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EFFECT OF NITROGEN SOURCES, SULPHUR AND BORON ON GROWTH PARAMETERS AND PRODUCTIVITY OF SPRING SUNFLOWER

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SUMMARY

A field experiment was conducted during spring seasons of 2005 and 2006 on a sandy loam soil at the research farm of the Division of Agronomy, Indian Agricultural Research Institute, New Delhi to study the effect of different nitrogen sources, sulphur and boron on growth, physiological parameters and productivity of spring sunflower (*Helianthus annuus* L.). The effect of the two sources of nitrogen, i.e. prilled urea (PU) and calcium ammonium nitrate (CAN) on various growth parameters of spring sunflower like leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR) and net assimilation ratio (NAR) were remained statistically on par with each other. However, the application of higher doses of sulphur (50 kg sulphur/ha) and boron (1.5 kg boron/ha) enhanced significantly all the growth parameters. LAI increased substantially between 50-75 days after sowing (DAS) and the highest values were recorded at 75 DAS. Application of the nutrients increased the dry matter accumulation of the crop plant and hence, other growth indices like CGR, RGR and NAR also increased significantly. The crop achieved the highest CGR in between 50-75 DAS while the RGR and NAR values were recorded highest at the initial crop growth stages and declined thereafter. The highest seed yield (2 011.9 & 2 001.9 kg/ha in 2005 and 2006 respectively) and total biological yield (4 207.1 & 4 177.4 kg/ha in 2005 and 2006, respectively) were obtained with application of 1.5 kg B/ha, S application also showed a significant effect on seed and biological yields. Harvest index (HI) was not influenced significantly due to above fertilization.

***Key words*: Boron, growth parameters, nitrogen, productivity, sulphur, sunflower**

INTRODUCTION

India has the fourth largest oilseed economy in the world, yet 40% of the edible oils available in India are imported to meet out their daily cooking requirement. Sunflower (*Helianthus annuus* L.) can help to meet out this shortage of edible oils due to its rich oil content, (up to 50%). It is photo-thermo insensitive and has wide adaptability under different agro-climatic regions, especially spring sunflower, as it can be grown when the field is otherwise fallow. It is the fourth most important oilseed crop of India, but the yield levels are very low because of the existed sub-optimal soil fertility conditions. Nitrogen supply strongly influences the crop growth through its effect on leaf area development and photosynthetic capacity (Tenebe *et al*. 1996, Tonev 2006). Ammonium (NH_4^+) and nitrate (NO_3^-) are the two sources of nitrogen supply, which influences crop growth, especially at the initial crop growth stage. Calcium ammonium nitrate is supposed to be a better source as it alters sugar metabolism and certain physiological phenomena. Sunflower is considered as a heavy feeder of nutrients, particularly sulphur, being an oilseed crop. Sulphur deficiency at vegetative growth stage cause

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*Corresponding author, E-mail: ysshivay@hotmail.com severe reduction in biomass and various growth indices like CGR, RGR, and NAR etc. The sunflower utilizes sulphur up to 45 kg/ha efficiently. The response of sulphur, in the terms of growth parameters like plant height, number of functional leaves, leaf area, leaf area index and stem girth has been reported by application of 40 kg sulphur per ha. Likewise, the influence of boron is so intense and visible in growth and development of sunflower that it has received maximum attention in the oilseeds research under Indian conditions. Boron reduced lignifications, enhances indole acetic acid (IAA) and hence promotes the overall growth and development of the crop plants. The response to the applied boron has been reported the highest between 1.0-1.5 kg/ha depending upon the initial soil status and quality of irrigation water. Being an introduced crop in India, studies pertaining to efficient and judicious management, especially with reference to micronutrients are scanty; hence, it's useful to study the effect of different nutrient combinations at various crop growth stages of the spring sunflower.

MATERIALS AND METHODS

Field experiments were conducted during the spring seasons of 2005 and 2006 on a sandy loam soil, low in available nitrogen (166.2 and 188.3 kg N/ha), medium in available phosphorus (16.4 and 15.1 kg P/ha) and also medium in available potassium (251.4 and 245.2 kg K/ha) in 2005 and 2006, respectively at the research farm of the Indian Agricultural Research Institute, New Delhi. The initial sulphur status was 24.5 kg/ha and 22.5 kg/ha and the available boron was 0.98 and 0.96 mg/kg soil, respectively during 2005 and 2006 cropping seasons. The experiment consisted of nineteen treatment combinations including 2 sources of nitrogen, *viz* prilled urea (PU) and calcium ammonium nitrate (CAN), 3 levels of sulphur i.e. 0, 25 and 50 kg/ha and 3 levels of boron i.e. 0, 0.75 and 1.5 kg/ha which were laid out in factorial randomized block design with 3 replications.

