

**OPTIMISATION OF NANO BORON
FERTILIZATION IN SUNFLOWER**
(Helianthus annuus L.)

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Thesis submitted to the

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In partial fulfillment of the requirements

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in

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Affectionately Dedicated to
My Beloved Parents,
Brothers, Sisters
and Dear one's

**DEPARTMENT OF AGRONOMY
UNIVERSITY OF AGRICULTURAL SCIENCES
GKVK, BENGALURU-560065**

CERTIFICATE

This is to certify that the thesis entitled "**OPTIMISATION OF NANO BORON FERTILIZATION IN SUNFLOWER (*Helianthus annuus* L.)**" submitted by **Ms. KAVITA MAHADEV GOUDAR, ID. No. PALB 5186** in partial requirements for the degree of **MASTER OF SCIENCE (Agriculture)** in **AGRONOMY** to the University of Agricultural Sciences, Bengaluru, is a record of bona-fide research work done by her during the period of her study in this University under my guidance and supervision. The thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

Bengaluru
July, 2017


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(Kavita Mahadev Goudar)

OPTIMISATION OF NANO BORON FERTILIZATION IN SUNFLOWER

(Helianthus annuus L.)

KAVITA MAHADEV GOUDAR

ABSTRACT

A field experiment was conducted to study the optimisation of nano boron fertilization in sunflower (*Helianthus annuus L.*) at Zonal Agricultural Research Station, UAS, GKVK, Bengaluru during late *khariif*-2016. The experiment was laid out in RCBD with ten treatments replicated thrice. Treatments consisting of application of recommended dose of fertilizer (RDF-90:90:60 kg NPK ha⁻¹ and 7.5 t FYM) alone, RDF along with application of borax and nano boron through seed treatment, spraying to capitulum at ray floret opening stage and soil application of borax at 11 kg ha⁻¹. The treatment with nano boron at 0.2 % seed priming resulted significantly higher seed and oil yield (2788 kg ha⁻¹ and 1022 kg ha⁻¹, respectively). It was attributed to higher SPAD (chlorophyll content) reading of 44.50 and lesser days for 50 % flowering (61.33 days), enhanced growth parameters viz., plant height (190.53 cm), number of leaves plant⁻¹ (26.67), leaf area (10589 cm² plant⁻¹), leaf area index (5.88), total dry matter (101.51 g plant⁻¹) at 60 DAS and yield attributes like increased head diameter (15.07 cm), test weight (4.78 g 100 seeds⁻¹), total seeds and filled seeds (1326 and 1293 head⁻¹, respectively), lower chaffiness (2.5 %), higher N (114.58 kg ha⁻¹), P (33.67 kg ha⁻¹) and K (72.67 kg ha⁻¹) uptake. Higher net returns (Rs 66950 ha⁻¹) and benefit cost ratio (2.72) was obtained the same treatment.

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(Major advisor)

ಸೂರ್ಯಕಾಂತಿ ಬೆಳೆಯಲ್ಲ ನ್ಯಾನೋ ಬೋರಾನ್ ಲಘುಪೋಷಕಾಂಶದ ಪ್ರಮಾಣ ನಿರ್ಧರಿಸುವಿಕೆ

ಕವಿತಾ ಮಹದೇವ ಗೌಡರ

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಸೂರ್ಯಕಾಂತಿ ಬೆಳೆಯಲ್ಲ ನ್ಯಾನೋ ಬೋರಾನ್ ಲಘುಪೋಷಕಾಂಶದ ಪ್ರಮಾಣ ನಿರ್ಧರಿಸುವಿಕೆಯ ಬಗ್ಗೆ ೨೦೧೬ರ ತಡವಾದ ಮುಂಗಾರು ಹಂಗಾಮಿನಲ್ಲ ವಲಯ ಕೃಷಿ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಕೃ. ವಿ. ವಿ., ಜಿ. ಕೆ. ವಿ. ಕೆ, ಬೆಂಗಳೂರಿನಲ್ಲ ಸಂಶೋಧನೆ ಕೈಗೊಳ್ಳಲಾಯಿತು. ಯಾದೃಷ್ಟಿಕ ಬ್ಲಾಕ್ ವಿನ್ಯಾಸದಲ್ಲಿ ೧೦ ಉಪಚಾರಗಳನ್ನು ಮೂರು ಬಾರಿ ಪ್ರತಿರೂಪಿಸಲಾಯಿತು. ನ್ಯಾನೋ ಬೋರಾನ್ ಮತ್ತು ಬೋರಾಕ್ಸ್ ಲಘುಪೋಷಕಾಂಶಗಳನ್ನು ವಿವಿಧ ವಿಧಾನಗಳಿಂದ ಉಪಚರಿಸಲಾಯಿತು. ಅವುಗಳೆಂದರೆ ನಿಯಂತ್ರಣ, ಬೋರಾಕ್ಸ್ ಮತ್ತು ನ್ಯಾನೋ ಬೋರಾನನ್ನು ಬೀಜೋಪಚಾರ (ಶೇ. ೦.೨ ಮತ್ತು ೦.೪), ಬೋರಾಕ್ಸ್ ಮತ್ತು ನ್ಯಾನೋ ಬೋರಾನನ್ನು ಹೂ ಅರಳುವ ಸಮಯದಲ್ಲ ಹೂವಿನ ಮೇಲೆ ಸಿಂಪರಣೆ (ಶೇ. ೦.೨ ಮತ್ತು ೦.೪) ಹಾಗೂ ಬೋರಾಕ್ಸ್‌ನ್ನು (ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ೧೧ ಕಿ. ಗ್ರಾಂ.) ಮಣ್ಣಿನ ಜೊತೆಗೆ ಮಿಶ್ರಮಾಡುವುದರ ಮುಖಾಂತರ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಾಯನಿಕ ಗೊಬ್ಬರದೊಂದಿಗೆ (೯೦: ೯೦: ೬೦ ಕಿ. ಗ್ರಾಂ ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ಸಾರಜನಕ, ರಂಜಕ, ಪೊಟ್ಯಾಶ್ ಹಾಗೂ ೭.೫ ಟನ್‌ನಂತೆ ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ಕೊಟ್ಟು ಗೊಬ್ಬರ ಅನುಕ್ರಮವಾಗಿ) ತಾಕುಗಳೆಲ್ಲ ಪರೀಕ್ಷಿಸಲಾಯಿತು. ಸಂಶೋಧನಾ ಫಲಿತಾಂಶಗಳ ಪ್ರಕಾರ, ವಿವಿಧ ಉಪಚಾರಗಳೆಲ್ಲ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಾಯನಿಕ ಗೊಬ್ಬರದ ಜೊತೆಗೆ ಶೇ. ೦.೨ ರ ನ್ಯಾನೋ ಬೋರಾನ್ ಬೀಜೋಪಚಾರದಲ್ಲ ಅತೀ ಹೆಚ್ಚು ಎಣ್ಣೆಯ ಇಳುವರಿ(೧೦೨೨ ಕಿ.ಗ್ರಾಂ/ಹೆ. ಗೆ) ಹಾಗೂ ಬೀಜದ ಇಳುವರಿ (೨೭೮೮ ಕಿ.ಗ್ರಾಂ/ಹೆ. ಗೆ) ದಾಖಲಾಗಿರುತ್ತದೆ. ಉತ್ತಮ ಬೆಳವಣಿಗೆಗೆ ಪೂರಕ ಅಂಶಗಳಾದ ಗಿಡದ ಎತ್ತರ (೧೯೦.೫ ಸೆಂ. ಮೀ.), ಎಲೆಯ ವಿಸ್ತೀರ್ಣ (೧೦೫೮೯ ಫನ ಸೆಂ. ಮೀ/ಗಿಡ), ಒಟ್ಟು ಒಣ ಗಿಡದ ತೂಕ (೧೦೧.೬ ಗ್ರಾಂ.), ತೆನೆಯ ವ್ಯಾಸ (೧೫.೦೭ ಸೆಂ.ಮೀ), ನೂರು ಬೀಜಗಳ ತೂಕ (೪.೭೮ ಗ್ರಾಂ.), ಒಟ್ಟು ಬೀಜಗಳು (೧೩.೨೬ ಪ್ರತಿತಲೆಗೆ), ತುಂಬದ ಬೀಜಗಳು (೧೨೯೬ ಪ್ರತಿ ತಲೆಗೆ) ಮತ್ತು ಕಡಿಮೆ ಜೊಳ್ಳು ಬೀಜಗಳ ಪ್ರಮಾಣ (೨.೫ ಶೇಕಡಾ) ಸೂರ್ಯಕಾಂತಿ ಬೀಜದ ಹೆಚ್ಚಿನ ಇಳುವರಿಗೆ ಕಾರಣವಾಗಿರುತ್ತವೆ. ಗಮನಾರ್ಹವಾಗಿ ಅಧಿಕ ಸಾರಜನಕ (೧೧೪.೫೮ ಕಿ. ಗ್ರಾಂ/ ಹೆ. ಗೆ), ರಂಜಕ (೩೩.೬೭ ಕಿ. ಗ್ರಾಂ/ಹೆ. ಗೆ ಮತ್ತು ಪೊಟ್ಯಾಶ್ (೭೨.೬೭ ಕಿ. ಗ್ರಾಂ/ಹೆ. ಗೆ) ಪೋಷಕಾಂಶಗಳ ಹೀರುವಿಕೆ ಕಂಡಿಬಂದಿರುತ್ತದೆ. ಅಧಿಕ ನಿವ್ವಳ ಆದಾಯ (ರೂ.೬೬೯೯೦/ಹೆ. ಗೆ) ಮತ್ತು ಅಧಿಕ ಲಾಭ : ವೆಚ್ಚದ ಅನುಪಾತವೂ (೨.೭೨) ಸಹ ಶಿಫಾರಸ್ಸು ಮಾಡಿದ ರಸಾಯನಿಕ ಗೊಬ್ಬರದ ಜೊತೆಗೆ ಶೇ. ೦.೨ ರ ನ್ಯಾನೋ ಬೋರಾನ್ ಬೀಜೋಪಚಾರದಲ್ಲ ಕಂಡುಬಂದಿದೆ.

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ಕೆ. ಎನ್. ಗೀತಾ

(ಪ್ರಧಾನ ಸಲಹೆಗಾರರು)

Optimisation of nano boron fertilization in sunflower

(*Helianthus annuus* L.)

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Introduction

- ✓ Sunflower is one of the important oilseed crop of India cultivated in an area of 0.55 million hectares with an annual production of 0.42 million tones and productivity of 752 kg ha⁻¹.
- ✓ In certain constraints like poor seed setting and seed filling of various degrees have come in the way of large scale commercial cultivation of this potential oilseed crop.
- ✓ The major causes for poor seed set is reported to be due to self-incompatibility, absence of pollen vectors and insufficient nutrient (boron) supply to the sink.
- ✓ Boron improves pollen viability, stigmatic receptivity and translocation of photosynthates from source to sink, resulting in higher seed set and yield.
- ✓ Nanotechnology precisely detects and delivers the correct quantity of nutrients and pesticides that promote productivity while ensuring environmental safety and higher use efficiency. Therefore an attempt has been made to study the present investigation with the following objectives.

Objectives.

- ✓ To study the influence of nano boron on growth and yield of sunflower.
- ✓ To study the influence of nano boron on economics of sunflower.

Material and Methods

Crop	: Sunflower
Hybrid	: KBSH-53
Spacing	: 60 cm x 30 cm
Replications	: Three
Treatments	: Ten
Design	: RCBD
Gross Plot Size	: 5.4 m x 4.8 m
Net Plot Size	: 4.2 m x 4.2 m
Location	: ZARS, GKVK, Bengaluru
Season	: Kharif-2016
Nano boron source	: Nano Boron nitride

Treatment details

T ₁	: Without boron/ control
T ₂	: Nano boron @ 0.2 % seed priming
T ₃	: Nano boron @ 0.4 % seed priming
T ₄	: Borox @ 0.2 % seed priming
T ₅	: Borox @ 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

RDF : Recommended Dose of Fertilizer (90 : 90 : 60 kg ha⁻¹) & FYM : Farm Yard Manure (7.5 t ha⁻¹) is common to all treatments.

Initial soil boron status: 0.29 ppm

Results

- Plant height recorded at harvest was found to be non-significant. However, treatment T₂ (Nano boron @ 0.2 % seed priming) has recorded higher plant height (196.47 cm) compared to all other treatments.
- Nano boron @ 0.2 % seed priming has influenced the days for 50 per cent flowering (61.33) significantly compared to borax nutrition (67) and control (69).
- Different nutrient application methods significantly influenced the test weight. Highest test weight (5.23 g) was observed in T₆ (Nano boron @ 0.2 % spray at ray floret opening stage) which was on par with Nano boron @ 0.2 % seed priming (4.78 g).
- Significantly higher seed yield (2788 kg ha⁻¹) and oil yield (1022 kg ha⁻¹) were recorded in T₂ (Nano boron @ 0.2 % seed priming) which was on par with T₆ (Nano boron @ 0.2 % spray to capitulum at ray floret opening stage) in which seed and oil yield was found to be 2773 kg ha⁻¹ and 1006 kg ha⁻¹ respectively.
- Significantly lower chaffiness percentage (2.10) was recorded with T₆ (Nano boron @ 0.2 % spray at ray floret opening stage), followed by T₂ [Nano boron @ 0.2 % seed priming (2.5)] compared to RDF alone (10.97 %).
- Higher net return (Rs. 62706 ha⁻¹) was obtained with application of 0.2 % nano boron seed priming.

Table 1: Effect of nano boron on growth and yield of sunflower

Treatments	Plant height (cm)	Days taken for 50 % flowering	100 Seed weight (g)	Oil (%)	Oil yield (kg ha ⁻¹)	Seed yield (kg ha ⁻¹)	% Chaffiness	HI
T ₁	171.1	69.00	3.78	34.96	570	1629	10.97	0.27
T ₂	196.5	61.33	4.78	36.74	1022	2788	2.50	0.35
T ₃	188.7	62.00	4.57	36.13	887	2451	3.96	0.32
T ₄	179.7	66.67	4.06	35.56	750	2107	5.32	0.30
T ₅	187.8	67.33	4.35	36.04	752	2084	7.96	0.31
T ₆	189.1	65.67	5.23	36.34	1006	2773	2.10	0.35
T ₇	184.7	66.67	4.77	36.24	878	2422	3.16	0.33
T ₈	183.7	67.67	4.53	34.68	714	2061	4.93	0.30
T ₉	189.4	67.33	4.49	35.34	768	2176	3.64	0.31
T ₁₀	186.7	68.00	4.42	34.57	839	2424	5.18	0.32
S.E.m.±	4.47	1.16	0.19	0.65	61.07	156.5	0.31	0.015
C.D (P=0.05)	NS	3.445	0.566	NS	181.438	464.9	0.911	8.247
CV (%)	4.17	3.03	7.34	3.14	12.92	11.83	10.68	8.25

Discussion

- ◆ Significantly higher plant height and seed yield were recorded with T₂ (Nano boron @ 0.2 % seed priming) because of seeds were treated with 0.2 % nano boron nitride has resulted enhanced cell division, cell elongation and improved meristematic activity and better uptake of nutrients in plant system.
- ◆ Significantly higher test weight, and lower chaffiness percentage were recorded with nano boron at 0.2 % spray at ray floret opening stage, this may be associated with boron role in increasing pollen viability, stigmatic receptivity and translocation of photosynthates or sugars towards sink that improved the seed setting percentage in the capitulum. Similar results were also observed by (Rani and Reddy, 1993).
- ◆ Nano boron nutrition improves solubility and dispersion of insoluble nutrients in soil, reduces soil fixation and increases the bioavailability (Cui *et al.*, 2010), which significantly improves the seed setting percentage, test weight and decreases percent chaffiness, by proper fertilization and filling of seeds contribute a lot towards economic yield.



Plate 1: Early flowering in sunflower crop as influenced by nano boron seed priming



Plate 2: Well filled sunflower heads in nano boron treated plots

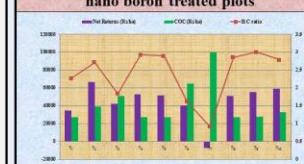


Fig 1: Net returns, cost of cultivation and benefit cost ratio as influenced of nano boron application

Summary

- ✓ Nano boron @ 0.2 % seed priming and spray at ray floret opening stage has recorded higher seed yield of 2788 kg ha⁻¹ and 2773 kg ha⁻¹ respectively over control (1629 kg ha⁻¹).
- ✓ Nano boron (0.2 %) seed priming has influenced the days for 50 per cent flowering significantly compared to borax nutrition and control.
- ✓ Nano boron seed priming is one of the effective nutrient use technology which helps to increase the seed yield and oil yield.
- ✓ Higher net return was obtained with seed priming with 0.2 % nano boron.

References

- ANONYMOUS, 2015, www.indiastat.com
- CUI, H. X., SUN, C.J., LIU, Q., JIANG, J. AND GU, W., 2010, International conference on Nanoagri, Sao pedro, Brazil, June, 20-25.
- RANI, P. L. AND REDDY, T. M., 1993, *J. Res. Andhra Pradesh Agric. Univ.*, 21(1): 39-41.

Advisory committee

- Chair person: Dr. K. N. Geetha
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Dr. D. C. Hanumantappa
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LIST OF ABBREVIATIONS

@	at the rate	kg	Kilogram
°C	Degree Centigrade	<i>Viz</i>	Namely
%	Per cent	LAI	Leaf Area Index
+	Plus	Ltd.	Limited
Anon.	Anonymous	m	Meter
Avail.	Available	m	Million
C. D.	Critical Difference	M ²	square meter
cm	Centimetre	m. ha	million hectares
CPE	Cumulative pan evaporation	m. t	million tonnes
C.V.	Co-efficient of Variation	N	Nitrogen
DAS	Days after sowing	B C ratio	Benefit cost ratio
dS m ⁻¹	deci Siemens per meter	NS	Non-significant
EC	Electrical conductivity	<i>i.e</i>	That is
<i>et al.</i>	Co workers	FYM	Farm yard manure
<i>etc.</i>	Etcetera (so on)	P	Phosphorus
Fig.	Figure	P ₂ O ₅	Available Phosphorus
g	Gram	S.Em	Standard error mean
g ⁻¹	per gram	q ha ⁻¹	Quintal per hectare
ha ⁻¹	per hectare	RDF	Recommended dose of
K	Potassium	t	Tonnes
K ₂ O	Available potassium	t ha ⁻¹	tonnes per hectare
kg ha ⁻¹	kilogram per hectare	MOP	Muriate of potash

I 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. Its oil is also called premium oil due to presence of oleic acid (16.2%) and linolenic acid (72.5%) with high percentage (60%) of poly unsaturated fatty acids (Rathore, 2001). Present day sunflower cultivars contain more than 40% oil and 18-20% protein. It is also a good source of calcium, phosphorus, nicotinic acid and vitamin E (Aslam *et al.*, 2010). 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). 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. Reddy *et al.* (2003) reported that inadequate and imbalanced nutrient supply is the reason for low productivity of sunflower. In recent years, micronutrient deficiencies and their impact on crop yields are widely reported in various parts. 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.

Micronutrients play a significant role in plant growth and metabolic processes associated with photosynthesis, chlorophyll formation, cell wall development and respiration, water absorption, xylem permeability, resistance to plant diseases, enzyme activities involved in the synthesis of primary and secondary metabolites, and nitrogen fixation (Adhikary *et al.*, 2010 and Vitti *et al.*, 2014). Accordingly, Zn, B, Fe, Mn and Cu are involved in many processes controlling plant growth, and their content in grains and leaves determine the quality of food. Micronutrient deficiencies in plants lead to reduced yields.

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). Boron is involved in the reproduction of plants and germination of pollen spikelet, pollen tube growth and seed development (Bolanos *et al.*, 2004). The role of B in stimulating pollen tube growth is well established and positive correlation could be found between B in the plant and the number of flowers, the proportion of flowers not aborted and fruit weight (O’Niell *et al.*, 2004). Both B deficiency and toxicity cause lower chlorophyll levels and the rate of photosynthesis may induce cell wall synthesis by an influence on the activity of the plasma lemma and can disturb the maintenance of meristem in plants (Bolanos *et al.*, 2004). The nutritional importance of boron for human is very important. It affects the metabolism of macro minerals, energy, nitrogen and brain function, reactive oxygen, psychomotor performance and the response to estrogen ingestion (Nielson, 2008).

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).

The potential of nanotechnology to revolutionise the health care, textile, materials, information and communication technology and energy sectors has been well publicised. The application of nanotechnology to the agricultural and food industries was first addressed by a United States Department of Agriculture in September 2003. The prediction is that nanotechnology will transform the entire food industry, changing the way food is produced, processed, packaged, transported and consumed. The market for the nanotechnology was 7.6 billion USD in 2003 and is expected to grow at projected compound annual growth rate (CAGR) of 17.7% over next five years to total \$ 31.8 billion by 2018. However, the full potential of nanotechnology in agricultural and food industry is still not been realised.

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 nanotechnology can be exploited in the value chain of entire agriculture production system (Tarafdar *et al.*, 2012a). Nanotechnology is emerging as the sixth revolutionary technology in the current era after the Industrial Revolution of Mid 1700s, nuclear energy revolution of the 1940s, the green revolution of 1960s, information technology revolution of 1980s and biotechnology revolution of the 1990s. It is now emerging and fast growing field of science which is being exploited over a wide range of disciplines such as physics, chemistry, biology, material science, electronics, medicine, energy, environment and health sectors.

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. It is anticipated that very soon the production of nano particles will be increased by manifold and released into the market. However with significant potential benefits, there are considerable uncertainties with regards to potential risks to the environment and human health that needs to be clarified. This fast growing technology is already having a significant commercial impact, which will certainly increase in the future. While nanotechnologies offer many opportunities for innovation, the use of nano materials in food and agriculture has also raised a number of safety, environmental, ethical, policy and regulatory issues (Tarafdar *et al.*, 2012b).

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.

The current situation in nanotechnology is one in which there is great potential for benefit but an equally high uncertainty in associated risks. There are evidences for both optimism and pessimism. Pessimism is because of the huge discrepancy between the scale of research being performed on the invention of materials such as nanoparticles and their associated risks. Optimism is because of the uniquely forward-looking attitude of policy makers and regulators. The unusual properties of nanoparticles may result in substantially different environmental fate and behaviors than their bulk counterparts but very few observations were made in higher plant growth and yield. Because nano particles are spherical or faceted metal particles typically < 100 nm in size. These nanoparticles are having high surface area (30-50 m²/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. In view of the above facts the present study entitled “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)” is taken up with the following objectives;

1. To optimise the concentration of nano boron and methods of application in sunflower.
2. To know the effect of nano boron on growth and yield of sunflower.
3. To know the effect of nano boron on nutrient uptake by sunflower.
4. To workout soil nutrient balance and economics as influenced by nano boron.

II REVIEW OF LITERATURE

Sunflower is one of the most important oilseed crop of India. Among non-traditional oilseed crops, sunflower has greater potential for narrowing up the gap between the supply and demand of edible oil. But sunflower yield in India is far lower than the genetic potential yield of crop due to different factors, such as nutrient imbalance, less irrigation, less plant population and low soil fertility. Among these factors, imbalanced nutrition is one of the major causes of low yield of sunflower in the country. Boron is an important micronutrient and has an important role in vegetative and reproductive growth i.e., pollen germination and sugar transportation. A brief review of work pertaining to the present investigation on “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)” is comprehensively presented in this chapter on the following subheadings.

- 2.1 Effect of seed priming of nano nutrient on growth, yield and nutrient uptake of crops.
- 2.2 Effect of foliar and soil application of nano nutrient on growth, yield and nutrient uptake of crops.
- 2.3 Effect of nano boron on growth, yield and nutrient uptake of crops.
- 2.4 Effect of nano micronutrient on soil microbial activity and soil physicochemical properties.
- 2.5 Toxicity or negative impact of nano micronutrients and borax on crop growth, yield and nutrient uptake of crops.
- 2.6 Effect of foliar and soil application of borax on growth, yield and nutrient uptake of crops.
- 2.7 Effect of seed priming of borax on growth yield and nutrient uptake of crops.

2.1 Effect of seed priming of nano nutrient on growth, yield and nutrient uptake of crops

Zheng *et al.* (2005) studied the effects of nano and non-nano titanium oxide (TiO₂) on the growth of naturally aged spinach seeds. It was reported that nano titanium oxide (TiO₂) treated seeds produced higher plant dry weight (73%), three times higher photosynthetic rate and 45% increase in chlorophyll-a formation compared to the control over germination period of 30 days. The growth rate of spinach seeds was inversely proportional to the material size indicating that smaller the nano materials the better the germination.

Asli and Neumann (2009) reported that the average particle exclusion diameter of cell wall pores (3.0 to 6.6 nm) of maize (*Zea mays* L.) seedlings in a hydroponic medium was decreased when exposed to a suspension of titanium oxide (TiO₂) nanoparticles and it lead to decrease in transpiration and leaf growth of maize plant. However, shoot production was not affected and a possible adaptation mechanism for inhibited translocation of nanoparticles to shoots was suggested by Du *et al.* (2011). Adsorption of TiO₂ nanoparticles at the root surface of wheat (*Triticum aestivum* L.) has recently been illustrated by transmission electron microscopy images of root tips of wheat plants.

Khodakovskaya *et al.* (2009) reported that MWCNTs (muliti walled corbon nano tubes) can penetrate tomato seeds and increase the germination rate by increasing the seed water uptake. The MWCNTs increased the seed germination to the extent of 90% compared to control (71 %).

Kasra *et al.* (2011) showed that effect of Nano priming with titanium oxide was significant effect on germination percentage, seedling dry weight and seedling vigour of green gram. Significantly highest germination percentage (93.33 %), seedling dry weight (0.59 g) and seedling vigour (55.06) were achieved by treatment with 0.02 percentage of titanium oxide.

Pramod *et al.* (2011) studied the effect of nano zinc oxide (ZnO) particles on the root and shoot growth of mung (*Vigna radiata*) and gram (*Cicer arietinum*) seedlings.

They found that at certain optimum concentration, the seedlings displayed good growth over control and beyond that concentration retardation in growth was observed.

Prapatsorn *et al.* (2011) conducted experiment on the effect of zinc oxide nanoparticles and titanium dioxide nanoparticles on rice (*Oryza sativa* L.) roots. The results revealed that there is no reduction in the per cent seed germination with both nanoparticles. However, nano zinc oxide (ZnO) is observed to have detrimental effects on rice roots at early seedling stage and found to inhibit root length and reduce number of roots. Whereas, nano-TiO₂ has no effect on root length. This study showed that direct exposure to specific types of nanoparticles causes significant phytotoxicity, emphasizing the need for ecofriendly disposal of wastes containing nanoparticles.

Hassan *et al.* (2012) use of nano sized titanium oxide (TiO₂) has a significant effect on the wheat germination time. The lowest and the highest mean germination time (0.89 vs. 1.35 days) were obtained in 10 ppm concentration of nano sized titanium oxide TiO₂ and control treatments, respectively. Shoot and seedling lengths at 2 and 10 ppm concentrations of nano sized TiO₂ were higher than those of the untreated control and bulk TiO₂ at 2 and 10 ppm concentrations. Employing nano sized TiO₂ in suitable concentration could promote the seed germination of wheat in comparison to bulk TiO₂ but at higher concentration had inhibitory effect on wheat. The lowest shoot length was achieved at 100 ppm nanosized TiO₂ and 2 ppm bulk TiO₂ treatments.

Application of nano scale zinc oxide (ZnO) (25 nm mean particle size) at 1000 ppm concentration in groundnut promoted seed germination, seedling vigour, early flowering and higher chlorophyll content in leaf. Nano scale zinc oxide recorded significantly higher pod yield to the extent of 34 % compared to chelated bulk ZnSO₄. Foliar application of nano ZnO at 15 times lower dose recorded 29.5% and 26.3% higher pod yield compared to the chelated ZnSO₄ (Prasad *et al.*, 2012).

Application of silver nanoparticles (Ag NPs) increased the plant growth parameters (Shoot and root length and leaf area) and biochemical attributes (chlorophyll,

carbohydrate, protein content and antioxidant enzymes) of *Brassica juncea*, common bean and corn (Salama 2012 and Sharma *et al.*, 2012).

Reyhaneh *et al.* (2013) reported that effects of concentrations of nano sized titanium oxide (TiO₂) at 0, 5, 20, 40, 60 and 80 mg L⁻¹ with bulk titanium oxide (TiO₂) on wheat grass seed germination and early growth stage. After 14 days of seed incubation, germination percentage improved by 9 percent following exposure to 5 ppm nanosized TiO₂ treatment compared to control. Similar positive effects occurred in terms of germination value and mean daily germination but application of bulk TiO₂ particles in 80 ppm concentration greatly decreased the majority of studied traits.

