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Sulphur, boron and zinc nutrition to improve productivity, profitability and oil quality in sunflower (*Helianthus annuus*)

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ABSTRACT

Yield response, profitability margins and oil quality in relation to macro (S) and micro (B and Zn) nutrients application with NPK recommendations were quantified in spring planted sunflower (*Helianthus annuus* L.). Significantly higher seed yield, synergism in nutrients uptake and superior oil quality was noticed through better expression of physio-morphic traits and yield components, increased nutrient accumulation and improvement in oil quality parameters with application of S, B and Zn. Supplemented nutrition proved to be economically more efficient and sustainable over recommended NPK as evident by relatively higher crop yield response (0.10-0.18 t ha^{-1}), production efficiency (4.7-8.0%), profitability (0.50-0.97 USD/ha/day), relative economic efficiency (4.64-9.05%) and sustainability yield index (5.1-8.5%). Improvement in saturated fatty acid (SFA): unsaturated fatty acid (UFA) ratio indicated improvement in oil quality, followed the trend of S>B=Zn. An inverse correlation ($r = -0.68^{**}$) between mono- (oleic) and poly- (linoleic) unsaturated fatty acids indicated the inter-dependence of these two quality parameters. The information generated would facilitate quantitative yield predictions in relation to macro (S) and micro (B and Zn) nutrient application with recommended fertilization in sunflower.

Key words: Economics, Micronutrients, Oil quality, Productivity, Sunflower

The shortage of edible oils has become a chronic problem in India with increasing demographic pressure, fast changing food habits, improved purchasing power and living standards of masses. The country imported more than 10 million tonnes of vegetable oil including 9% sunflower oil during 2014-15 (Anonymous 2016). To bridge up the demand-supply gap, sunflower (*Helianthus annuus* L.). offers tremendous plasticity to adapt contrasting environmental conditions because of its desirable attributes such as early maturity with higher per day productivity, responsiveness to better production management practices, photo-thermo insensitivity and quality edible oil rich in linoleic and oleic acids (Hegde 2012, Sheoran *et al.* 2015).

No doubt, mineral nutrition is indispensable for profitable crop production. Agrarian farmers apply more than recommended NPK fertilizers in terms of increasing yields giving minimal consideration to depletion of the finite secondary macro and micronutrient reserves of soils and actual crop demand. Sulphur (S) and micronutrient (Zn and B) deficiencies have been reported in intensive, irrigated production systems globally (Mirzapour and Khoshgoftar 2006, Tahir *et al.* 2014). Field-scale widespread deficiency of sulphur (41%), zinc (43%) and boron (18.3%) have been identified as one of the critical bottlenecks in sustaining crop production (Shukla *et al.* 2015). These deficiencies are reported as the main causes for yield plateau or declining yield levels due to fast adoption of new agricultural technology, including cultivation of high yielding crop varieties/hybrids, crop intensification, expansion of irrigation facilities, increased use of high analysis fertilizers devoid of these nutrients, limited use of organic manures and poor quality irrigation water (Nayyar 1999).

Large scale yield benefits have been recorded with the application of these nutrients along with N and P (Rego *et al.* 2007) in the present exploitive agriculture. Sulphur demand of oilseed crops is higher than those of cereal crops (Scherer 2001) requiring about the same amount of S as, or more than, phosphorus for high yield and product quality (Jamal *et al*. 2010). Sulphur performs various physiological and metabolic roles in the plant systems, oil and protein synthesis as well as quality of produce (Roche *et al.* 2004, Hussain *et al.* 2011, Sheoran *et al.* 2013). Zinc nutrition of crops is of particular interest because of its importance in

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maintaining the membrane integrity of root cells (Cakmak and Marschner 1988) and the possible role of Zn in reducing the toxic effects of boron (B), sodium (Na), and chloride (Cl). Boron nutrition has special importance in sunflower being used as indicator plant and plays key role during flowering, pollen germination, pollen tube growth, stigma receptivity and seed development (Cakmak and Romheld 1997).

Limited studies have been performed of the response of oilseed sunflower to sulphur, zinc and B fertilization. In this backdrop, the present investigation was carried out to quantify their role in yield, quality and nutrient uptake in sunflower in the intensive cropping system.