'JK Chitra', a hybrid of sunflower suitable to grow in spring season was grown at the spacing of 45 cm x 20 cm; keeping line to line and plant-to-plant distance, respectively. Basal doses of fertilizers, consisting of half the dose of nitrogen and full doses of sulphur and boron were applied before sowing of spring sunflower by drilling through funnel attached behind the country plough in the rows dropping the fertilizers precisely. The rest half of the nitrogen was applied at 35 days after sowing (DAS) and was supplied through two sources i.e. prilled urea (PU) and calcium ammonium nitrate (CAN). Sulphur was applied through 'Cosavet', which contains 80% sulphur and boron through borax having 11% boron content. Seeds were sown at 5 cm depth using dibbling method manually. After 15 days of sowing, thinning was done to maintain the optimum plant population. During each year of experimentation, 4-5 irrigations were given to raise the crop successfully. Other improved agronomic management practices were followed as per the standard packages and practices. Leaf area was measured at 25, 50 and 75 DAS by using the Model 8100 Area Meter (Li-COR). Leaf area index was calculated by formula given by Mckee (1964). Every time five plants were uprooted at 25, 50 and 75 DAS and also at harvest. After sun drying, these plant samples were oven-dried at 65 $\pm$ 2^0C temperature for 24 hours and dry weight was recorded. From above observations, CGR, RGR and NAR were calculated using the formula given by Watson *et al.* (1952) and Gardner *et al.* (1984). At maturity, heads were harvested in two pickings and these were dried in the sun before threshing. The sunflower seed and stover yields were recorded at the time of harvesting and expressed in kg/ha. The total biological yield was calculated by the summation of seed and stover yield and also expressed in kg/ha.

RESULT AND DISCUSSION

The findings showed that total dry matter accumulation per plant was significantly influenced by application of various fertilizers treatments at different crop growth stages. It could be a function of various external and internal factors, nutrient supply being one of the important parameters. Dry matter accumulation in different plant parts of spring sunflower increased progressively from 25 DAS until harvest stage in both the years of the study. The rate of increase of dry matter accumulation was higher during the initial crop growth stages, and declined at the time of harvest due to natural senescence of vegetative parts. At all the crop growth stages, nitrogen application produced higher dry matter accumulation and both the sources were remained statistically on par with each other, although dry matter produced by calcium ammonium nitrate was numerically higher than prilled urea. Nitrogen helps to impart early growth and quick seedling establishment. Steer and Hocking (1984) recorded the positive impact of nitrogen supply on stem, leaf and capitulum dry matter accumulation. They also recorded that adequate amount of nitrogen at early crop growth stage allowed fullest development of root mass and floret numbers.

Sulphur application also enhanced the total dry matter accumulation by the crop plants. At 25 DAS, the application of sulphur at the rate of 25 kg/ha increased 10% total dry matter accumulation and further increment in sulphur dose enhanced only 3% dry matter. At later stages, the overall higher growth of the crop plant increased the demand of sulphur by the crop and sulphur application at the rate of 50 kg/ha increased total dry matter accumulation by 13% at the harvest stage compared to control. The increment in total dry matter accumulation even after 75 DAS was due to higher contribution of developing head. In control plots, the ratio of stem: root was very less and as the sulphur dose increased, the ratio widened. This could be due to the fact that under limited sulphur conditions, root exploration is higher and when sulphur is supplied, quick uptake is seen and a good proliferation of canopy took place. Sunflower being an oilseed crop, has higher sulphur requirement which is taken up during the entire life cycle of the crop plant. Oil being the final produce, more dry matter accumulation in head was recorded due to sulphur application compared to nitrogen application.

