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Response of sunflower (*Helianthus annuus* L.) to nano boron nitride fertilization

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Abstract
Field experiment was conducted during *Kharif*-2016 at Zonal Agricultural Research Station, University of Agricultural Sciences, Bengaluru to study the "Response of sunflower (*Helianthus annuus* L.) to nano boron nitride fertilization". The experiments were laid out in Randomized Complete Block Design with ten treatments and replicated thrice. The results showed that significantly higher seed (2788 kg ha^{-1}) and stalk yield (5256 kg ha^{-1}) were recorded with nano boron @ 0.2% seed priming, which was on par with nano boron @ 0.2% spray to capitulum at ray floret opening stage (2773 and 5069 kg ha^{-1}, respectively) and soil application of borax @ 11 kg ha^{-1} (2424 and 5037kg ha^{-1}, respectively) at the time of sowing. Significantly lowest seed yield was recorded with control (1629 and 4429 kg ha^{-1}, respectively).

Keywords: borax, nano-boron nitride, sunflower

Introduction

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crop in the world belonging to family Asteraceae. Throughout the world, sunflower is the major authoritative sources of vegetable oil. Sunflower ranks third in the world for total production of oilseeds. It is extensively grown in Argentina, France, Spain, USA, China, Ukraine and India. It is primarily grown for edible oil which has high concentration of polyunsaturated fatty acids (Linoleic and oleic acids) and hence considered as good quality from the health point of view. Sunflower is known for its wider adaptability to different agro-climatic zones and soil types, easy crop management, photo-insensitivity, short duration and high seed multiplication ratio (1:100). In India, sunflower occupies the fourth position among oilseed crops in terms of acreage and production. Sunflower in the country is being cultivated in an area of 5.2 lakh hectares with a production of 3.35 lakh tonnes and productivity of 643 kg/ha. Karnataka accounts for 3.6 lakh hectares in terms of area with the annual production and productivity of 2.1 lakh tonnes and 579 kg ha^{-1} respectively (Anon., 2016) [2]. Karnataka contributes 69.2 per cent of the total acreage and 62.7 per cent of the national sunflower production hence Karnataka is popularly known as the "Sunflower State" in the oilseed scenario of India.

Introduction of high yielding varieties and hybrids, intensive agriculture, use of commercial conventional fertilizer devoid of micronutrients, lesser use of organic fertilizer resulted in impaired soil health. Among different micronutrient deficiencies, boron deficiency is the second most dominant problem globally. Boron deficiency has been reported in 80 countries around the world and in 132 crops.

Boron (B) is one of the micronutrient required for normal growth and plant development of many crops. Sunflower is sensitive to boron deficiency and is sometimes used as an indicator for assessing available boron in soils. The role of B in plant has been proposed including functions in cell wall structure, cell wall synthesis, sugar translocation, cell division, enzymatic reactions, indirectly involved in activation of dehydrogenase enzyme and plant growth regulation (Blevins and Lukaszewski, 1998) [3]. Boron is involved in the reproduction of plants and germination of pollen spikelet, pollen tube growth and seed development (Bolanos *et al*., 2004) [4].

Nanotechnology is a new emerging and fascinating field of science, permits advanced research in many areas and nanotechnological discoveries could open up novel applications in the field of biotechnology and agriculture. Nanotechnology is providing feasibility of exploiting nanoscale nanostructure materials as fertilizer carriers or controlled- release vectors for building of so called "smart fertilizer" as new facility to enhance nutrient use efficiency and reduce costs of environmental protection (Chinnamuthu and Boopathi, 2009) [5]. Nanotechnology to precisely detects and delivers the correct quantity of nutrients and pesticides that promote productivity while ensuring environmental safety and higher use efficiency. The recent statistics suggest that about 90% of the nano-based patents and products have come from just seven countries (China, Germany, France, Japan, Switzerland, South Korea and USA), while India's investments and progress is far from satisfactory. However, to take advantage of the fascinating field of nano-science, the Government of India has invested` 1000 crore through the Nano Mission Project during 11th five year plan and the investment is likely to be several folds higher during the 12th five year plan period. Nanotechnology has been described as the next great frontier of agricultural science and occupies a prominent position in transforming agriculture and food production through efficient management of soil nutrients. Nano boron has many merits like quick and easy uptake by plants. It has lower tendency to leach *via* soil and appear its impact for shorter times. It improves solubility and dispersion of insoluble nutrients in soil, reduces soil fixation and increases the bioavailability. Nano particles are spherical or faceted metal particles typically < 100 nm in size. These nanoparticles are having high surface area (30-50 m^2/g), high activity, better catalytic surface, rapid chemical reaction, rapidly dispersible and adsorb abundant water. So nano fertilizers may increase the efficiency of nutrient uptake, enhance yield and nutrient content in the edible parts and also minimize its accumulation in the soil.