Tapan *et al.* (2013) reported that significantly higher growth was found at 40 ppm (SiO₂) nano particles and 5 ppm Mo nano particles for rice seedlings. Beyond this concentration, the growth was inhibited in case of Mo nano particles.

Jayarambabu *et al.* (2014) revealed that nanoparticles of metal oxides with 20 mg/l significantly recorded the lower germination per cent in mung bean crop. Due to their quick movement into the plant it showed good shoot and root growth compared to other concentrations and control.

Foliar application of nano iron chelate at tillering stage was more effective. Foliar application in this stage had the effective impact on quantitative characteristics of wheat. Maximum Fe, starch, dry matter, crude protein and crude fibre percentage between the varieties was related to Zare variety (Harsini *et al.*, 2014).

Laware and Raskar (2014) conducted experiment to study the influence of zinc oxide nanoparticles on growth, flowering and seed productivity of onion. The results revealed that the plants treated with ZnO nanoparticles at the concentrations of 20 and 30 µg ml/ml showed better growth and flowered 12-14 days earlier than the control. Further, the treated plants showed significantly higher seeds per umbel, seed weight per umbel and 1000 seed weight over control plants. These results indicate that ZnO nanoparticles can reduce flowering period in onion by 12-14 days and even produce healthy seeds.

Sonia and Thukral (2014) reported that macro and nano cobalt was added to the sand medium at four levels (50 to 200 mg kg⁻¹ sand). Macro-Co was found to increase the growth of both shoots and roots at concentrations up to 200 mg Co kg⁻¹ sand. Increase in concentration of nano-Co decreased the root length. Lipid peroxidation was maximum at 200 mg Co kg⁻¹ sand for macro-Co in roots. Increase in the lipid peroxidation was found in nano-Co treated roots and shoots. Nano and macro-Co₃O₄ behaved differently with respect to effects on barley seedlings.

Alam *et al.* (2015) reported that wheat seed germination and seedlings growth was regularly affected with 1.0 to 2.0 ppm (shoot length and root length for 0, 1.0, 1.5, 2.0 and 2.5 ppm Fe nanoparticles were 2.7, 3.7, 5.2, 6.7 cm and 3.7, 5.1, 7.02, 7.96 cm respectively) but decreased significantly at 2.5 ppm of iron nanoparticles (shoot length was 1.9 cm and root length -2.3 cm).

Dimkpa *et al.* (2015) studied the response of bean (*Phaseolus vulgaris*) to commercial ZnO nanoparticles (NPs). Application of ZnO nanoparticles ranging from 250–1000 mg Zn kg⁻¹ had significant impact on root elongation after 7 days. Whereas, shoot growth was significantly inhibited at 1000 mg kg⁻¹.

Mahnaz Valadkhan *et al.* (2015) revealed the nano-iron chelate fertilizer increased seed number per pod, pod number per plant, 100 seed weight and grain yield of chick pea compared to control treatment (17, 48, 13 and 65% respectively). Seed priming with Zn, Fe and Ca nano particles improved 100 seed weight (27.8, 28.01 and 27.9 g respectively) and grain yield (72.9, 72.7 and 73.3 kg ha⁻¹ respectively) compared to untreated control (26.8 g 100 seed weight and 70.4 % grain yield respectively). Archana and satyavikas (2016) revealed that combination of N: P: K (12.5; 12.5; 12.5 kg ha⁻¹) and zinc oxide (ZnO) NP @ 4500 mg ha⁻¹ yielded 91% and 45.3% higher brinjal and biomass respectively than the treatment with only RDF.

Zhao *et al.* (2015) showed that nano CeO₂ and nano ZnO 400 and 800 mg kg⁻¹ changed the concentration of calcium in kernels compared to control. In nano CeO₂ treated plants, Cu, K, Mn and Zn were mainly localized at the insertion of kernels into

cobs but Ca and Fe were distributed in other parts of the kernels. They also reported that application of nano CeO₂ and nano ZnO reduced the corn yield and altered quality of corn.

Reyhaneh *et al.* (2016) reported that seeds scarified and treated with 40 or 60 mg l⁻¹ of silicon oxide (SiO₂) nanoparticles showed the improved germination (57 % and 41.50 % respectively) in *Astragalus squarrosus* compared to 80 mg l⁻¹ of SiO₂ seed treatment (17 %) and control (35.50 %).

2.2 Effect of foliar application and soil application of nano nutrient on growth yield and nutrient uptake of crops

Ma *et al.* (2010) revealed that the possible interactions of nanoparticles with higher plants (radish, rape, tomato, lettuce, wheat, cabbage and cucumber) are adsorption to the root surfaces, incorporation into the cell walls and uptake into the cells and all these processes primarily dependent on the physico-chemical properties of nanoparticles.

Fan *et al.* (2012) recorded significantly higher dry biomass of aerial part of rice A₁ (N 215 kg hm⁻² + nano-carbon 1.194 kg hm⁻²), A₂ (N 150.5 kg hm⁻² + nanocarbon 0.836 kg hm⁻²) and A₃ (N 107.5 kg hm⁻² + nanocarbon 0.597 kg hm⁻²) treatments with 58, 15.7 and 19.3 % compared to B₁ (N 215 kg hm⁻²), B₂ (N 150.5 kg hm⁻²) and B₃ (N 107.5 kg hm⁻²) treatments, respectively. The yield recorded under combined application of N and nano-carbon were higher than those in treatments received only nitrogenous fertilizer. The yield of A₁, A₂ and A₃ treatments were 18.36 per cent, 8.51 per cent and 10.19 per cent higher compared to B₁, B₂ and B₃.

Significant increase in yields have been observed due to foliar application of nano particles as fertilizer (Tarafdar *et al.*, 2012a). It was shown that 640 mg/ ha foliar application (40 ppm concentration) of nanophosphorous gave 80 kg/ ha P equivalent yield of clusterbean and pearl millet under arid environment. Fertilizers encapsulated in nanoparticles will increase the uptake of nutrients (Tarafdar *et al.*, 2012b).

Burmana *et al.* (2013) conducted an experiment on ten days old seedlings of chickpea (*Cicer arietinum* L.). The seedlings were sprayed with 1.5 or 10 ppm aqueous solution of zinc oxide (ZnO) nanoparticles and their effects were compared with corresponding concentration of zinc sulphate and ZnO of normal size. Maximum promotory response with respect to shoot dry weight was observed in seedlings treated with 1.5 ppm ZnO nanoparticles, whereas at 10 ppm the nanoparticles exerted adverse effects on root growth. However, overall biomass accumulation improved with the ZnO nanoparticles treated seedlings compared to zinc sulphate and ZnO of normal size.

Ghafari and Jamshid (2013) reported that wheat harvest index, 1000-grain weight and chlorophyll content increased as the rate of iron sulphate and iron chelate increased but these parameters decreased at the higher rate of nano iron oxide. Significantly higher 1000-grain weight, harvest index, grain and grain carbohydrate yields were produced by application of 8 g L⁻¹ iron sulphate followed by application of 2 g L⁻¹ of nano iron oxide.

Mahajan *et al.* (2013) reported that among the different nanoparticle suspensions the maximum growth was found at 50 ppm ZnFeCu-oxide followed by 50 ppm FeO and lowest were at 20 ppm ZnO over control in mungbean crop.

Morteza *et al.* (2013) reported that effect of nano titanium oxide (TiO₂) was significant on chlorophyll content (a and b), total chlorophyll (a + b), chlorophyll a/b, carotenoids and anthocyanins of maize. The maximum amount of pigment was recorded from the treatment nano TiO₂ (0.3%) spray at the reproductive stage (appearance of male and female flowers) in comparison with control.

It was found that the seedlings of greengram displayed good growth over control, demonstrating a positive effect of the nanoparticle treatment. The best performance was observed with nano Zn/CuFe-Oxide followed by nano FeO and nano ZnO. Increased absorption of nanoparticles by plant leaves was also detected by inductive coupled plasma / atomic emission spectroscopy (Shailesh *et al.*, 2013).

Sedgi *et al.* (2013) reported that significantly higher germination percentage, root length, root fresh and dry weight in soybean crop were noticed when seeds were treated

with different concentrations of poly ethylene glycol (PEG) and nano zinc oxide under drought stress conditions. Application of nano zinc oxide followed by stress occurrence caused decrease in seed residual fresh and dry weight.

Abasalt *et al.* (2015) revealed that application of 400 kg per ha K nano fertilizer recorded significantly higher plant height (92 cm) and stem diameter (4 cm) compared to control (77 cm and 3 cm respectively). Results also showed that application of 300 kg per ha K nano fertilizer had the higher number of fruit per plant (38), fruit weight (75 gm), fruit diameter (5.7 cm) and fruit yield (90 tonnes per hectare) of tomato compared to control (23, 62 g, 5 cm, 46 tonnes per ha respectively).

Afshar *et al.* (2014) studied the effects of different spraying concentrations of nano zinc oxide and zinc oxide on wheat crop. Results revealed that nano-compounds are quickly absorbed by plants in large amounts and hence it can be toxic on plants and plant products when it applied at higher concentration.

Azamal and Khawaja (2014) reported that fullerene, C₆₀ and carbon nanotubes have been shown to increase the water retaining capacity, biomass and fruit yield in plants up to 118% and fullerene treated bitter melon seeds also increase the phytomedicine contents such as cucurbitacin-B (74%), lycopene (82%), charantin (20%) and insulin (91%). Since as little as 50µg mL⁻¹ of carbon nanotubes increase the tomato production by about 200%, it can be exploited to enhance the agriculture production in future.

Abdul Hafeez *et al.* (2015) reported that soil application of copper nanoparticles (Cu-NPs) at 30 ppm produced significantly higher chlorophyll content (51.37), leaf area (12.79 cm² plant⁻¹), number of spikes/pot (19), number of grains/spike (31), 100 grain weight (6.45 g) and grain yield (13.51 g) of wheat as compared to control (38.43, 6.85 cm² plant⁻¹, 13, 23, 4.08 g, 6.42 g respectively).

Amin Farnia and Mohammad Mehdi Omid (2015) showed that use of Zn Nano fertilizer and Nano biofertilizer treatment recorded significantly higher (17000 kg ha⁻¹) biomass yield and control treatment had the lowest (11000 kg ha⁻¹) biomass yield in

maize. They also studied the comparison of the mean values of the grain yield for interaction between water stress and Zn Nano fertilizer showed that 7 day irrigation period treatment with use of Zn Nano fertilizer had the higher (10.5 ton ha⁻¹) grain yield and non application of Zn Nano fertilizer in 21 day irrigation period treatment recorded lower grain yield (2.7 ton ha⁻¹).

Mohsen *et al.* (2016) showed that foliar application of zinc nano-chelate with nano-titanium dioxide (2000 ppm) could increase most of the important traits of barley such as thousand grain weight, grain yield, straw yield and harvest index and resulted in sustainable and high crop production with foliar application of nanoparticle.

2.3 Effect of foliar application of nano boron on growth, yield and nutrient uptake of crops

Mahmoud (2014) reported that combined application of wheat seed sprout at 0.5 to 2.0 % and nano-boron at 0.25 to 0.1% was considerably very effective in enhancing all growth characters, plant pigments, total carbohydrates, nutrients, bunch weight, yield as well as both physical and chemical characteristics of the date palms fruit compared to control.

Mohsen *et al.* (2016) reported that seed treatment with nano chelated boron increased the plant height (193.91 cm), leaf length adjacent to ear (7.85 cm), leaf area per plant (2771 cm²) and number of rows per cob in maize (15.64) compared to other treatments.

Sohrab *et al.*, (2016) reported that single foliar spray with relatively low amounts of nano Zn or nano B chelated fertilizer (636 mg Zn per tree or 34 mg B per tree respectively) led to increase in the pomegranate fruit yield. This is mainly due to increase in the number of fruits per tree.

2.4 Effect of nano micronutrient on soil microbial activity and soil physico-chemical properties

The mobility and aggregation of nanoparticles in soils are strongly affected by the surface charge of the nanoparticles which is pH-dependent. As the pH reaches the point of zero charge of the manufactured nanoparticles, the greatest self-aggregation (homo-coagulation) occurs (Illes and Tombacz, 2006).

Vijendra and Ashok (2009) evaluated the effects of metal nano particles like fullerenes, gold, silver, aluminium and others on the plant growth promoting bacteria (PGPR). Altogether, the study suggested that metal nanoparticle could significantly produce ecotoxicity and killing of phytostimulatory soil bacteria. Thus, the engineered nanoparticle (ENPs) should be further tested as a possible ecofriendly agent.

Organic macro molecules are ubiquitous in the soil environment their effects on the surface reactions and mobility of nanoparticles in the soil may be the same as their effect on nanoparticles in the aquatic environment. The physico-chemical nature of organic matter can determine the stability of nanoparticles. The dissolved organic matter in soil can be sorbed on to nanoparticle surfaces and affect their surface speciation and charge through steric or charge alteration and increased hydrophilicity of the surfaces (Ghosh *et al.*, 2008).

Yang *et al.* (2009) observed that coating of metal oxides (TiO₂, Al₂O₃, ZnO) nanoparticles with humic acids decreased their zeta potential indicating enhanced electrostatic repulsion between nanoparticles and increased stability in the environment.

Concentration of salts in the soil solution may strongly affect the aggregation and deposition of nanoparticles. As the ionic strength of the soil solution increases, electrostatic repulsion between particles reduces and van der Waals attractions outweigh the repulsion (Hotze *et al.*, 2010).

Wang *et al.* (2010) observed that the behavior of nanoparticles in the soil environment (containing organic matter and clay minerals) was different to that of non reactive porous media.

Collins *et al.* (2012) studied the physico-chemical characteristics of nanoparticles (*viz.*, shape, size and surface charge) on soil (*viz.*, pH, ionic strength, organic matter and clay content). They noticed that soil properties will affect physical and chemical processes of NP resulting in dissolution, agglomeration and aggregation. The behaviour of nanoparticles in soil which in turn control their mobility and their bioavailability to soil organisms.

Srivathsan *et al.* (2012) reported that antimicrobial activity of the silver nanoparticles was investigated against the soil bacteria isolated from rhizospheric regions through *in-vitro* and *in-vivo* culture. In these tests, the agar plates were used and the silver nano particles of various concentrations were supplemented. Results showed that, the soil bacteria were inhibited at the low concentration of silver nanoparticles in both *in vitro* and *in vivo*. The silver nanoparticles can be used as effective growth inhibitors in various bacteria and making them applicable to various antibacterial control systems.

Zhao *et al.* (2013) observed that zinc oxide (ZnO) nanoparticles co-existing with Zn dissolved species were continuously released Zn to the soil solution to replenish the Zn ions or ZnO NPs scavenged by roots compared to soil treated with alginate which promotes the bio-accumulation of Zn in maize plant tissues.

2.5 Toxicity or negative impact of nano micronutrients and borax on crop growth, yield and nutrient uptake

Study was conducted to compare the effects of broadcast and foliar applications of B at rates of 0 to 2.24 kg ha⁻¹ for soybean and they revealed that broadcast applications of B caused no apparent vegetative damage but the 1.12 and 2.24 kg ha⁻¹ foliar applications resulted in leaf burn, malformed leaves and delayed maturity because of toxicity of boron (Touchton and Boswell, 1990).

Plants exposed to excess of boron have reduced vigour, retarded development due to the reduced root cell division, decreased shoot and root growth, leaf burn (chlorotic and necrotic patches in older leaves) and decreased number, size, and weight of fruits (Nable *et al.*, 1997).

Boron toxicity can influence transpiration rates of sunflower by reducing uptake of water. Leaf symptoms generally develop in later stages of plant growth as plants must control the boron distribution to maintain adequate levels in the cell (Moore, 1994).

Boron toxicity exerts different effects on very diverse process in vascular plants such as altered metabolism, reduced root cell division, lower leaf chlorophyll contents and photosynthetic rates and decreased lignin and suberin levels (Reid, 2007).

Boron toxicity negatively affects plant growth, which results in reduced vigour, stunted plant growth, delayed development, decrease number, size and weight of fruits and discoloration of leaves in tomato (Munthean, 2009).

Monica *et al.* (2011) reported that nano titanium oxide (TiO₂) particles, after short-term exposure delayed germination progression for the first 24 hr of *Vicia narbonensis* seed materials. Root elongation was affected only after treatment with the higher nano-TiO₂ concentration. Further significant effects were detected showing mitotic index reduction and concentration-dependent increase in the aberration emergence that evidenced a nano-TiO₂-induced genotoxic effect.

Boron toxicity is an important agricultural problem that limits crop productivity in different regions of the world and can occur in B-rich soils or in soils exposed to B-rich irrigation water, fertilizers, sewage sludge or fly ash (Luis *et al.*, 2012).

Salama (2012) showed that lower concentrations of silver nanoparticles had a stimulating effect on the growth of the plants, whereas under higher concentrations induced an inhibitory effect. Increased concentration of silver nanoparticles up to 60 ppm has led to an increase in shoot and root length, leaf surface area, chlorophyll content, carbohydrate and protein content of the common bean and corn.

Lin and Xing (2007) evaluated phytotoxicity of nanomaterials (MWCNTs, Aluminum oxide- Al_2O_3 , ZnO, Al and Zn) and its impact on germination rates in radish, rape canola, rye grass, lettuce, corn and cucumber. They conferred the hypothesis that the higher concentrations (2000 mg/L) of nano-sized Zn (35 nm) and ZnO (20 nm) inhibited the germination in rye grass and corn, respectively. Root length of studied species was also inhibited with use of 200 mg/L nano-Zn and ZnO. Phytotoxicity of nano-Al and Al_2O_3 significantly affected root elongation of rye grass and corn, respectively.

Ma *et al.* (2010) reported that the nano- CeO_2 did not affect root elongation in plant species except for lettuce at 2000 mg/L concentration. However, nanoparticles La_2O_3 , Gd_2O_3 , Yb_2O_3 greatly affected root growth at same concentration and the inhibitory effect of these nanoparticles were observed during different stages of root growth.

Wenchao *et al.* (2010) reported that both titanium oxide (TiO_2) and zinc oxide (ZnO) of the nanoparticles reduced the biomass of wheat. The TiO_2 nanoparticles were retained in the soil for long periods and primarily adhered to cell walls of wheat. The ZnO nanoparticles dissolved in the soil, thereby enhancing the uptake of toxic Zn by wheat. The nanoparticles also induced significant changes in soil enzyme activities, which are bioindicators of soil quality and health. Soil protease, catalase and peroxidase activities were inhibited in the presence of the nanoparticles and urease activity was unaffected. The nanoparticles themselves or their dissolved ions were clearly toxic for the soil ecosystem.

Ghosh *et al.* (2014) reported the toxicity of that nano-CuO in barley seedlings. prolonged nano-CuO treatment triggers oxidative burst, nano-stress induced changes in antioxidant enzymes activity and strongly indicate disruption of ROS/antioxidant balances.

Harajyoti Mazumdar (2014) reported that significant inhibition on shoot fresh weight of *V.radiata* and *B.campestris* was observed at $1000 \mu\text{g mL}^{-1}$ silver nanoparticle solution after treatment period. *V.radiata* showed significant retardation on dry weight of

root at 1000 $\mu\text{g/mL}$ of Ag^+ ions solution after 12th day. The decrease on shoot dry weight with increase in nanoparticle and ion concentration was also observed after 12th day. Exposure to 1000 $\mu\text{g mL}^{-1}$ of Ag nanoparticles reported significant retardation on total chlorophyll content of *V. radiata* and *B. campestris* when compare to control after 12th day of treatment.

Shaw *et al.* (2014) reported the negative impacts of nano-CuO (copper oxide) stress on physio-biochemical as well as photosynthetic performance of Syrian barley. Nano CuO (copper oxide) at higher concentration (0.5 mM) had marked impact in disrupting plant defense system.

Vinoth Kumar and Udayasoorian (2014) studied the toxic potential of three different metal oxide nanoparticles *viz.*, zinc oxide (ZnO), aluminum oxide (Al_2O_3) and titanium oxide (TiO_2) by using maize as test plant for germination study. A significant toxic effect was observed on growth parameters like germination percentage, vigour index, shoot and root length of maize. Among the tested concentrations of three different metal oxide nanoparticles, the concentration of 2000 mg L^{-1} displayed highest toxic effect followed by 1000 mg L^{-1} . A significant toxic effect of metal oxide nanoparticles was observed on growth parameters of maize and it was in the order of $\text{ZnO} > \text{TiO}_2 > \text{Al}_2\text{O}_3$.

2.6 Effect of foliar application and soil application of borax on growth, yield and nutrient uptake of crops

Ahmed Khan *et al.* (1990) reported that increase in yield attributes of some oilseed crops like sunflower, sesame and Indian mustard with the foliar application of boron at seed-filling stage.

Aulakh *et al.* (1990) reported that foliar application of borax @ 0.3 % recorded higher siliquae plant⁻¹, seeds siliqua⁻¹ and test weight because of increased translocation of photosynthates from source to sink in oilseeds.

Radeva (1991) reported that two foliar spray with 250 and 500 g boron ha⁻¹ applied at flowering and the seed filling stage to groundnut gave higher seed yield of 1.90

and 2.37 t ha⁻¹ respectively and increased the number of pods plant⁻¹ by 10 and 37 % and seed weight plant⁻¹ by 13 and 59 %.

Malewar *et al.* (1992) concluded that foliar application of phosphorous through boronated single super phosphate was beneficial in increasing yield and uptake of phosphorus and boron in the cotton and groundnut.

In a field experiment during *kharif*-1991 at Hyderabad, borax @ 2 kg ha⁻¹ was dusted and sprayed (0.4%). The sunflower seed yields were 1.23, 1.30 and 1.36 tonnes ha⁻¹ with no boron, dusting and spraying, respectively (Rani and Reddy, 1993).

Bowszys (1996) reported that, foliar spray of boron (0.4 kg ha⁻¹) at the bud stage significantly increased the seed yield and seed oil content in rape and number of seeds siliqua⁻¹, 1000 seed weight, seed yield, seed oil content in toria.

Susheela (1996) revealed that foliar spraying of borax at 0.2 % increased pollen germination, pollen viability and fertilization thus resulted in higher percentage of filled seeds in sunflower.

Venkatakrishnan and Balasubramaniam (1996) obtained the highest mean seed yield of sunflower, Cv. Co.2 (1.31t ha⁻¹) due to combined application of 40:20:20 kg NPK ha⁻¹ along with 25 kg S and 0.2 % borax spray as compared to application of NPK alone (1.11 t ha⁻¹).

Tamak *et al.* (1997) revealed that application of 0.2 % borax as foliar spray at 50 per cent flowering stage in sunflower increased the capitulum diameter, 100 seed weight, seed yield, oil content and its yield but decreased the protein content.

Josten and Kutschera (1999) reported that the solution of boron micronutrient @ 0.1mM caused the development of numerous adventitious roots (10) compared to no adventitious roots (1-2) in control in case of three days old sunflower seedlings.

Hemantharajan *et al.* (2000) reported that in green house experiment foliar application of B @ 50 ppm and soil application of S @ 40 mg kg⁻¹ of soil and Fe @ 15

mg kg⁻¹ of soil recorded higher plant height, root length, chlorophyll content, total dry matter production and seed yield of soyabean compared to control.

Jeybal *et al.* (2000) reported that application of FYM + *Azospirillum* + phosphobacteria + 0.2 % borax spray with recommended NPK significantly increased the capitulum diameter (19.1 cm), total seeds (1092 capitulum⁻¹), filled seeds (974 capitulum⁻¹) and seed yield (1.77 t ha⁻¹) than application of recommended NPK alone in sunflower.

Vyakaranahal (2001) reported that boron at 0.1 *per cent* spray at ray floret stage increased the processed seed yield by 49.0 and 43.1 *per cent* during *kharif* and *summer* sunflower, respectively. These foliar sprays also increased the capitulum diameter, number of filled seeds capitulum⁻¹, seed set percentage, seed yield plant⁻¹, 100 seed weight, volume weight of seed, oil content in seed, germination percentage, seedling dry weight and seedling vigour index.

Reddy *et al.* (2002) reported that maximum seed yield of sunflower was obtained through application of 100 *per cent* RDF (60:90:60 kg N: P₂O₅: K₂O ha⁻¹) + 500 kg gypsum ha⁻¹ (2145 kg ha⁻¹) which was on par with the seed yield obtained through 100 % RDF (60:90:60 kg N, P₂O₅, K₂O ha⁻¹) + 500 kg gypsum ha⁻¹ + borax spraying (0.2 %) at the ray floret initiation stage (2140 kg ha⁻¹).

Asad *et al.* (2003) foliar application of boron can increase the vegetative and reproductive biomass of sunflower under boron deficient condition. They have reported that foliar application of 28-1200 micro molar B increased the total dry mass of the most B deficient plants by more than three-fold and that of plants grown initially with 1.72 micro molar B in solution by 37-49 *per cent*. In this treatment the dry weight of the capitulum was similar to that achieved under control condition.

Foliar application of B improved seed germination and increased seedling vigour increased by 27% as compared with the control in alfalfa crop (Dordas, 2006).

Murthy (2006) reported that spectacular positive responses of boron were observed with major oilseed crops and response varied from 5 to 20 kg ha⁻¹. Synergistic interactions of B with P, S, Ca and Zn in augmenting oilseed yield and quality were reported. Application of 10-15 kg Borax ha⁻¹ in coarse textured soils and 15-20 kg Borax ha⁻¹ in calcareous and fine textured soils is recommended.

Patil *et al.* (2006) reported that boron application @ 0.1 % spray at ray floret stage recorded significantly maximum capitulum diameter (13.74 cm), total number of seeds (638.8) and filled seeds weight (17.1 g) per capitulum compared to control in sunflower. And zinc sulphate foliar spray @ 0.1 % significantly increased the seed yield by 18 % over the control (567.4 kg ha⁻¹) in sunflower.

Tejeswara Rao and Subbaiah (2006) found that in Indian mustard foliar application of B + Mo (1 ppm borax and 0.1 % ammonium molybdate) recorded the highest seed yield (1349 kg ha⁻¹), 1000 seed weight (3.9 g) compared to recommended NPK alone i.e., seed yield (1020 kg ha⁻¹) and 1000 seed weight (2.7 g).

Application of RDF (62.5:75:62.5 kg NPK ha⁻¹) + FYM 8 t ha⁻¹ + borax @ 6 kg ha⁻¹ in sunflower recorded higher plant height (32.57, 142.33 and 150.97 cm) at 30, 60 and 90 DAS, respectively and capitulum diameter (20.67 cm), seed yield plant⁻¹ (18.52 g), per cent seed filling (76.33 %), processed seed yield (965 kg ha⁻¹) and seed recovery percentage (92.47 %) over control. Also recorded significantly higher seed quality parameters such as seedling length (26.67 cm), vigour index (2230), seedling dry weight (375 mg) and germination percentage (90.00 %) over control (Byrareddy *et al.*, 2007).

Deperon *et al.* (2007) observed that boron greatly affected the dry matter production of the aerial parts of sunflower, among the aerial parts the greatest symptoms were on the leaves closest to the capitulum especially in the ones that suffered deformations. Boron deficiency harmed the allocation of net assimilates and grain production making the new leaves necrotic besides deforming and reducing the size of the sunflower capitulum.

Dixit and Elamathi (2007) reported that foliar application of boron (0.2 %) in green gram increased the plant height (32.26 cm), number of nodules plant⁻¹ (30.8) and dry weight plant⁻¹ (12.9 g), number of pods plant⁻¹ (18.1), 1000 seed weight (28.7 g), grain yield (7.53 q ha⁻¹) and haulm yield (30.0 q ha⁻¹).

Experiment comprised five levels of sulphur viz., 0, 10, 20, 30 and 40 kg S ha⁻¹ and five levels of boron viz., 0, 0.5, 1.0, 1.5 and 2.0 kg B ha⁻¹. The highest yield (1831 kg ha⁻¹) and 100 seed weight (13.26 g), harvest index (46.3 %), S (0.418 %) and B (0.422 %) uptake, protein and oil contents and B:C ratio (1: 3.23) of soybean grain were significantly increased by the application of sulphur @ 30 kg S ha⁻¹ and 1.5 kg B ha⁻¹ (Konhouja *et al.*, 2007).

Results obtained by Oyinlola (2007) showed that there were cultivar differences in response to boron fertilizer in sunflower. Record variety recorded the highest plant height at 8 kg B ha⁻¹ while, Funtua have the highest seed yield @ 4 kg borax ha⁻¹. The highest percentage oil content was recorded by Isaanka variety. Toxicity symptoms and reduction in yield were observed at the highest level borax (12 kg borax ha⁻¹) in all the varieties. Percentage oil content correlated with capitulum diameter and seed yield. Regression analysis also revealed that the optimum B rate for the three cultivars and four years of trial for the various parameters determined ranged from 5.60-8.40 kg borax ha⁻¹.