A higher amount of dry matter accumulation was observed due to boron application since it is an important element for growth and development of crops. Akcam and Demiray (2004) also reported that the boron application increased root and shoot length due to increase in indole acetic acid (IAA) content, a growth promoter hormone. Even the first dose of boron application (0.75 kg/ha) proved very beneficial. The possible reason could be low leakage of solutes in boron sufficient leaves. Leakage of phenolics, amino acids and

Table 1. Effect of nitrogen sources, sulphur and boron on total dry matter accumulation in spring sunflower

Treatments	**Total dry matter (g/plant)**							
	25 DAS		**50 DAS**		**75 DAS**		**At harvest**	
	2005	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**
Nitrogen sources								
PU	1.95	1.77	31.45	29.08	86.70	80.15	109.09	102.56
CAN	1.96	1.85	30.83	30.35	87.51	83.12	107.84	106.66
LSD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sulphur levels (kg/ha)								
0	1.87	1.65	28.53	26.47	83.17	75.79	104.25	96.01
25	2.01	1.88	30.37	29.23	87.59	81.80	107.50	105.09
50	2.06	1.95	34.49	33.47	90.50	87.35	113.63	112.75
LSD (P=0.05)	**0.11**	**0.10**	**1.67**	**2.15**	**4.59**	**3.54**	**5.53**	**6.75**
Boron levels (kg/ha)								
0	1.80	1.65	28.62	26.60	79.95	75.56	99.84	95.81
0.75	1.98	1.84	31.77	29.43	87.70	80.45	109.18	103.21
1.50	2.08	1.98	33.00	33.12	93.66	88.79	116.36	114.82
LSD (P=0.05)	**0.11**	**0.10**	**1.67**	**2.15**	**4.59**	**3.54**	**5.53**	**6.75**
Absolute control	1.22	1.11	22.12	19.93	65.32	62.60	87.58	83.13
Rest	1.95	1.81	31.13	29.71	87.09	81.63	108.46	104.61
LSD (P=0.05)	**0.020**	**0.08**	**4.68**	**4.98**	**3.51**	**5.35**	**5.09**	**5.63**

PU = prilled urea, CAN = calcium ammonium nitrate, DAS = days after sowing sucrose increased due to boron deficiency. In physiological respect, boron application results in immediate decrease in K^+ efflux. Hence boron has role in maintaining the integrity of plasma membrane. An increment of 18% in total dry matter accumulation was recorded due to application of boron at the rate of 1.5 kg/ha at the harvest stage. The contribution of boron to total dry matter accumulation was more significant at later crop growth stages through head dry matter accumulation, as boron is important for fertilization and seed filling.

Leaf area index values recorded the lowest at 25 DAS, and thereafter increased rapidly at 50 DAS and however, the highest increased was recorded in between 50 to 75 DAS. The two sources of nitrogen failed to give any significant difference at any of the crop growth stages except at 25 DAS, although slightly higher values were recorded with prilled urea than calcium ammonium nitrate. Comparatively at 25 DAS, the significantly higher leaf area index values were recorded when nitrogen was applied through prilled urea. The reason for this might be that prilled urea provides nitrogen in readily available NO_3^- form, which initiate quick growth but at the later crop growth stages, calcium ammonium nitrate also became equally competent and the effect of prilled urea was diluted.

Table 2. Effect of nitrogen sources, sulphur and boron on leaf area index of spring sunflower

Treatments	Leaf area index (LAI)					
	25 DAS		50 DAS		75 DAS	
	2005	**2006**	**2005**	**2006**	**2005**	**2006**
Nitrogen sources						
PU	0.26	0.24	1.88	1.71	4.65	4.36
CAN	0.25	0.22	1.84	1.75	4.66	4.19
LSD (P=0.05)	**0.009**	**0.003**	**NS**	**NS**	**NS**	**NS**
Sulphur levels (kg/ha)						
0	0.24	0.21	1.71	1.62	4.42	4.07
25	0.26	0.24	1.94	1.73	4.73	4.28
50	0.27	0.26	1.92	1.84	4.80	4.47
LSD (P=0.05)	**0.012**	**0.006**	**0.08**	**0.13**	**0.22**	**0.22**
Boron levels (kg/ha)						
0	0.24	0.21	1.72	1.61	4.33	3.91
0.75	0.26	0.23	1.85	1.70	4.71	4.22
1.50	0.28	0.26	1.94	1.89	4.92	4.70
LSD (P=0.05)	**0.012**	**0.006**	**0.08**	**0.13**	**0.22**	**0.22**
Absolute control	0.17	0.16	1.38	1.27	3.36	3.27
Rest	0.26	0.23	1.85	1.73	4.65	4.27
LSD (P=0.05)	**0.02**	**0.01**	**0.12**	**0.14**	**0.18**	**0.18**