Material Methods

A Field experiment was conducted during *Kharif*-2016 at Zonal Agricultural Research Station, University of Agricultural Sciences, Bengaluru to study the "Response of sunflower (*Helianthus annuus* L.) to nano boron nitride fertilization". Soil texture of the experimental site was red sandy loam. Representative soil samples from experimental site were collected and analyzed for chemical properties. The soil was low in nitrogen, high in phosphorus and medium in potassium. The experiment was laid out in Randomized Complete Block Design with three replications. Treatments consisting of T_1: Control, T_2: Nano Boron @ 0.2% seed priming, T_3: Nano Boron @ 0.4% seed priming, T_4: Borax @ 0.2% seed priming, T_5: Borax @ 0.4% seed priming, T_6: Nano Boron @ 0.2% spray to capitulum at ray floret opening stage, T_7: Nano Boron @ 0.4% spray to capitulum at ray floret opening stage, T_8: Borax @ 0.2% spray to capitulum at ray floret opening stage, T_9: Borax @ 0.4% spray to capitulum at ray floret opening stage. T_{10}: Soil application of Borax @ 11 kg ha^{-1}. The sunflower hybrid KBSH-53 was used for the study. The sunflower hybrid seed was sown on 60 x 30 cm. The seeds were manually treated at 0.2%, 0.4% nano boron and borax solution for 4 hours at room temperature and seeds were allowed to dry for 4 hours at room temperature. The experimental data collected on various growth and yield parameters of sunflower plant was subjected to Fishers method of "Analysis of Variance" (ANOVA) as outlined by Gomez and Gomez (1984) [8]. All the data were analyzed and the results were presented and discussed at a probability level of 5 per cent for field experiment and 1 per cent for laboratory experiment.

Results and Discussion

One of the main reasons of low yield of the sunflower is the deficiency of micronutrients. The use of essential micronutrients in the right proportion and optimum quantity is the key to boost and sustain crop productivity. Among micronutrient deficiency, boron deficiency is the second most dominant problem in the world, which is involved in the reduction of sunflower production by so many reasons. Among the various factors affecting the growth and yield of sunflower, boron nutrition plays a vital role. Presently, borax is the major source for boron, in order to enhance nutrient use efficiency of boron nano technology (nano boron) is taken for this study. Continuous soil application of borax may have toxic effect on soil and human health in future. To combat this foliar application and seed treatment with minute quantity of nano boron helps to achieve actual yield potential of sunflower and reduces the problems associated with sunflower cultivation.

Effect of nano boron and borax on growth and growth attributes of sunflower

Yield and its attributes indirectly depends on growth attributes *viz.* plant height, number of leaves, leaf area, leaf area index and dry matter production. Application of nano boron and borax significantly influenced the growth and growth attributes of sunflower. At 60 DAS the higher plant height, number of leaves, leaf area and leaf area index were observed with the application of nano boron @ 0.2% seed priming (190.5 cm, 26.67, 10589 cm^2 $plant^{-1}$, 5.88, respectively) (Table 1). Whereas lower plant height, leaf area, number of leaves and leaf area index was recorded with control treatment (157.1 cm, 3632 cm^2 $plant^{-1}$, 21.33 cm and 2.02) this might be due to deficiency of micronutrient in the soil which reduced the metabolic activity of the plant and reduced enzymatic activity in sunflower. Application of nano boron @ 0.2% seed priming had showed higher leaf area at 30 and 60 DAS (1014 and 10589 cm^2 $plant^{-1}$ respectively), compared to control (611, 3632 cm^2 $plant^{-1}$). This shows that seed treatment with nano boron with enhanced the nutrient uptake and dry matter accumulation which increased the leaf area. Similar results were observed in maize, application of nano chelated boron showed higher plant height, leaf area compared to control (Mohsen *et al.*, 2016) [13].