MATERIALS AND METHODS

The field experiment was initiated in 2007 and continued upto 2010 on a fixed plot layout in sunflower-based cropping sequence at the research farm of Punjab Agricultural University, Ludhiana (30°56' N, 75°52' E, 247 m above msl) located in the Indo-Gangetic alluvial plains of Punjab, northwest of India. The objective of the experiment was to study the role of sulphur, boron and zinc application on nutrient uptake, yield and fatty acid composition of sunflower. The experimental site has semi-arid, monsoonal climate with an average annual precipitation of 760 mm occurring mainly (about 80%) between July and mid September. Winter and spring seasons, remain dry and receive few showers of cyclic rains. The soil of the experimental field was well drained sandy loam (typicustipsamment), non-saline, low in organic carbon and available N, medium in available P; high in available K; low in available S and medium in available Zn and B at 0-15 cm soil depth (Table 1).

Supplemental application of S, B and Zn as per treatments was made to sunflower crop during spring season (January/February-May/June) as surface broadcast before the final land preparation. There were five treatments, viz. recommended NPK (T_1); T_1 + S @ 20 kg/ha; T_1 + B @ 1 kg/ha in alternate years; T_1 + Zn @ 5 kg/ha and absolute control (without S, Zn and B), which were allocated in randomized block design in three replications. All plots received the same treatment throughout the period of study. The land preparations were done mechanically with proper care to avoid mixing of soil from adjacent plots. The seeds of sunflower hybrid PSH 569 were hand dibbled putting 2-3 seeds/hill at spacing of 0.6 m between rows and 0.3 m within rows in seven-row plots measuring 5.1 m in length. At about four leaf stage, extra plants were manually thinned out to retain one plant per hill. Each plot was uniformly fertilized with 60 kg N (Urea; 46%), 13 kg P (DAP; 18% N, 46% P_2O_5) and 25 kg K/ha as MOP (60% K_2O). Half dose of N and full P and K were drilled at the time of sowing while remaining half dose of N was top-dressed 30-35 days after planting of sunflower. Sulphur, boron and zinc were applied through gypsum (15% S), borax (10% B) and zinc sulphate heptahydrate (21% Zn), respectively. The crop was grown with assured irrigated facilities. Other management practices, including insect-pests and weed control, were followed according to recommended agronomic practices for the region unless otherwise indicated.

The yield data were recorded from the central five rows by discarding two external rows (one on each side) of each plot. Samples were dried to a constant weight and threshed manually to determine the economic yield from each net plot which was expressed in t/ha. Plant samples from each plot were also collected at harvest and oven dried to determine nutrient concentrations by employing standard analytical procedures. Total N, P and K concentrations in seed and stalk was determined by modified kjeldahl (Bremner and Mulvaney 1982), vanadomolybedo phosphoric acid yellow colour (Koeing and Johnson 1942) and flame photometric (Antil *et al.* 2002) methods, respectively. Zinc in plant samples was determined by di-acid digestion using atomic absorption spectrophotometer (Shaw and Dean 1952). Total S and B in plant were determined by ICP-AES by digesting the samples in nitric acid (Mills and Jones 1996). Nutrient uptake was estimated by multiplying nutrient concentration of plant samples with their respective dry weight and summed up to obtain the total uptake.

Oil content in the whole seed was determined by nuclear magnetic resonance spectroscopy employing non-destructive method of oil estimation as described by Alexander *et al.* (1967). A simple and convenient method for the quantitative preparation of volatile methyl esters of fatty acids (FA) isolated by CS2 extraction and a TLC technique was followed (Luddy *et al.* 1968). The concentration of individual FA in the sunflower seed samples is given as per cent by weight of the total FA in the oil from each treatment.

Production efficiency (PE) was worked out as incremental seed yield on a daily basis (Tomar and Tiwari 1990) by the formula

$$PE = (SYe - \sigma)/\Delta n$$

where, PE is the production efficiency in kg/ha/day, SY_e is the economic yield in kg/ha, σ=estimate of standard error and Δn is the duration of the crop.