PU = prilled urea, CAN = calcium ammonium nitrate, DAS = days after sowing

Sulphur application resulted in a significant increase in the leaf area index at all the crop growth stages. The rate of increase was much higher in between 25 to 50 and 50-75 DAS. Sulphur at the rate of 25 kg/ha increased leaf area index substantially at all the crop growth stages. The addition of sulphur at the rate of 50 kg/ha also brought a slight increase in the leaf area index values but it remained statistically on par with sulphur applied at the rate of 25 kg/ha. Sulphur application helps in vigorous leaf growth and their foliage. Accordingly, more number of leaves with expanded leaf area produced and resulted in increased leaf area index (Prasad 1999).

The application of boron, maintained superiority with regard to increased leaf area index compared to control. At all crop growth stages, application of boron at the rate of 0.75 kg/ha caused significant increase in leaf area index. The significant response of boron application was observed up to 1.5 kg/ha. Boron application recorded higher leaf area index values at all the crop growth stages due to its marked effect in metabolic roles in nitrogen assimilation and carbohydrate metabolism, which modify favourably the vegetative growth in terms of leaf area. Other than increasing the total leaf area, boron also maintained the functionality of leaves as it enhances the photosynthetic oxygen evolution by leaves, the apparent quantum yield and quantum efficiency of PS II electron transport (Kastori *et al.* 1995).

The average data on CGR has been recorded in between 25-50, 50-75 and 75 DAS to harvest (Table 3). Crop growth rate increased till 50-75 DAS and declined thereafter following an exponential relationship with time. Since, CGR is a function of dry matter accumulated by the crop plant; it followed the similar pattern because the rate of dry matter accumulation was lesser at the last crop growth stage and accordingly CGR values also declined sharply. Crop growth rate of sunflower increased to just double in between 50-75 DAS as compared to 25-50 DAS and reduced later in between 75 DAS and the harvest. Nitrogen application through different sources was unable to cause any significant difference on CGR in between 25-50 and 50-75 DAS, while calcium ammonium nitrate was found to be a superior source in between 75 DAS and the harvest. Sulphur application had a significant effect on CGR at all the crop growth stages irrespective of the base values. During the year 2005, the rate of increase was higher at 25 kg sulphur per ha application. The response up to 50 kg sulphur per ha was also recorded, but it was relatively lesser. Similarly, in the year 2006, the higher response was recorded up to 50 kg sulphur per ha, although the rate of increase of CGR certainly declined, especially between 75 DAS to the harvest stage. Better expansion of leaf is associated with enhanced photosynthesis, which could be the reason for sulphur proved more beneficial (Legha and Giri 1999).

Table 3. Effect of nitrogen sources, sulphur and boron on crop growth rate (CGR) of spring sunflower

Treatments	CGR (g/cm^2/day)					
	25-50 DAS		50-75 DAS		75 DAS-harvest	
	2005	**2006**	**2005**	**2006**	**2005**	**2006**
Nitrogen sources						
PU	1.17	1.08	2.21	2.05	0.93	0.91
CAN	1.15	1.11	2.26	2.14	0.79	0.95
LSD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**0.03**	**0.03**
Sulphur levels (kg/ha)						
0	1.06	0.98	2.13	1.99	0.82	0.82
25	1.13	1.07	2.22	2.12	0.79	0.93
50	1.29	1.24	2.35	2.17	0.97	1.03
LSD (P=0.05)	**0.06**	**0.14**	**0.15**	**0.09**	**0.05**	**0.13**
Boron levels (kg/ha)						
0	1.06	0.97	2.06	1.96	0.78	0.82
0.75	1.17	1.08	2.25	1.98	0.85	0.92
1.50	1.26	1.22	2.39	2.30	0.95	1.06
LSD (P=0.05)	**0.06**	**0.14**	**0.15**	**0.09**	**0.05**	**0.13**
Absolute control	0.83	0.79	1.72	1.63	0.61	0.58
Rest	1.16	1.09	2.23	2.09	0.86	0.93
LSD (P=0.05)	**0.08**	**0.12**	**0.18**	**0.08**	**0.08**	**0.10**