Table 1: Plant height, number of leaves, leaf area and leaf area index of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	Plant height (cm)		Number of leaves per plant		Leaf area (cm^2 $plant^{-1}$)		Leaf area index	
	60 DAS	At harvest	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1: Control (without boron)	157.1	171.1	10.53	21.33	611	3632	0.339	2.02
T_2: Nano boron nitride@ 0.2% seed priming	190.5	196.5	15.33	26.67	1014	10589	0.563	5.88
T_3: Nano boron nitride@ 0.4% seed priming	185.9	188.7	14.00	26.27	866	8742	0.481	4.86
T_4: Borax @ 0.2% seed priming	179.1	179.7	13.80	25.00	760	6354	0.422	3.53

T_5: Borax @ 0.4% seed priming	184.3	187.8	14.14	25.93	797	7562	0.443	4.20
T_6: Nano boron nitride @ 0.2% spray to capitulum at RFO stage	184.1	189.1	13.50	24.20	886	7115	0.492	3.95
T_7: Nano boron nitride @ 0.4% spray to capitulum at RFO stage	181.1	184.7	13.80	24.80	755	6762	0.419	3.76
T_8: Borax @ 0.2% spray to capitulum at RFO stage	172.5	183.7	13.67	24.73	828	6770	0.460	3.76
T_9: Borax @ 0.4% spray to capitulum at RFO stage	171.3	189.4	13.00	23.67	823	6354	0.457	3.53
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	183.0	186.7	14.22	23.80	754	7106	0.419	3.95
SEm±	4.87	4.47	0.77	0.92	40.58	312.9	0.026	0.484
CD (P=0.05)	14.48	NS	2.30	2.74	121	930	0.077	1.44
CV (%)	7.72	4.17	9.85	6.47	8.69	7.63	8.97	6.89

Note: RFO stage- ray floret opening stage

Higher SCMR values at 60 days after sowing (44.50) were recorded in treatment with nano boron @ 0.2% seed priming it was found to be on par with nano boron @ 0.2% spray to capitulum at ray floret opening stage (43.50) and borax @ 0.4% spray to capitulum at ray floret opening stage (41.90) (Table 4). Similar results were observed with Mahmoud *et al*., 2014 [12] in datepalm. The dry matter production is the result of cumulative and complementary effect of various components. Dry matter production depends on the photosynthetic capacity of the plant and also better availability and uptake of nutrients which in turn depends on the dry matter accumulation in leaves, chlorophyll content, plant height, number of leaves, root weight and leaf area. Dry matter production differed significantly due to application of different levels and methods of nano boron and borax fertilization. Dry matter production (Table 2) at 30 (18.33g $plant^{-1}$) and 60 (101.6 g $plant^{-1}$) DAS, was higher with the treatment nano boron @ 0.2% seed priming. Dry matter production is an indication of the overall utilization of resources and better light interception. Maintenance of dry matter production over a particular period of time is very much essential for prolonged supply of photo synthases to the developing sink. Increase in dry matter was mainly due to increased root and shoot dry weight as boron role in enhancing metabolic activity and physicochemical activity in plant system. Lower dry matter production was with the control treatment at 30 (12.45 g $plant^{-1}$) and 60 (58.01g $plant^{-1}$) DAS (Table 2). It might be due to boron micronutrient deficiency which hindered the plant growth and dry matter accumulation in sunflower.

Higher root to shoot ratio (0.153) at 30 and (0.18) at 60 DAS was recorded in nano boron @ 0.2% seed priming and lowest root to shoot ratio was with control treatment (0.119 & 0.11 respectively) (Table 3). Increase in root to shoot ratio might be due to the role of boron in cell elongation, cell division and enhanced terminal meristematic activity increased the root and shoot growth as reported by Khan *et al.* (2006) [10]. Also, nano boron @ 0.2% seed priming has influenced the days to 50 per cent flowering (61.33) significantly (Table 4). The result was on par with nano boron @ 0.4% seed priming (62) compared to control (69). This might be due to nano nutrient seed priming enahanced the speed of germination and seedling establishment because they were able to penetrate the seed coat easily allowing the water and sufficient quantity of sugars and other nutrients in right quantity in right time to various parts of plant which encouraged the plant to flower early and attain the physiological maturity.