Table 1 Physico-chemical properties of experimental soil

Parameter	Value	Category
Texture		Sandy loam
Sand (%)	66.4±0.84	
Silt (%)	20.8±0.16	
Clay (%)	12.8±0.08	
pH (1:2 soil water suspension)	8.0	Normal
Electrical conductivity (dS/m)	0.21	Non-saline
Organic C (g/kg soil)	1.5	Low
Alkaline $KMnO_4$ oxidizable N (mg/kg)	50.1	Low
0.5 M $NaHCO_3$ extractable P (mg/kg)	6.7	Medium
1 N NH_4OAc exchangeable K (mg/kg)	81.7	High
0.15% $CaCl_2$ extractable S (mg/kg)	8.9	Low
DTPA extractable Zn (mg/kg)	0.94	Medium
Hot water extractable B (mg/kg)	0.64	Medium

The sustainability yield index (SYI) denoted as 'η' of a treatment 't' over a period of 'n' years was derived to identify the sustainable nutrient management practice as per Vittal *et al.* (2003).

$$\eta_t = (Y_t - \sigma)/Y_{max}$$

where, Y_t=estimated mean yield of t; σ = estimate of standard error; Y_{max}=observed maximum yield.

The net returns were calculated by deducting the total expenditure incurred on field preparation, seeds, fertilizers, irrigation, agrochemicals for insect-pests and diseases, harvesting, and threshing from the gross returns. The profitability was calculated to determine per day return. Profitability was calculated as:

$$P = NR/D$$

where, P is the profitability in USD/ha/day, NR is the net returns, and D is the duration of the crop. Mean prices of sunflower seed, gypsum, borax, zinc sulphate, urea, di-ammonium phosphate and muraite of potash were 0.61, 0.05, 4.52, 0.42, 0.09, 0.38 and 0.24 USD/kg, respectively.

The comparative advantage achieved through superimposition of different treatments is represented through relative economic efficiency (REE), expressed in percentage (Parasd *et al.* 2011). The REE of different treatments was calculated by using the following formula:

$$REE = (\Delta NR/A) * 100$$

where, ΔNR is the difference in the net returns from different nutrient management practices treatments over the control, i.e. recommended fertilization (NPK), A is the net returns from recommended fertilization (NPK) plots.

Individual parameters were subjected to one-way analysis of variance (ANOVA) technique as per randomized block design to determine the treatment effects using statistical programme CPCS1 and OPSTAT (https://www.hau.ernet.in/opstat.html). Mean comparison was performed based on Duncan's Multiple Range Test (DMRT) at the 0.05 probability level.

RESULTS AND DISCUSSION

Growing seasons

Analysis of variance (Table 2) showed seasonal variability in terms of capture and utilization of environmental driven resources during the crop growing period (2007-10), elucidating significant effect of environmental factors on the maturity duration, yield and oil quality of sunflower. The mean sum of squares for interaction between growing seasons and nutrient treatments revealed their influence on seed and oil yields through growth and yield parameters. Total crop growth period (CGP), considered as the time of period from emergence to physiological maturity ranged between 102 (2010) and 111 days (2008) with a mean value of 106 days with CV of 3.5% (Table 3). Significant variation in seed yield of sunflower was recorded in different years and it followed the trend 2009 > 2008 > 2007 > 2010. Such differences in yield may be ascribed to variation in weather parameters. The daily mean aerial temperature during the seed development period was relatively higher (0.2–1.5°C) in 2007 and 2010 (data not shown) which curtailed the reproductive period having significant impact on economic yield parameters and sunflower seed yield (Table 3). Favourable environmental conditions, extended reproductive period as well as crop maturity might have resulted in more translocation of assimilates from source to sink ultimately culminating in better expression of physio-morphic traits and yield components towards relatively higher yields in 2009 and 2008 (Kaleem *et al.* 2010). Oil yields mirrored the response of seed yields, being highest (0.97 t/ha) in 2009 and lowest (0.74 t/ha) in 2010. Chromatographic analysis of seed oil showed that fatty acid composition of sunflower oil altered substantially by changes in environmental conditions

Table 3 Seasonal changes in maturity duration, yield and fatty acid composition of sunflower

Parameter	2007	2008	2009	2010
Maturity duration (days)	106.4[b]	110.6[c]	105.3[b]	101.8[a]
Seed yield (t/ha)	1.96[c]	2.35[b]	2.45[a]	1.93[c]
Oil content (%)	38.2[a]	34.2[b]	38.1[a]	38.3[a]
Oil yield (t/ha)	0.75[c]	0.83[b]	0.97[a]	0.74[c]
Palmitic acid (%)	6.84[c]	7.59[d]	6.46[b]	6.27[a]
Stearic acid (%)	3.43[c]	3.21[a]	3.31[b]	3.69[d]
Oleic acid (%)	47.09[d]	48.69[c]	53.69[a]	50.70[b]
Linoleic acid (%)	42.54[a]	40.36[b]	36.30[d]	39.26[c]
SFA : UFA ratio	0.114[b]	0.121[c]	0.108[a]	0.110[a]

Values followed by different letters are statistically different (DMRT, significance level=0.05, within row comparison).