Brighenti and Castro (2008) reported that foliar application of boron @ 400 g ha⁻¹ from two sources (boric acid and sodium tetraborate) along with herbicides Haloxyfomethyl increased the leaf B content significantly 63.1 mg kg⁻¹ and 66.9 mg kg⁻¹ compared to herbicide application alone 56.6 mg kg⁻¹ in sunflower .

Eracan Ceyhan *et al.* (2008) revealed that AS-615 sunflower variety responded positively to the soil application of borax @ 7.5 kg ha⁻¹ and recorded highest plant height (128.5 cm), capitulum diameter (13.3 cm), 1000 seed weight (49.1 g), seed yield (3.75 t ha⁻¹) and oil yield (1.37 t ha⁻¹) over the control.

Kapila Shekhawat and Shivay (2008) reported that application of S @ 25 kg ha⁻¹ and B @ 1.5 kg ha⁻¹ along with RDF in sunflower gave the highest seed yield (2.01 t ha⁻¹)

which was 13.5 % more than of the control. It also increased the total nutrient concentration and their uptake, content of unsaturated fatty acids (linoleic and oleic) and reduced the saturated fatty acids (palmitic and stearic) and saponification.

Karthikeyan and Shukla (2008) reported that in a green house experiment application of S @ 60 mg kg⁻¹ and B @ 2 mg kg⁻¹ of soil along with RDF in sunflower has recorded significantly higher seed yield (33.2 g plant⁻¹), dry matter (70.2 g plant⁻¹), B uptake (1915 mg plant⁻¹) and S uptake (498.8 mg plant⁻¹) over control (10.3 g, 33.2 g, 482 mg and 132 mg plant⁻¹ respectively).

Foliar split rate application of boron @ 150 g ha⁻¹ at four leaves development stage and 150 g ha⁻¹ at terminal bud formation stage recorded significantly higher biomass production, achen development, seed yield, oil yield and concentration of boron in all parts of the sunflower plant (Skarpa, 2008).

Aravinda Kumar *et al.* (2010) found that in case of sunflower hybrid DSH-1, the seed yield of 757 kg ha⁻¹ in control increased to the maximum of 983 kg ha⁻¹ in boron (0.3 %) foliar application, which is 29 % higher than control. The application of Zn and Fe also caused significant increase in yield compared to control due to improvement in growth and yield attributes.

Arnab *et al.* (2010) noticed that application of recommended dose of fertilizer along with FYM (7.5 t ha⁻¹), foliar spray of ZnSO₄ @ 0.5 % and borax @ 0.2 % at floret initiation stage recorded significantly higher values of all the yield parameters like total number of filled seeds (794.56 capitulum⁻¹), 100 seed weight (5.89 g) and significantly lower percentage of chaffiness (6.33 %) compared to control (570.44 capitulum⁻¹, 4.68 g and 8.01 %, respectively) in sunflower.

Martin *et al.* (2010) reported that foliar application of boron in sunflower increased the uptake of macro nutrients (especially N), dry matter yield of the plants both in leaves (21.0-22.5 %) and in stem (18.6-36.0 %), seed yield (8.3-10.2 %) over no application of boron.

Al-Amery *et al.* (2011) found that in autumn sunflower crop, the relationship between boron and dry matter yield was linear and application @ 250 mg B L⁻¹ of water increased the dry matter significantly (23 t ha⁻¹) compared to control (15 t ha⁻¹). For spring sunflower crop, boron tended to decrease empty seeds percentage (15.7 % in control plot) and 8.5 % in 250 mg L⁻¹ boron plots. Boron application has given the significant increase in yield compared to control.

Ayad Shaker and Saad Mohammed (2011) reported that in sunflower application of boron as foliar spray during budding stage on different genotypes recorded the significant increase in leaf area, capitulum diameter, number of seeds capitulum⁻¹, 1000 seed weight, seed yield and oil yield both in spring season and autumn season.

Murthy (2011) reported that safflower responded significantly to the application of Zn @ 20 kg ha⁻¹ as ZnSO₄ and borax @ 1.5-2.5 kg ha⁻¹ which increased the safflower growth and seed yield in different locations.

Ramulu *et al.* (2011) revealed that application of 100 % RDF (63:75:63 N:P₂O₅:K₂O ha⁻¹) + borax (12.5 kg ha⁻¹) + ZnSO₄ (10 kg ha⁻¹) + FYM (7.5 t ha⁻¹) in sunflower increased the seed yield by 28.12 q ha⁻¹. Higher seed yield is the resultant of higher leaf area, capitulum diameter (17.1 cm), 100 seed weight (9.03 g), dry matter accumulation (76.7 g plant⁻¹), uptake of Zn (1124.2 g ha⁻¹), B (1440.5 g ha⁻¹) and macronutrients compared to control (no FYM and RDF) i.e., 9.72 q ha⁻¹, 491.3 g ha⁻¹ and 396 g ha⁻¹, respectively.

An experiment was conducted with four levels of nitrogenous fertilizer *viz.*, 100, 150, 200, 250 kg ha⁻¹ N and two levels of Boron *viz.*, 15 kg ha⁻¹ borax and no borax in *Brassica juncea* and results revealed that highest seed yield (1296 kg ha⁻¹), seed quality parameters like test weight, germination percent (86.50 %) and vigour index (1003) were obtained with 200 kg ha⁻¹ N applied along with 15 kg ha⁻¹ borax (Khanal *et al.*, 2012).

Arporn Krudnak *et al.* (2013) reported that sunflower variety S473 responded to boron application more than Pacific 77. Results revealed that application of borax @ 5.6

and 11.3 kg ha⁻¹ recorded maximum pollen germination and viability but further increased dose of borax tended to decrease pollen viability and seed set due to toxicity.

Muhammad et al. (2013) reported that plant height (174.62 cm), stem diameter (2.47 cm), capitulum diameter (17.69 cm), number of achenes capitulum⁻¹ (828), 1000 achene weight (59.87 g), biological yield (13980 kg ha⁻¹), achene yield (3659.3 kg ha⁻¹), oil contents (47.0 %) and protein contents (22.42 %) were significantly higher in sunflower hybrid (Hysun-33) when boron was applied as 500 g ha⁻¹ as boric acid source.

Seema Choudhary and Bhogal (2013) revealed that application of borax @ 20 kg ha⁻¹ in mustard has recorded significantly higher mean dry weight (11.95 q ha⁻¹), seed yield (7.8 q ha⁻¹) and uptake of B (16.9 mg kg⁻¹) over control.

Kallol Bhattacharyya *et al.* (2014) reported that application of recommended dose of fertilizer along 0.2 % foliar spray of borax at ray floret opening in sunflower recorded significantly higher capitulum diameter (18.7 cm) seed yield (2029 kg ha⁻¹), stalk yield (6089 kg ha⁻¹) and harvest index (0.24) as compared to RDF alone (14.3 cm, 1041 kg ha⁻¹, 6000 kg ha⁻¹ and 0.22, respectively).

Imran Khan *et al.*, 2015 revealed that sunflower hybrid Patron 551 and foliar application of B (200 mg·L⁻¹) at ray floret stage were shown significantly higher head diameter (18.30 cm), number of achene per head (1266), 1000-achene weight (43.17 g) achene yield (2039.33 kg·ha⁻¹), biological yield (9223.11 kg·ha⁻¹) and harvest index (22.10 %) compared to control (16.99 cm, 1142, 39.82, 1866 kg⁻¹, 9117 kg ha⁻¹ and 20.49%, respectively).

2.7 Effect of seed priming of borax on growth, yield and nutrient uptake of crops

Balamurugan *et al.* (2003) noticed that seed yield of sesame was increased by 20.6 % over control by pelleting the seed with gypsum + ammonium molybdate + ZnSO₄ + MnSO₄ + borax (300 mg kg⁻¹ of seed). The pelleted seeds showed significant increase in seed germination and vigour by 2 and 6 % respectively.

Niranjana *et al.* (2005) reported that, application of micronutrients (B, Zn and Mo) through seed treatment recorded significant increase in growth parameters, seed yield and oil content in groundnut compared to control.

In pigeonpea, B application through seed treatment (4 g borax kg⁻¹ of seed) was more effective and economical in increasing seed yield by 10.53 % compared with the control and soil application (10 kg borax ha⁻¹) increased yield by 5.26 % (Malla *et al.*, 2007).

Seed priming with B also has a profound influence on advanced growth stages. In a study on pea (*Pisum sativum* L.), Kumar *et al.* (2008) reported increased plant height, fruiting and pod yield when seeds were primed in 0.5 % B solution with a concomitant reduction in days to 50 % flowering.

In vegetable cowpea seed pelleting with borax (100 mg kg⁻¹ seed) substantially improved pod weight, seeds pod⁻¹ and pod weight plant⁻¹ resulted in 37.25 % pod yield gain over non-pelleted control (Masuthi *et al.*, 2009).

Muneeb Munawar *et al.* (2013) reported that, seed priming with Zn (1.5 %) solution, B (1.5 %) and Mn (2 %) observed highest seedling emergence, vigour index, 1000 seedling weight compared to water soaked and untreated seeds (control) in carrot.

Noor un nisa memon *et al.* (2013) reported that seed priming with boron is beneficial to improve germination and other growth related attributes of the seedlings of broccoli.

Habtamu Ashagre *et al.* (2014) reported that seed treatment with boron (@ 0.25 mg kg⁻¹ of seed) recorded significantly higher germination (100 %), shoot length (6.40 cm) and root length (9.08 cm) and increased the boron concentration to @ 8 mg kg⁻¹ and 10 mg kg⁻¹ of seed caused a complete failure of germination in safflower. Similar results were also reported by Brown *et al.* (2002).

Prathima *et al.* (2016) reported that at 7 and 15 DAS seed treatment with borax at 2 gm per kg recorded significantly higher seed germination (100%), root length (5.07cm and 7.27cm respectively), shoot length (7.80cm and 11.47cm respectively) and vigour index (1286 and 1773 respectively). Significantly lower seed germination (36.67 %), root length (0.60cm and 0.97cm respectively), shoot length (1.60cm and 1.93cm respectively) and vigour index (79.33 and 105.1 respectively) were recorded in seed treatment with borax @ 20 gm per kg of seed treatment.

III MATERIAL AND METHODS

A field study was conducted during late *Kharif*-2016 at ZARS, UAS, GKVK, Bengaluru on the “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)”. The details of the materials used and the techniques adopted during the course of investigation are described here under.

3.1 Preliminary laboratory experiment

Boron nitride (as a source of nano boron which is having particle size of 70 nm) and borax (lab grade commercial product) were used in the study. Preliminary studies to test the efficacy of nano boron fertilizer applications on sunflower plant and to standardize the concentrations for seed priming under laboratory conditions were carried out at the Department of Agronomy, UAS, GKVK, Bengaluru prior to taking up the field experiment.

3.1.1 Preparation of particle suspensions for seed priming

Since bulk boron nitride (BN) nano fertilizer will not dissolve in water and plants cannot absorb it, the materials were suspended directly in hot deionised water and dispersed by ultrasonic vibration (100 W, 40 KHz, 68 amplitude) for 15 minutes. The nano scale suspensions appear as clear solutions. The pH of all the prepared suspension was found to be 6.5-7.0. An absolute control was also maintained.

3.1.2 Details of laboratory experiments

Laboratory experiment was conducted to investigate the effect of different levels of nano boron on germination, seedling length and seedling vigor. The experiment was arranged in completely randomized design with five replications. Cultivar KBSH-53 was treated with different levels of Nano boron and borax (0, 0.2, 0.4, 0.5, 0.6 %). Petri plates with filter papers were used for sowing the seeds. Seeds were treated according to treatments. After treating ten seeds were uniformly placed per petri plate using a forceps and kept at room temperature (28 ± 2 °C). Germinated seeds were counted after 6 days of sowing. Parameters such as per cent germination was calculated according to ISTA

(1999) and root and shoot lengths of seedling were measured at 8, 15 and 22 DAS using a measuring scale. The seedling vigor index (SVI) was worked out by using Hosseini and Kasra (2011) formula.

3.2 Field experiment

3.2.1 Location of the experimental site

A field experiment was carried out on the “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)” during late *Khariif*-2016 at Zonal Agricultural Research Station, University of Agricultural Sciences, Bengaluru. The experimental site is located at latitude of 12° 58' N latitude, 77° 35' E longitude and at an altitude of 930 meters above mean sea level.

3.2.2 Soil characteristics of the experimental site

Soil texture of the experimental site was red sandy loam. Representative soil samples from experimental site were collected and analyzed for chemical properties. The values obtained along with the methods followed for soil analysis are furnished in the Table 3.1.

The soil samples were analyzed initially and also after the harvest of crop for various chemical properties like pH, EC, organic carbon, available nitrogen, available phosphorus, available potassium, boron, zinc and sulphur.

3.2.3 Climatic conditions

The normal as well as actual weather conditions such as rainfall, temperature (maximum and minimum), relative humidity, daily bright sunshine hours and open pan evaporation prevailed during the crop growth period is presented in Table 3.2 and Fig 3.1.

3.2.3.1 Normal weather conditions

The average of forty three years (1972-2015) data has been considered to calculate normal climatic conditions of Zonal Agricultural Research Station, UAS,

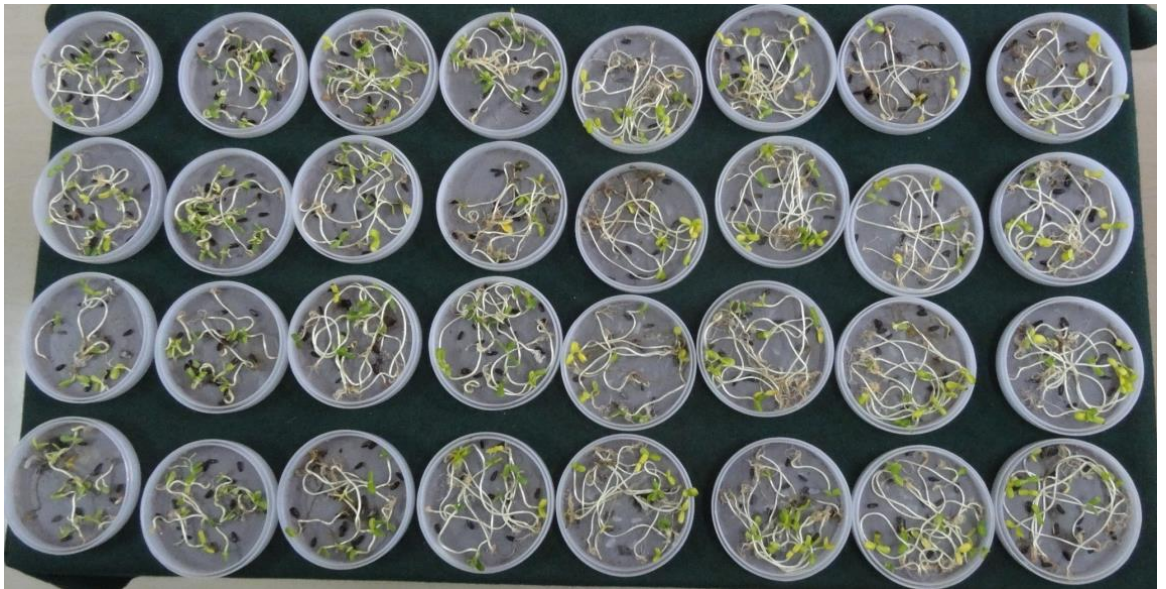


Plate 1. General view of the laboratory studies

GKVK, Bengaluru. The normal annual rainfall of the station was 904.7 mm and the major portion of rain was received during the months of July to October and maximum amount of rainfall was received during September and October months. The normal mean maximum air temperature ranged from 26.2°C to 33.8°C. Whereas, normal mean minimum air temperature ranged between 14.0°C to 20.5°C. The normal mean monthly maximum relative humidity ranged from 75.3 to 89.0 per cent and the normal mean sunshine hours varied from 4.3 to 9.4 hours.

3.2.3.2 Actual weather conditions

Total rainfall received during the year 2016 was 709.4 mm. The highest rainfall was received in the month of July (271.4mm) and the lowest rainfall is in the month of October (31 mm). Total rainfall received during crop growth period (September to December) was 146.8 mm with 11 rainy days. The actual mean monthly maximum temperature was higher than the normal during the crop growth period in October and November which is 29.6 °C. The actual mean minimum temperature is higher in September month (19.0 °C) and actual mean minimum temperature was lower in December (14.7 °C) compared to the normal temperature. The actual mean sunshine hours has been recorded higher in November (8.5 hours) and lower in September (3.5 hours). Mean monthly relative humidity varied from 82 to 94 per cent during crop growth period (Table 3.2 and Fig. 3.1).

There was large variation in the rainfall during the experimental period from that of the normal (mean of 43 years). The mean temperature and relative humidity existed during the period of experimentation was conducive to the crop growth and development of sunflower. In general, the plant growth was not affected by these parameters throughout the crop duration except rainfall. The rainfall during the cropping period was deficit. The crop was given protective irrigation and hence the crop growth was not affected by deficit rainfall.

Table 3.1: Initial chemical properties of the soil

Chemical properties	values	status	Method followed
Soil pH	6.15	Neutral	Potentiometry method, pH meter (Piper, 1966)
Electrical conductivity (d Sm ⁻¹)	0.15	Normal	Conductometry (Jackson, 1973)
Organic carbon (%)	0.55	Medium	Walkey and Black's Wet Oxidation method (Piper, 1966)
Available N (kg ha ⁻¹)	279	Low	Alkaline permanganate method (Subbaiah and Asija, 1956)
Available P ₂ O ₅ (kg ha ⁻¹)	39.3	High	Bray's method (Jackson, 1973)
Available K ₂ O (kg ha ⁻¹)	260.2	Medium	Neutral normal NH ₄ OAC extraction method (Jackson, 1973)
Available B (ppm)	0.29	Neutral	Hot water extraction method (Berger and Troug, 1939)
Available Zn (ppm)	2.31	High	DTPA extraction method (Brown <i>et al.</i> , 1973)
Available S (ppm)	12.8	Medium	Turbidometric method (Jackson, 1973)
Farm yard manure (FYM)			
Available N (%)	0.4	H ₂ SO ₄ digestion method	
Available P ₂ O ₅ (%)	0.2	Digestion method	
Available K ₂ O (%)	0.3	Digestion method	

Table 3.2: Meteorological data of the experimental area during 2016 at GKVK, Bengaluru

Year/ Months	Rainfall (mm)			Mean temperature (°C)						Mean Relative Humidity (%)			Mean Sunshine hours (hr day ⁻¹)		
				Maximum			Minimum								
	N	A	D	N	A	D	N	A	D	N	A	D	N	A	D
2016	N	A	D	N	A	D	N	A	D	N	A	D	N	A	D
January	1.3	2.4	1.1	27.5	27.5	0	14.0	14.7	0.7	86.0	90	3.9	8.8	7.6	-0.6
February	9.3	0	-9.4	29.8	31.2	1.4	15.3	16.2	0.9	80.7	85	4.2	9.4	9	-3.5
March	12.6	4.2	-8.5	32.6	34.0	1.4	18.0	19.9	1.9	75.3	86	10.4	9.3	8.2	-0.5
April	46.3	1.2	-45.3	33.8	35.8	2.0	20.5	23.1	2.5	79.3	84	4.6	8.9	9.1	1.2
May	99.7	115	15.3	33.1	33.1	0.0	20.5	21.4	0.9	81.5	88	6.3	8.2	7.8	1.0
June	77.9	140.4	62.5	29.5	28.4	-1.2	19.6	19.9	0.3	85.8	92	6.0	5.7	4.7	-0.5
July	105.7	271.4	166.0	28.1	27.6	-0.6	19.1	19.3	0.2	88.1	94	5.8	4.3	4.1	-2.0
August	131.5	28	-103.7	27.6	28.1	0.5	18.9	19.5	0.6	89.0	92	2.9	4.7	5.7	0.0
September	191.1	51.4	-140.0	28.0	27.8	-0.3	18.8	19.0	0.2	88.9	92	3.0	5.7	3.5	-2.0
October	164.3	31	133.6	27.8	29.6	1.8	18.2	18.0	-0.3	88.0	85	-2.9	6.0	7.9	1.3
November	52.0	0.0	52.0	26.7	29.6	2.9	16.5	16.2	-0.3	84.7	82	-2.7	6.2	8.5	2.3
December	13.0	64.4	51.4	26.2	27.2	1.0	14.5	14.7	-0.2	84.4	85	0.6	7.2	6.9	-0.3
Total/Mean	904.7	709.4	-195.3	29.22	29.99	0.77	16.11	18.49	2.38	84.30	87.91	6.47	7.03	6.91	-0.3

Note: N- Normal meteorological data (mean of 1972 – 2015), A - Actual meteorological data (2016), D - Deviation from the normal (A-N)

Details of the experiment

Crop	: Sunflower
Hybrid	: KBSH-53
Replications	: Three
Treatments	: 10
Design	: RCBD (Randomized Complete Block Design)
Gross plot	: 5.4 m x 4.8 m
Net plot	: 4.2 m x 4.2 m
Spacing	: 60 x 30 cm
Location	: ZARS, GKVK, Bengaluru
Season	: <i>Kharif</i> -2016

There are ten treatments, replicated thrice which were included in the experiment. The treatments combinations included for the study as furnished below;

3.2.4 Treatment details

- T₁:** Control
- T₂:** Nano Boron @ 0.2 % seed priming
- T₃:** Nano Boron @ 0.4 % seed priming
- T₄:** Borax @ 0.2 % seed priming
- T₅:** Borax @ 0.4 % seed priming
- T₆:** Nano Boron @ 0.2 % spray to capitulum at ray floret stage
- T₇:** Nano Boron @ 0.4 % spray to capitulum at ray floret stage
- T₈:** Borax @ 0.2 % spray to capitulum at ray floret stage
- T₉:** Borax @ 0.4 % spray to capitulum at ray floret stage
- 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.

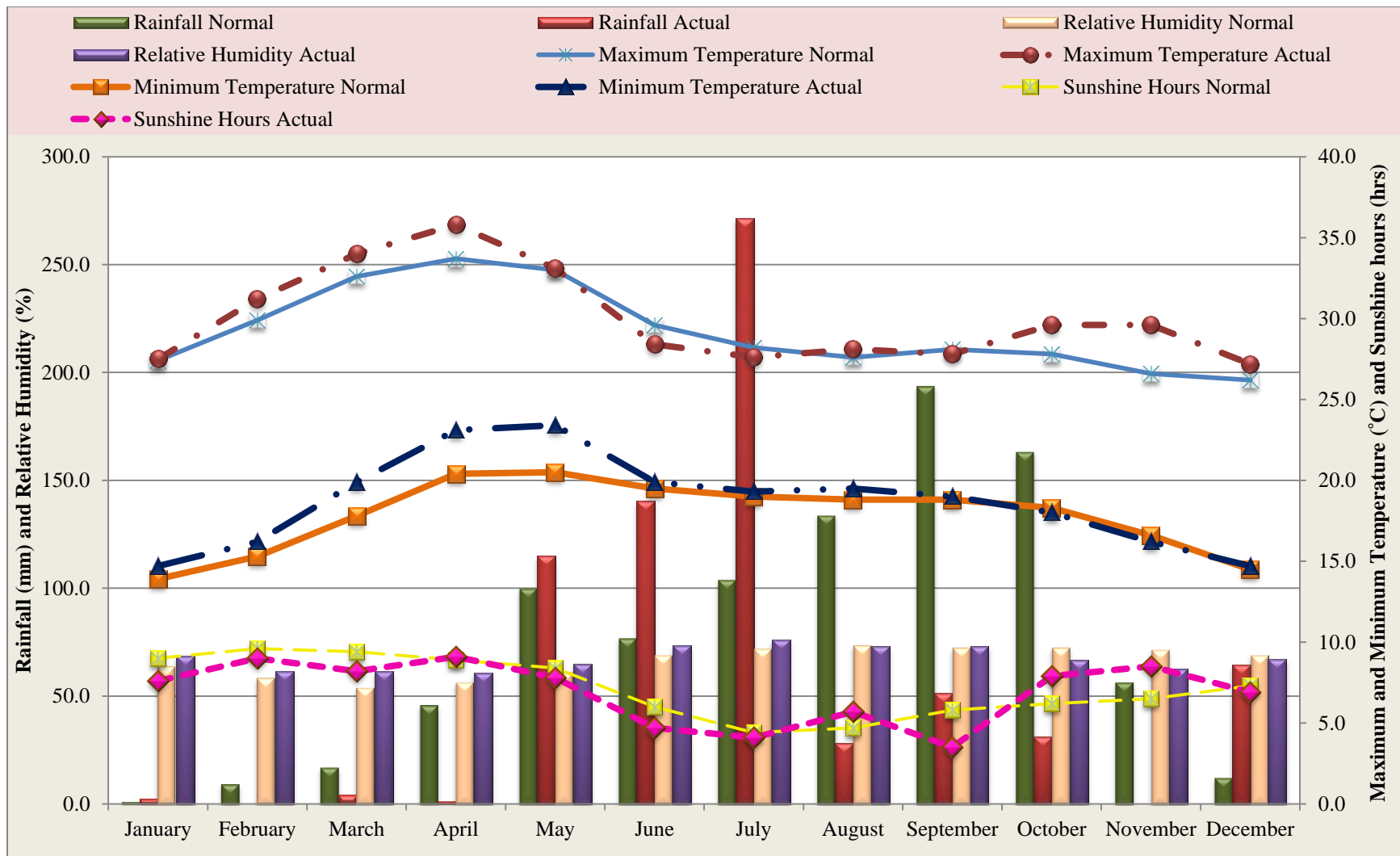


Fig. 3.1: Mean monthly weather data of ZARS, UAS, GKVK, Bengaluru during 2016

3.2.5 Design and layout

The layout of the experiment is depicted in Fig 3.2.

3.2.6 Hybrid used

The sunflower hybrid KBSH-53 developed by *All India Coordinated Research Project (AICRP)* on Sunflower, UAS, GKVK, Bengaluru during 2008 was used for the study. The crop duration of this hybrid is 100-110 days. The oil content of the seeds ranges from 42 to 44 per cent and it is moderately resistant to powdery mildew disease.

3.2.7 Cultural operations

3.2.7.1 Land preparation

The land was prepared by passing a tractor drawn disc plough followed by shallow cultivation using cultivator. Weeds and stubbles were removed manually to obtain fine seed bed. Later the field was demarcated for layout of experiment as per the plan. The individual plots were prepared manually by using spade (according to the plot size). Each plot was prepared by making the bunds of 60 cm width and 20 cm height around it. A channel of 90 cm width was opened in between the treatment plots for irrigation purpose. The experimental layout was presented in the plate-5.

3.2.7.2 Nutrient management

Urea, single super phosphate (SSP) and muriate of potash (MOP) were used as sources of NPK and borax (11% B) and nano boron nitride (10.8 % B) as source of boron. According to the treatments micronutrients were applied to respective plots. The full dose of phosphorus and potassium were applied at the time of sowing but the nitrogen fertilization has been given in two split doses, 50 per cent of recommended dose of nitrogen was given at the time of sowing and remaining 50 per cent at the time of earthing up. FYM was applied at the rate of 7.5 t ha⁻¹ before two weeks of sowing.

3.2.7.3 Seed treatment

According to the treatments, manually seeds were 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.

3.2.7.4 Sowing

Furrows were opened at 60 cm distance and two to three seeds were placed per hill at depth of 4-5 cm with intra-row spacing of 30 cm. Treated seeds were dibbled in respective plots according to the treatment and covered with soil on 13th September, 2016.

3.2.7.5 Thinning

The thinning operation was carried out by leaving one healthy seedling per hill at 15 DAS in order to maintain optimum plant population with the required spacing and to avoid competition between the seedlings.

3.2.7.6 Weed management

Pre-emergence herbicide Lasso at the rate of 2 liters ha⁻¹ was applied to control the weeds. Weeds were also managed manually with hand weeding at 30 and 60 days after sowing.

3.2.7.7 Earthing-up and top dressing

Earthing-up operation was carried out at 35 DAS and at the same time remaining 50 per cent of recommended dose of nitrogen has been top dressed.

3.2.7.8 Plant protection measures

One spray of quinolphos @ 2 ml L⁻¹ at 30 DAS was to control caterpillars. Drenching with bavistin 2 g L⁻¹ + mancozeb 2 g L⁻¹ to control *Rhizoctonia* root rot and *Alternaria* leaf spot were also done at 45 DAS.