Table 2: Root dry weight, shoot dry weight and total dry matter of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	Dry matter production at (g $plant^{-1}$) 30 DAS			Dry matter production at (g $plant^{-1}$) 60 DAS		
	Root	Shoot	Total	Root	Shoot	Total
T_1: Control (without boron)	1.38	11.07	12.45	5.71	52.30	58.01
T_2: Nano boron nitride@ 0.2% seed priming	2.43	15.90	18.33	15.70	85.87	101.6
T_3: Nano boron nitride@ 0.4% seed priming	1.90	13.43	15.34	11.07	79.00	90.07
T_4: Borax @ 0.2% seed priming	1.80	13.33	15.13	7.63	61.03	68.67
T_5: Borax @ 0.4% seed priming	1.76	13.60	15.36	8.37	75.53	83.90
T_6: Nano boron nitride @ 0.2% spray to capitulum at RFO stage	1.70	14.33	16.03	9.04	79.27	88.30
T_7: Nano boron nitride @ 0.4% spray to capitulum at RFO stage	1.73	12.97	14.69	8.23	68.03	76.26
T_8: Borax @ 0.2% spray to capitulum at RFO stage	1.54	12.57	14.11	7.63	54.23	61.87
T_9: Borax @ 0.4% spray to capitulum at RFO stage	1.60	13.13	14.73	8.13	57.50	65.63
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	1.99	15.43	17.42	10.21	73.17	83.38
SEm±	0.09	0.56	0.67	0.40	2.79	3.25
CD (P=0.05)	0.26	1.66	2.01	1.18	8.27	9.65
CV (%)	8.32	7.11	7.60	7.53	7.03	7.23

Note: RFO stage- ray floret opening stage

Table 3: Root to shoot ratio values of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	30 DAS	60 DAS
T_1:Control (without boron)	0.119	0.110
T_2: Nano boron nitride@ 0.2% seed priming	0.153	0.180
T_3: Nano boron nitride@ 0.4% seed priming	0.144	0.140
T_4: Borax @ 0.2% seed priming	0.135	0.130
T_5: Borax @ 0.4% seed priming	0.131	0.120

T_6: Nano boron nitride @ 0.2% spray to capitulum at RFO stage	0.125	0.110
T_7: Nano boron nitride @ 0.4% spray to capitulum at RFO stage	0.133	0.120
T_8: Borax @ 0.2% spray to capitulum at RFO stage	0.124	0.140
T_9: Borax @ 0.4% spray to capitulum at RFO stage	0.122	0.140
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	0.129	0.140
SEm±	0.005	0.008
CD (P=0.05)	0.02	0.02
CV (%)	6.83	10.61

Note: RFO stage- ray floret opening stage

Table 4: SPAD Chlorophyll meter reading and Days taken for 50% flowering values of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	SPAD Chlorophyll meter reading (SCMR) values	Days to 50% flowering
	60 DAS	
T_1: Control (without boron)	33.43	69.00
T_2: Nano boron nitride@ 0.2% seed priming	44.50	61.33
T_3: Nano boron nitride@ 0.4% seed priming	40.33	62.00
T_4: Borax @ 0.2% seed priming	37.40	66.67
T_5: Borax @ 0.4% seed priming	35.43	67.33
T_6: Nano boron nitride @ 0.2% spray to capitulum at RFO stage	43.53	65.67
T_7: Nano boron nitride @ 0.4% spray to capitulum at RFO stage	39.93	66.67
T_8: Borax @ 0.2% spray to capitulum at RFO stage	34.67	67.67
T_9: Borax @ 0.4% spray to capitulum at RFO stage	41.90	67.33
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	37.40	68.00
SEm±	1.23	1.16
CD (P=0.05)	3.64	3.45
CV (%)	5.52	3.03