Table 2 Pooled ANOVA of experiment conducted during 2007-2010

Source of variation	df	Mean Sum of Square							
		Maturity duration (days)	Seed yield (t/ha)	Oil content (%)	Oil yield (t/ha)	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)
Growing seasons (E)	3	555.5*	1.174*	61.32*	0.162*	5.07*	0.63*	121.51*	101.21*
Nutrient management (NM)	4	2.5*	2.464*	6.33*	0.387*	15.51*	12.28*	21.21*	8.98*
Interaction (E × NM)	12	10658.3	0.025*	0.01	0.003*	0.29	0.23*	0.68	0.39
Error	38	101.8	0.016	0.53	0.003	0.20	0.55	0.53	0.33

df= Degree of freedom; *Significant at $P < 0.05$

across different growing seasons. Significant variation in the proportion of unsaturated (oleic and linoleic) and saturated (palmitic and stearic) fatty acids was recorded within cropping seasons. The oleic: linoleic ratio was maximum (1.48) in 2009 and minimum (1.21) in 2008.

Crop productivity, sustainability and profitability

Seed yield and quality traits of sunflower were significantly influenced by the nutrient management practices as indicated by significance of mean sum of squares (Table 2). Application of macro (S) and micro (B and Zn) nutrients in combination with recommended NPK resulted in significant ($P<0.05$) crop yield response in all the years of study (Table 4). Crop nutrition through different nutrient management practices (T_1-T_4) resulted in definite edge in respect of growth and development over the absolute control (T_5: $N_0P_0K_0$). Better partitioning of photosynthates from source to sink with application of nutrients might have led to statistically higher values of growth (capitulum diameter, stem girth) and yield indices (number of seeds/capitulum, 100-seed weight) (Table 5), finally culminating in significantly higher sunflower yield (64.3-77.2%) compared to unfertilized control. These results are in accordance with the earlier findings of Suryavanshi *et al.* (2015) and Sheoran *et al.* (2016).

Table 4　Seed yield of sunflower as influenced by nutrient management practices over four year crop cycle

Nutrient management practices	Sunflower yield (t/ha)			
	2007	2008	2009	2010
NPK* (T_1)	2.08[a]	2.46[b]	2.59[b]	1.94[b]
NPK + S[#] (T_2)	2.16[a]	2.66[a]	2.77[a]	2.19[a]
NPK + B[†] (T_3)	2.13[a]	2.58[ab]	2.73[a]	2.14[a]
NPK + Zn[‡] (T_4)	2.13[a]	2.48[b]	2.69[ab]	2.17[a]
Unfertilized control (T_5)	1.28[b]	1.55[c]	1.47[c]	1.21[c]

*NPK @ 60:13:25 kg/ha; #20 kg sulphur/ha through gypsum (15% S); †1 kg boron/ha in alternate years through borax (10% B); ‡5 kg zinc ha^{-1} through zinc sulphate (21% Zn). Values followed by different letters are statistically different (DMRT, significance level=0.05, within column comparison).

Soil application of 20 kg S/ha through gypsum proved beneficial in achieving significantly higher yield (0.18 t/ha) indicating 7.8% yield gain over the recommended NPK (T_1 : 60 kg N + 13 kg P + 25 kg K/ha). Role of S in improving cell division, photosynthetic rate and assimilating efficiency contributed to improved capitulum diameter and 100-seed weight and ultimately higher yields confirming the earlier findings of Ozer *et al.* (2004) and Sheoran *et al.* (2013). Boron application @ 1 kg/ha in alternate years through borax (10% B) significantly improved sunflower yield (5.6%) over the treatment receiving no B application (T_1). The capitulum size and seed number increased with B application (Table 5). Boron is known to enhance metabolic and photosynthetic activities and promotes plant growth and biomass accumulation. These results corroborate with the findings of Zahoor *et al.* (2011) and Silva *et al.* (2011). Additional nutrition through Zn yielded 4.5 and 4.7% more seed and oil yield in comparison to treatment receiving no Zn (T_1). Beneficial role of Zn nutrition in enhancing sunflower yield has also been reported by Suresh *et al.* (2013).

