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Research Article

Synergic effect of nano urea, sulphur and boron fertilization on growth, yield and quality of sunflower (*Helianthus annuus* L.)

Anamika Roy
Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara (Punjab), India
Maninder Singh
Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara (Punjab), India

*Corresponding author. E-mail: ms23049@gmail.com

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Abstract
Nutrient use efficiency may be reduced due to overuse of fertilizers, leaching, volatilization and denitrification in most Indian soils. Nano urea and other micronutrients are used as foliar applications to reduce losses and increase agriculture production. Considering this, a field experiment was carried out to check the different levels of sulphur (S) and boron (B) along with nano urea on sunflower's growth, yield and quality. The treatment consisted of two levels of sulphur (30 & 45 kg/ha) and boron (100 & 200 ml/ha) along with nano urea except for control. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments (T_0 to T_8). The results revealed that the crop raised with nano urea plus 45 kg/ha S and 200 ml/ha B significantly impacted sunflowers growth, yield and quality. The highest values in plant height (181.6 cm), no. of leaves (31.7), stem girth (11.16 cm), dry matter production (121.5 g/plant), and Leaf area index (5.06), diameter of the head (19.59 cm), no. of filled seeds/head (753.3), weight of 100 seeds (5.46) were registered in T_8. Ultimately, treatment T_8 has an impeccable influence on improving seed yield (3140.8 kg/ha) and stover yield (5570.0 kg/ha). The same treatment also showed maximum oil content (44.20 %), oil yield (1388.34 kg/ha), and crude protein content (16.07 %) . The study suggests that the sulphur, boron, and nano urea had a synergistic relationship, and proper dosages, application methods, and time for the above nutrients can significantly improve sunflower production.

Keywords: Growth, Nutrients, Quality, Sunflower, Sustainability, Yield

INTRODUCTION

Oil seed crops are one of the major agronomic crops worldwide. These crops are mainly grown for the extraction of oil; other than that, they have huge potential to produce ample amounts of byproducts. Thus, the production of oil seed crops coexists with sustainability and eco-friendliness. Sunflower is one of the important oil seed crops native to South America and is now cultivated worldwide. It is widely known for its medicinal properties and nutritional value (Adeleke *et al.,* 2020). India is currently the largest edible oil importer in the world. Around 62% of palm oil, 22% of soybean oil, and 15% of sunflower oil out of total edible oil imported are from countries like Indonesia, Malaysia, Brazil, Ukraine, and Russia. According to the Indian Vegetable Oil Producer's Association (IVPA), vegetable oil import is expected to decline to 16.2 metric tonnes in 2023-24. India's growing population, expanding food processing sector, and shifting dietary habits, to the country's growing need for edible oil (Manchanda *et al*., 2016).
The Ministry of Agriculture and Farmers Welfare data depicts the projected yield of 36.56 MT of nine oilseeds that were cultivated in 2020–21. Currently, only 45 per cent of the nation's demand can be satisfied by domestic production. Therefore, India must be self-sufficient in its oil production to meet domestic consumption needs. Nutrient management is using crop nutrients efficiently in all possible manners to improve crop productivity while having a positive relationship with the environment. Applying the right source of nutrients in the right amount at the most suitable time and place is a crucial factor for nutrient management. In the year 2021- 2022, sunflower production in India was 2.50 lakh MT and in the year 2022-23, it was 3.63 lakh MT and the estimated data for 2023-24 was 0.64 lakh MT (Chandhana *et*

al., 2022). Nutrient management's main motive is to accelerate the yield of the respective crop, and effective planning for the utilization of the resources can help increase the yield to a noticeable extent. Besides the increase in yield, it enhances and maintains the soil's capacity for chemical, biological, and physical processes and reduces the nutrient loss to the atmosphere, soil and surface water bodies, and soil by encouraging carbon sequestration (Howarth *et al.,* 2005)