3.2.7.9 Foliar application of micronutrients

Treatments were imposed when the crop was at ray floret stage. Foliar application of nano boron and borax spray @ 0.2 % and 0.4 % was carried out by taking calculated quantity of nano boron and borax and dissolving in hot water to prepare solutions of required concentrations and sprayed to capitulum according to the treatments.

3.2.7.10 Harvesting and threshing

The crop was harvested at physiological maturity as indicated by lemon yellow colour on the back side of the capitulum, drying of leaves and seeds become hard. The capitulum were harvested separately treatment wise. Threshing was done by beating the capitulum with the stick. The produce was cleaned and net plot seed yield was recorded after thorough drying. The stalks were cut close to the ground and were left in the field for sun drying and then stalk yield was recorded.

3.2.8 Collection of experimental data

3.2.8.1 Observation on growth parameters

Periodical observations were taken on growth parameters at 30 and 60 DAS and yield components were recorded at harvest. Individual plants were chosen for destructive sampling for further observations.

3.2.8.2 Germination percentage

The number of seedlings germinated in each treatment was recorded by visual observation. Germination percentage was estimated using the formula,

$$\text{Germination percentage} = \frac{\text{No. of germinated seeds}}{\text{Total No. of seeds kept for germination}} \times 100$$

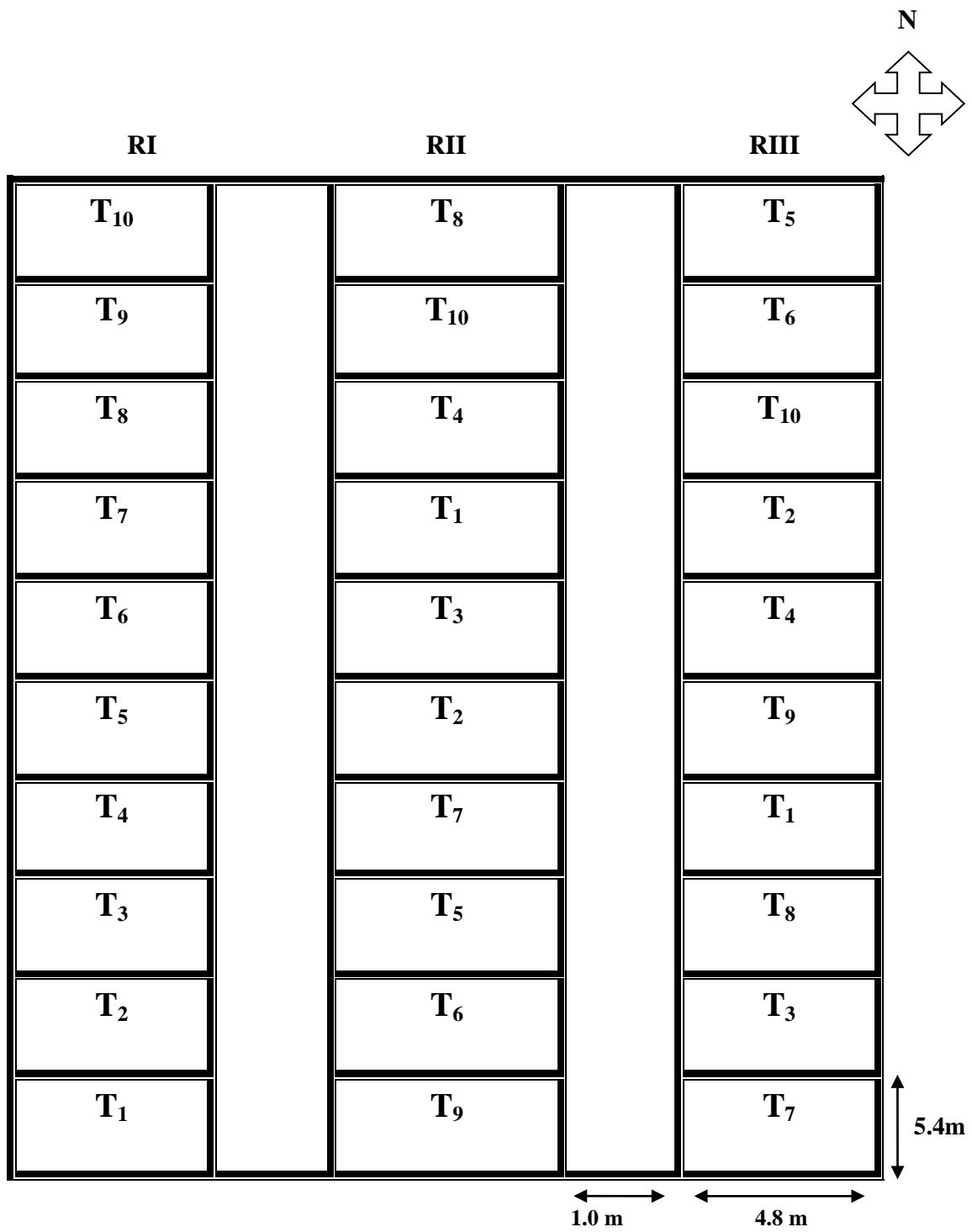


Fig 3.2: Plan of layout of experimental plot

3.2.8.3 Vigour index

In laboratory experiment the shoot and root length of sunflower plants were recorded to work out vigour index by using the formula

$$\text{Vigour index} = [\text{Root length (cm)} + \text{Shoot length (cm)}] \times \text{Germination percentage}$$

3.2.8.4 Plant height (cm)

The plant height was recorded from the randomly selected five plants in each treatment at base of plant to the growing tip or point of attachment of the capitulum at 30 and 60 DAS and at the time of harvest by using measuring scale and the average height of the plants in each plot is obtained.

3.2.8.5 Number of leaves per plant

Numbers of fully opened leaves from base of plant to the tip of terminal bud was counted at 30 DAS and 60 DAS.

3.2.8.6 Leaf area (cm² plant⁻¹)

Leaf area was measured at 30 and 60 DAS by using leaf area meter. Three plants from each plot were uprooted and all fresh leaves from individual plants from different plots were collected and fed to leaf area meter and observations were recorded and averaged.

3.2.8.7 Leaf Area Index (LAI)

Leaf area index is the ratio of leaf area to ground area occupied by the crop plant. Leaf area index was worked out using the following formula (Watson, 1952).

$$\text{LAI} = \frac{\text{Leaf area (cm}^2 \text{ plant}^{-1}\text{)}}{\text{Spacing (cm}^2 \text{ plant}^{-1}\text{)}}$$

3.2.8.8 Determination of leaf nitrogen status as indicated by chlorophyll (SPAD) reading

Leaf nitrogen status is normally manifested with the leaf chlorophyll content. A device developed by Minolta corp, Ramosey, N. J., measures the light attenuation at 430 nm (the peak wavelength for chlorophyll a & b absorption) and at 750 nm (near infrared) with no transmittance. The unit less values measured by the chlorophyll meter (SPAD-502) termed as SCMR (SPAD chlorophyll meter reading), is a good estimate of chlorophyll content. The SPAD meter (Soil plant Analysis Development) is a simple hand held equipment which operates with De power (Volts) and is portable. SCMR values were recorded in plants grown at different treatments. The third fully expanded leaf from the apex was used for the SCMR determination. Several measurements were made on each leaf at top and middle and averaged to make an appropriate estimate of leaf chlorophyll and there by the leaf N status of the plant were determined.

3.2.8.9 Days to 50 per cent flowering

The number of days taken for 50 per cent flowering of the plant population from each plot from the date of sowing was recorded based on visual assessment and expressed in days.

3.2.8.10 Total dry matter production (g plant^{-1})

Dry matter production was recorded at 30 and 60 DAS. Destructive sampling was done to estimate the total dry matter. Three plants from each net plot were uprooted at different stages and it was shade dried for few days followed by oven dried at 60-65°C until a constant weight was obtained. Then it was weighed and expressed as g per plant.

3.2.8.11 Days taken for maturity

The number of days taken for maturity was recorded from each plot by the indications such as drying of the leaves, lemon yellow colour on the back side of the capitulum and hardening of seeds.

3.2.8.12 Observation on yield parameters

Observations on yield parameters such as head diameter, test weight, seed yield per plant, seed yield per net plot, seed yield per hectare, oil yield etc., are recorded at harvest.

3.2.8.13 Capitulum diameter (cm)

The distance between two diagonally opposite edges of the capitulum was recorded from five randomly selected plants and mean diameter was expressed in centimetres (cm).

3.2.8.14 Stem girth at harvest

Five plants from each treatment plot were selected randomly and stem girth was recorded using vernier slide calipers and the average stem girth was recorded and expressed in centimeter (cm).

3.2.8.15 Number of seeds per capitulum (Filled seeds + Chaffy seeds)

The average number of filled seeds and chaffy seeds per capitulum were counted manually from five plants and expressed as number of seeds per capitulum.

3.2.8.16 Seed yield per plant (g)

Five capitulum from each net plot were collected and seeds are separated, dried and weighed at 8 % moisture. The average weight is expressed as mean seed yield per plant (g).

3.2.8.17 Seed yield per hectare (kg ha⁻¹)

Capitulum in net plot were harvested, seeds were separated by hand threshing, dried and weighed at 8 per cent moisture. Seed yield was computed per hectare (kg ha⁻¹) based on area of each net plot.

3.2.8.18 Per cent chaffiness

Per cent chaffiness was calculated from five plants from each plot by separating pure and chaffy seeds manually and expressed in percentage.

$$\text{Per cent chaffiness} = \frac{\text{Number of unfilled seeds per capitulum}}{\text{Total number of seeds per capitulum}} \times 100$$

3.2.8.19 100 seed weight (g 100 seeds⁻¹)

Sample seeds from each plot were drawn and 100 medium seeds were counted in an unbiased way manually (regardless of seed size), weighed at 8 per cent moisture and expressed in gram.

3.2.8.20 Volume weight (g 100 ml⁻¹)

Seeds were measured in 100 ml beaker and the weight of these seeds was recorded in grams and expressed as volume weight.

3.2.8.21 Stalk yield (kg ha⁻¹)

Weight of stalks per net plot was recorded after complete sun drying of stalks and stalk yield per hectare was worked out and expressed in kg per hectare.

3.2.8.22 Harvest index (HI)

The harvest index was calculated by using the following formula (Donald, 1962)

$$\text{Harvest index} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}}$$

3.2.8.23 Oil content (%) and Oil yield (kg ha⁻¹)

Oil content of the seeds in different plots is estimated by using Nuclear Magnetic Resonance (NMR model mimispec 20 pi) technique and the oil yield per hectare is obtained by multiplying oil per cent of individual treatment by seed yield per hectare and expressed in kg per hectare (kg ha⁻¹).

$$\text{Oil yield (kg ha}^{-1}\text{)} = \frac{\text{Oil percent in seed X Seed yield (kg ha}^{-1}\text{)}}{100}$$

3.2.9 Soil analysis

3.2.9.1 Soil sampling and processing

Representative soil samples (0-20 cm depth) from the experimental site were collected before and after the experiment and used for determining the basic chemical properties and to know the changes in nutrient status of soil. The collected bulk soil samples reduced by following quadratic rule, then dried under shade, powdered using pestle and mortar and passed through 2 mm sieve and preserved for analysis. For organic carbon analysis, the 2 mm sieved soil samples were subjected for further grinding and passed through 0.2 mm sieve.

3.2.9.2 pH

Soil pH was determined in 1: 2.5 soil : water suspension using a digital pH meter having the glass electrode as described by Jackson (1973).

3.2.9.3 Electrical Conductivity (d Sm^{-1})

Electrical conductivity of the soil samples was measured in 1: 2.5 soil: water extract using a conductivity bridge (Jackson, 1973).

3.2.9.4 Organic Carbon (%)

A known weight of 0.5 g (0.2 mm sieved) of soil was treated with a known excess volume of potassium dichromate. After oxidation of organic carbon present in soil, the unreacted left in the contents was back titrated against standard ferrous ammonium sulphate solution using diphenylamine indicator (Walkley and Black, 1934).

3.2.9.5 Available Nitrogen (kg ha^{-1})

Ten gram of soil was distilled with 25 ml of 0.32 per cent KMnO_4 and 25 ml of 2.5 per cent NaOH . The ammonia released was trapped in 4 per cent boric acid

containing mixed indicator and titrated against standard sulphuric acid solution (Subbiah and Asija, 1956).

3.2.9.6 Available Phosphorus (kg ha⁻¹)

The available phosphorus in soil was estimated by Vanadomolybdate phosphoric yellow colour method, (Jackson, 1973) by using spectro-photometer at 660 nm and expressed as kg per hectare.

$$\text{Available P}_2\text{O}_5 \text{ (kg ha}^{-1}\text{)} = \frac{\text{Graph ppm} \times \text{Vol. of extractant} \times \text{Vol. Made} \times 2 \times 10^6 \times 2.26}{10^6 \times \text{Weight of soil} \times \text{Aliquot taken}}$$

3.2.9.7 Available Potassium (kg ha⁻¹)

Available potassium in soil was extracted with neutral normal ammonium acetate and potassium content in the extract was determined by using flame photometer.

$$\text{Available K}_2\text{O (kg ha}^{-1}\text{)} = \frac{\text{Graph ppm} \times \text{Vol. of extractant} \times \text{Vol. Made} \times 2 \times 10^6 \times 1.20}{10^6 \times \text{Weight of soil}}$$

3.2.9.8 Available Sulphur (ppm)

Available sulphur in soil is extracted with 0.15 % CaCl₂ solution and the extracted sulphate is treated with barium chloride to convert into barium sulphate in the presence of conditioning agent. The turbidity formed is estimated using a spectrophotometer at 420 nm and expressed in ppm.

$$\text{Sulphur (ppm)} = \frac{\text{Graph ppm} \times \text{Vol. of extractant} \times \text{Vol. Made}}{\text{Weight of soil} \times \text{Aliquot for turbidity development}}$$

3.2.9.9 Available Zinc (ppm)

Diethylene Triamine Penta Acetic acid (DTPA) is used to extract the available zinc from soil. Concentration of zinc in extractant is determined by using Atomic Absorption Spectrophotometer.

$$\text{Concentration in ppm} = \frac{\text{Graph value} \times \text{Volume of the extractant}}{\text{Weight of the soil}}$$

3.2.9.10 Available Boron

Available Boron in soil was determined by hot water extraction method (Berger and Troug, 1939), expressed in ppm.

$$\text{Concentration in ppm} = \frac{\text{Graph value} \times \text{Volume of extractant} \times \text{volume made}}{\text{Aliquot taken} \times \text{weight of soil}}$$

3.2.10 Plant nutrient analysis

3.2.10.1 Collection and preparation of plant samples

Plant samples were collected from the field at the time of harvesting and dried at 60 °C in hot air oven, after complete drying, the samples were powdered with the help of grinder and preserved in polythene bags for further analysis of nitrogen, phosphorus, potassium, sulphur, zinc and boron content (Jackson, 1973).

3.2.10.2 Estimation of nitrogen (%)

Total nitrogen content in plant samples was determined by micro Kjeldhal's method as described by Jackson (1973). In this method the powdered samples were digested with the concentrated sulfuric acid in presence of digestion mixture (K_2SO_4 : $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$: Selenium in the proportion of 100:20:1) and distilled under alkaline medium. The liberated NH_3 was trapped in boric acid containing mixed indicator and titrated against standard sulphuric acid and nitrogen content is expressed in percentage. The nitrogen content of plant samples is calculated by using the following relationship

$$1 \text{ ml of } 1 \text{ N H}_2\text{SO}_4 = 0.014 \text{ g of N}$$

$$\text{Nitrogen (\%)} = \frac{\text{TV} \times \text{N of acid} \times 0.014 \times \text{Volume of digested sample} \times 100}{\text{Weight of sample} \times \text{Aliquot taken}}$$

3.2.10.3 Digestion of plant samples

With di-acid mixture a powdered sample of 0.5 g of plant was predigested with 5 ml of concentrated HNO_3 and again digested with a di-acid mixture (HNO_3 and HClO_4 in 9:4 ratio). Volume of the digest was made up to 100 ml with distilled water and preserved for total elemental analysis (Jackson, 1973).

3.2.10.4 Estimation of phosphorus (%)

The total phosphorus content of plant samples of sunflower was determined by measuring a known volume of predigested sample by adopting the vanodomolybdophosphoric yellow color method as described by Jackson (1973) and expressed in percentage.

$$\text{Phosphorus(\%)} = \frac{\text{Graph ppm} \times \text{Volume of digested sample} \times \text{Volume made up} \times 100}{10^6 \times \text{Weight of sample} \times \text{Aliquot taken}}$$

3.2.10.5 Estimation of potassium (%)

The total potassium content of plant samples was estimated by atomizing the diluted digest to a calibrated flame photometer under suitable measuring conditions as described by Jackson (1973) and the potassium content of samples was expressed in percentage.

$$\text{Potassium(\%)} = \frac{\text{Graph ppm} \times \text{Volume of digested sample} \times \text{Volume made up} \times 100}{10^6 \times \text{Weight of sample} \times \text{Aliquot taken}}$$

3.2.10.6 Estimation of sulphur (%)

The sulphur content of plant samples was estimated using turbidometric method with the help of spectrophotometer at 420 nm and expressed in percentage.

$$\text{Sulphur (\%)} = \frac{\text{Graph ppm} \times \text{Volume of digested sample} \times \text{Volume made up} \times 100}{10^6 \times \text{Weight of sample} \times \text{Aliquot taken}}$$

3.2.10.7 Estimation of zinc (ppm)

The zinc content of plant sample was estimated by feeding the predigested samples to the atomic absorption spectrophotometer having appropriate hollow cathode lamps. The values were recorded and the graph ppm was obtained by drawing the graph. Zinc content of samples is expressed in ppm.

$$\text{Zinc (ppm)} = \frac{\text{Graph ppm} \times \text{Volume of digested sample}}{\text{Weight of sample}}$$

3.2.10.8 Estimation of boron (ppm)

Boron content in the plant samples was determined by hot water extraction method (Berger and Troug, 1939).

$$\text{Boron (ppm)} = \frac{\text{Graph ppm} \times \text{Volume of digested sample}}{\text{Weight of sample}}$$

3.3 Economics of sunflower cultivation

3.3.1 Cost of cultivation (₹ ha⁻¹)

Cost of cultivation was calculated by considering the different variable cost of items and the expenditure incurred for land preparation, seed material, chemical fertilizers, plant protection chemicals, herbicides and labour wages at prevailing market price during the year 2016-2017 in Bengaluru. Labour requirement was worked out on the basis of number of labourers engaged in performing different field operations.

3.3.2 Gross returns (₹ ha⁻¹)

The gross returns per hectare is calculated by multiplying the prevailing market price (₹ q⁻¹) and total yield (kg) obtained per hectare.

$$\text{Gross returns} = \text{market price (₹ ha}^{-1}\text{)} \times \text{seed yield (kg ha}^{-1}\text{)}$$

3.3.3 Net returns (₹ ha⁻¹)

The net returns per hectare is calculated by deducting the cost of cultivation per hectare from the gross returns per hectare.

$$\text{Net returns} = \text{Gross returns (₹ ha}^{-1}\text{)} - \text{Cost of cultivation (₹ ha}^{-1}\text{)}$$

3.3.4 Benefit cost ratio

The benefit cost ratio was worked out as follows.

$$\text{B: C} = \frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

Statistical analysis and interpretation of data

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). Wherever the F-test was found significant for comparison among treatment means, an appropriate value of critical difference (CD) was worked out. Otherwise the abbreviation NS was indicated against the CD values. 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.

IV EXPERIMENTAL RESULTS

The results of the laboratory studies as well as the field experiment on “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)” conducted at Zonal Agricultural Research Station, Gandhi Krishi Vignana Kendra, Bengaluru during late *kharif*- 2016 are presented in this chapter.

4.1 Growth observations in preliminary laboratory experiment

4.2 Growth and growth parameters

4.3 Yield and yield attributes

4.4 Nutrient uptake

4.5 Chemical properties of soil after harvest

4.6 Economics of sunflower cultivation

4.1 Growth observations in preliminary laboratory experiment

4.1.1 Germination (%), root length (cm), shoot length (cm) and vigour index

The data on growth observation made on germination, root length, shoot length and vigour index of sunflower as influenced by the seed treatment with nano boron and borax at different levels are presented in Table 4.1, 4.2 and 4.3.

Laboratory experiment I

Germination (%)

It was observed that the treatments affected the seed germination significantly. Significantly higher seed germination (94.0 %) was recorded in seed treatment with nano boron @ 0.2 % over all other treatments (Table 4.1). However, significantly lower seed germination was recorded with control (80.8 %) and it was on par with seed priming with 0.4 % nano boron (85.5 %), 0.4 % borax (84.4 %) and 0.2 % borax (81.8 %).

Root length (cm)

The data revealed that there was a significant difference with respect to root length at 8 DAS and 15 DAS as influenced by different levels of nano boron and borax seed priming (Table 4.1). At 8 DAS seed priming with nano boron (0.2 %) and control recorded significantly higher root length (5.65 cm and 5.82 cm respectively) compared to all other treatments. However, the root length decreased significantly with the increase in nano boron concentration more than 0.2 %. The lowest root length (2.63 cm) was recorded in seed priming with borax @ 0.4 % followed by seed priming with borax @ 0.2 % (2.84 cm). But similar trend was not observed at 15 DAS. Maximum root length (9.02 cm) was obtained with seed priming of nano boron @ 0.2 % which was significantly superior to all other treatments. The minimum root length was recorded with seed priming with borax @ 0.4 % (4.96 cm) which was on par with seed priming with borax @ 0.2 % (5.21 cm).

Shoot length (cm)

Seed treatment with nano boron and borax at different levels showed a significant influence on seedling vigour index at 8 and 15 DAS (Table 4.1). Significantly higher shoot length was recorded in the control treatment (7.97 cm) and which was on par with the 0.2 % nano boron and 0.4 % nano seed treatment (7.60 and 7.42 cm respectively). But similar trend was not observed at 15 DAS, significantly higher shoot length was recorded with 0.2 % seed treatment with nano boron (11.17 cm) followed by 0.4 % seed treatment with nano boron (10.58 cm). Significantly lower shoot length was recorded with treatment receiving 0.2 % borax seed treatment (6.86 cm).

Vigour index

Different treatments significantly influenced the seedling vigour index at 8 and 15 DAS (Table 4.1). The maximum seedling vigour index was recorded in seed treatment with 0.2 % nano boron at 8 and 15 DAS (1244 and 1899 plant⁻¹, respectively) and which was significantly higher over all other treatments. Significantly lower seedling vigour index was recorded with treatment 0.4 % borax (435 plant⁻¹) at 8 DAS and 0.2 % borax seed treatment at (987 plant⁻¹) 15 DAS.

0.2 % NB 0.2% B Control



0.2 % NB 0.2% B Control



Plate 2: Photographs of the seedling showing differences in root growth after the treatment

Laboratory experiment II

Germination (%)

It was observed that the treatments affected the seed germination significantly. Significantly higher seed germination (94 %) was recorded in seed treatment with nano boron @ 0.2 % seed priming over all other treatments (Table 4.2). However, Significantly lower seed germination was recorded with control (80.9 %) it was on par with seed priming with 0.4 % nano boron (85.5 %), 0.4 % borax (84.4 %) and 0.2 % borax (81.8 %).

Root length (cm)

Different nano boron and borax treatments significantly influenced the root length at 8 and 15 DAS (Table 4.2). Significantly higher root length was recorded with nano boron 0.2% seed priming (6.56, 11.91 cm respectively) at 8 and 15 DAS. Lower root length was recorded with control (3.72 cm) at 8 DAS and 0.2 % borax seed treatment at 15 DAS (5.93 cm) followed by control (6.84 cm).

Shoot length (cm)

The data revealed that there was a significant difference with respect to shoot length at 8 DAS and 15 DAS as influenced by different levels of nano boron and borax seed priming (Table 4.2). Significantly higher shoot length was recorded with treatment 0.2 % nano boron (7.58 cm and 12.71 cm, respectively) at 8 and 15 DAS. Lower shoot length was recorded with 0.4 % borax (2.60 cm) at 8 DAS and 0.2 % borax (7.87 cm) at 15 DAS.

Vigour index

Seed treatment with nano boron and borax at different levels showed a significant influence on seedling vigour index at 8 and 15 DAS (Table 4.2). The maximum seedling vigour index was recorded with 0.2 % nano boron (1329 and 2314 plant⁻¹ respectively). Significantly lower seedling vigour index was recorded with 0.4 % borax seed priming (555.1 plant⁻¹) at 8 DAS and 0.2 % borax (1129 plant⁻¹) at 15 DAS.

Laboratory experiment III

Germination (%)

It was observed that the treatments affected the seed germination significantly. Significantly higher seed germination (88.3 %) was recorded in seed treated with nano boron @ 0.2 % over all other treatments (Table 4.3). However, it was found on par with seed priming with 0.4 % nano boron (81.7 %), 0.6 % nano boron (81.7 %) and seed priming with borax @ 0.2 % and 0.4 % (85 % and 86.7 % respectively). Significant decrease in germination % was observed at higher levels of borax concentrations. Significantly lower germination was recorded in control (75 %) followed by seed priming with borax @ 0.6 % (76.7 %), seed priming with borax @ 0.5 % and nano boron @ 0.5 % (78.3 %).

Root length (cm)

The data revealed that different treatments significantly influenced the root length at 8 DAS and 15 DAS (Table 4.3). Significantly higher root length was recorded with 0.2 % nano boron seed priming (5.65 cm) followed by 0.4 % nano boron seed priming (4.48 cm). Considerably lower root length was recorded with increased concentration of borax. Treatment receiving 0.5 % borax seed priming recorded lower root length (0.48 cm), followed by 0.6 % borax seed priming (0.58 cm).

At 15 DAS maximum root length was recorded with 0.2 % nano boron seed priming (11.4 cm) and lower root length was recorded with treatment 0.6 % borax (1.28 cm) which was on par with 0.5 % borax seed priming (1.30 cm). Higher concentration of borax inhibited the root growth in sunflower.

Shoot length (cm)

The results showed that there was a significant difference with respect to shoot length at 8 DAS and 15 DAS as influenced by different levels of nano boron and borax seed priming (Table 4.3). Significantly maximum shoot growth was recorded with 0.2% nano boron seed priming (7.35 cm). Seed treatment with borax at higher levels

significantly reduced the shoot length, least shoot length (0.93 cm) was recorded with 0.5 % borax seed priming

Similar trend also observed at 15 DAS, seed treatment with nano boron @ 0.2 % recorded significantly higher shoot length (18.14 cm). Lowest shoot length was recorded in 0.6 % borax seed treatment (5.66 cm) and it was on par with 0.5 % borax seed treatment (5.75 cm).

Vigour index

Seed treatment with nano boron and borax at different levels showed a significant influence on seedling vigour index at 8 and 15 DAS (Table 4.3). The maximum seedling vigour index was recorded in 0.2 % nano boron seed priming (1145 and 2608 plant⁻¹ respectively), which was significantly higher over all other treatments. The seedling vigour index tends to decrease at higher levels of borax. Significantly lower seedling vigour index was recorded with treatment receiving 0.5 % borax (109 plant⁻¹) at 8 DAS and it was on par with 0.6 % borax seed priming (121 plant⁻¹). At 15 DAS lower seedling vigour was observed with 0.6 % borax seed priming (532.2 plant⁻¹) and it was on par with 0.5 % borax seed priming (550.3 plant⁻¹).

Tolerance assay

Root growth inhibition of sunflower seeds by boron nano particles and borax.

In order to develop comprehensive toxicity profile for nano boron particles, their phytotoxicity- the ability to cause injury to plants was also investigated. These study examined the effect of five levels of nanoparticles on seed germination (Table 4.3) and seedling growth of sunflower crop and also observed that higher levels (Plates 4) of the nano boron particles had inhibition on root growth of the sunflower seedlings (Blackening of the root tips: Plate 3). This study confirms the toxicity levels of nano boron use in sunflower or inhibition of sunflower seedling growth (root growth) by boron nano particles.