PU = prilled urea, CAN = calcium ammonium nitrate, DAS = days after sowing

The two successive doses of boron significantly increased the CGR at all crop growth stages but the increase was higher at the two initial crop growth stages of the recorded observations. At the last stage of the observations, the CGR increment was lower, both at successive doses and when compared to earlier stages of crop growth. Crop growth rate was also increased with increase in leaf area index and the highest crop growth rate was recorded in between 50-75 DAS. Similarly, the highest leaf area index was recorded at 75 DAS. The decrease in CGR towards maturity might be due to natural senescence of older leaves (Sarkar *et al*. 1998). A quick response was observed at 0.75 kg boron per ha which was higher than the increased rate of boron application i.e. 1.5 kg/ha.

Sulphur application at the rate of 25 kg/ha significantly improved CGR at all the crop growth stages but the increase was higher in between 50-75 DAS. Reddy and Khera (1999) also recorded that addition of sulphur at the rate of 30 kg/ha increased total dry matter accumulation. Further increase in CGR was comparatively lower with sulphur application at the rate of 50 kg/ha and it could be due to the initial available soil sulphur status, which reached at a sufficient level even with application of 25 kg sulphur per ha.

Data pertaining to RGR at three crop growth stages i.e. in between 25-50, 50-75 and 75 DAS to the harvest stages have been recorded for both 2005 and 2006 cropping seasons (Table 4). Relative growth rate showed a declining trend from the initial crop growth stage till the harvest stage, where the decline was sharper in between 50-75 DAS and in between 75 DAS to till harvest. Although, nitrogen sources could not make any significant impact, the application of sulphur, produced significantly the higher RGR of spring sunflower at 25 DAS but interestingly, the response at 50 kg sulphur per ha was remained statistically on par with 25 kg sulphur per ha in between 25-50 DAS during 2005 cropping season. During the same year, in between 50-75 DAS, both sulphur doses were unable to cause a significant effect on RGR. There was no significant increase with regard to RGR in between 75 DAS and at the harvest stage also. Application of sulphur also improved RGR due to good crop growth attained by the crop under good supply of nutrients was much helpful in utilization of available water and other nutrients during pre-flowering stage. Relative growth rate declined thereafter and did not change under sulphur application at the rate of 50 kg/ha. This might be due to reduced uptake of nutrients and water as the roots start getting suberized after completion of active vegetative growth (Russell 1952). The response of boron was more or less similar to sulphur application with regards to RGR of spring sunflower. During both the years of the study, the higher dose of boron i.e. 1.5 kg/ha remained statistically on par with 0.75 kg boron per ha in between 25-50 DAS. At 50-75 DAS, boron was able to cause a significant effect on RGR in 2006 cropping season but again at 75 DAS to the harvest stage, the effect was diluted and almost similar RGR was produced at both the doses of boron. However, there was no discernible significant effect of boron application on RGR at any of the crop growth stages. The RGR values recorded under boron was more or less same. No definite trend in the RGR values were recorded because of the reason that there was very low rate of increase in dry matter accumulation beyond a certain limit and base level of dry matter accumulation was highly variable (Singh and Agarwal 2001).

Data recorded on NAR at three-crop growth stages in between 25-50, 50-75 and 75 DAS to the harvesting stage have been shown in Table 5. The highest NAR values were recorded in between 25-50 DAS, followed by 50-75 DAS and the lowest in between 75 DAS to the harvest stage indicating higher assimilation and

Table 4. Effect of nitrogen sources, sulphur and boron on relative growth rate (RGR) of spring sunflower

Treatments	**RGR (g/g/day)**					
	25-50 DAS		**50-75 DAS**		**75 DAS-harvest**	
	2005	**2006**	**2005**	**2006**	**2005**	**2006**
Nitrogen sources						
PU	0.111	0.112	0.041	0.051	0.009	0.010
CAN	0.110	0.113	0.041	0.048	0.008	0.010
LSD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sulphur levels (kg/ha)						
0	0.108	0.111	0.038	0.041	0.008	0.009
25	0.109	0.112	0.039	0.050	0.008	0.010
50	0.114	0.115	0.049	0.056	0.010	0.009
LSD (P=0.05)	**0.005**	**NS**	**NS**	**0.013**	**NS**	**NS**
Boron levels (kg/ha)						
0	0.110	0.105	0.041	0.041	0.008	0.009
0.75	0.111	0.113	0.041	0.048	0.008	0.010
1.50	0.111	0.119	0.041	0.059	0.009	0.010
LSD (P=0.05)	**0.005**	**0.006**	**NS**	**0.013**	**NS**	**NS**
Absolute control	0.08	0.110	0.043	0.010	0.001	0.008
Rest	0.11	0.112	0.041	0.049	0.008	0.010
LSD (P=0.05)	**0.004**	**NS**	**NS**	**0.012**	**0.004**	**NS**