Apart from major plant nutrients (N, P, K), sulphur and boron are important in improving sunflower seeds' oil and protein content (Barthwal *et al.,* 2022). Oil seed crops are sulphur-loving and play a crucial role in plant metabolism, boosting the amount of organic compounds, oil retrieval in oil glands, and vitamin B1 (Shelke *et al.,*2014). In plants, sulphur is found in amino acids, vitamins, proteins, and enzyme structures that affect oil seed productivity and total oil content (Paul *et al.,*2019). In addition to improving root development and being necessary for the synthesis of chlorophyll, sulphur also plays a role in synthesising vitamins and enzymes that the plant needs to carry out its biochemical functions (Jat *et al.,* 2017). Similarly, boron plays a key role in root elongation, tissue differentiation, the formation of cell walls, pollen tube formation, glucose metabolism, and nucleic acid synthesis (Koshiba *et al.,* 2009). Plant B requirements are primarily determined by two factors: the kind of plant and its developmental stage and oilseed plants require more B than any other type of plant, and this requirement is larger during the reproductive stages of growth than it is during the vegetative stages (Broadley *et al.,* 2012; Dinh *et al.,* 2022). Several studies have been done on foliar application of nitrogen (nanourea) on sunflower (Bhakher *et al.,* 2023). Wagh *et al.* (1991) stated that nanotechnology is the understanding and control of matter at dimensions of approximately 1-100 nm, where unique physical properties make novel applications possible. Foliar application of nano N has shown promise in providing N to field crops. Vyankatrao *et al.* (2024) on the application of nano urea, shows a positive effect on the growth and production of sunflower. Since these nutrients are important to the performance of sunflowers, a field experiment was conducted to check the effect of S and B along with the application of nano urea.

MATERIALS AND METHODS

Study area

Field experiments were conducted at an experimental farm of the School of Agriculture of Lovely Professional University, Phagwara, in the Doaba region of the state of Punjab, during the season February-May 2023 to study the influence of different nutrient management on the growth attributes of sunflower *(Helianthus annuus* L.*).* The variety taken was PSH 2080, produced by Punjab Agriculture University in 2019. It is a short-duration, medium-tall hybrid that matures in 97 days. The experimental site of study is geographically located at latitude 31.253609°N and longitude 75.70367°E. The soil of the experimental field was sandy loam in texture with 0.46% organic carbon and alkaline in nature (pH of 7.81), low in available nitrogen (242.09 kg/ha), high in available phosphorus (44.68 kg/ha) and high in available potassium (262.30 kg/ha). A composite soil sample was taken at 0-30 cm depth. The sample was oven-dried and tested for physical and chemical properties. Soil pH analysed by pH meter and electrical conductivity by EC meter (Jackson,1973). Organic carbon determined by Wet digestion method (Walkley and black 1934). Available nitrogen was analysed by Alkaline permanganate method, available P by Olsen method (1954), and available K by Neutral normal ammonium acetate method (Jackson 1973) .

This experiment consisted of nine treatments including control and it was carried out in Randomized Block Design (RBD). The treatments were: T_0 - Control (no RDF), T_1- Nano urea + S @30 kg/ha, T_2 - Nano urea + S @45 kg/ha, T_3 - Nano urea + B @100 ml/ha, T_4 - Nano urea + B @200 ml/ha, T_5 - Nano urea + S @30 kg/ha + B @100 ml/ha, T_6 - Nano urea + S @30 kg/ha + B @200 ml/ha, T_7 - Nano urea + S @45 kg/ha + 100 ml/ha, T_8 - Nano urea + S @ 45 kg/ha + B @200 ml/ha. The treatment imposed in this experiment with two levels of sulphur (30, 45 kg/ha) through elemental sulphur (90% S) and two levels of boron (100, 200 ml/ha) through Bortrac as a foliar application at ray floret stage and Nano urea which contained 4% of total nitrogen (w/v), was applied at the rate of 2-4ml/lit after 35 days after sowing in all the treatments. The recommended dose of fertilizer, N, P, K of 60:30:30 kg per hectare was applied as a form of Urea, DAP and MOP, respectively. Half a dose of the N through Urea was applied as basal dose, and the remaining half was applied with nanourea as a foliar application after 35 days. The entire dose of P and K was applied as a basal dose. The experiment readings were taken on the 30^{th},60^{th}, and 90^{th} days after sowing, at 30-day intervals and harvest.