Table 4.1: Germination, root length, shoot length and vigour index of sunflower seedling as influenced by different levels of nano boron and borax seed treatment (8 and 15 DAS, lab studies DOS : 19. 08. 2016 - 02. 09. 2016)

Treatments	8 DAS				15 DAS		
	Germination %	Root length (cm)	Shoot length (cm)	Vigour index	Root length (cm)	Shoot length (cm)	Vigour index
Control	80.8	5.82	7.97	1114	7.44	9.34	1358
0.2 % Nano Boron	94.0	5.65	7.60	1244	9.02	11.17	1899
0.4 % Nano Boron	85.5	4.54	7.42	1022	8.83	10.58	1659
0.2 % Borax	81.8	2.84	4.64	612	5.21	6.86	987
0.4 % Borax	84.4	2.63	2.52	435	4.96	8.07	1104
S Em±	1.58	0.09	0.125	19.9	0.157	0.174	25.52
CD (P= 0.01)	6.54	0.39	0.52	82.3	0.65	0.72	105.4
CV (%)	4.12	4.952	4.624	5.22	4.942	4.219	4.07

Table 4.2: Germination, root length, shoot length and vigour index of sunflower seedling as influenced by different levels of nano boron and borax seed treatment (8 and 15 DAS, lab studies DOS : 03.09.2016 - 17.10.2016)

Treatments	8 DAS				15 DAS		
	Germination %	Root length (cm)	Shoot length (cm)	Vigour index	Root length (cm)	Shoot length (cm)	Vigour index
Control	80.9	3.72	6.88	858	6.84	9.06	1286
0.2 % Nano Boron	94.0	6.56	7.58	1329	11.91	12.71	2314
0.4 % Nano Boron	85.5	4.06	6.80	928	8.16	9.67	1524
0.2 % Borax	81.8	3.79	4.11	646	5.93	7.87	1129
0.4 % Borax	84.4	3.98	2.60	555	8.80	8.85	1489
S Em±	1.68	0.09	0.12	18.1	0.16	0.21	26.62
CD (P= 0.01)	6.98	0.37	0.48	74.7	0.66	0.88	109.95
CV (%)	4.42	4.52	4.65	4.68	4.29	4.92	3.86

Table 4.3: Germination, root length, shoot length and vigour index of sunflower seedling as influenced by different levels of nano boron and borax seed treatment (8 and 15 DAS, lab studies DOS : 3.01. 2017 - 18.01.2017)

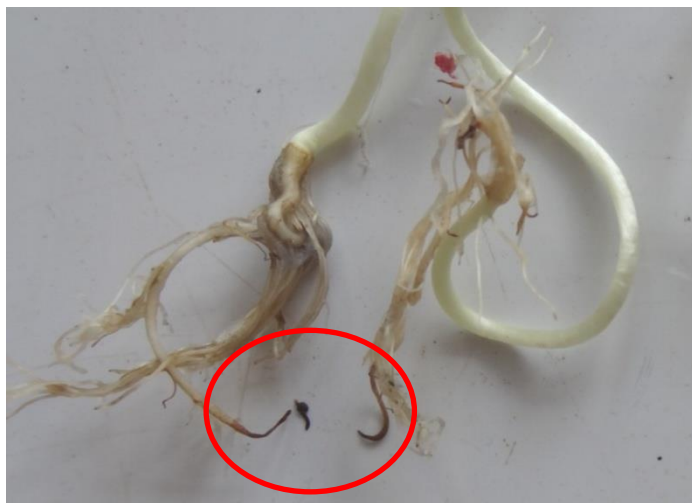
Treatments	8 DAS				15 DAS		
	Germination (%)	Root length (cm)	Shoot length (cm)	Vigour index	Root length (cm)	Shoot length (cm)	Vigour index
Control	75	3.25	6.37	717	7.43	14.30	1619
0.2 % Nano Boron	88.3	5.65	7.35	1145	11.4	18.14	2608
0.4 % Nano Boron	81.7	4.48	6.52	901	8.24	15.91	1973
0.5 % Nano Boron	78.3	3.90	6.05	781	5.08	13.53	1457
0.6 % Nano Boron	81.7	3.01	6.49	777	4.25	12.13	1338
0.2 % Borax	85	2.36	3.56	503	4.89	14.35	1631
0.4 % Borax	86.7	3.15	4.53	668	8.53	14.48	1992
0.5 % Borax	78.3	0.48	0.93	109	1.30	5.75	550
0.6 % Borax	76.7	0.58	1.03	121	1.28	5.66	532
S Em±	2.02	0.14	0.09	16.6	0.27	0.26	36.8
CD (P= 0.01)	7.98	0.57	0.34	65.5	1.05	0.99	146
CV (%)	4.97	9.62	4.084	5.21	9.11	4.52	4.84



0.5 % Nano Boron and Borax



0.5 % and 0.6 % Nano Boron



0.5 % Nano Boron and Borax



0.5 % and 0.6 % Nano Boron

Plate 3: Toxic effect of nano boron treated seedling at 22 days after sowing in petriplates

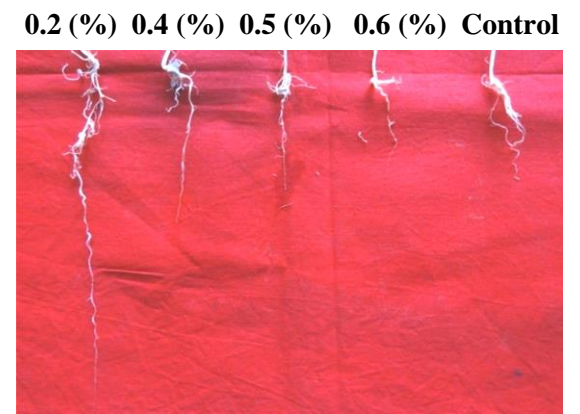


Plate 4: Difference in root growth as influenced by different levels of nano boron seed treatment

Preliminary laboratory results showed that the seed priming with nano boron 0.2 % showed an increase in germination percentage, root and shoot length compared to all other treatments (Plate 2). Germination per cent, shoot and root length decreased significantly with further increase in nano boron concentrations (0.5 % and 0.6 %)

4.2 Field experiment results

The data pertaining to field experiment of sunflower cultivation as influenced by “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)” are presented in the following headings.

4.2.1 Growth and growth parameters

The growth parameters differed significantly due to different treatments at 30 and 60 DAS.

4.2.1.1 Plant height

The data on plant height of sunflower hybrid (KBSH-53) recorded at 30, 60 DAS and at harvest as influenced by different levels and methods of nano boron and borax application are presented in the Table 4.4.

4.2.1.1.1 At 30 days after sowing

Plant height at 30 DAS in sunflower shows significant difference due to different treatments. Treatment with borax @ 0.2 % spray to capitulum at ray floret opening stage recorded significantly higher plant height (23.20 cm) and which was on par with all other treatments except application of borax @ 0.4 % seed priming. While, application of borax @ 0.4 % seed priming recorded significantly lower plant height (18.63 cm).

4.2.1.1.2 At 60 days after sowing

Data on plant height at 60 DAS revealed that different levels and methods of nano boron and borax application significantly influenced the plant height. The higher plant height was recorded with the treatment receiving nano boron @ 0.2 % seed priming (190.5 cm) which was on par with nano boron @ 0.4 % seed priming (185.9 cm), borax

@ 0.2 % seed priming (179.1 cm), borax @ 0.4 % seed priming (184.3 cm), nano boron @ 0.2 % spray to capitulum at ray floret opening stage (184.1), soil application of borax @ 11 kg ha⁻¹ (183 cm) and nano boron @ 0.4 % spray to capitulum at ray floret opening stage (181.1 cm). Significantly lower plant height was recorded with the control (157.1 cm) followed by borax @ 0.4 % spray to capitulum at ray floret opening stage (171.3 cm) and borax @ 0.2 % spray to capitulum at ray floret opening stage (172.5 cm).

4.2.1.1.3 At harvest

Plant height recorded at harvest was found to be non-significant. However, treatment receiving nano boron @ 0.2 % seed priming has recorded higher plant height (196.5 cm) compared to all other treatments. Lower plant height was recorded with control (171.1 cm).

4.2.1.2 Number of leaves

Number of green leaves per plant differed significantly due to the application of different levels and methods of nano boron and borax at 30 and 60 DAS are presented in Table 4.5.

4.2.1.2.1 At 30 days after sowing

Data on number of leaves at 30 DAS revealed that different levels and methods of nano boron and borax application has influenced the number of leaves. At 30 DAS, significantly higher number of green leaves plant⁻¹ was recorded with nano boron @ 0.2 % seed priming (15.33) and which was on par with all other treatments except control and borax @ 0.4 % spray to capitulum at ray floret opening stage. The treatment control has resulted in significantly less number of leaves plant⁻¹ (10.53) followed by borax @ 0.4 % spray to capitulum at ray floret opening stage (13).

4.2.1.2.2 At 60 days after sowing

Seed priming with nano boron @ 0.2 % recorded significantly more number of green leaves plant⁻¹ (26.67) and which was on par with the treatment nano boron @ 0.4 % seed priming and borax @ 0.4 % seed priming (26.27 and 25.93 leaves plant⁻¹,



Plate 5: Field layout of experiment



Plate 6: General view of experimental plot at different growth stages

respectively). While, treatment control has recorded significantly less number of leaves plant⁻¹ (21.33).

4.2.1.3 Leaf area (cm² plant⁻¹)

The data pertaining to leaf area (cm² plant⁻¹) of sunflower recorded at 30 and 60 DAS as influenced by different levels and methods of nano boron and borax application are presented in Table 4.5 and depicted in Fig. 5.4.

4.2.1.3.1 At 30 days after sowing

The leaf area at 30 DAS of sunflower significantly influenced by different levels and methods of nano boron and borax application. Significantly higher leaf area was recorded in application of nano boron @ 0.2 % spray to capitulum at ray floret opening stage (1014 cm² plant⁻¹). Significantly lower leaf area was recorded with the treatment control (610.9 cm² plant⁻¹) followed by the treatment with soil application of borax @ 11 kg ha⁻¹ at the time of sowing (753.5 cm² plant⁻¹).

4.2.1.3.2 At 60 days after sowing

The data pertaining to leaf area indicates that different levels and methods of nano boron and borax application significantly influenced the leaf area plant⁻¹ at 60 DAS. Significantly higher leaf area was recorded with treatment receiving nano boron @ 0.2 % seed priming (10589 cm² plant⁻¹) compared to control (3632 cm² plant⁻¹).

4.2.1.4 Leaf area index

Application of different levels and methods of nano boron and borax application significantly influenced the LAI at 30 and 60 DAS.

4.2.1.4.1 At 30 days after sowing

Higher LAI (0.563) was recorded with the application of nano boron at 0.2 % seed priming which was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (0.492). Lower LAI was recorded with control treatment (0.339).

Table 4.4: Plant height of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	Plant height (cm)		
	30 DAS	60 DAS	At harvest
T ₁ : Control	21.25	157.1	171.1
T ₂ : Nano Boron @ 0.2 % seed priming	22.97	190.5	196.5
T ₃ : Nano Boron @ 0.4 % seed priming	20.47	185.9	188.7
T ₄ : Borax @ 0.2 % seed priming	22.80	179.1	179.7
T ₅ : Borax @ 0.4 % seed priming	18.63	184.3	187.8
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	21.17	184.1	189.1
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	20.63	181.1	184.7
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	23.20	172.5	183.7
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	21.59	171.3	189.4
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	22.73	183.0	186.7
SEm±	1.09	4.87	4.47
CD (P=0.05)	3.23	14.48	NS
CV (%)	8.73	7.72	4.17

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

Table 4.5: 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	Number of leaves per plant		Leaf area (cm ² plant ⁻¹)		Leaf area index	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T ₁ : Control	10.53	21.33	611	3632	0.339	2.02
T ₂ : Nano Boron @ 0.2 % seed priming	15.33	26.67	1014	10589	0.563	5.88
T ₃ : Nano Boron @ 0.4 % seed priming	14.00	26.27	866	8742	0.481	4.86
T ₄ : Borax @ 0.2 % seed priming	13.80	25.00	760	6354	0.422	3.53
T ₅ : Borax @ 0.4 % seed priming	14.14	25.93	797	7562	0.443	4.20
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	13.50	24.20	886	7115	0.492	3.95
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	13.80	24.80	755	6762	0.419	3.76
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	13.67	24.73	828	6770	0.460	3.76
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	13.00	23.67	823	6354	0.457	3.53
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	14.22	23.80	754	7106	0.419	3.95
SEm±	0.77	0.92	40.58	312.9	0.026	0.484
CD (P=0.05)	2.30	2.74	121	930	0.077	1.44
CV (%)	9.85	6.47	8.69	7.63	8.97	6.89

Note : RFO stage- ray floret opening stage

4.2.1.4.2 At 60 days after sowing

Significantly higher LAI (5.88) was recorded with nano boron at 0.2 % seed priming which was on par with nano boron @ 0.4 % seed priming (4.86). Lower LAI was recorded with the control (2.02).

4.2.1.5 Dry matter production and distribution

The total dry matter accumulation and its distribution in root and shoot (stalk and leaves) were recorded at 30 and 60 DAS are presented in Table 4.6.

4.2.1.5.1 Root dry matter production (g plant⁻¹)

Data pertaining to root dry matter production at 30 and 60 DAS as influenced by different nano boron and borax fertilization are presented in Table 4.6.

4.2.1.5.1.1 At 30 days after sowing

Among different treatments significantly higher root dry matter production was recorded with nano boron @ 0.2 % seed priming (2.43 g plant⁻¹) and significantly lower root dry weight was recorded with control treatment (1.38 g plant⁻¹) followed by the application of borax @ 0.2 % spray to capitulum at ray floret opening stage (1.54 g plant⁻¹).

4.2.1.5.1.2 At 60 days after sowing

Application of nano boron @ 0.2 % seed priming recorded significantly higher root dry weight (15.70 g plant⁻¹) as compared to rest of the treatments. Whereas, lower root dry weight was recorded with control (5.71 g plant⁻¹) followed by the treatments receiving borax @ 0.2 % seed priming (7.63 g plant⁻¹) and borax @ 0.2 % spray to capitulum at ray floret opening stage (7.63 g plant⁻¹).

4.2.1.5.2 Shoot dry matter production

4.2.1.5.2.1 At 30 days after sowing

The shoot dry matter production recorded at 30 DAS was significantly higher with application of nano boron @ 0.2 % seed priming (15.90 g plant⁻¹) and which was on par with soil application of borax @ 11 kg ha⁻¹(15.43 g plant⁻¹) at the time of sowing. However, lower dry weight of shoot recorded with control treatment (11.07 g plant⁻¹) followed by borax @ 0.2 % spray to capitulum at ray floret opening stage (12.57 g plant⁻¹).

4.2.1.5.2.2 At 60 days after sowing

The shoot dry matter production recorded at 60 DAS was significantly higher with the application of nano boron @ 0.2 % seed priming (85.87 g plant⁻¹), the result was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (79.27 g plant⁻¹) and nano boron @ 0.4 % seed priming (79.0 g plant⁻¹). Control treatment had shown significantly lower shoot dry weight (52.3 g plant⁻¹).

4.2.1.5.3 Total dry matter production

4.2.1.5.3.1 At 30 days after sowing

The total dry matter production recorded at 30 DAS was significantly higher with treatment receiving nano boron @ 0.2 % seed priming (18.33 g plant⁻¹). The result was on par with the soil application of borax @ 11 kg ha⁻¹ (17.42 g plant⁻¹) at the time of sowing. The control treatment had shown significantly lower total dry weight (12.45 g plant⁻¹) at 30 DAS.

4.2.1.5.3.2 At 60 days after sowing

Results indicated that there was a significant difference with respect to total dry matter production due to different methods of nano boron and borax fertilization at 60 days after sowing. Higher total dry matter production per plant was recorded with nano boron @ 0.2 % seed priming (101.6 g) compared to control (58.01 g) treatment.

4.2.1.5.4 Root to shoot ratio

The data pertaining to root to shoot ratio as influenced by different nano boron and borax fertilization at 30 and 60 DAS are presented in Table 4.7.

4.2.1.5.4.1 At 30 days after sowing

Application of different methods and levels of nano boron and borax influenced significantly the root to shoot ratio at 30 DAS. Application of nano boron @ 0.2 % seed priming has recorded higher root to shoot ratio (0.153). The result was on par with the treatment receiving nano boron @ 0.4 % seed priming (0.144) and control treatment showed lower root to shoot ratio (0.119).

4.2.1.5.4.1.2 At 60 days after sowing

Results showed that there was a significant difference with respect to root to shoot ratio due to different nano boron and borax nutrition at 60 days after sowing. Higher root to shoot ratio was recorded in nano boron @ 0.2 % seed priming (0.18) compared to control (0.11) and nano boron @ 0.2 % spray to capitulum at ray floret opening stage (0.11).

4. 2.1.6 SPAD Chlorophyll Meter Reading (SCMR) values

Data pertaining to SCMR values as influenced by different levels and methods of nano boron and borax application in sunflower at 30 and 60 DAS are presented in Table 4.8.

4. 2.1.6.1 At 30 days after sowing

The SPAD chlorophyll meter values at 30 DAS in sunflower differed significantly due to different treatments. Significantly higher SCMR was recorded with the application of nano boron @ 0.2 % seed priming (37.13) and which was on par with borax @ 0.4 % seed priming (36.67). Lower SCMR values was recorded in borax @ 0.2 % spray to capitulum at ray floret opening stage (33.97).

Table 4.6: 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	1.38	11.07	12.45	5.71	52.30	58.01
T ₂ : Nano Boron @ 0.2 % seed priming	2.43	15.90	18.33	15.70	85.87	101.6
T ₃ : Nano Boron @ 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 @ 0.2 % spray to capitulum at RFO stage	1.70	14.33	16.03	9.04	79.27	88.30
T ₇ : Nano Boron @ 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 4.7: 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	0.119	0.110
T ₂ : Nano Boron @ 0.2 % seed priming	0.153	0.180
T ₃ : Nano Boron @ 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 @ 0.2 % spray to capitulum at RFO stage	0.125	0.110
T ₇ : Nano Boron @ 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 4.8: 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
	30 DAS	60 DAS	
T ₁ : Control	34.57	33.43	69.00
T ₂ : Nano Boron @ 0.2 % seed priming	37.13	44.50	61.33
T ₃ : Nano Boron @ 0.4 % seed priming	34.93	40.33	62.00
T ₄ : Borax @ 0.2 % seed priming	34.80	37.40	66.67
T ₅ : Borax @ 0.4 % seed priming	36.67	35.43	67.33
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	35.80	43.53	65.67
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	35.77	39.93	66.67
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	33.97	34.67	67.67
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	34.93	41.90	67.33
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	35.43	37.40	68.00
SEm±	0.35	1.23	1.16
CD (P=0.05)	1.05	3.64	3.45
CV (%)	1.72	5.52	3.03

Note : RFO stage- ray floret opening stage

4.2.1.6.2 At 30 days after sowing

The data indicates that application of different levels and methods of nano boron and borax in sunflower influenced the SCMR significantly at 60 DAS. Higher SCMR was recorded in the treatment receiving nano boron @ 0.2 % spray to capitulum at ray floret opening stage (44.50) and which is on par with the nano boron @ 0.2 % spray to capitulum at ray floret opening stage (43.53) and borax @ 0.4 % spray to capitulum at ray floret opening stage (41.90). Significantly lower SCMR was recorded in control (33.43).

4.2.1.7 Days to 50 per cent flowering

Days to 50 per cent flowering was found to be significant due to different levels and methods of nano boron and borax application in sunflower are presented in Table 4.8 and Plate 7. It was observed that the application of nano boron @ 0.2 % seed priming has influenced the days for 50 per cent flowering (61.33) significantly compared to other treatments, the result was on par with the nano boron @ 0.4 % seed priming (62). Whereas treatment control has taken 69 days for 50 % flowering followed by soil application of borax @ 11 kg ha⁻¹ (68).

4.3 Yield and yield attributes

4.3.1 Days to physiological maturity, plant stand at maturity, capitulum diameter (cm) and stem girth (cm)

The data pertaining to days to physiological maturity, plant stand at maturity, stem girth and capitulum diameter as influenced by different levels and methods of nano boron and borax application are presented in Table 4.9.

4.3.1.1 Days to physiological maturity

It is evident from the results, that nano boron @ 0.2 % seed priming hastened physiological maturity (84 days) which was on par with the nano boron @ 0.4 % seed priming (86.33 days) compared to control (93 days).



Nano boron seed priming



Borax seed priming

Nano boron seed priming

Borax seed priming

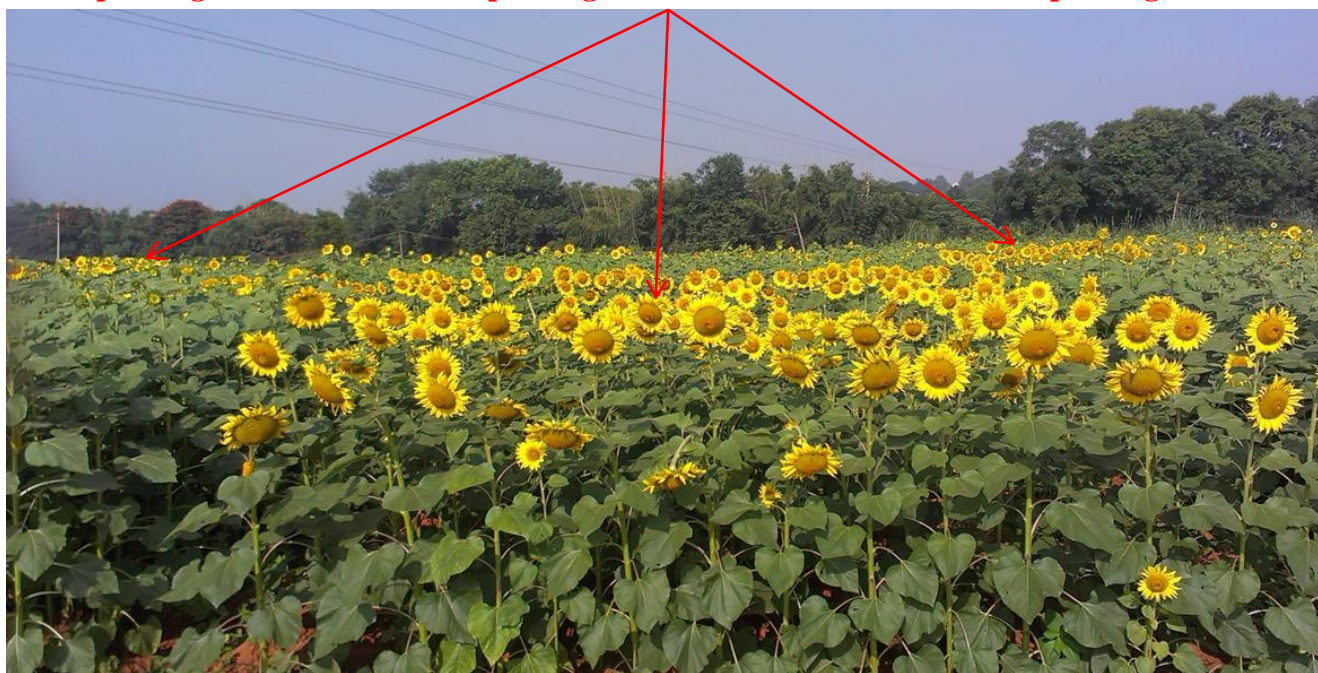


Plate 7: Early flowering in Nano boron treated plots

4.3.1.2 Plant stand at maturity

The observation on plant stand at maturity revealed that there was no significant difference with respect to plant stand at maturity. However, soil application of borax @ 11 kg ha⁻¹ at the time of sowing recorded higher plant stand (115) at maturity followed by 0.2 % nano boron seed priming (114).

4.3.1.3 Stem girth (cm)

Stem girth in sunflower at harvest responded significantly due to different levels and methods of nano boron and borax fertilization. Higher stem girth recorded with treatment receiving nano boron @ 0.2 % seed priming (2.97 cm). Whereas significantly lower stem girth was recorded with control treatment (2.19 cm).

4.3.1.4 Head diameter (cm)

Data revealed that different levels and methods of nano boron and borax fertilization did not influenced the head diameter significantly. However, higher head diameter was recorded in treatment borax @ 0.4 % spray to capitulum at ray floret opening stage (15.40 cm) compared to control (14.47 cm).

4.3.1.5 100 seed weight (g 100 seeds⁻¹)

Significant difference was noticed in test weight due to the different levels and methods of nano boron and borax application (Table 4.10). Significantly higher test weight was recorded with application of nano boron @ 0.2 % spray to capitulum ray floret opening stage (5.23 g), which was on par with nano boron @ 0.2 % seed priming (4.78 g) and nano boron @ 0.4 % spray to capitulum at ray floret opening stage (4.77 g). Significantly less test weight was recorded in control treatment (3.78 g).

4.3.1.6 Volume weight (g 100 ml⁻¹)

The data revealed that different treatments significantly influenced the volume weight due to the application of different treatments (Table 4.10). Application of nano boron @ 0.2 % spray to ray floret opening stage recorded significantly higher volume weight (46.60 g 100 ml⁻¹) which was on par with borax @ 0.4 % spray to capitulum ray

floret opening stage (46.36 g 100 ml⁻¹), nano boron @ 0.2 % seed priming (46.17 g 100 ml⁻¹) and borax @ 0.2 % spray to capitulum at ray floret opening stage (44.40 g 100 ml⁻¹). Significantly less volume weight was recorded in borax @ 0.2 % seed priming (40.00 g 100 ml⁻¹) which was found to be on par with borax @ 0.4 % seed priming (40.90 g 100 ml⁻¹).

4.3.2 Seed yield per plant (g), number of seed per capitulum and chaffiness percentage

The data on seed yield plant⁻¹, total seed (capitulum⁻¹) and chaffiness (%) as influenced by different levels and methods of nano boron and borax application are presented in the Table 4.10.

4.3.2.1 Seed yield per plant (g)

Seed yield was significantly influenced by different levels and methods of nano boron and borax application. Significantly higher seed yield was recorded in nano boron @ 0.2 % seed priming (63.55 g plant⁻¹) and which was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (63.17 g plant⁻¹), nano boron @ 0.4 % spray to capitulum at ray floret opening stage (60.13 g plant⁻¹) and nano boron @ 0.4 % seed priming (57.55 g plant⁻¹). Lower seed yield plant⁻¹ was recorded in control treatment (39.67 g plant⁻¹) followed by borax @ 0.2 % spray to capitulum at ray floret opening stage (48.32 g plant⁻¹).

4.3.2.2 Number of seeds per capitulum

Total number of seed per capitulum was significantly differed due to application different levels and methods of nano boron and borax. Application of nano boron @ 0.2 % spray to capitulum ray floret opening stage has shown significantly higher number of total seeds per capitulum (1384) which was on par with application nano boron @ 0.2 % seed priming (1326). Significantly lower number of total seeds per capitulum (1059) was recorded in borax @ 0.4 % seed priming, which was on par with borax @ 0.2 % seed priming (1089) and control (1094).

4.3.2.3 Number of filled seeds per capitulum

Number of filled seeds per capitulum was significantly higher with the application of nano boron @ 0.2 % spray to capitulum at ray floret opening stage (1355), which was on par with application nano boron @ 0.2 % seed priming (1293). Significantly less number of filled seeds per capitulum were recorded in control treatment (974) followed by the treatment borax @ 0.4 % seed priming (975).

4.3.2.4 Number of unfilled seeds number per capitulum

Significantly higher number of unfilled seeds per capitulum was found in control treatment (119.9), which was followed by application of borax @ 0.4 % seed priming (84). The number of unfilled seeds per capitulum recorded less in treatment with the application of nano boron @ 0.2 % spray to capitulum ray floret opening stage (28.51) followed by nano boron @ 0.2 % seed priming (33.20).

4.3.2.5 Per cent chaffiness

It was observed that the application of different levels and methods of nano boron and borax significantly influenced the per cent chaffiness in sunflower. Chaffiness percentage was significantly reduced in the treatment receiving nano boron @ 0.2 % spray to capitulum at ray floret opening stage (2.10 %), which was on par with the application of borax @ 0.2 % spray to capitulum at ray floret opening stage (2.50 %). The control treatment has resulted in higher per cent chaffiness (11 %).

4.3.3 Seed yield (kg ha⁻¹), stalk yield (kg ha⁻¹), oil content (%), oil yield (kg ha⁻¹) and harvest index

Data pertaining to seed yield (kg ha⁻¹), stalk yield (kg ha⁻¹), oil content (%), oil yield (kg ha⁻¹) and harvest index as influenced by different levels and methods of nano boron and borax application are presented in the Table 4.11.

4.3.3.1 Seed yield (kg ha⁻¹)

Seed yield was significantly influenced by application of nano boron and borax at different levels and methods.