PU = prilled urea, CAN = calcium ammonium nitrate, DAS = days after sowing

Table 5. Effect of nitrogen sources, sulphur and boron on net assimilation rate (NAR) of spring sunflower

Treatments	**NAR (g/cm^2/day)**					
	25-50 DAS		**50-75 DAS**		**75 DAS-harvest**	
	2005	**2006**	**2005**	**2006**	**2005**	**2006**
Nitrogen sources						
PU	1.57	1.61	0.79	0.81	0.31	0.34
CAN	1.60	1.52	0.82	0.83	0.36	0.34
LSD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sulphur levels (kg/ha)						
0	1.53	1.49	0.78	0.78	0.31	0.31
25	1.55	1.57	0.80	0.83	0.32	0.35
50	1.68	1.64	0.84	0.87	0.38	0.38
LSD (P=0.05)	**0.06**	**0.12**	**0.02**	**0.04**	**0.016**	**0.06**
Boron levels (kg/ha)						
0	1.55	1.51	0.80	0.75	0.32	0.31
0.75	1.60	1.57	0.81	0.82	0.33	0.34
1.50	1.61	1.60	0.82	0.89	0.36	0.38
LSD (P=0.05)	**0.06**	**0.12**	**0.02**	**0.04**	**0.016**	**0.06**
Absolute control	1.60	1.51	0.65	0.70	0.32	0.25
Rest	1.58	1.56	0.80	0.82	0.33	0.34
LSD (P=0.05)	**NS**	**NS**	**0.06**	**0.04**	**NS**	**0.09**

PU = prilled urea, CAN = calcium ammonium nitrate, DAS = days after sowing growth during earlier phases. Nitrogen sources could not make much difference in NAR of spring sunflower. Although, the values of NAR were little higher with calcium ammonium nitrate application but remained statistically at par with prilled urea. During 2005 cropping season, sulphur application proved superior both numerically and statistically in between 25-50 DAS. At the advanced stage the difference due to sulphur doses became lesser and in the 2006 cropping season, sulphur application statistically enhanced NAR values. The sulphur application at the rate of 25 kg/ha was remained statistically on par with 50 kg/ha. Effect of boron application on NAR was not recorded consistent during both the years of experimentation. In 2005 cropping season, the effect of boron on NAR in between 25-50 and 50-75 DAS was significant. During the last stage, a slightly lesser significant result was observed in NAR at both the doses of boron. During 2006 cropping season, boron enhanced NAR with greater increment with the application of 0.75 kg/ha than with 1.5 kg boron per ha at all the crop growth stages.

Due to application of different fertilizer treatments, initially the NAR values were not significantly higher over absolute control, but near to the harvest stage absolute control was significantly inferior to all the other treatments. In the early and late crop growth stages, growth rates were slower than at the grand growth stage. Growth rate at the later stage was reduced due to self shading and ageing (Nkoa *et al*. 2001). Leaves are the net assimilatory parts and they degenerate and die off at the later crop growth stage resulting in the decline in NAR. Nitrogen is the main element required for vegetative growth of the plant. Increase in NAR due to nitrogen application at an early stage might be due to increase in CO_2 assimilation. In addition, the mobile nature of nitrogen also gives significant boost to dry matter accumulation in stem and leaf.

Application of sulphur enhanced the assimilatory substrate for photosynthesis. Sulphur application at the rate of 25 kg/ha increased NAR and also at 50 kg sulphur per ha, but remained statistically on par with each other. Since as sulphur applied at the rate of 25 kg/ha was sufficient to make a required enhancement and the higher dose was not able to increase the uptake of sulphur by the plant. Application of boron tended to increase NAR probably on account of higher rate of expansion of leaf surface area as boron might have played specific roles in enzyme activities.