To estimate the oil content (%) in the sunflower seeds, the Soxhlet extraction method was performed using petroleum ether as solvent. The oil yield (kg/ha) was estimated by multiplying seed yield (kg/ha) with oil content (%). The crude protein (%) in the seeds was evaluated by estimating the nitrogen content (%) in the seed by the Kjeldhal method (Jackson. 1967) first and then multiplying it with a constant factor of 6.25.

Statistical analysis

The data collected from the field and the laboratory were subjected to statistical analysis using cvstat software and the treatment variations were tested for significance at a 5% level (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Growth attributes

The growth attributes of sunflower (*Helianthus annuus* L.) and their analysis are presented in Table 1. The results depict that increasing levels of sulphur and boron along with nano urea have improved the growth characteristics of sunflower. The plant height at maturity and the number of leaves per plant, stem girth (cm), and Dry Matter Production (DMP) gm/plant at harvest were significantly (at 0.05 level) influenced by the application of the nutrients. Among all the treatments, the maximum plant height of 181.6 cm was achieved in T_8 (nano urea + S @ 45 kg/ha + B @200 ml/ha), whereas the minimum plant height 165 cm was recorded in T_0 (control, no RDF).The increase in plant height with the application of nano urea + S @ 45 kg/ha + B @200 ml/ha might be due to the synergistic effect of these nutrients . Combined application of S with nanourea resulted enhancement in the growth of the plant. Plant height increases by increasing the sulphur level from 30-45 kg/ha. Sulphur is responsible for cell elongation, multiplication, and expansion throughout the crop's growth period. A higher sulphur level also activates many enzymes responsible for the shoot elongation (Kumar *et al.,* 2011). The results follow the research done by Ravikumar *et al.,* (2020) on sunflower while sulphur was applied at @45 kg/ha. Besides boron has a significant role in cell wall formation, and its continuous supply reduces the incidence of lignification, so basically, the plant cell continues to grow, mainly at the epical region with elongation of epicotyls and hypocotyls (Ravikumar *et al.,* 2021).The application of different treatments also influenced the number of leaves per plant. The maximum number of leaves per plant (31.7) was recorded in T_8 (nano urea+S@45kg/ha+B@200ml/ha) and the minimum number of leaves per plant (25.7) is found in T_0 (control, no RDF). The sufficient supply of sulphur leads to increased production of photosynthates and their transportation to the growing parts of the plant, ultimately enhancing plant growth attributes such as the number of leaves (Kumar *et al.,* 2011). The external application of boron was observed to boost the vegetative and reproductive growth of sunflower plants (Asad *et al.,* 2003).

The thickest stem girth of 11.16 cm was obtained in T_8 (nano urea+S@45kg/ha+B@200ml/ha) while the thinnest stem girth of 9.13 cm was observed in T_0 (control, no RDF). This response might be due to a good amount of uptake of sulphur in the plant. Also, sulphur plays a predominant role in synthesising amino acids that elevate the chlorophyll content in the growing parts of the plant and help to enhance photosynthesis. Similar to the results of Saleem *et al.* (2019), that says increasing the sulphur level from 15 to 20 kg/ha improves the thickness of the stem in sunflower. Zahoor *et al.* (2011) stated that the sunflower crop treated with a higher dose of boron (1 kg boron/ha) produced a higher number of leaves per plant (23.20) and a larger stem girth (3.06 cm). Higher doses of sulphur and boron with nano urea increased Dry Matter Production (DMP) in sunflower. At harvest, the highest DMP of 121.5 g/plant was recorded in T8 (nano urea+S@45kg/ha+B@200ml/ha) and the minimum DMP of 106.72 g/plant was recorded in T_0 (control, no RDF). Nitrogen is an essential nutrient that promotes plant growth and dry matter production. Foliar application of nano urea at 2-4 ml/lit could significantly improve the growth of sunflower when compared to no nitrogen application (Madhavi *et al.,* 2022). Similarly, the application of a higher rate of sulphur (40 kg/ha) along with nano urea (@4 ml/lit) was found to result in higher plant dry weight (70.08 gm) (Bhakher *et al.,* 2023). The maximum Leaf Area Index (LAI) of 5.06 at the flowering stage were recorded in T_8 (nano urea+S@45kg/ha+B@200ml/ha) and the minimum LAI of 3.02 was recorded in T_0 (control, no RDF). A sufficient supply of sulphur led to a larger generation of photosynthates and their translocation to sinks, resulting in a linear and significantly higher leaf area index with increases in phosphorus fertilizer levels from 0 to 45 kg/ha (Vijayakumar *et al.,* 2003).