Note: RFO stage- ray floret opening stage

Effect of nano boron and borax on yield and yield attributes of sunflower

Yield and yield attributes were significantly influenced by different levels and methods of nano boron and borax application in sunflower (Tables 5, 6 & 7). Achene yield is a function of integrated effects of the various yield components. Among the different treatments, seed yield was significantly higher (2788 kg ha^{-1}) with the application of nano boron @ 0.2% seed priming. However nano boron @ 0.2% spray to capitulum at ray floret opening stage was also found to be on par (2773 kg ha^{-1}). These results are in line with those of Oyinlola, (2007) [14] and Patil *et al*. (2006) [15]. Increase in fruit yield with foliar application of nano boron have been reported in different fruit crops, including date palm (Mahmoud, 2014) [13] pomegranate (Sohrab *et al*., 2016) [18]. However, lowest achene yield 1629 kg ha^{-1}) was recorded with the treatment without boron, these results are in line with those of Gitte *et al*. (2005) [7]. They reported that initial application (as seed priming or soil application) of boron increase the seed yield of sunflower and boron deficiency affect the inner tissues of the stem top, which may lead to unfilling of seed and lower translocation of photo synthases to head seed formation, finally decreases the yield.

Table 5: Days to physiological maturity, plant stand at maturity, capitulum diameter and stem girth of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	Physiological maturity (Days)	Number of plants per net plot	Stem girth (cm)	Head diameter (cm)
T_1: Control (without boron)	93.00	106	2.19	14.47
T_2: Nano boron nitride@ 0.2% seed priming	84.00	114	2.97	15.07
T_3: Nano boron nitride@ 0.4% seed priming	86.33	110	2.49	15.13
T_4: Borax @ 0.2% seed priming	92.00	103	2.49	15.13
T_5: Borax @ 0.4% seed priming	90.67	112	2.44	14.93
T_6: Nano boron nitride @ 0.2% spray to capitulum at RFO stage	92.00	113	2.44	15.00
T_7: Nano boron nitride @ 0.4% spray to capitulum at RFO stage	91.00	104	2.46	15.07
T_8: Borax @ 0.2% spray to capitulum at RFO stage	89.33	111	2.46	15.13
T_9: Borax @ 0.4% spray to capitulum at RFO stage	90.00	107	2.51	15.40
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	90.67	115	2.47	14.93
SEm±	0.83	4.15	0.07	0.28
CD (P=0.05)	2.46	NS	0.21	NS
CV (%)	1.59	6.57	4.97	3.23

Note: RFO stage- ray floret opening stage

Table 6: 100 Seed weight, volume weight, seed yield, number of seeds and chaffiness as influenced by different levels and methods of nano boron and borax application

Treatments	100 Seed weight (g 100 seeds^{-1})	Volume weight (g 100 ml^{-1})	Seed yield (g / plant)	Number of seeds per capitulum			
				Filled seeds	Unfilled seeds	Total seeds	Per cent chaffiness
T_1: Control	3.78	41.27	39.67	974	119.9	1094	11
T_2: Nano boron nitride @ 0.2% seed priming	4.78	46.17	63.55	1293	33.20	1326	2.50
T_3: Nano boron nitride @ 0.4% seed priming	4.57	43.57	57.55	1127	46.43	1173	3.96
T_4: Borax @ 0.2% seed priming	4.06	40.00	53.27	1031	57.87	1089	5.32
T_5: Borax @ 0.4% seed priming	4.35	40.90	48.44	975	84.25	1059	7.96
T_6: Nano boron nitride @ 0.2% spray to capitulum at RFO stage	5.23	46.60	63.17	1355	28.51	1384	2.10
T_7: Nano boron nitride @ 0.4% spray to capitulum at RFO stage	4.77	43.47	60.13	1076	34.93	1111	3.16
T_8: Borax @ 0.2% spray to capitulum at RFO stage	4.53	44.40	48.32	1104	56.90	1161	4.93
T_9: Borax @ 0.4% spray to capitulum at RFO stage	4.49	46.36	52.57	1144	43.06	1187	3.64
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	4.42	43.93	54.56	1079	59.07	1138	5.18
SEm±	0.19	1.04	2.75	42.53	3.07	41.76	0.31
CD (P=0.05)	0.57	3.09	8.17	126.4	9.11	124.1	0.91
CV (%)	7.34	4.12	8.80	6.60	9.41	6.17	10.68