Nutrient uptake

All the fertilizer treatments improved the uptake of various nutrients by sunflower (Fig 1). The magnitude of uptake for different nutrients followed the order: K> N> P> S> Zn > B in accordance with seed yield and respective nutrient concentration in seed and stalk. The total uptake of N, P, S and Zn was higher in seeds and that of K and B was higher in stalk. Synergistic effect of S application in sunflower was observed in both seed and stalk reflecting in total uptake of other nutrient (N, K, B and Zn), however, P uptake numerically enhanced in comparison to control (T_1: recommended NPK). Sulphur nutrition in sunflower excelled total nutrient uptake by 21.1% for N, 2.1% for P,

Table 5　Effect of nutrient management practices on yield and quality parameters of sunflower

Nutrient management practices	NPK* (T_1)	NPK + S[#] (T_2)	NPK + B[†] (T_3)	NPK + Zn[‡] (T_4)	Unfertilized control (T_5)	Mean
Plant height (cm)	155.8[a]	154.2[a]	154.1[a]	153.7[a]	130.9[b]	149.7±1.28
Stem girth (cm)	7.54[b]	7.73[a]	7.57[b]	7.67[a]	5.83[c]	7.27±0.09
Capitulum diameter (cm)	16.13[b]	16.40[b]	17.03[a]	16.33[b]	13.31[c]	15.84±0.29
No. of seeds per capitulum	782[c]	804[ab]	822[a]	796[bc]	694[d]	780±18.9
100-seed weight (g)	5.95[c]	6.14[a]	6.08[ab]	6.04[b]	5.07[d]	5.86±0.10
Seed yield (t/ha)	2.27[d]	2.44[b]	2.39[bc]	2.37[c]	1.379[e]	2.170±0.02
Oil content (%)	37.04[a]	37.76[ab]	37.22[b]	37.26[ab]	36.03[c]	37.06±0.26
Oil yield (t/ha)	0.89[b]	0.92[a]	0.90[b]	0.91[b]	0.50[c]	0.83±0.01
UFA:SFA ratio	0.113[c]	0.092[a]	0.103[b]	0.102[b]	0.159[d]	0.114±0.02

*NPK @ 60:13:25 kg/ha; #20 kg sulphur/ha through gypsum (15% S); †1 kg boron/ha in alternate years through borax (10% B); ‡5 kg zinc ha^{-1} through zinc sulphate (21% Zn). Values followed by different letters are statistically different (DMRT, significance level=0.05, within row comparison)

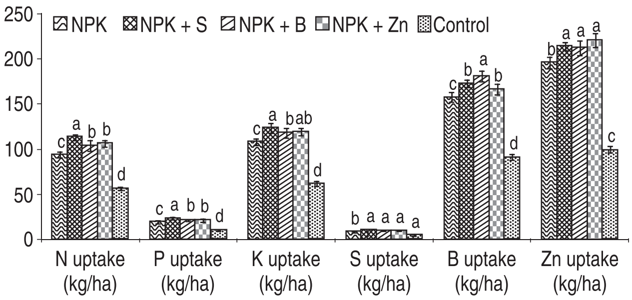

Fig 1 Total nutrient uptake pattern of sunflower as influenced by nutrient management practices. Mean values with the same letter(s) are not significantly different (DMRT, significance level=0.05).

14.4% for K, 25.6% for S, 9.7% for B and 9.3% for Zn uptake as compared to treatment without S application (Fig 1). Increased uptake of N due to S application may be the result of complementary assimilation pattern of N and S in plant (Dayanand and Shivran 2002) and increased nitrogen metabolism and partitioning of more N to seed by favourable N:S ratio in the plant tissue (Kumar *et al.* 2006). Beneficial role of sulphur in mobilizing soil P and increased uptake of K by various plant parts, leading to increased total P and K uptake was reported earlier by Jain and Saxena (1991).

Similar positive influence of B and Zn fertilization was evident from increased nutrient accumulation and their uptake in sunflower (Fig 1) following the descending synergism of S>N>K>Zn>P uptake with B application and N>S>K>B>P uptake with Zn application compared to the treatments devoid of B or Zn nutrition (T_1). Zinc application had no appraisal effect on total P uptake. Boron and nitrogen concentrations of seed and stalk significantly increased with B application leading to enhanced total B and N uptake. In case of P, S, and Zn, the nutrient concentrations significantly increased but in case of K, it remained unchanged in stalk. Better translocation of applied nutrients to reproductive parts showed synergistic effect of B and Zn on nutrient absorption and their utilization by the crop (Sinha e*t al.* 2000, Dash *et al.* 2015).