Table 1 also shows that the individual application of sulphur (T_1, T_2) or boron (T_3, T_4) can improve the growth parameters of the plant, but the combination of these two nutrients gives better results than individual application. Foliar application of urea results in more efficient nitrogen absorption, and its higher use efficiency (>80%) increases nitrogen availability in plants and helps the plants grow profusely. The synergetic relation between nanourea, sulphur and boron was significant in the growth attributes of sunflower in all the growth stages. Sulphur application increases the amino acid synthesis, which is responsible for more protein content, leading to increased nitrogen content in soil. The more uptake of nitrogen by plant resulted in healthy plant. The similarity was found with the study done by Ravikumar *et al.* (2021) who reported that the combination of boron@0.3% along with sulphur @40 kg/ha increase all the growth parameters of sunflower.

Yield attributes

The diameter of the head, the number of filled seeds per head, 100 seed weight, seed yield and stover yield were significantly influenced by the application of nano urea, sulphur and boron (Table 2). The noticeable yield attributes, such as the largest diameter of the head (19.59 cm) was recorded in T_8 (nano urea+S@45kg/ha+B@200ml/ha). The smallest diameter of the head (13.29 cm) is found in T_0 (control, no RDF). Applying sulphur was also very helpful in increasing the diameter of the capitulum. Given that it is an ingredient that

Table 1. Synergic effect of nano urea, sulphur and boron on the growth attributes of sunflower

Treatments	Plant height	No. of leaves	Stem girth	DMP	Leaf Area
T_0- Control (No RDF)	165	25.7	9.13	106.7	3.02
T_1- Nano urea + S @30 kg/ha	172	28.3	10.50	107.8	4.22
T_2- Nano urea + S @45 kg/ha	175	32.0	10.60	114.1	4.23
T_3- Nano urea + B @100 ml/ha	176.3	26.3	10.23	111.0	4.38
T_4- Nano urea + B @200 ml/ha	176.8	27.7	10.43	114.9	4.92
T_5 - Nano urea + S @30 kg/ha + B @100 ml/ha	177.5	27.3	11.13	115.3	5.03
T_6- Nano urea + S @30 kg/ha + B @200 ml/ha	178.8	30.0	10.86	115.6	4.92
T_7- Nano urea + S @45 kg/ha + 100 ml/ha	180.2	30.7	11.03	119.3	4.99
T_8- Nano urea + S @ 45 kg/ha + B @200 ml/ha	181.6	31.7	11.16	121.5	5.06
SE ±	1.392	1.2	0.298	0.640	0.287
CD (P =0.05)	4.173	3.7	0.895	1.919	0.860
CV%	1.4	7.4	4.9	1.0	11.0

S **=** Sulphur, B = Boron; SE =Standard error; CD = Critical difference; CV = Critical variance RDF = 60:30:30 kg/ha

Table 2. Synergic effect of nano urea, sulphur and boron on the yield attributes of sunflower