In both the years, the two sources of N (PU and CAN) did not differ significantly with respect to seed yield. Although there was an increase of 2.9 and 5.1% with CAN over PU during 2005 and 2006 respectively (Table 6). Both the N sources had a positive effect on seed yield increase. Sulphur application had a significant effect on seed yield of spring sunflower during both years of study. The application of 50 kg S/ha increased the seed yield 11.6 & 2.0 and 15.3 & 5.5% over 0 and 25 kg S/ha, respectively, during 2005 and 2006. This increase in seed yield of spring sunflower might be due to significant increase in yield attributes *viz* capitulum's diameter, number of seeds/capitulum, seed weight/ capitulum and 1 000-seed weight with S application. Boron was also found to be a good nutrient since the

Table 6. Effect of nitrogen sources, sulphur and boron on seed and bilogical yields and harvest index of spring sunflower

Treatments	**Seed yield (kg/ha)**		**Biological yield (kg/ha)**		**Harvest index (%)**	
	2005	**2006**	**2005**	**2006**	**2005**	**2006**
Nitrogen sources						
PU	1 885.1	1 825.5	3 981.4	3 795.3	47.6	48.0
CAN	1 940.5	1 918.9	4 122.4	4 090.0	46.6	46.8
LSD (P=0.05)	**NS**	**NS**	**94.48**	**202.48**	**NS**	**NS**
Sulphur levels (kg/ha)						
0	1 787.6	1 730.4	3 899.2	3 651.4	45.8	48.7
25	1 955.8	1 890.5	4 093.7	3 981.2	47.7	46.8
50	1 995.1	1 995.7	4 163.3	4 196.5	47.9	46.9
LSD (P=0.05)	**110.04**	**77.03**	**114.09**	**210.17**	**NS**	**NS**
Boron levels (kg/ha)						
0	1 825.4	1 725.2	3 866.1	3 658.2	47.2	47.1
0.75	1 901.6	1 889.5	4 082.9	3 992.4	46.5	47.3
1.50	2 011.9	2 001.9	4 207.1	4 177.4	47.7	47.8
LSD (P=0.05)	**110.04**	**77.03**	**114.09**	**210.17**	**NS**	**NS**
Absolute control	1 121.2	1 098.1	2 791.5	2 770.1	40.1	39.6
Rest	1 912.8	1 872.2	4 051.9	3 942.7	47.1	47.4
LSD (P=0.05)	**196.56**	**153.03**	**224.26**	**167.70**	**3.89**	**1.61**

PU = prilled urea, CAN = calcium ammonium nitrate, NS = non significant maximum total seed yield was recorded with B application. Increase in the each successive level of B application increased significantly the seed yield during both years of study. Application of B @ 1.50 kg/ha recorded 10.2 & 5.8 and 16.0 & 5.9% more seed weight/ capitulum over control and 0.75 kg B/ha, respectively, during 2005 and 2006 (Table 6). Boron is important as its deficiency produces flower with damaged pistils. Without B application majority of the pollens are aborted. Lack of B causes typical seed malformation, seed number, seed weight and total biological yield reduced significantly (Lieten 2004). All the treatments produced significantly higher seed yield over absolute control during both years of study. Total biological yield is a summation of seed and stover yield therefore higher the seed and stover yield, more will be the total biological yield. Application of N sources had a significant effect on total biological yields and CAN produced significantly more biological yield compared to PU. Calcium ammonium nitrate produced 3.5 and 7.7% more biological yield than PU during 2005 and 2006, respectively. Sulphur application had a significant impact on biological yield and the highest biological yield was recorded with application of 50 kg S/ha. The percentage increases with 50 kg S/ ha was 6.8 & 1.7 and 14.9 & 5.4% more over control and 25 kg S/ha, respectively, during 2005 and 2006 (Table 6). Sulphur also plays an important role in vegetative growth and it improves seed yield of sunflower as well, hence a higher biological yield was recorded during both the years. Boron application had a significant effect on total accumulation of biomass yield during both years of study. In 2005, increase in each successive level of B increased total biological yield significantly, however, during 2006 significant increase was recorded only up to 0.75 kg B/ha. Seed yield enhanced due to B application was probably because of a good balance between photosynthesis and respiration. Since the final yield depends upon the translocation of photosynthates from the source to sink, B is supposed to play an important role here. Boron maintains assembly and mechanical properties of cell walls; it maintains structural and functional integrity of cell walls. Boron removal alters cell wall physics, with a transitory decrease of elasticity modulus and followed by a secondary hardening and a reduction in incidence plasma-membrane bound reductase activity for better translocation to sink. This reduces the total seed yield as reported by Yu *et al*. (2002). Total biomass yield was significantly lower in absolute control plot than rest of the treatments. The harvest index (HI) of sunflower remained unaffected significantly due to N sources, S levels and also B levels. However, following the trend up to now, absolute control plot produced significantly the lowest HI.