Fatty acid composition

Significant differences in fatty acid composition of oil were observed due to nutrient application to sunflower (Fig 2). Unsaturated fatty acids (UFA) constitute about 90% of the total fatty acids, rest being the saturated fatty acids (SFA) in sunflower. Sulphur, boron and zinc application proved to be useful in increasing the proportion of unsaturated fatty acids (oleic and linoleic) and reducing that of undesirable saturated fatty acids (palmitic and stearic) in comparison to control (T_1). The highest improvement was recorded with S nutrition as evident from relatively lower value of SFA : UFA ratio (0.093) followed by boron or zinc (0.103) application.

Efficiency indices

Production efficiency (PE) indicates a larger translocation capacity of the source towards the sink. Mean PE calculated over 4 years cropping period (Fig 3) varied from 21.3 kg/ha/day (NPK) to 23.0 kg/ha/day (NPK + S) compared to 13.0 kg ha/day under absolute control (T_5). About 4.7 to 8.0% higher production efficiency was recorded with supplemental nutrition which might be due to higher assimilation of metabolites in crop plants, relatively higher root biomass, root absorption, better nutrient uptake, increased above ground dry matter accumulation and higher production in unit time (Hao *et al.* 2008). The nearness of sustainability yield index (SYI) to 1.0 implies the closeness to an ideal situation that can sustain maximum crop yields over years, while deviation from 1.0 indicates departure from sustainability for the proposed practice. This study revealed SYI of more than 0.70, suggesting that the balanced nutrition through S, B and Zn application is advantageous, economically viable, and environmental friendly (Fig 3). The highest SYI was recorded with NPK + S (0.78), followed by NPK + Zn (0.75) in comparison to SYI of 0.71 achieved with recommended fertilization (T_1) and SYI of 0.60 was recorded in absolute control plot (T_5). Suryavanshi *et al.* (2015) have also reported the role of balanced nutrition in sustaining the productivity sunflower-based cropping system. Supplemental nutrition which included S, B and Zn application enhanced profitability margins by 0.50 to 0.97 USD ha/day as compared to existing recommendations of N, P and K only (T_1). Lowest monetary returns (5.38 USD ha/day) was recorded in absolute control plot (T_5).

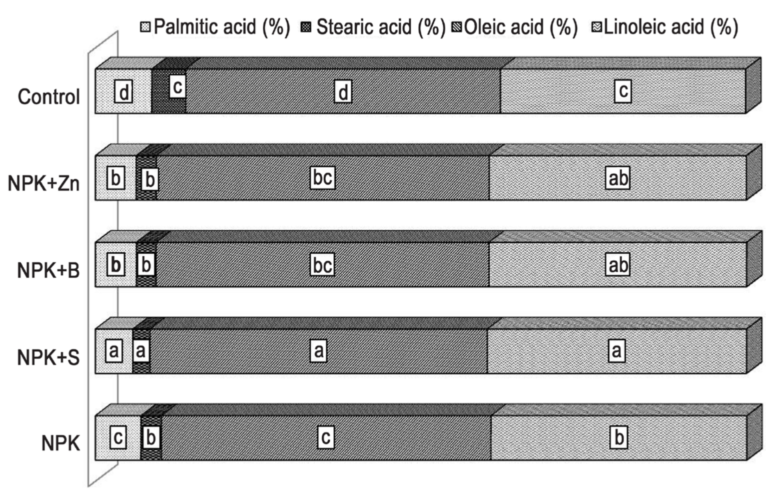

Fig 2 Changes in fatty acid composition of sunflower in relation to nutrient management practices. Mean values across different treatments (shown by similar pattern) with the same letter(s) are not significantly different (DMRT, significance level=0.05).

Yield response and monetary returns with applied nutrients

Considerable increase in sunflower yield was recorded with supplemental nutrition which included S, Zn and B application along with recommended NPK in sunflower (Table 6).