Table 4.9: 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 @ 0.2 % seed priming	84.00	114	2.97	15.07
T ₃ : Nano Boron @ 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 @ 0.2 % spray to capitulum at RFO stage	92.00	113	2.44	15.00
T ₇ : Nano Boron @ 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 4.10: 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 @ 0.2 % seed priming	4.78	46.17	63.55	1293	33.20	1326	2.50
T ₃ : Nano Boron @ 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 @ 0.2 % spray to capitulum at RFO stage	5.23	46.60	63.17	1355	28.51	1384	2.10
T ₇ : Nano Boron @ 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 4.11: Seed yield, stalk yield, oil content, oil yield and harvest index 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)	Oil content (%)	Oil yield (kg ha ⁻¹)	HI
T ₁ : Control	1629	4429	34.96	570	0.27
T ₂ : Nano Boron @ 0.2 % seed priming	2788	5256	36.74	1022	0.35
T ₃ : Nano Boron @ 0.4 % seed priming	2451	5072	36.13	887	0.32
T ₄ : Borax @ 0.2 % seed priming	2107	4969	35.56	750	0.30
T ₅ : Borax @ 0.4 % seed priming	2084	4529	36.04	752	0.31
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	2773	5069	36.34	1006	0.35
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	2422	4948	36.24	878	0.33
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	2061	4910	34.68	714	0.30
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	2176	4925	35.34	768	0.31
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	2424	5037	34.57	839	0.32
SEm±	156.5	88.35	0.65	37.06	0.02
CD (P=0.05)	464.9	262.51	NS	110.10	0.03
CV (%)	11.83	6.11	3.14	7.84	8.25

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

Significantly higher seed yield (2788 kg ha⁻¹) was 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 kg ha⁻¹) and soil application of borax @ 11 kg ha⁻¹ (2424 kg ha⁻¹) at the time of sowing. Significantly lowest seed yield was recorded with control (1629 kg ha⁻¹).

4.3.3.2 Stalk yield (kg ha⁻¹)

Stalk yield significantly responded to different levels and methods of nano boron and borax application in sunflower.

Application of nano boron @ 0.2 % seed priming recorded significantly higher stalk yield (5256 kg ha⁻¹) which was on par with nano boron @ 0.4 % seed priming (5072 kg ha⁻¹), nano boron @ 0.2 % spray to capitulum at ray floret opening stage (5069 kg ha⁻¹) and soil application of borax @ 11 kg ha⁻¹ (5037 kg ha⁻¹). The control treatment had shown significantly lower stalk yield (4429 kg ha⁻¹) which was on par with borax @ 0.4 % seed priming of seed (4529 kg ha⁻¹).

4.3.3.3 Oil content (%)

Oil content did not differ significantly due to different levels and methods of nano boron and borax application. However higher oil content (36.74 %) was recorded with application of nano boron @ 0.2 % seed priming followed by nano boron @ 0.2 % spray to ray floret opening stage (36.34 %).

4.3.3.4 Oil yield (kg ha⁻¹)

Different treatments significantly influenced the oil yield in sunflower due to application of different treatments. Significantly higher oil yield was recorded with nano boron @ 0.2 % seed priming (1022 kg ha⁻¹) compared to all other treatments. The result was on par with application of nano boron @ 0.2 % spray to capitulum at ray floret opening stage (1006 kg ha⁻¹). Significantly lower oil yield was recorded in control treatment (570 kg ha⁻¹) followed by borax @ 0.2 % spray to capitulum at ray floret opening stage (714 kg ha⁻¹).

4.3.3.5 Harvest index

It was observed that different treatments significantly influenced the harvest index in sunflower. Harvest index was significantly higher with the application of nano boron @ 0.2 % seed priming (0.35) and nano boron @ 0.2 % spray to capitulum at ray floret opening stage (0.35) compared to other treatments. However, the result was on par with nano boron @ 0.4 % spray to capitulum at ray floret opening stage (0.33) and nano boron @ 0.4 % seed priming (0.32). Significantly lower harvest index was recorded with treatment control (0.27).

4.4 Nutrient uptake

Data on the uptake of major nutrients (nitrogen, phosphorus, potassium), secondary nutrient (sulphur) and micronutrients (zinc and boron) at harvest as influenced by different levels and methods of nano boron and borax application are presented in the Tables 4.12, 4.13 and fig. 5.6, 5.7.

4.4.1 Nitrogen (kg ha^{-1})

Data pertaining to uptake of nitrogen in sunflower (kg ha^{-1}) are presented in the Table 4.12.

4.4.1.1 Accumulation of nitrogen by seed

Accumulation of nitrogen in sunflower significantly influenced by different levels and methods of nano boron and borax application. Higher seed nitrogen accumulation was recorded with nano boron @ 0.2 % seed priming (86.57 kg ha^{-1}), which was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (84.48 kg ha^{-1}), nano boron @ 0.4 % seed priming (84.34 kg ha^{-1}) and soil application of borax @ 11 kg ha^{-1} at the time of sowing (84.17 kg ha^{-1}). Significantly lower seed nitrogen was recorded with control (60.91 kg ha^{-1}) followed by borax @ 0.4 % seed priming (71.30 kg ha^{-1}).

4.4.1.2 Accumulation of nitrogen by stalk

Accumulation of nitrogen in sunflower stalk was significantly higher with the treatment receiving nano boron @ 0.2 % seed priming (28.01 kg ha⁻¹) which was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (27.79 kg ha⁻¹), borax @ 0.2 % seed priming (26.92 kg ha⁻¹) and soil application of borax @ 11 kg ha⁻¹ at the time of sowing (25.99 kg ha⁻¹). The control treatment showed significantly less nitrogen accumulation in stalk (19.50 kg ha⁻¹).

4.4.1.3 Total nitrogen uptake

Total uptake of nitrogen in sunflower was found to be significantly higher with the application Nano boron @ 0.2 % seed priming (114.58 kg ha⁻¹) compared to all other treatments. The control treatment showed significantly less total nitrogen accumulation in sunflower (80.41 kg ha⁻¹).

4.4.2 Phosphorus uptake (kg ha⁻¹)

The data on uptake of phosphorus in sunflower (kg ha⁻¹) as influenced by levels and methods of nano boron and borax application are presented in the Table 4.12.

4.4.2.1 Accumulation of phosphorus by seeds

Phosphorus uptake by sunflower seeds responded significantly to different nutrient application methods. Higher phosphorus uptake (20.10 kg ha⁻¹) was recorded with nano boron @ 0.2 % seed priming which was on par nano boron @ 0.2 % spray to capitulum at ray floret opening stage (18.45 kg ha⁻¹). The control treatment showed significantly less phosphorous accumulation in seed (10.60 kg ha⁻¹).

4.4.2.2 Accumulation of phosphorus by stalk

Accumulation of phosphorus in sunflower stalk was significantly higher with the treatment receiving Nano boron @ 0.2 % seed priming (13.57 kg ha⁻¹) compared to other treatments. The results was on par with with soil application of borax @ 11 kg ha⁻¹ (13.55 ka ha⁻¹), nano boron @ 0.4 % seed priming (13.19 ka ha⁻¹) and nano boron @ 0.2 %

spray to capitulum at ray floret opening stage (13.01 kg ha⁻¹). The control treatment showed significantly less phosphorous accumulation in stalk (8.65 kg ha⁻¹).

4.4.2.3 Total phosphorus uptake

Total uptake of phosphorous in sunflower was found to be significantly higher under the application of Nano boron @ 0.2 % seed priming (33.67 kg ha⁻¹) compared to other treatments. It was on par with application of nano boron @ 0.2 % spray to capitulum at ray floret opening stage (31.46 kg ha⁻¹), soil application of borax @ 11 kg ha⁻¹ (30.57 kg ha⁻¹) and nano boron @ 0.2 % seed priming (30.45 kg ha⁻¹). The control treatment showed significantly less total phosphorous accumulation in sunflower (19.25 kg ha⁻¹).

4.4.3 Potassium uptake (kg ha⁻¹)

The data on uptake of potassium in sunflower (kg ha⁻¹) as influenced by levels and methods of nano boron and borax application are presented in the Table 4.12.

4.4.3.1 Accumulation of potassium by seed

Significantly higher potassium accumulation by sunflower seed was recorded with nano boron @ 0.2% spray to capitulum at ray floret opening stage (25.67 kg ha⁻¹) which was on par with Nano boron @ 0.2 % seed priming (24.17 kg ha⁻¹). The control treatment showed significantly less potassium accumulation in seed (17.97 kg ha⁻¹).

4.4.3.2 Accumulation of potassium by stalk

Accumulation of potassium in sunflower stalk was significantly higher with the application of nano boron @ 0.2% spray to capitulum at ray floret opening stage (48.93 kg ha⁻¹) compared to other treatments. The control treatment showed significantly less potassium accumulation in stalk (41.97 kg ha⁻¹).

4.4.3.3 Total potassium uptake

Total uptake of potassium in sunflower was found to be significantly higher under the application of nano boron @ 0.2 % spray to capitulum at ray floret opening stage

(74.60 kg ha⁻¹) compared to other treatments. It was on par with Nano boron @ 0.2 % seed priming (72.67 kg ha⁻¹), soil application of borax @ 11 kg ha⁻¹ (71.43 kg ha⁻¹) and nano boron @ 0.4 % spray to capitulum at ray floret opening stage (70.21 kg ha⁻¹). The control treatment showed significantly less total potassium accumulation in sunflower (59.94 kg ha⁻¹).

4.4.4 Sulphur uptake (kg ha⁻¹)

The data on uptake of sulphur in sunflower (kg ha⁻¹) as influenced by levels and methods of nano boron and borax application are presented in the Table 4.13.

4.4.4.1 Accumulation of sulphur by seed

Significantly higher sulphur accumulation by sunflower seed was recorded with the application of Nano boron @ 0.2 % seed priming (11.3 kg ha⁻¹). It was on par with the application of Nano boron @ 0.2 % spray to capitulum at ray floret opening stage (11.1 kg ha⁻¹). The control treatment showed significantly less sulphur accumulation in seed (7.70 kg ha⁻¹).

4.4.4.2 Accumulation of sulphur by stalk

Sulphur accumulation by sunflower stalk was significantly higher under the treatment Nano boron @ 0.2 % seed priming (10.2). The treatment without boron showed significantly less sulphur accumulation in seed (6.0 kg ha⁻¹).

4.4.4.3 Total sulphur uptake

The total uptake of sulphur by sunflower was significantly higher under the treatment receiving nano @ 0.2 % seed priming (21.5 kg ha⁻¹) and which was on par with 0.2 % nano boron spray to capitulum at ray floret stage (20.3 kg ha⁻¹). The control treatment showed significantly less sulphur accumulation in sunflower (13.7 kg ha⁻¹).

4.4.5 Zinc uptake (g ha⁻¹)

The data on uptake of zinc in sunflower (g ha⁻¹) as influenced by levels and methods of nano boron and borax application are presented in the Table 4.13.

4.4.5.1 Accumulation of zinc by seed

Zinc uptake by sunflower significantly differed with nano boron and borax fertilization methods. Application of Nano boron @ 0.2 % spray to capitulum at ray floret opening stage (190.4 g ha^{-1}) compared to all other treatments. The control treatment showed significantly less zinc accumulation in seed (157.8 kg ha^{-1}).

4.4.5.2 Accumulation of zinc by stalk

Significantly higher zinc accumulation in sunflower stalk was recorded with the application of nano @ 0.2 % seed priming (358.7 g ha^{-1}). The result was on par with the application of borax @ 0.4 % spray to capitulum at ray floret opening stage (348.3 g ha^{-1}), nano boron @ 0.4 % spray to capitulum at ray floret opening stage (348.8 g ha^{-1}), nano boron @ 0.2 % spray to capitulum at ray floret opening stage (347.1 g ha^{-1}), soil application of borax @ 11 kg ha^{-1} (333.3 g ha^{-1}). Significantly lower zinc accumulation was recorded with control treatment (271.1 g ha^{-1}).

4.4.5.3 Total zinc uptake

Total zinc uptake significantly influenced by different method and levels of nano boron and borax fertilization. Higher zinc uptake was recorded with nano @ 0.2 % seed priming (547.1 g ha^{-1}) compared to all other treatments. The control treatment showed significantly less total zinc accumulation in sunflower (429.4 g ha^{-1}).

4.4.6 Boron uptake (g ha^{-1})

The data on uptake of boron in sunflower (g ha^{-1}) as influenced by levels and methods of nano boron and borax application are presented in the Table 4.13.

4.4.6.1 Accumulation of boron by seed

Significantly higher boron accumulation by sunflower seed was recorded with the application of nano boron @ 0.4 % spray to capitulum at ray floret opening stage (170.8 g ha^{-1}). The treatment with borax @ 0.4 % seed priming showed significantly less boron accumulation by seed (117.00 g ha^{-1}).

Table 4.12: Nitrogen, phosphorous and potassium uptake in sunflower as influenced by different levels and methods of nano boron and borax application

Treatment	Nitrogen (kg ha ⁻¹)			Phosphorous (kg ha ⁻¹)			Potassium (kg ha ⁻¹)		
	Seed	Stalk	Total	Seed	Stalk	Total	Seed	Stalk	Total
T ₁ : Control	60.91	19.50	80.41	10.60	8.65	19.25	17.97	41.97	59.94
T ₂ : Nano Boron @ 0.2 % seed priming	86.57	28.01	114.58	20.10	13.57	33.67	24.17	48.51	72.67
T ₃ : Nano Boron @ 0.4 % seed priming	84.34	26.69	111.03	17.26	13.19	30.45	21.13	45.33	66.47
T ₄ : Borax @ 0.2 % seed priming	74.78	26.92	101.70	14.58	10.34	24.92	20.90	44.73	65.64
T ₅ : Borax @ 0.4 % seed priming	71.30	23.65	94.95	14.07	10.22	24.28	19.33	43.12	62.45
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	84.48	27.79	112.27	18.45	13.01	31.46	25.67	48.93	74.60
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	79.51	23.65	103.16	15.25	11.57	26.82	23.20	47.01	70.21
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	68.80	22.21	91.00	13.00	10.23	23.23	21.23	45.12	66.35
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	77.46	22.57	100.04	15.25	10.62	25.87	20.54	45.19	65.73
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	84.17	25.99	110.17	17.02	13.55	30.57	22.90	48.53	71.43
SEm±	1.82	0.88	4.57	0.61	0.54	0.79	0.79	2.04	2.20
CD (P=0.05)	5.40	2.62	13.57	1.82	1.60	2.34	2.35	6.06	6.55
CV (%)	4.08	6.19	7.76	6.80	8.14	5.17	6.32	7.71	5.65

Note : RFO stage- ray floret opening stage

Table 4.13: Sulphur, Zinc and Boron uptake in sunflower as influenced by different levels and methods of nano boron and borax application

Treatment	Sulphur (kg ha ⁻¹)			Boron (g ha ⁻¹)			Zinc (g ha ⁻¹)		
	Seed	Stalk	Total	Seed	Stalk	Total	Seed	Stalk	Total
T ₁ : Control	7.70	6.00	13.7	120.0	75.33	195.3	157.8	271.6	429.4
T ₂ : Nano Boron @ 0.2 % seed priming	11.3	10.20	21.5	130.8	88.53	219.4	188.4	358.7	547.1
T ₃ : Nano Boron @ 0.4 % seed priming	9.70	8.80	18.5	132.3	86.67	219.0	185.1	331.4	516.5
T ₄ : Borax @ 0.2 % seed priming	9.00	8.20	17.2	127.3	90.21	217.5	180.5	317.7	498.2
T ₅ : Borax @ 0.4 % seed priming	8.80	6.50	15.3	117.0	77.68	194.7	172.8	300.7	473.4
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	11.10	9.20	20.3	159.8	96.70	256.5	190.4	347.1	537.5
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	8.80	8.60	17.4	170.8	95.07	265.8	182.8	348.8	531.6
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	7.80	6.80	14.6	145.3	93.53	238.9	165.0	294.7	459.7
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	8.70	7.90	16.7	153.3	94.73	248.1	179.6	348.3	513.0
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	9.60	8.80	18.4	132.7	96.00	228.7	185.3	333.3	518.7
SEm±	0.30	0.30	0.60	3.045	2.128	3.539	6.4	8.9	12.51
CD (P=0.05)	0.90	0.90	1.90	9.05	6.32	10.52	18.9	26.5	37.19
CV (%)	5.80	6.70	6.50	3.80	4.12	2.68	6.20	4.70	5.60

Note : RFO stage- ray floret opening stage

4.4.6.2 Accumulation of boron by stalk

Boron accumulation by sunflower stalk was significantly higher with treatment receiving nano boron @ 0.2 % spray to capitulum at ray floret opening stage (96.70 g ha⁻¹) compared to other treatments. It was on par with the application of soil application of borax @ 11 kg ha⁻¹ (96.00 g ha⁻¹), nano boron @ 0.4 % spray to capitulum at ray floret opening stage (95.07 g ha⁻¹), borax @ 0.4 % spray to capitulum at ray floret opening stage (94.73 g ha⁻¹) and borax @ 0.2 % spray to capitulum at ray floret opening stage (93.53 g ha⁻¹). The control treatment showed significantly less boron accumulation by stalk (75.33 g ha⁻¹).

4.4.6.3 Total boron uptake

The total uptake of boron by sunflower was significantly higher with the application of nano boron @ 0.4 % spray to capitulum at ray floret stage (265.81g ha⁻¹). The result was on par with the application of nano boron @ 0.2 % spray to capitulum at ray floret stage (256.45 g ha⁻¹). Significantly lower total boron uptake was recorded with borax @ 0.4 % seed priming (194.68 g ha⁻¹).

4.5 Chemical properties of soil after harvest

The soil was analysed after the harvest of the crop from each treatment plot for the different chemical parameters and are presented in Table 4.14.

4.5.1 pH

No significant difference was observed among the treatments with respect to pH. All the treatments recorded nearly neutral pH ranging from 6.07 in nano boron @ 0.4 % seed priming to 6.50 in borax @ 0.2 % spray to capitulum at ray floret opening stage.

4.5.2 Electrical Conductivity (dSm⁻¹)

No significant difference was observed among the treatments with respect to electrical conductivity (EC). It ranges from 0.10 d Sm⁻¹ to 0.23 d Sm⁻¹ among the treatments.

4.5.3 Soil Organic Carbon (%)

Soil organic carbon status after harvest of sunflower crop did not influenced by different nutrient levels and methods of nano boron application. It ranges from 0.43 % to 0.5 % among different treatments.

4.5.4 Available Nitrogen in soil (N kg ha⁻¹)

Different nano boron application methods significantly influenced the available status of soil after harvest of sunflower crop. Higher available nitrogen content was recorded with control treatment (279.9 kg ha⁻¹) which was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (275.3 kg ha⁻¹) and nano boron @ 0.4 % seed priming (274 kg ha⁻¹). Significantly lower soil nitrogen was recorded with borax @ 0.4 % seed priming (219.3 kg ha⁻¹).

4.5.5 Available phosphorus in soil (P₂O₅ kg ha⁻¹)

Available phosphorus content of soil after harvest of sunflower crop did not responded to different method and levels of nano boron and borax application methods significantly. However, higher build up of available phosphorus content was recorded with nano boron @ 0.4 % seed priming (42.10 kg ha⁻¹) followed by borax @ 0.2 % spray to capitulum at ray floret opening stage (41.87 kg ha⁻¹).

4.5.6 Available potassium in soil (K₂O kg ha⁻¹)

Nano boron nutrition in sunflower crop significantly influenced the available status of soil after harvest. Higher (284.3 kg ha⁻¹) available potassium content was recorded with Soil application of borax @ 11 kg ha⁻¹ and which was on par with borax @ 0.2 % spray to capitulum at ray floret opening (273.4 ka ha⁻¹), control (273.3 ka ha⁻¹) and nano boron @ 0.4 % seed priming (270.9 ka ha⁻¹). Significantly lower potassium was recorded with borax @ 0.4 % seed priming (220.9 ka ha⁻¹) followed by nano boron @ 0.2 % spray to capitulum at ray floret opening stage (222.0 kg ha⁻¹).

Table 4.14: Chemical properties of soil after harvest of sunflower as influenced by different levels and methods of nano boron and borox application

Treatment	pH	EC (dSm ⁻¹)	OC (%)	Available N (kg ha ⁻¹)	Available P ₂ O ₅ (kg ha ⁻¹)	Available K ₂ O (kg ha ⁻¹)	Boron (ppm)	Zinc (ppm)	Sulphur (ppm)
T ₁ : Control	6.49	0.12	0.43	279.9	39.33	273.3	0.29	0.71	12.44
T ₂ : Nano Boron @ 0.2 % seed priming	6.25	0.21	0.46	266.3	41.26	259.6	0.38	0.99	12.88
T ₃ : Nano Boron @ 0.4 % seed priming	6.07	0.22	0.48	274.0	42.10	270.9	0.39	1.22	12.48
T ₄ : Borax @ 0.2 % seed priming	6.42	0.16	0.49	251.5	40.77	228.2	0.32	0.79	12.51
T ₅ : Borax @ 0.4 % seed priming	6.34	0.13	0.45	219.3	38.70	220.9	0.34	0.87	12.73
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	6.33	0.23	0.50	275.3	41.07	222.0	0.42	1.01	14.33
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	6.48	0.12	0.48	226.3	41.25	224.3	0.29	0.87	14.42
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	6.50	0.10	0.48	233.9	41.87	273.4	0.42	1.01	13.11
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	6.41	0.12	0.50	248.1	37.67	250.8	0.40	1.12	13.35
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	6.39	0.15	0.48	228.7	40.07	284.8	0.54	1.04	13.74
SEm±	0.16	0.05	0.02	13.58	1.09	10.22	0.04	0.10	0.75
CD (P=0.05)	NS	NS	NS	40.33	NS	30.38	0.12	NS	NS
CV (%)	4.35	8.70	7.23	9.39	4.69	7.06	17.83	18.70	9.85

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

4.5.7 Available boron in soil (ppm)

Significant differences were observed in boron status of soil after harvest of sunflower crop. Higher boron content (0.54 ppm) was recorded with soil application of borax @ 11 kg ha⁻¹ at the time of sowing compared to control (0.29 ppm) and nano boron @ 0.4 % spray to capitulum at ray floret opening stage (0.29 ppm).

4.5.8 Available zinc in soil (ppm)

Different nano boron nutrition methods failed to influence the available soil zinc content after harvest of sunflower crop. However higher available zinc was recorded with treatment nano boron @ 0.4 % seed priming 0.71 ppm compared to all other treatments.

4.5.9 Available sulphur in soil (ppm)

Different nano boron and borax nutrition methods did not influenced the available soil sulphur content after harvest of sunflower crop. However higher available sulphur was recorded with application of borax @ 0.2 % spray to capitulum at ray floret opening stage (14.42).

4.6 Economics

The data pertaining to cost of cultivation, gross returns net returns and benefit cost ratio as influenced by different levels and methods of nano boron and borax application are presented in Table 4.15.

4.6.1 Total cost (₹ ha⁻¹)

Nano boron @ 0.4 % spray to capitulum at ray floret opening stage recorded higher cost of cultivation (₹ 99577 ha⁻¹) followed by nano boron @ 0.2 % spray to capitulum at ray floret opening stage (₹ 64935 ha⁻¹). The lowest cost of cultivation was recorded in control (₹ 27296 ha⁻¹).

4.6.2 Gross returns (₹ ha⁻¹)

Highest gross returns (₹ 105956 ha⁻¹) was recorded with application of nano boron @ 0.2 % seed priming, nano boron @ 0.2 % spray to capitulum ray floret opening stage (₹ 105368 ha⁻¹) and nano boron @ 0.4 % seed priming (₹ 93122 ha⁻¹) were found next in order. The lowest gross returns (₹ 61920 ha⁻¹) was recorded with control treatment.

4.6.3 Net returns (₹ ha⁻¹)

Different levels and methods of nano boron application in sunflower influenced the net returns. A highest net return (₹ 66950 ha⁻¹) was recorded in nano boron @ 0.2 % seed priming over all other treatments. Treatments with the application of Soil application of borax @ 11 kg ha⁻¹ (₹ 55196 ha⁻¹) and borax @ 0.2 % seed priming (₹ 52729 ha⁻¹) were found next in order. The lowest gross returns (₹ -7549 ha⁻¹) was recorded in nano boron @ 0.4 % spray to capitulum at ray floret opening stage and control (₹ 34624 ha⁻¹).

4.6.4 Benefit cost ratio

Benefit cost ratio of sunflower crop influenced by the application of different treatments. Highest B: C ratio (3.01) was recorded in borax @ 0.4 % spray to capitulum at ray floret opening stage. Treatments with the application of borax @ 0.2 % seed priming (2.93) and borax @ 0.4 % seed priming (2.90) were found next in order. The lowest B: C ratio was recorded in nano boron @ 0.4 % spray to capitulum at ray floret opening stage (0.92).

Table 4.15: Economics of sunflower as influenced by different levels and methods of nano boron and borax application

Treatments	Cost of cultivation (₹ ha ⁻¹)	Gross returns (₹ ha ⁻¹)	Net returns (₹ ha ⁻¹)	B:C Ratio
T ₁ : Control	27296	61920	34624	2.27
T ₂ : Nano Boron @ 0.2 % seed priming	39006	105956	66950	2.72
T ₃ : Nano Boron @ 0.4 % seed priming	50716	93122	42406	1.84
T ₄ : Borax @ 0.2 % seed priming	27318	80047	52729	2.93
T ₅ : Borax @ 0.4 % seed priming	27341	79183	51843	2.90
T ₆ : Nano Boron @ 0.2 % spray to capitulum at RFO stage	64935	105368	40433	1.62
T ₇ : Nano Boron @ 0.4 % spray to capitulum at RFO stage	99577	92028	-7549	0.92
T ₈ : Borax @ 0.2 % spray to capitulum at RFO stage	27402	78319	50917	2.86
T ₉ : Borax @ 0.4 % spray to capitulum at RFO stage	27508	82704	55196	3.01
T ₁₀ : Soil application of Borax @ 11 kg ha ⁻¹	32994	92111	59117	2.79

Note : RFO stage- ray floret opening stage

V DISCUSSION

The main objective of the present investigation was to study the “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)” conducted at Zonal Agricultural Research Station, UAS, GKVK, Bengaluru during late *kharif*-2016. The results of the present investigation are discussed in this chapter under various headings.

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.

5.1 Effect of weather on crop performance

Crop growth is the net result of interplay of diverse metabolic activities taking place in different parts of a plant during its growth and development. The synthesis, accumulation and translocation of metabolites to the economic part are often influenced by environmental conditions, thereby influencing the yield potential of the crop.

The normal and actual weather data that prevailed during 2016-17 with respect to rainfall, maximum and minimum temperature mean relative humidity and sunshine hours are presented in Fig. 1. Rainfall received during crop growth period (September to December) was 146.8 mm in late *kharif* -2016. The total rainy days during crop growth period were 11. The maximum and minimum temperature ranged from 27.2 to 29.6 °C

and 14.5 to 18.8 °C, respectively. The actual mean sunshine hours considerably lower during crop growth period as compared to normal. The rainfall during the cropping period was deficit. The crop was given protective irrigation and hence the crop growth was not affected by deficit rainfall.

5.2 Effect of seed treatment of nano boron and borax on the germination, root length, shoot length and vigour index of sunflower under preliminary laboratory experiment

Laboratory experiment I

Laboratory studies (Table 4.1) indicated that seed treatment with nano boron @ 0.2 % recorded higher seed germination in all the three experiment (94 %) compared to control (80.8 %).

At 8 DAS seed treatment with nano boron at 0.2 % and control recorded significantly higher root length (5.65 cm and 5.82 cm, respectively) and shoot length (7.60 cm and 7.97 cm). At 15 DAS maximum root length (9.02 cm) was observed with nano boron @ 0.2 % seed priming which was significantly superior to all other treatments. This might be due role of boron in cell division, cell elongation, improved terminal meristematic activity which increases the root and shoot growth. The results are in line with Khan *et al.* (2006) and Noor un nisa memon *et al.* (2013).

The maximum seedling vigour index was recorded in seed priming with nano boron @ 0.2 % at 8 and 15 DAS (1245 and 1899 plant⁻¹, respectively) (Table 4.1) compared to all other treatments. This was mainly due to the increased germination percentage, root length and shoot length of sunflower seedlings. Significantly lower seedling vigour index was recorded with seed priming of borax @ 0.4 % (435 plant⁻¹) at 8 DAS and seed priming of borax @ 0.2 % (987 plant⁻¹).

Laboratory experiment II

The results of laboratory experiment II (Table 4.2) followed the similar trend as that of experiment I.