Note: RFO stage- ray floret opening stage

Table 7: Seed yield, stalk yield, harvest index, oil content and net returns of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	Seed yield (kg ha^{-1})	Stalk yield (kg ha^{-1})	HI	Oil content (%)	Net returns (`ha^{-1})
T_1: Control	1629	4429	0.27	34.96	34624
T_2: Nano Boron @ 0.2% seed priming	2788	5256	0.35	36.74	66950
T_3: Nano Boron @ 0.4% seed priming	2451	5072	0.32	36.13	42406
T_4: Borax @ 0.2% seed priming	2107	4969	0.30	35.56	52729
T_5: Borax @ 0.4% seed priming	2084	4529	0.31	36.04	51843
T_6: Nano Boron @ 0.2% spray to capitulum at RFO stage	2773	5069	0.35	36.34	40433
T_7: Nano Boron @ 0.4% spray to capitulum at RFO stage	2422	4948	0.33	36.24	-7549
T_8: Borax @ 0.2% spray to capitulum at RFO stage	2061	4910	0.30	34.68	50917
T_9: Borax @ 0.4% spray to capitulum at RFO stage	2176	4925	0.31	35.34	55196
T_{10}: Soil application of Borax @ 11 kg ha^{-1}	2424	5037	0.32	34.57	59117
SEm±	156.5	88.35	0.02	0.65	-
CD (P=0.05)	464.9	262.51	0.03	NS	-
CV (%)	11.83	6.11	8.25	3.14	-

Note: RFO stage- ray floret opening stage **NS**: Non-significant

The higher seed yield might be attributed to improvement in yield contributing characters *viz.*, seed yield per plant (63.55 g), higher head diameter (15.07 cm), higher number of seeds per capitulum (1326), 100 seed weight (4.78 g) and volume weight (46.17 g 100 ml^{-1}). This improvement in yield components was in turn due to improved growth parameters such as higher plant height, chlorophyll content, higher leaf area and total dry matter production and distribution in different parts. Similarly improved yield attributing characters were observed with application of chelated nano boron in maize (Mohsen *et al*., 2016) [13]. Improvement in yield components as a result of application of nano-micronutrients might be due to the enhanced photosynthetic and other metabolic activity which leads to an increase in various plant metabolites responsible for cell division and elongation as opined by Hatwar *et al*. (2003) [9], Liu *et al*. (2005) [11] in peanut, Sheykhbaglou *et al*. (2010) [17] in soyabean.

Higher seed yield might be associated with application of nano boron (both seed treatment and foliar spray) met the crop nutrient demand for boron during the pollen development, which may result in increased pollen germination and pollen viability and increasing the translocation of sugars and photos synthases from source to sink which in turn enhances the seed setting percentage in the capitulum. Increase in seed yield of sunflower may also be through a prolonged photosynthetic capacity during flowering and seed set or through improved partitioning from the increased biomass (Al-Amery *et al*., 2011) [1]. Application of nano boron and borax at ray floret opening stage helps to meet the crop nutrient requirement quickly compared to other methods of application because boron is applied in the dissolved form, which resulted in better absorption by the plant. These results were in accordance with Rani and Reddy (1993) [16] and Tamak *et al*. (1997) [19]. Nano boron nutrition improves solubility and dispersion of insoluble nutrients in soil, reduces soil fixation and increases the bioavailability, which significantly improves the nutrient availability, seed setting percentage, test weight and decreases percent chaffiness, by proper fertilization and filling of seeds contribute to the higher economic yield.

Treatment with no boron application (control) recorded significantly lower yield (1629 kg ha^{-1}) as compared to all other treatments. Yield components such as capitulum diameter (14.47 cm), number of seeds capitulum^{-1} (1094), stem girth (2.19 cm), 100 seed weight (3.78 g) volume weight (41.27) and seed yield plant^{-1} (39.67 g) (Table 5, 6 & 7) are low with the treatment without boron or control. It might be due to micronutrient deficiency which in turn resulted in reduction of growth and development of plant, less photosynthetic activity and less translocation of photo synthates to sink reduced source to sink ratio which further resulted in decreased yield and yield attributes. Among different treatments higher stalk yield (5256 kg ha^{-1}) was recorded with nano boron @ 0.2% seed priming compared to control (4429 kg ha^{-1}). This might be due to role of boron in cell division, cell elongation, improved meristematic activity, better uptake of nutrients and biomass accumulation resulted in higher growth and development.