Treatments	Head diameter (cm)	No. of filled seeds/head	100 seed weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)
T_0- Control (No RDF)	13.29	636	5.05	2177.0	4779.3
T_1- Nano urea + S @30 kg/ha	17.16	714.0	5.16	2307.0	4879.3
T_2- Nano urea + S @45 kg/ha	18.10	726.3	5.22	3000.0	5504.0
T_3- Nano urea + B @100 ml/ha	14.28	667.3	5.15	2254.4	5207.7
T_4- Nano urea + B @200 ml/ha	14.53	663.7	5.21	2288.1	5300.3
T_5 - Nano urea + S @30 kg/ha + B @100 ml/ha	17.96	719.3	5.26	2316.2	5380.7
T_6- Nano urea + S @30 kg/ha + B @200 ml/ha	18.44	743.3	5.33	2334.0	5394.3
T_7- Nano urea + S @45 kg/ha + 100 ml/ha	18.53	747.3	5.40	3089.5	5531.7
T_8- Nano urea + S @ 45 kg/ha + B @200 ml/ha	19.59	753.3	5.46	3140.8	5570.0
SE ±	0.273	9.4	0.0128	34.4	9.5
CD (P =0.05)	0.818	28.18	0.0384	103.025	28.331
CV%	2.8	2.3	0.4	2.3	0.3

S = Sulphur, B = Boron, SE =Standard error, CD = Critical difference, CV = Critical variance RDF = 60:30:30 kg/ha

oilseeds cannot avoid, a larger redirection towards the head is necessary (Shekhawat *et al.,* 2008). Hassan et al. (2007) have stated that sunflower head diameter increases with the increase of sulphur doses. The maximum number of filled seeds/head (753.34) was obtained in T_8 (nano urea+S@45kg/ha+B@200ml/ha) and the minimum number of filled seeds/head (636) is obtained in T_0 (control, no RDF). When there is sufficient nitrogen (100% RN) available, boron has a positive effect on pollen germination, development, anther viability, anthesis, cell division, increased enzymatic activity, and sugar availability, all of which contribute to the formation of more seeds (Shehzad *et al.,*2015*)*. Further, the foliar application of nano urea in low-input agriculture practice on rice crops can give promising output (Velmurugan *et al.,* 2021). Boron may have a stimulatory effect on sunflower plants because of its contribution to improved pollen tube growth and metabolic processes (Khan *et al.,* 2015). Kaleri *et al.,* (2024) reported that the application of 60 kg of sulfur greatly enhanced the filled pods in mustard where 250 kg of gypsum was applied. The application of higher doses of sulphur, boron and nano urea greatly influenced the seed weight. The highest seed weight of 100 seeds (5.46 g) was recorded in T_8 and the lowest value (5.05) in T_0 (control, no RDF). Boron is involved in transpiration, sugar transfer, photosynthesis, and cell elongation, which could be the reason for the increase in seed weight, size, and yield (Indu *et al.,* 2020). Reddy *et al.* (2003) said that a higher transfer of photosynthates from vegetative sources towards the reproductive organs might cause the sunflower's increased 1000-achene weight when boron was applied. The impressive seed yield was obtained when sulphur and boron doses were increased. Seed yield was found highest in T_8 (nano urea+S@45kg/ha+B@200ml/ha) as 3140.8 kg/ha. And the lowest seed yield (2177 kg/ha) in T_0 (control, no RDF). The buildup of more dry matter and improved photosynthetic translocation increased yield components, producing a rise in seed yield (Singh *et al.,* (2017). A similar result was found in the study of Sheoran *et al.* (2018) when recommended NPK was combined with the application of macro (S) and micro (B and Zn) nutrients; crop yield response was considerable ($P<0.05$) significant. Also, the maximum stover yield of 5570 kg/ha was recorded in T_8 (nano urea+S@45kg/ha+B@200ml/ha) and the minimum (4779.3 kg/ha) was in T_0 (control, no RDF). This increase in straw yield could be attributed to tissue differentiation from somatic to reproductive, meristematic activity, and the development of floral primodia, potentially resulting in more flowering and, ultimately, siliquae. When sulfur doses increased, there was a gradual rise in straw yield in sunflower (Rakesh *et al.,* 2012).

The result implies that the different dosages of sulphur and boron can improve the yield-related features when individually applied, but when applied in combination, they can show better results. This might be due to the synergistic interaction between nitrogen, sulphur and boron. Because of sulphur's ability to properly distribute photosynthetic energy from source to sink, it is essential for synthesising amino acids and positively impacting yield aspects. The findings are in conformity with a study done by Kalaiyarasan *et al.* (2020) on sunflower when S@60kg/ha and B @1 kg/ha were used .The foliar application of nano urea at 35 days of sowing and recommended soil-applied urea gives optimistic results (Oad *et al.,*2018). Besides, similar results from other literature confirm the synergistic interaction of sulphur and boron (Saleem *et al.,* 2019).