Laboratory experiment III

Results from (Table 4.3) showed that higher seed germination was recorded with 0.2 % nano boron seed priming (88.33 %) compared to control (75.0 %). Seed priming with nano boron @ 0.2 % recorded maximum root length (5.65 cm and 11.38 cm) and shoot length (7.35 cm and 18 cm) at 8 and 15 DAS respectively. However, the root length and shoot length were decreased significantly with the increase in borax concentration. The lowest root length (0.58 cm and 1.28 cm, respectively) and shoot length (1.03 cm and 5.66 cm, respectively) were recorded in seed priming with borax @ 0.6 % which was on par with 0.5 % borax seed priming. The decrease in root and shoot length was mainly due to boron at higher levels which inhibits root and shoot growth primarily through limiting cell elongation and cell division (Brown *et al.*, 2002). Maximum seedling vigour was recorded with 0.2 % nano boron seed priming (1145 plant⁻¹ and 2608 plant⁻¹) at 8 and 15 DAS respectively. This was mainly due to the increased germination percentage, root length and shoot length of sunflower seedlings. Significantly lower seedling vigour index was recorded at seed treatment with borax @ 0.6 % (121 and 532 plant⁻¹ respectively) at 8 and 15 DAS. The results are in conformity with the findings Habtamu Ashagre *et al.*, 2014 and Prathima *et al.*, 2016)

The observed increase in primed treatments, may be due to rapid and appropriate establishment of seedling (Farooq *et al.*, 2008), minimization of time between seed sowing and emergence and the synchronization of emergence, better utilization of nutrient, soil moisture and solar radiation, photosynthetic rate and stomatal conductance (Fariduddin *et al.*, 2003).

5.3 Effect of different levels and methods of nano boron and borax application on yield and yield parameters of sunflower

Yield is a complex character which involves the interaction of several intrinsic and external factors. It largely depends upon the production and mobilization of carbohydrates, uptake of water and nutrients from the soil, in addition to several environmental factors to which crop is exposed during the growing period (Schonfeld *et al.*, 1988). Several approaches *viz.*, seed treatment, soil and foliar fertilization, improved

crop systems, application of soil amendments and organic nutrient sources, use of efficient micronutrient fertilizer are possible ways to correct micronutrients deficiency in plants.

Yield and yield attributes were significantly influenced by different levels and methods of nano boron and borax application in sunflower (Tables 4.9, 4.10 and 4.11). 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) and Patil *et al.* (2006). Increase in fruit yield with foliar application of nano boron have been reported in different fruit crops, including date palm (Mahmoud, 2014) pomegranate (Sorhab *et al.*, 2016). 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). They reported that initial application (as seed priming or soil application) 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 photosynthates to head seed formation, finally decreases the yield.

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) (Fig. 5.2 and Fig.5.3). 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).

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), Liu *et al.* (2005) in peanut, Sheykhbaglou *et al.* (2010) 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 development pollen tubes synchronized, which may result in increased pollen germination and pollen viability and increasing the translocation of sugars and photosynthates 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). 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) and Tamak *et al.* (1997). Nano boron nutrition improves solubility and dispersion of insoluble nutrients in soil, reduces soil fixation and increases the bioavailability (Cui *et al.*, 2010), 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) (Fig. 5.2 and 5.3) 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 photosynthates to sink reduced source to sink ratio which further resulted in decreased yield and yield attributes.

Higher oil yield was recorded with application of nano boron @ 0.2 % seed priming (1022 kg ha^{-1}) which was on par with application of nano boron @ 0.2 % spray to capitulum at ray floret opening stage (1006 kg ha^{-1}). It was mainly due to higher seed

yield (2788 kg ha⁻¹, 2733 kg ha⁻¹) in turn resulted in higher oil yield as depicted in Fig. 5.1. The results are inline with Ayad Shaker and Saad Mohammed (2011) and Muhammad *et al.* (2013).

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 (1384), 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 (1094, 120, 10.97 % respectively). 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) and Al-Amery *et al.* (2011).

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 Venkatakrisnan and Balasubramaniam (1996). 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.

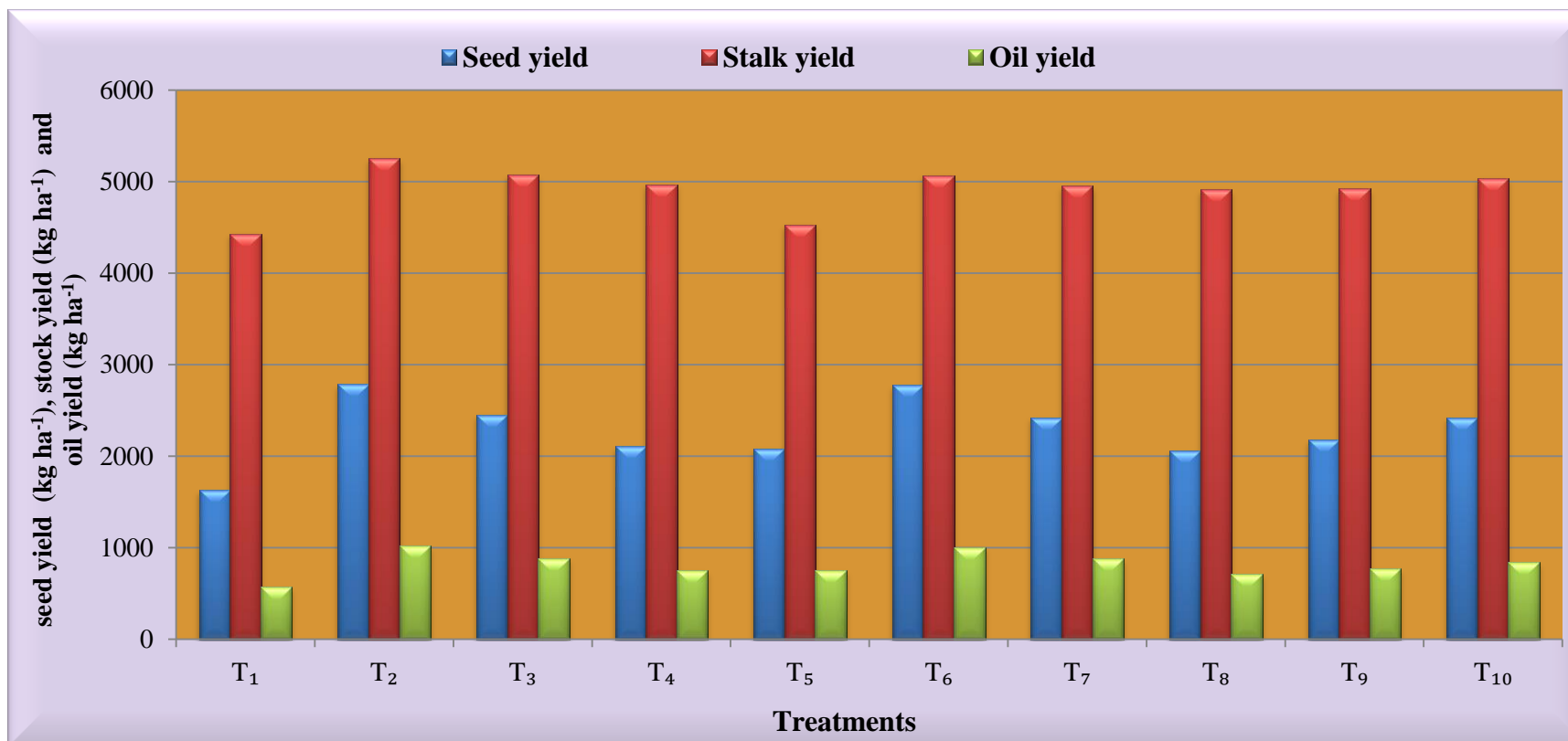


Fig. 5.1: Effect of different method of application of nano boron and borax on seed, stalk and oil yield of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

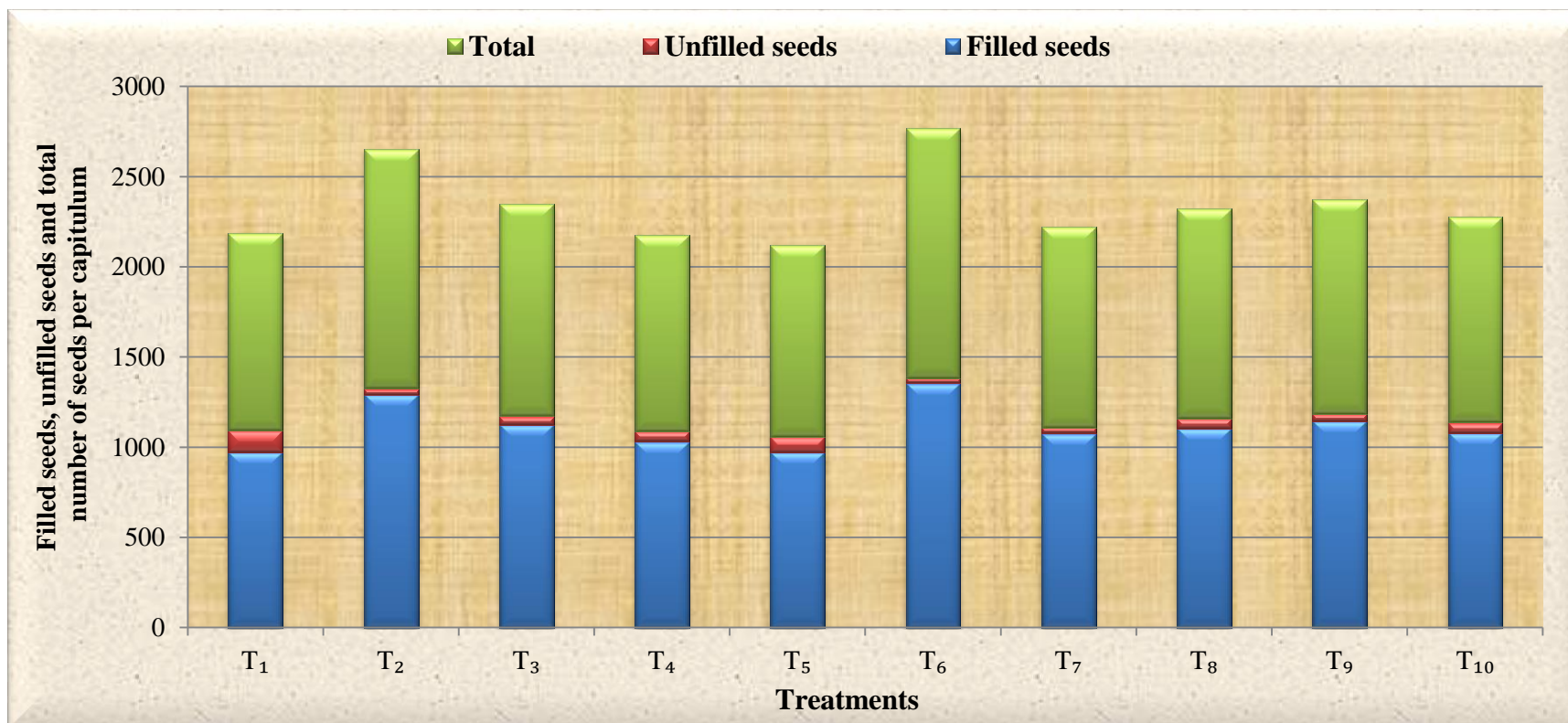


Fig. 5.2: Effect of different method of application of nano boron and borax on filled seeds, unfilled seeds and total number of seeds per capitulum of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

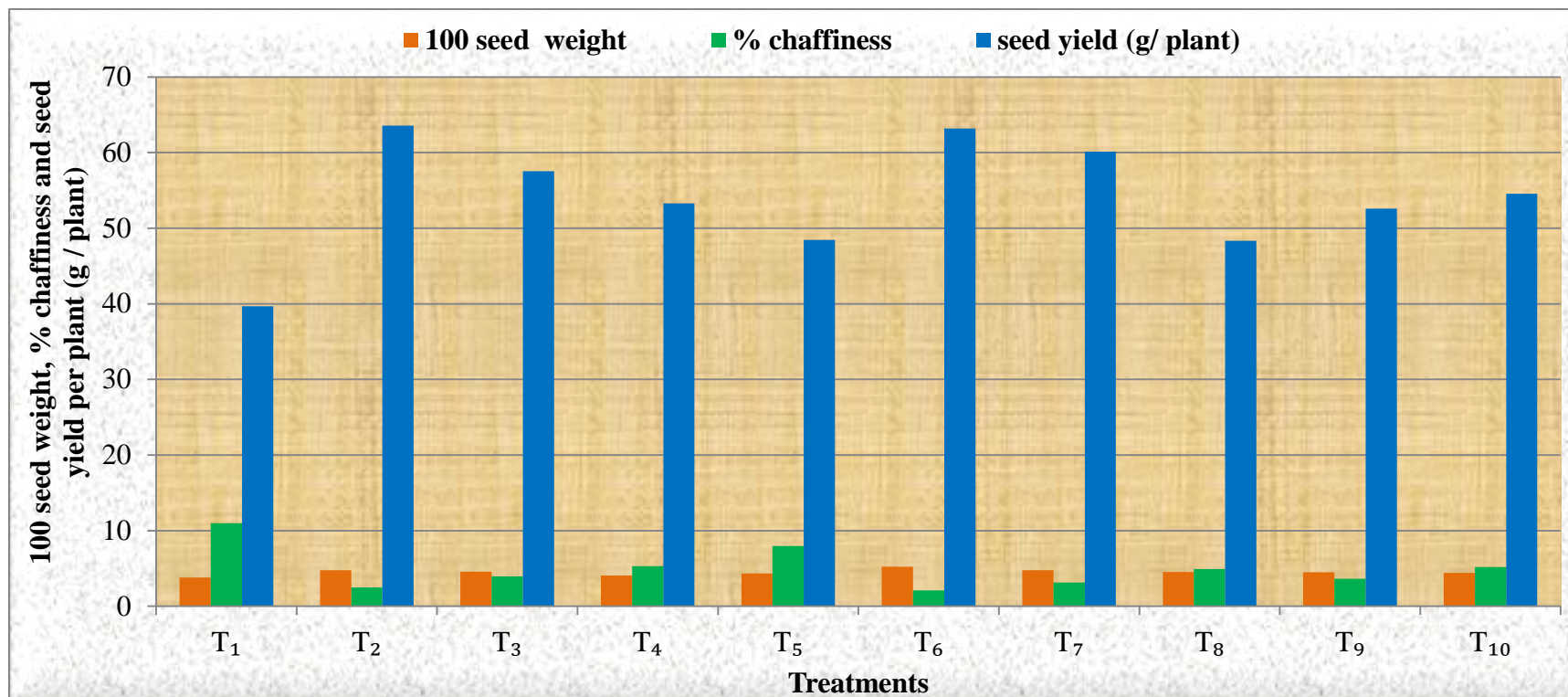


Fig. 5.3: Effect of different method of application of nano boron and borax on 100 seed weight, % chaffiness and seed yield (g/plant) of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

5.4 Effect of different method of application 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 cm² plant⁻¹, 0.58, respectively) (Tables 4.4 and 4.5). Whereas lower plant height, leaf area, number of leaves and leaf area index was recorded with control treatment (157.1 cm, 3632 cm² plant⁻¹, 21.33 cm and 0.339) 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 cm² plant⁻¹ respectively), compared to control (611, 3632 cm² 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).

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). Similar results were observed with Mahmoud *et al.*, 2014 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 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 photosynthates 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. 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 4.7). 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).

Nano boron @ 0.2 % seed priming has influenced the days to 50 per cent flowering (61.33) significantly. 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 enhanced 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.

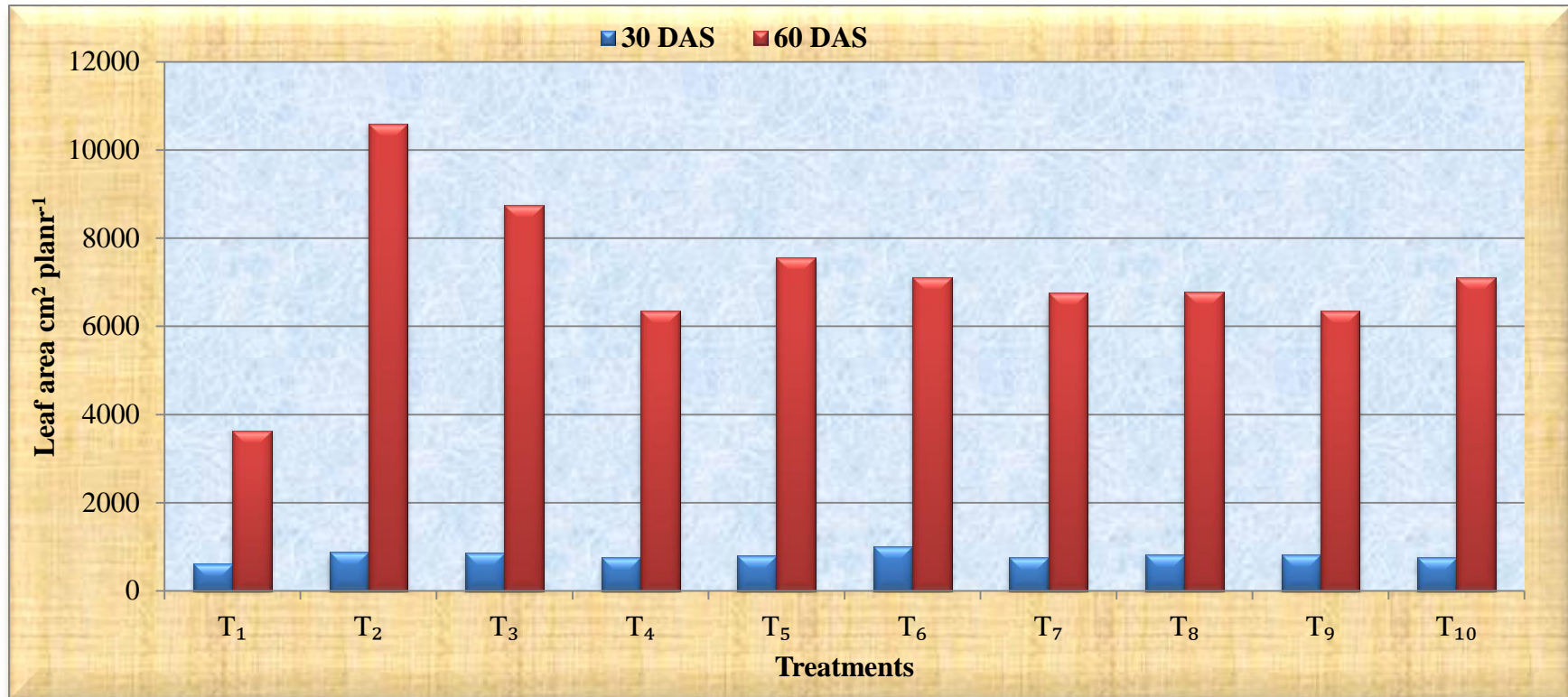


Fig. 5.4: Effect of different method of application of nano boron and borax on leaf area of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

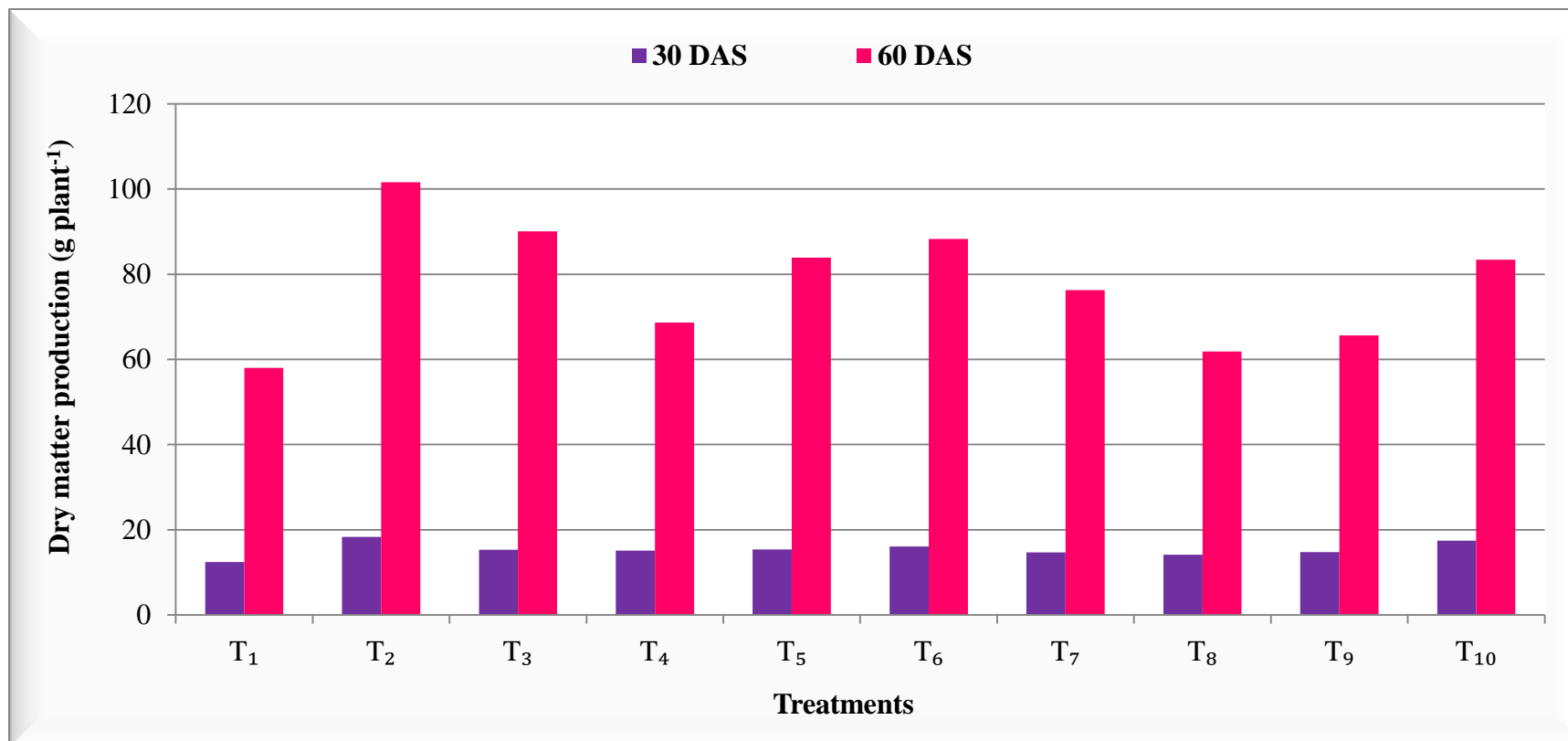


Fig. 5.5: Effect of different method of application of nano boron and borax on dry matter production of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

5.5 Effect of different levels and methods of nano boron and borax fertilization on nutrient uptake of crops

Among different treatments, nitrogen, phosphorous, potassium, sulphur and zinc uptake by sunflower crop at harvest was significantly higher in nano boron @ 0.2 % seed priming (114.58 kg ha⁻¹, 33.67 kg ha⁻¹, 72.67 kg ha⁻¹, 21.5 kg ha⁻¹ and 547.1 g ha⁻¹, respectively) (Tables 4.12 & 4.13 and Fig. 5.6 & 5.7). Higher boron uptake was recorded with 0.4 nano boron spray to capitulum at ray floret opening stage (265.8 g ha⁻¹) which was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (256.5 g ha⁻¹). This increase in nutrient uptake by sunflower might be due to role of boron in improving the photosynthetic ability and assimilating capacity of crop as it is a component of various enzymatic and other biochemical reactions. Adequate boron nutrition improves the crop uptake by maintaining proper function (through ATPase activity) and structure of root cell membranes. Boron has an important role in colonization of roots with mycorrhizal fungi, which contributes to root uptake of P and other important nutrients (Brown, 2016).

Whereas, the lowest uptake of nitrogen, phosphorous, potassium, sulphur, zinc and boron uptake by sunflower crop was recorded in control (80.41 kg ha⁻¹, 19.25 kg ha⁻¹, 59.94 kg ha⁻¹, 13.7 kg ha⁻¹, 429.4 g ha⁻¹ and 195.3 g ha⁻¹, respectively). It might be due to boron deficiency during the crop growth of sunflower which might have resulted in lower dry matter production and nutrient uptake.

5.6 Effect of different levels and methods of nano boron and borax application on nutrient status of soil after harvest of sunflower crop.

There was no significant difference between different treatments with respect to macronutrients (P and S), micronutrient (Zn) and organic carbon status of soil after harvest of crop.

Nitrogen status of the soil after the harvest of the crop significantly influenced by borax and nano boron fertilization in sunflower. Higher available nitrogen content was recorded in without boron / control (279.9 kg ha⁻¹). The results was on par with nano boron @ 0.2 % spray to capitulum at ray floret opening stage (275.3 kg ha⁻¹) and nano

boron @ 0.4 % seed priming (274 kg ha⁻¹). Lower soil nitrogen was recorded with Borax @ 0.4 % seed priming (219.3 kg ha⁻¹).

Boron status of soil after harvest of sunflower crop was significantly influenced by different levels and methods of nano boron and borax application. Higher boron content was (0.54 ppm) recorded with soil application of borax @ 11 kg ha⁻¹ compared to control/ without boron (0.29 ppm) and nano boron @ 0.4 % spray to capitulum at ray floret opening stage (0.29). Only a small portion of the applied boron might have utilised by crop and remaining portion of nutrient might have contributed to higher residual boron content in the soil. Similar results were reported by Ramulu *et al.* (2011), Prathima (2015) (Table 4.14).

5.6 Effect of different levels and methods of nano boron and borax application on economics of sunflower cultivation

Spraying of borax @ 0.4 % to capitulum at ray floret opening stage recorded higher B: C ratio (3.01) followed by borax @ 0.2 % seed priming (2.93). Higher net return was recorded with nano boron @ 0.2 % seed priming (₹ 66950) because of higher cost of nano boron which has resulted in higher cost of cultivation (₹ 39006) and comparatively lower B: C ratio (2.72). Lowest B: C ratio was recorded with nano boron @ 0.4 % spray to capitulum at ray floret opening stage (0.92) and negative net returns of ₹ -7549. This was mainly due to higher cost of nano boron which was used for foliar application at ray floret opening stage.

5.8 Practical utility

This study has established the following practical utility.

- ✓ 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 (36.84 %) and net returns (Rs. 66950 ha⁻¹) as compared to other treatments.