Significantly higher number of filled seeds (1355), less number of unfilled seeds (28.51), lower per cent chaffiness (2.10%) were recorded with the foliar application of nano boron at 0.2% at ray floret opening stage compared to control (974, 120, 10.97% respectively) (Table 6 & Fig. 1). This might be due to boron role in improved partitioning of photosynthates from source to sink, improved stigma receptivity, translocation of sugars from source to sink resulted in higher pollen germination and fertilization improves the seed setting percentage, number of filled seeds per capitulum and lower chaffiness percentage. By proper fertilization, filling of seeds contributes a lot towards economic yield. This result was in conformity with the findings of Patil *et al*. (2006) [15] and Al-Amery *et al*. (2011) [1].

Nano boron seed priming nitride **Borax seed priming**

Nano boron nitride seed priming **Borax seed priming**

Plate 1: Early flowering in Nano boron nitride treated plots

Significantly higher harvest index (0.35) of sunflower was recorded with the application of nano boron @ 0.2% seed priming and nano boron @ 0.2% spray to capitulum at ray floret opening stage compared to other treatments. However application of nano boron @ 0.4% spray to capitulum at ray floret initiation stage (0.33), nano boron @ 0.4% seed priming (0.32) and soil application of borax @ 11 kg ha^{-1} (0.32) found to be on par with each other. The increase in harvest index may be attributed to better utilization of photo-assimilates for seed formation. Similar results have also been discussed by Venkatakrishnan and Balasubramaniam (1996) [20]. Lowest harvest index (0.27) was recorded in control this might be due to absence of boron which hindered the production of photosynthates and translocation of sugars and photosynthates to achene.

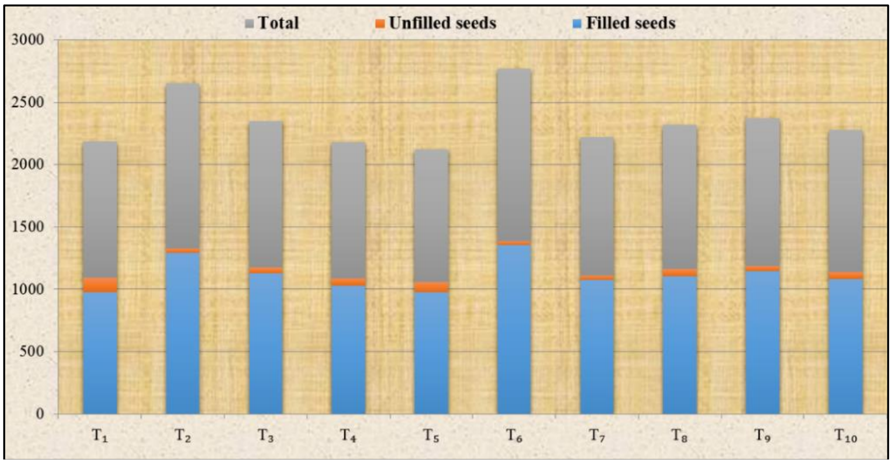

Fig 1: Effect of different method of application of nano boron nitride and borax on filled seeds, unfilled seeds and total number of seeds per capitulum of sunflower

T1:	Control	**T6:**	Nano Boron @ 0.2% spray to capitulum at ray floret stage
T2:	Nano Boron @ 0.2% seed priming	**T7**:	Nano Boron @ 0.4% spray to capitulum at ray floret stage
T3:	Nano Boron @ 0.4% seed priming	**T8:**	Borax @ 0.2% spray to capitulum ray floret stage
T4:	Borax @ 0.2% seed priming	**T9:**	Borax @ 0.4% spray to capitulum at ray floret stage
T5:	Borax @ 0.4% seed priming	**T10:**	Soil application of Borax @ 11 kg ha-1

Note: (RDF- 90:90:60 kg NPK ha-1 and FYM 7.5 t ha-1) was common to all treatments

Conclusion

Application of 0.2% Nano boron either seed priming or spray to capitulum at ray floret opening stage along with the RDF gives the higher seed yield (2788 kg ha^{-1}), oil content (36.74%) and net returns (Rs. 66950 ha^{-1}) as compared to other treatments.

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