Quality attributes

The oil content (%) and crude protein content (%) of sunflower seeds were significantly influenced by applying nano urea, sulphur and boron application. The highest oil content and oil yield of 44.20 % and 1388.34 kg/ha were recorded in T_8 (nano urea plus 45 kg/ha and boron @200 ml/ha). The interaction impact of the nutrients had a positive effect on the oil content and oil yield. The minimum oil content of 36.53 % and oil yield of 795.34 kg/ha were observed in control (T_0). Sulphur has a very prominent role in influencing the oil content and quality of oil in sunflower (Saleem *et al.,* (2019). The increase in oil content can be explained by sulphur's influence on nitrogen's quick conversion to crude protein, which leads to the production of oil (Kalaiyarasan *et al.,* 2019). Because sulfur is a component of numerous amino acids necessary for protein synthesis, the application of sulfur coupled with borate boosted the oil levels (Muhammad Tahir *et al.,* 2014). Besides, the availability of sulphur was found to improve the uptake of nitrogen in plants. The sufficient amount of nitrogen in plants and seeds is directly proportional to the crude protein content in the seed. Table 3 shows the maximum crude protein content of 16.07% for T_8, where a higher level of sulphur (45 kg/ha), boron (@200 ml/ha) and nano urea was applied and the lowest crude protein content of 14.28 % was recorded in T_0

Table 3. Synergic effect of nano urea, sulphur and boron on the oil content, oil yield and crude protein content of sunflower

Treatments	Oil content (%)	Oil yield (kg/ha)	Crude protein content (%)
T_0- Control (No RDF)	36.53	795.34	14.28
T_1- Nano urea + S @30 kg/ha	37.40	862.81	14.87
T_2- Nano urea + S @45 kg/ha	38.53	1155.92	15.80
T_3- Nano urea + B @100 ml/ha	38.06	858.15	15.49
T_4- Nano urea + B @200 ml/ha	38.20	874.08	15.95
T_5 - Nano urea + S @30 kg/ha + B @100 ml/ha	40.73	943.53	15.72
T_6-Nano urea + S @30 kg/ha + B @200 ml/ha	41.53	969.38	15.75
T_7- Nano urea + S @45 kg/ha + 100 ml/ha	43.06	1330.68	15.69
T_8- Nano urea + S @ 45 kg/ha + B @200 ml/ha	44.20	1388.34	16.07
SE ±	0.178	16.311	0.132
CD (P =0.05)	0.536	48.895	0.396
CV%	0.8	2.8	1.5

S = Sulphur, B = Boron, SE =Standard error, CD = Critical difference, CV = Critical variance RDF = 60:30:30 kg/ha (control, no RDF). A similar report confirms that the application of boron and sulphur had a considerable and synergistic effect on the oil (31.8 %) and protein content (17.1%) of oilseeds (Barthwal *et al.,*2022). One of the other reasons behind the increase in crude protein content can be the higher use efficiency and availability of nitrogen from the application of nano urea.

Conclusion

The present study concluded that an increase in two different doses of sulphur (30 and 45 kg/ha) and two different doses of boron (100 and 200 ml/ha) along with nano urea showed a synergistic impact on the growth, yield and quality attributes of sunflower (*Helianthus annuus* L.). The combined application of nano urea + S @ 45 kg/ha + B @200 ml/ha enhanced all sunflower growth, yield and quality attributes compared to control and individual application of sulphur and boron. The results showed that the combined supply of S and B and nano urea to the sunflower crop in an appropriate method and time, along with the necessary nutrients (N, P, K) in the soil, are important factors for its productivity which may be due to the synergic effect of sulphur and boron. However, more research is needed to draw a reliable conclusion before the farming community's final recommendation.

Conflict of interest

The authors declare that they have no conflict of interest.

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