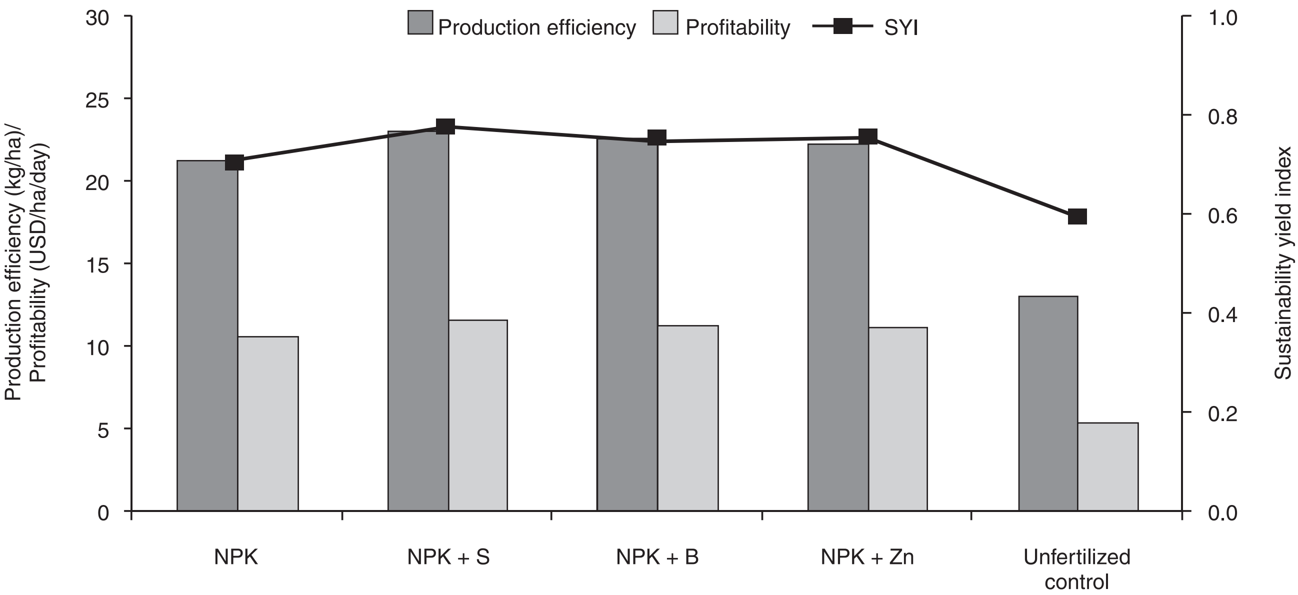

Fig 3 Production efficiency, profitability and sustainability yield index of sunflower under different nutrient management practices.

Highest crop yield response was observed with S (0.18 t/ha) followed by B (0.13 t/ha) and Zn (0.10 t/ha) fertilization. The highest relative economic efficiency (9.1%) was also recorded with sulphur application (Table 6). This implies that with the given amount of inputs and management, additional nutrition through sulphur was 9.1% more economically efficient, over recommended fertilization (NPK). Supplemented B and Zn nutrition were 5.9 and 4.6% more efficient over recommended fertilization (NPK). The B:C ratio calculated on the basis of net returns over variable cost indicated monetary benefits of USD 16.8 for S, 6.9 for B and 5.4 for Zn with each USD invested on additional nutrient.

Correlation studies

Positive and significant correlation of seed yield with stem girth ($r=0.460^{*}$), capitulum diameter ($r=0.766^{**}$), number of seeds per capitulum ($r=0.826^{**}$) and seed weight ($r=0.675^{**}$) indicated adequate accumulation of metabolites during vegetative period and their efficient translocation to sink during reproductive phase for improving yield attributes, which ultimately contributed towards relatively higher yields (Table 7). Positive and highly significant correlation ($r=0.964^{**}$) of seed yield with oil yield indicated direct dependence of oil productivity on seed yield and oil concentration. Strong correlation was discerned between S, B and Zn supply and concomitant uptake of other nutrients implying the synergistic response of sunflower crop to balanced nutrition (Table 7). Further, strong but negative correlation of saturated fatty acids and highly significant positive relationship of unsaturated fatty acids with oil yield confirms the beneficial role of supplemental nutrition in improving the oil quality of sunflower. The study results indicated an inverse correlation ($r= -0.68^{**}$) between mono- (oleic) and poly- (linoleic) unsaturated fatty acids suggesting an inter-dependence among these two seed oil quality parameters.