It can be inferred from the present study that application of 80 kg nitrogen per ha, either through prilled urea or calcium ammonium nitrate, sulphur doses in between 25-50 kg/ha through ‘Cosavet’ and 0.75 kg boron per ha through borax is sufficient to sustain the higher growth, physiological parameters and productivity of spring sunflower under north Indian conditions.

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REFERENCES

Akcam, O.E. and Demiray, P. (2004). The effects of B on the growth of sambro No.3 sunflower. *Ege-Universitesi-Ziraat-Fakultesi-Dergisi* **41:** 181-190.

Gardner, F.P., Pearce, R.B. and Mitchell, R.L. (1984). Growth and Development. In : Physiology of Crop Plants, pp. 187-208. The Iowa State University Press.

Kastori, R., Plesnicar, M., Pankovic, D. and Sakac, Z. (1995). Photosynthesis, chlorophyll fluorescence and soluble carbohydrate in sunflower leaves as affected by B deficiency. *J. Plant Nutr.* **18:** 1751-1763.

Legha, P.K. and Giri, G. (1999). Influence of N and S on growth, yield, oil content of sunflower grown in spring season. *Indian J. Agron.* **44:** 408-412.

Lieten, P. (2004). B deficiency of strawberry grown in substrate culture. *Acta Horticulture* **567** : IV International Strawberry Symposium, Hungary.

Mckee, G.W. (1964). A coefficient for computing leaf area in hybrid corn. *Agron. J.* **56:** 240-241.

Nkoa, R., Coulombe, J., Desjardins, Y. and Tremblay, N. (2001). Towards optimization of growth via nutrient supply phasing: N supply phasing increases broccoli growth and yield. *J. Exp. Bot.* **52:** 821-827.

Prasad, R. (1999). Nutrient management. In : R. Prasad (ed.), A Textbook of Rice Agronomy, pp. 99-130. Jain Brothers, New Delhi.

Reddy, D.D. and Khera, M.S. (1999). Fertilizer, plant density and variety: Interaction and soil nutrient status under maximum yield research on maize-sunflower system. *International J. Trop. Agric.* **17:** 61-68.

Russell, E.J. (1952). The development of plant root in soil. In: Soil Conditions and Plant Growth. (VIII Edn.), pp. 421-432. Congmans Green & Co. Ltd., London.

Sarkar, R.K., Sasmal, T.K., Chakraborty and Bala, B. (1998). Effect of micronutrient on physiological parameters in relation to yield of sunflower in rice-fallow gangetic alluvial soil. *Indian Agriculturist* **33:** 39-45.

Singh, R. and Agarwal, S.K. (2001). Growth and yield of wheat as influenced by levels of FYM and N. *Indian J. Agron.* **46:** 462-467.

Steer, B.T. and Hocking, P.J. (1984). N nutrition of sunflower: Acquisition and partitioning of dry matter and N by vegetative organs and their relationship by seed yield. *Field Crops Res.* **9:** 237-251.

Tenebe, V.A., Pal, U.R., Okonkwo, C.A. and Auwalu, B.M. (1996). Response of rainfed sunflower (*Helianthus annuus* L.) to N rates and plant population in the semi arid Savana region of Nigeria. *J. Agron. Crop Sci.* **177:** 207-215.

Tonev, T.K. (2006). Agronomic characteristics of high yielding sunflower crop. Research Communication of USB branch. *Dobrech* **8:** 162-173.

Watson, D.J., Thorne, G.N. and French, S.A. (1952). Analysis of growth and yield of winter and spring wheats. *Ann. Bot.* **27:** 1-22.

Yu, Q., Hlavacka, A., Matoh, T., Volkmanm, D., Menzel, D. and Baluska, F. (2002). Short term B deprivation inhibits endocytosis of cell wall pectins in meristematic cells of maize and wheat root apices. *Plant Physiol.* **130:** 415-421.