embryo together with shorter accumulation period, it results in poorly filled achenes in the centre of disc (Killi and Altunbay, 2005).

Table 4: Effect of different levels of soil applied boron on percentage change (means of two sowing dates) in yield and yield attributes of sunflower

Boron Levels (kg B ha^{-1})	Capitulum Diameter	Number of achenes per head	1000-achene weight	Achene yield	Achene oil contents
B_1 (control)	---	---	---	---	---
B_2 (water spray)	2.28	3.21	0.62	3.95	0.50
B_3 (1.5 kg B ha^{-1} at button)	8.25	20.29	10.95	29.33	9.63
B_4 (2 kg B ha^{-1} at button)	13.74	27.62	14.22	38.18	14.85
B_5 (2.5 kg B ha^{-1} at button)	21.69	36.75	18.15	48.39	15.16
B_6 (1.5 kg B ha^{-1} at ray floret)	17.23	32.74	13.69	42.04	11.42
B_7 (2 kg B ha^{-1} at ray floret)	25.37	41.39	22.45	54.91	17.16
B_8 (2.5 kg B ha^{-1} at ray floret)	25.68	42.01	22.71	55.46	17.33

1000-achene weight

1000-achene weight was significantly affected by boron application and differences in sowing date. Mean maximum 1000-achene weight (45.58 g) was observed in B_8 (2.5 kg B ha^{-1} at ray floret stage) which was 22.71% higher than that of control followed by B_7 (2 kg B ha^{-1} at ray floret stage) with 1000-achene weight of 45.43 g (22.45% higher than control) (Table 4). Both B_8 and B_7 shared the same letter indicating that they differed non-significantly with each other however differed significantly with all other treatments. Similar to that of boron levels, sowing date also significantly affected the 1000-achene weight with higher value of 1000-achene weight in case of normal sowing date. Interactive influence of sowing date and boron levels showed maximum 1000-achene weight (50.01 g) in case of B_8S_1 (2.5 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) followed by B_7S_1 (2 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) (Table 3).

Weight of thousand achenes was significantly increased by soil applied boron especially at ray floret stage. Reddy *et al.* (2003) commented that increased 1000-achene weight of sunflower by the application of boron may be due to increased translocation of photosynthates from vegetative sources towards the reproductive organs. According to Naik (1991) increase in 1000-achene weight by the application of boron at ray floret stage was due to the role of boron in reproductive growth. In another study Zahoor *et al.* (2011) reported that 1000-achene weight was significantly increased by different levels of soil applied boron especially when boron was applied at ray floret stage

Achene yield

Maximum achene yield (2396.42 kg ha^{-1}) was recorded in case of B_8 (2.5 kg B ha^{-1} at ray floret stage) which was 55.46 % higher than that of control followed by B_7 (2 kg B ha^{-1} at ray floret stage) with achene yield of 2367.10 kg ha^{-1} (54.91 % higher than control) and then by B_5 (2.5 kg B ha^{-1} at button) respectively, when compared with control (B_1, without boron application) (Table 4). In both of the sowing dates minimum value of 1000-achene weight was calculated in B_1 (control, without boron application). Thousand-achene weight also differed significantly in different sowing dates with comparatively higher value in case of February sown sunflower. Regarding the interactive influence of boron and sowing date on 1000-achene weight, maximum 1000-achene weight (2847.58 kg ha^{-1}) was recorded in B_8S_1 (2.5 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) followed by B_7S_1 (2 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) (Table 3).

Increased achene yield may be due to increase in yield contributing parameters (i.e., size of head, number of achenes, 1000-achene weight etc.), increased activity and strength of sink and increased mobilization of assimilates. Reddy *et al.* (2003) reported increased achene yield of sunflower due to active role of boron in translocation of photosynthates especially when applied at ray floret stage. In another experiment, Reddy *et al.* (2002) found increased head diameter, achene yield and biological yield by the application of boron. Similarly Castro *et al.*. (2006) found increased achene yield of sunflower by the application of boron. Increased achene yield by the application of boron has also been reported by Renukadevi and Savithri (2003). Increased achene yield due to earlier sowing of sunflower is supported by the findings of Qadir *et al.* (2007). Delay in sowing resulted in poor economic yield due to poor fertilization, abortion of embryo and poor filling of achenes (Killi and Altunbay, 2005).

Achene oil and protein contents are two most important determinants of quality of sunflower. Quality attributes of sunflower were significantly affected by the application of boron and sowing date differences.

Achene oil contents

Maximum achene oil contents (43.27 %) was recorded in case of B_8 (2.5 kg B ha^{-1} at ray floret stage) which was 17.33% higher than that of control followed by B_7 (2 kg B ha^{-1} at ray floret stage) which was at par with B_8 with achene yield of 43.18 % (17.16 % higher than control) and then by B_5 (2.5 kg B ha^{-1} at button) respectively, when compared with control (B_1, without boron application) (Table 4). In both of the sowing dates minimum value of achene oil contents was calculated in B_1 (control, without boron application). Achene oil contents also differed significantly in different sowing date with comparatively higher value of achene oil contents in case of February sown sunflower. Regarding the interactive influence of boron and sowing date on achene oil contents, maximum achene oil contents (46.47 %) was recorded in B_8S_1 (2.5 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) closely followed by B_7S_1 (2 kg B ha^{-1} applied at ray floret stage in normal sown sunflower) (Table 3).

Zahoor *et al.* (2011) reported that soil application of boron especially at ray floret stage and optimum sowing of sunflower resulted in significantly increased value of achene oil contents. Castro *et al.* (2006) reported that increased levels of boron as boric acid resulted in increased achene oil contents in sunflower. Renukadevi and Savithri (2003) found that enhanced uptake of boron resulted in significant increase in achene oil contents.

Conclusion

Dry matter accumulation, mobilization and partitioning of photoassimilates increased with increasing levels of soil applied boron and sowing of sunflower at optimum sowing date. Soil application of boron was also found to reduce the influence of delayed sowing on growth, yield and quality attributes of sunflower. Out of different levels of soil applied boron, 2-0-2.5 kg B ha^{-1} may be used for maximum increase in dry matter accumulation, growth, yield and oil content of sunflower.

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