The present investigation revealed the profound role of balanced fertilization in improving the productivity, profitability and sustainability of spring planted sunflower. Application of S, B and Zn fertilizers with recommended NPK resulted in significantly better expression of physio-morphic traits (plant height, stem girth, capitulum diameter) and yield components (number of seeds per capitulum, 100-seed weight) which culminating in 0.10-0.18 t/ha more (4.5-7.8%) seed yield over the existing fertilizer recommendations (60 kg N + 13 kg P + 25 kg K/ha). Synergistic effect of additional nutrition on nutrient acquisition with differential magnitude (K> N> P> S> Zn > B) was observed in accordance with seed yield and respective nutrient concentration in seed and stalk. Increase in proportion of both MUFA (oleic) and PUFA

Table 6 Crop yield response, relative economic efficiency and benefit : cost ratio of nutrients applied to sunflower

Nutrient	Details	Average response ($t\ ha^{-1}$)	Correlation coefficient (r)	Relative economic efficiency (%)	Benefit : cost ratio
S	20 kg sulphur/ha through gypsum	0.18	0.965^{**}	9.05	16.8 : 1
B	1 kg boron/ha through borax†	0.13	0.971^{**}	5.93	6.9 : 1
Zn	5 kg zinc/ha through zinc sulphate	0.10	0.980^{**}	4.64	5.4 : 1

† in alternate years

Table 7 Correlation matrix showing inter-relationships between growth and yield parameters, yield, nutrient uptake and fatty acids of sunflower

Parameter	Seed yield	Oil yield	Oil content	Plant height	Stem girth	Capitulum diameter	100-seed weight	N uptake	P uptake	K uptake	S uptake	B uptake	Zn uptake	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
Seed yield	1.0																
Oil yield	0.964**																
Oil content	0.008^{NS}	0.225^{NS}															
Plant height	0.362^{NS}	0.470*	0.641**														
Stem girth	0.460*	0.482*	0.381^{NS}	0.829**													
Capitulum diameter	0.766**	0.646**	-0.376^{NS}	0.143^{NS}	0.405*												
100-seed weight	0.675**	0.816**	0.665**	0.541**	0.356^{NS}	0.214^{NS}											
N uptake	0.982**	0.944**	0.027^{NS}	0.346^{NS}	0.479*	0.724**	0.658**										
P uptake	0.970**	0.937**	0.066^{NS}	0.372^{NS}	0.520**	0.716**	0.656**	0.995**									
K uptake	0.994**	0.959**	0.031^{NS}	0.371^{NS}	0.492*	0.749**	0.672**	0.996**	0.988**								
S uptake	0.970**	0.936**	0.077^{NS}	0.390^{NS}	0.536**	0.713**	0.662**	0.994**	0.999**	0.988**							
B uptake	0.991**	0.949**	0.010^{NS}	0.372^{NS}	0.467*	0.756**	0.675**	0.972**	0.957**	0.986**	0.959**						
Zn uptake	0.989**	0.961**	0.050^{NS}	0.406*	0.527**	0.765**	0.676**	0.985**	0.976**	0.995**	0.975**	0.982**					
Palmitic acid	-0.646**	-0.720**	-0.616**	-0.755**	-0.762**	-0.250^{NS}	-0.740**	-0.702**	-0.736**	-0.690**	-0.746**	-0.650**	-0.696**				
Stearic acid	-0.894**	-0.884**	-0.190^{NS}	-0.596**	-0.695**	-0.748**	-0.643**	-0.900**	-0.916**	-0.906**	-0.923**	-0.885**	-0.908**	0.791**			
Oleic acid	0.632**	0.733**	0.370^{NS}	0.398^{NS}	0.212^{NS}	0.038^{NS}	0.756**	0.632**	0.621**	0.629**	0.616**	0.618**	0.613**	-0.620**	-0.473*		
Linoleic acid	-0.047^{NS}	-0.132^{NS}	-0.034^{NS}	0.179^{NS}	0.444*	0.396^{NS}	-0.254^{NS}	-0.016^{NS}	0.023^{NS}	-0.015^{NS}	0.038^{NS}	-0.031^{NS}	0.010^{NS}	-0.118^{NS}	-0.269^{NS}	-0.679**	

*, ** Significant at 5% and 1% levels respectively.

(linoleic) with concomitant reduction in SFA:UFA ratio indicated substantial improvement in sunflower oil quality parameters with added nutrients. Supplemental nutrition enhanced profitability margins by 0.50-0.97 USD/ha/day with relatively higher economic efficiency (4.64-9.05%) and sustainability yield index (5.1-8.5%) compared to existing recommendations of NPK only. The information generated would aid in enhancing productivity, profitability and improved oil quality in sunflower crop on sustained basis with application of S, B and Zn under similar environmental conditions.

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