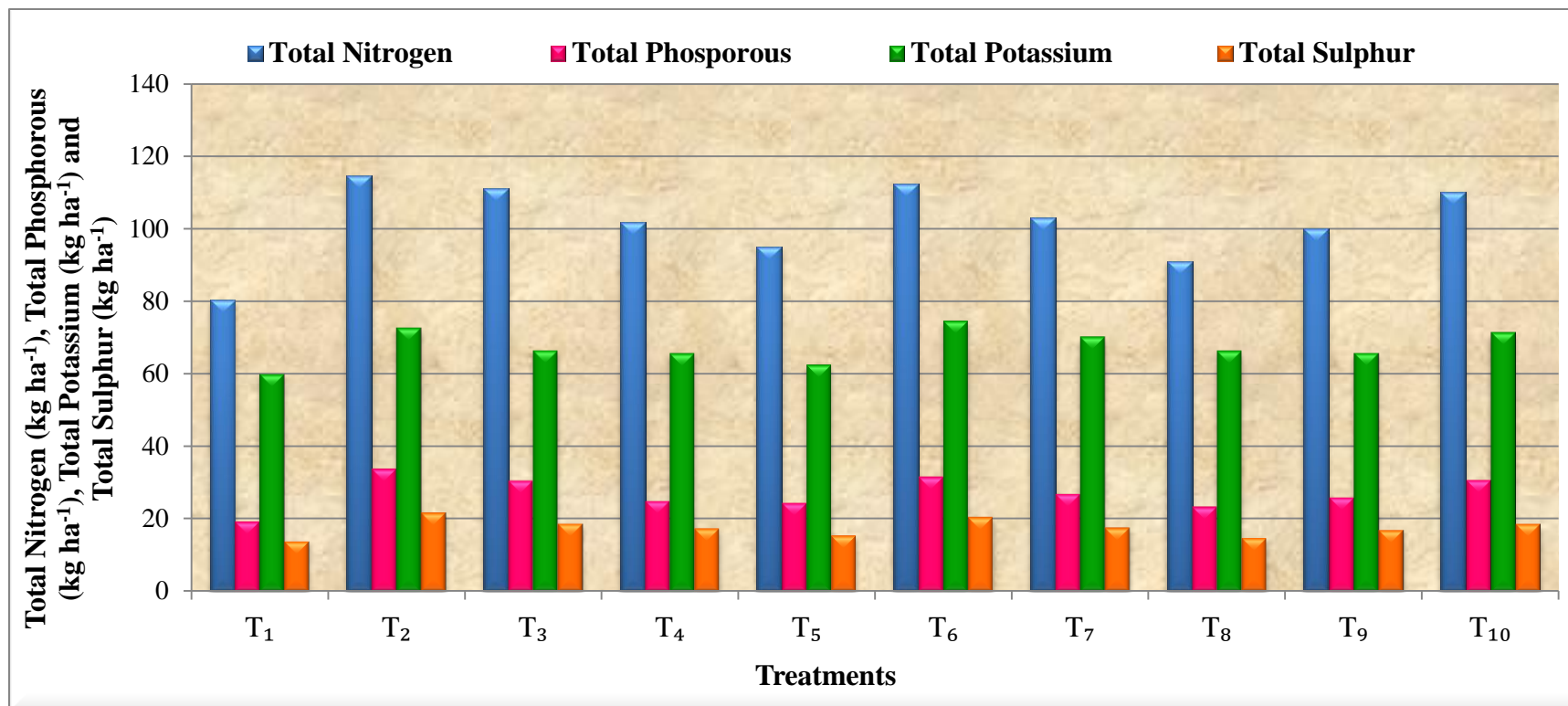


Fig. 5.6: Effect of different method of application of nano boron and borax total nitrogen, phosphorus, potassium and sulphur uptake of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

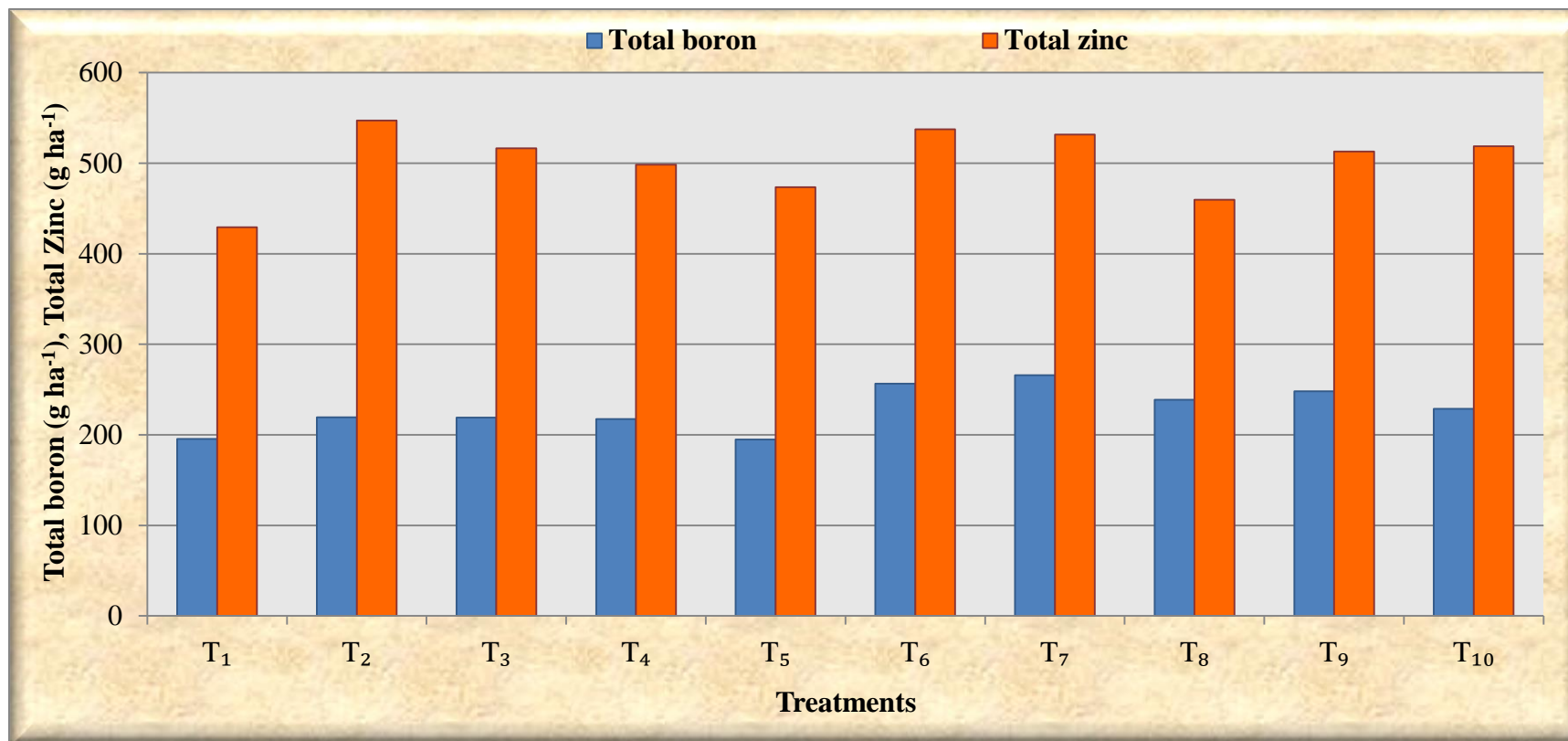


Fig. 5.7: Effect of different method of application of nano boron and borax total boron and zinc uptake of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

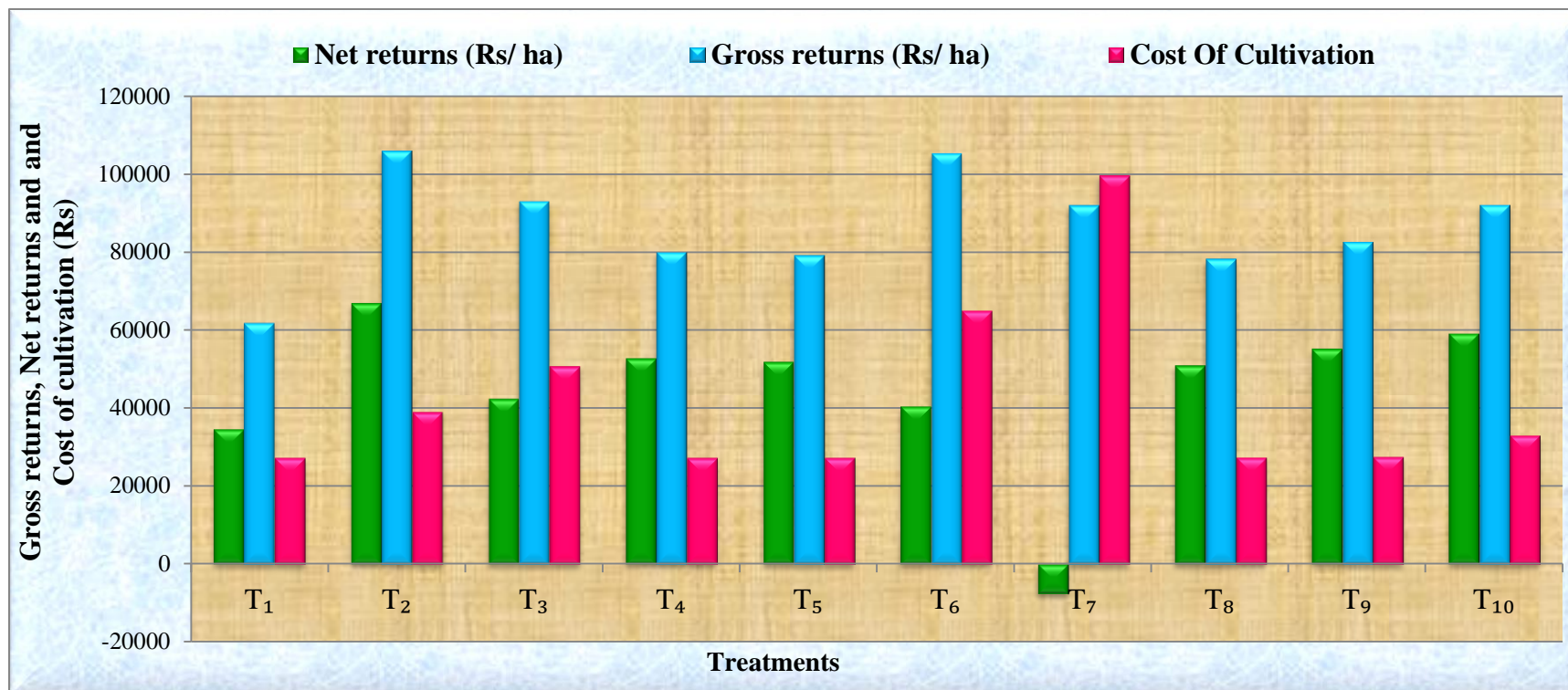


Fig. 5.8: Effect of different method of application of nano boron and borax on Net returns, Gross returns and Cost of cultivation of sunflower

T₁: Control

T₂: Nano Boron @ 0.2 % seed priming

T₃: Nano Boron @ 0.4 % seed priming

T₄: Borax @ 0.2 % seed priming

T₅: Borax @ 0.4 % seed priming

T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret stage

T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret stage

T₈: Borax @ 0.2 % spray to capitulum at ray floret stage

T₉: Borax @ 0.4 % spray to capitulum at ray floret stage

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

5.9 Future line of work

- Preparation of nano boron (commercial grade) at institution levels is required.
- Research is required in different agro-ecological zones to determine the effects of different nano boron sources on sunflower growth and yield.
- Interaction effect of seed priming and foliar application of nano boron at varied levels is required.
- Further experimentation is needed to consolidate the findings and to have a precise recommendation (seed priming and foliar application) of nano boron for sunflower.
- Impact of nano boron on human health need to be addressed.

VI SUMMARY

A field experiment was conducted at ZARS, GKVK, Bengaluru during late *Kharif*-2016, under assured rainfall condition to study the effect of “Optimisation of nano boron fertilization in sunflower (*Helianthus annuus* L.)”. The experiment was laid out in randomized complete block design with ten treatments replicated thrice. Treatments consisting of T₁: Control, T₂: Nano Boron @ 0.2 % seed priming, T₃: Nano Boron @ 0.4 % seed priming, T₄: Borax @ 0.2 % seed priming, T₅: Borax @ 0.4 % seed priming, T₆: Nano Boron @ 0.2 % spray to capitulum at ray floret opening stage, T₇: Nano Boron @ 0.4 % spray to capitulum at ray floret opening stage, T₈: Borax @ 0.2 % spray to capitulum at ray floret opening stage, T₉: Borax @ 0.4 % spray to capitulum at ray floret opening stage. T₁₀: Soil application of Borax @ 11 kg ha⁻¹. This investigation was corroborated by laboratory studies to ascertain the tolerance limits of seed treatment with nano boron and borax at varied levels 0-0.6 %. From these studies, two levels of 0.2 % and 0.4 % were selected under seed priming for further studies. The findings of the study are summarized below.

- The laboratory studies indicated that, germination percentage, root length, shoot length and vigour index of sunflower differed significantly among the treatments. The maximum germination (80.80 %), root length (5.65 cm and 9.60 cm), shoot length (9.02 cm and 11.17 cm) and vigour index (1245 and 1899 plant⁻¹) were recorded in seed priming with 0.2 % nano boron at 8 and 15 DAS, respectively. Higher levels of nano boron seed priming at 0.5 % and 0.6 % had shown inhibition of root growth of sunflower seedlings (blackening of root tip) @ 22 DAS.
- Seed priming @ 0.2 % nano boron recorded higher chlorophyll (SPAD) reading (37.13 and 44.50) and root to shoot ratio (0.153 and 0.18) at 30 and 60 DAS.
- Nano boron seed treatment @ 0.2 or 0.4 per cent significantly reduced the days taken to 50 per cent flowering by 7 to 8 days.
- Seed priming with 0.2 % nano boron or spraying 0.2 % nano boron to capitulum at ray floret opening stage produced significantly higher seed (2788 and 2773 kg

ha⁻¹) yield compared to control (1629 kg ha⁻¹). Similar trend was observed in oil yield.

- Nano boron and borax nutrition had significant effect on 100 seed weight, total number of seed per capitulum and number of filled seeds per capitulum. Higher 100 seed weight (5.23 g), total seed (1384 capitulum⁻¹) and number of filled seed (1355 capitulum⁻¹) were recorded with application nano boron @ 0.2 % spray to capitulum at ray floret opening stage. The results were on par with nano boron @ 0.2 % seed priming (4.78 g, 1293 capitulum⁻¹ and 1325 capitulum⁻¹ respectively).
- Chaffiness was significantly lower (2.10 %) with nano boron @ 0.2 % spray to capitulum at ray floret opening stage which was on par with nano boron @ 0.2 % seed priming (2.50 %) as compared to control (11 %).
- Days to physiological maturity was significantly shorter with Nano boron @ 0.2 % seed priming (84 days) which was on par with nano boron @ 0.4 % spray to capitulum at ray floret opening stage (86.33 days) as compared to control (93 days).
- Different levels and methods of nano boron and borax application did not influenced the oil content.
- Soil application of borax @ 11 kg ha⁻¹ recorded higher B (0.54 ppm) content in the soil after harvest of sunflower crop.
- Application of nano boron @ 0.2 % seed priming has recorded higher amount of uptake of nitrogen, phosphorous, potassium, sulphur and zinc (114.58 kg ha⁻¹, 33.67 kg ha⁻¹, 72.67 kg ha⁻¹, 21.5 kg ha⁻¹ and 547.1 g ha⁻¹, respectively). Application of nano boron @ 0.4 % spray to capitulum at ray floret opening stage has recorded higher boron uptake (265.8 g ha⁻¹).
- Application of nano boron @ 0.2 % seed priming recorded higher net returns (₹ 66950 ha⁻¹) and B: C ratio (2.72) compared to all other treatments.

VII REFERENCES

- ABASALT, R. A., MORAD, S. AND ZAHRA, R. M., 2015, Effect of K nano-fertilizer and N bio-fertilizer on yield and yield components of tomato (*Lycopersicon esculentum* L.). *Int. J. Adv. Biol. Biom. Res.*, **3**(1):138-143.
- ABDUL HAFEEZ, ABDUL RAZZAQ, TARIQ MAHMOOD, HAFIZ MUHAMMAD JHANZAB., 2015, Potential of copper nanoparticles to increase growth and yield of wheat. *J. Nanosci. Adv. Tech.*, **1**(1): 6-11.
- ADHIKARY, B. H., SHRESTHA, J. AND BARAL, B. R., 2010, Effects of micronutrients on growth and productivity of maize in acidic soil. *Int. Res. J. Appl. Basic Sci.*, 1:8-15.
- AFSHAR, I., RAHIMI HAGHIGHI, A. AND MINOOSHIRAZI, 2014, Comparison the effects of spraying different amounts of nano zinc oxide and zinc oxide on wheat. *Int. J. Plant. Anim. Environ. Sci.*, **3**(4): 688-693.
- AHMED KHAN, T., VENUGOPAL, K., DEVAIH, C. AND SEENAPA, K., 1990, Effect of secondary nutrients and boron on growth characters and yield in oilseeds. *J. Oilseeds Res.*, **7**(2): 136-139.
- ALAM, M. J., SULTANA, F. AND IQBAL, M. T., 2015, Potential of iron nanoparticles to increase germination and growth of wheat seedling. *J. Nanosci. Adv. Tech.*, **1**(3): 14-20.
- AL-AMERY, MUSHTAQ ALI AND QUMAR MOHYUDDIN, 2011, Effect of boron foliar application on reproductive growth of sunflower (*Helianthus annuus* L.). *Int. J. Agron.*, **1**: (1-5).
- AMIN FARNIA AND MOHAMMAD MEHDI OMIDI, 2015, Effect of nano-zinc chelate and nano-biofertilizer on yield and yield components of maize (*Zea Mays* L.), under water stress condition. *Indian J. Natural Sci.*, **29**(5): 0976 – 0997.

- ANONYMOUS, 2016, Director's report, ICAR-IIOR., Rajendranagar. Pp.16.
- ARAVINDAKUMAR, B. N., BHAT, S. N. AND SHANWAD, U. K., 2010, Effect of micronutrients on growth and yield of sunflower (*Helianthus annuus*). *Curr. Adv. Agril. Sci.*, **2**(1): 51-52.
- ARCHANA, P. K. AND SATYAVIKAS, N. G., 2016, Studies on nanoparticle induced nutrient use efficiency of fertilizer and crop productivity. *Green Chemistry and Technology Letters.*, **2**(2): 88-92.
- ARNAB, M. L., ASHOK, S., SAJJAN, BALIKAI, R. A., JOLLI, R. B. AND GUGGARI, A. K., 2010, Effect of foliar application of micronutrients on seed yield and quality in sunflower. *Int. J. Plant Prod.*, **3**:179-182.
- ARPORN KRUDNAK, SODCHOL WONPRASAID AND THITIPORN MACHIKOWA, 2013, Boron affects pollen viability and seed set in sunflower. *African J. Agril. Res.*, **8**(2): 162-166.
- ASAD, A., BLAMEY, F. P. C. AND EDWARDS, D. G., 2003, Effects of boron foliar applications on vegetative and reproductive growth of sunflower. *Ann. Bot.*, **92**(4): 565-570.
- ASLAM, S., MULK KHAN, S., SALEEM, M., QURESHI, S. A., KHAN, A., ISLAM, M. AND KHAN, S, 2010, Heterosis for the improvement of oil quality in sunflower (*Helianthus annuus* L.). *Pak. J. Bot.*, **42**(2): 1003-1008.
- ASLI, S. AND NEUMANN, P. M., 2009, Colloidal suspensions of clay or titanium dioxide nanoparticles can inhibit leaf growth and transpiration via physical effects on root water transport. *Plant Cell Environ.*, **32**: 577-584.
- AULAKH, M. S., PASRICHA, N. S. AND SAHOTA, N. S., 1990, Yield, nutrient concentration and quality of mustard crop as influenced by nitrogen and boron fertilizers. *J. Agri. Sci.*, **94**: 545-549.

- AYAD SHAKER, T. AND SAAD MOHAMMED, 2011, Effect of different levels and timing of boron foliar application on growth, yield and quality of sunflower (*Helianthus annuus* L.) genotypes. *Mesopotamia J. Agric.*, **39**(3): 16-26.
- AZAMAL, H. AND KHAWAJA, S. S., 2014, Carbon and fullerene nanomaterials in plant system. *J. Nanobiotechnol.*, **12**: 16.
- BALAMURUGAN, M. A., FAROOQ, M., TABASSUM, R. AND AHMAD, N., 2003, Physiological and bio-chemical aspects of seed vigour enhancement treatments in sesame. *Seed Sci. Tech.*, **30**: 623-628.
- BERGER, K. C. AND TRUOG, E., 1939, Boron determination in soil and plants. *Indian Eng. Chem. Anal. Ed.*, **11**: 540-545.
- BLEVINS, D. G. AND LUKASZEWSKI, K. M., 1998, Boron in plant structure and function. *J. Plant Physiol.*, **49**: 481-500.
- BOLANOS, L., LUKASZEWSKI, K., BONILLA, I. AND BLEVINS, D., 2004, Why boron? plant physiol. *Boichem.*, **42**: 907-912.
- BOWSZYS, T., 1996, Response of winter rape to foliar application of boron fertilizer. *Zeszyty Problemowe Portepow Nauk Rolniczych*, **434**(1): 71-76.
- BROWN, A. L., QUICK, J. AND EDDINGS, J. L., 1971, A comparison of analytical methods for soil zinc. *Soil Sci. Soc. American Proc.*, **35**: 105-107.
- BROWN, P. H., BELLALOU, N., WIMMER, M., BASSIL, E. S., RIUZ, J., HU, H., PFEFFER, H., DANNE, F. AND ROMHELD, V., 2002, Boron in plant biology. *Plant Biol.*, **4**: 205-227.
- BROWN, P. H., 2016, Boron nutrition for optimal plant growth. *Agrisight*, **12**:1-2.
- BRIGHENTI, A. M. AND CASTRO, C., 2008, Boron foliar application on sunflower (*Helianthus annuus* L.) associated with the herbicides. *Helia*, **48**: 127-136.

- BURMANA, U., SAINIB, M. AND PRAVEEN-KUMAR, 2013, Effect of zinc oxide nanoparticles on growth and antioxidant system of chickpea seedlings. *Toxicological & Environmental Chem.*, **95**(4): 605-612.
- BYRAREDDY, K., UPPAR, D. S., VYAKARANAHAL, B. S., HIREMATH, S. M., RAVI HUNJE AND NADAF, H. N., 2007, Effect of integrated nutrient management on sunflower hybrid (KBSH-1) seed production. *Karnataka J. Agric. Sci.*, **21**(2): 171-175.
- CAKMAK, I. AND ROMHELD, V., 1997, Boron deficiency induced impairments of cellular functions in plants. *Plant Soil*, 193: 71-83.
- CHINNAMUTHU, C. R. AND BOOPATHI, P. M., 2009, Nanotechnology and agroecosystem. *Madras Agric. J.*, **96**: 17-31.
- COLLINS, D., LUXTON, T., KUMAR, N., SHAH, S. AND WALKER, V. K., 2012, Assessing the impact of copper and zinc oxide nanoparticles on soil : A field study. **7**(8): 50-54.
- CUI, H. X., SUN, C. J., LIU, Q., JIANG, J. AND GU, W., 2010, Applications of nanotechnology in agrochemical formulation, perspectives, challenges and strategies. *Int. Conference on Nanoagri*, Sao pedro, Brazil.
- DEPERON, R. H., MILANEZ, C. R. D., MORAES DALLAQUA, M. A. AND ROSOLEM, C. A., 2007, Boron deficiency inhibits cell development and reduces growth of sunflower. *J. Plant Nutri.*, **29**: 2039-2048.
- DEVIRIAN, T. A. AND VOLPE, S. L., 2003. The physiological effect of dietary boron. *Critical reviews in Food Science And Nutrition*, **43**: 219-231.
- DIMKPA, C. O., HANSEN, T., STEWART, J., MCLEAN, J. E., BRITT, D. W. AND ANDERSON, A. J., 2015, ZnO nanoparticles and root colonization by a beneficial pseudomonad influence essential metal responses in bean (*Phaseolus vulgaris*). *Nanotoxicology*, **9**(3): 271-278.

- DIXIT, P. M. AND ELAMATHI, S., 2007, Effect of foliar application of DAP, micronutrients and NAA on growth and yield of green gram (*Vigna radiata* L.). *Legume Res.*, **30**: 305-307.
- DONALD, C. M., 1962, Insearch of yield. *J. Aust. Inst. Agric. Sci.*, **28**:171-178.
- DORDAS, C., 2006, Foliar boron application improves seed set, seed yield, and seed quality of alfalfa. *Agron. J.*, **98**: 907-913.
- DU, W., YUANYUAN, S., RONG, J., ZHU, J., WU, J. AND HONGYAN GUO, 2011, TiO₂ and ZnO nanoparticles negatively affect wheat growth and soil enzyme activities in agricultural soil. *J. Environ. Monit.*, **13**:822-828.
- ERCAN CEYHAN, MUSTAFA ONDER, OZDEN OZTURK, MUSTAFA HARMANKAYA, MEHMET HAMURCU AND SAIT GEZGIN., 2008, Effects of boron application on yields, yield component and oil content of sunflower in boron-deficient calcareous soils. *African J. Biotech.*, **7**(16): 2854-2861.
- FAN, L., YUNHE, W., XIWEN, S., YANQIU, G., ZHICHUN, W., YUN, M. AND JIAN, L., 2012, Effects of combined nitrogen fertilizer and nano-carbon application on yield and nitrogen use of rice grown on saline-alkali soil. *J. Food Agric. Environ.*, **10**(1): 558-562.
- FARIDUDDIN, Q., HAYAT S. AND AHMAD, A., 2003, Salicylic acid influences net photosynthetic rate, carboxylation efficiency, nitrate reductase activity and seed yield in *Brassica juncea*. *Photosynthetica*, **41**:281- 284.
- FAROOQ, M., BASRA, S. M. A., REHMAN, H. AND SALEEM, B. A., 2008, Seed priming enhances the performance of wheat (*Triticum aestivum* L.) by improving chilling tolerance late sown. *J. Agro. Crop Sci.* **94**: 5560
- GHAFAARI, H. AND JAMSHID, R., 2013, Effect of foliar application of nano-iron oxidase, iron chelate and iron sulphate rates on yield and quality of wheat. *Int. J. Agron. Plant Prod.*, **4**(11): 2997-3003.

- GHOSH, S. H., MASHAYEKHI, B., PAN, P., BHOWMIK AND XING, B. S., 2008, Colloidal behavior of aluminium oxide nanoparticles as affected by pH and natural organic matter. *Langmuir*, **24**: 12385-12391.
- GHOSH, S., ARUN, K. S., HAZEM, M., KALAJI, K. B., MARIAN, B., MAREK, Z. AND ZAHED, H., 2014, Nano-CuO stress induced modulation of antioxidative defense and photosynthetic performance of Syrian barley (*Hordeum vulgare* L.). *Environ. Experimental Bot.*, **112**: 2775-2785.
- GITTE, A. N., PATIL, S. R. AND TIKE, M. A., 2005, Influence of zinc and boron on biochemical and yield characteristics of sunflower. *Indian J. Plant Physiol.*, **10**: 400-403.
- GOLDBERG, S. AND GLAUBIG, R. A., 1985, Boron absorption on aluminum and iron oxide minerals. *Soil Sci. Soc. American J.*, **49**: 1374-1379.
- GOMEZ, K. A. AND GOMEZ, A., 1984, Statistical procedures for Agricultural Research. 2nd edition, John Willey and Sons, Inc. New York, USA.
- HABTAMU ASHAGRE, IBRAHIM, A. H., URGECHA FITA AND ERMIA ESTIFANOS, 2014, Boron toxicity on seed germination and seedling growth of safflower (*Carthamus tinctorius* L.). *Herald J. Agri. Food Sci. Res.*, **3**(1): 1-6.
- HARAJYOTI MAZUMDAR, 2014, The impact of silver nanoparticles on plant biomass and chlorophyll content. *Int. J. Engineering Sci.*, **4**(7): 12-20.
- HARSINI, M. G., HABIBI, H. AND TALAEI, G. H., 2014, Effect of nano iron foliar application on quantitative characteristics of new line of wheat. *Scientific J. Crop Sci.*, **3**(4): 37-42.
- HASSAN, F., PARVIZ, R., MOGHADDAM, N., SHAHTAH, M. AND AMIR, F., 2012, Impact of bulk and nanosized titanium dioxide (TiO₂) on wheat seed germination and seedling growth. *Biol. Trace Elem. Res.*, **146**: 101-106.

- HATWAR, G. P., GONDANE, S. V., URKUDE, S. M. AND GAHUKAR, O. V., 2003, Effect of micronutrients on growth and yield of chilli. *Soil and Crop*, **13**: 123-1254.
- HEDIAT, M. AND SALAMA, H., 2012, Effects of silver nanoparticles in some crop plants, common bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.). *Int. Res. J. Biotechnol.*, **3**(10): 190-197.
- HEMANTHARANJAN, A., TRIVEDI, A. K. AND MANIRAM, K., 2000, Effect of foliar applied boron and soil applied iron and sulphur on growth and yield of soybean (*Glycine max* L. Merr). *Indian J. Plant Physio.*, **5**: 141-144.
- HOSSEIN, A. F., KASRA, M., 2011, Effect of hydropriming on seedling vigour in basil (*Ocimum basilicum* L.) under salinity conditions. *Adv. Enviorn. Biol.*, **5**(5): 828-833
- HOTZE, E. M., PHENRAT, T. AND LOWRY, G. V., 2010, Nanoparticle aggregation : Challenges to understanding transport and reactivity in the environment. *J. Environ. Qual.*, **39**: 1909-1924.
- ILLES, E. AND TOMBACZ, E., 2006, The effect of humic acid adsorption on pH-dependent surface charging and aggregation of magnetite nanoparticles. *J. Colloid Interface Sci.*, **295**: 115-123.
- IMRAN KHAN, SHAKEEL AHMAD ANJUM¹, RASHAD WASEEM KHAN QARDRI, MUQARRAB ALI, MUHAMMAD UMER CHATTHA, MUHAMMAD ASIF, 2015, Boosting achene yield and yield related traits of sunflower hybrids through boron application strategies. *American J. Plant Sci.*, **6**:1752-1759.
- JACKSON, M. L., 1973, Soil chemical Analysis, Ed. Prentice Hall of India Pvt. Ltd., New Delhi. pp. 121-125.

- JAYARAMBABU, A. N., SIVA KUMARI, A. B., VENKATESWARA, B. K. AND PRABHU, Y. T., 2014, Germination and growth characteristics of mungbean seeds (*Vigna radiata* L.) affected by synthesized zinc oxide nanoparticles. *Int. J. Curr. Engng. Tech.*, **4**(5): 20-25.
- JEYBAL, K., AYTAC, S. AND KARACA, E., 2000, A study on yield and some characters of sunflower applied with different molybdenum, boron and zinc doses. *Ondokuz Mays Univ.*, **19**(2): 54-58.
- JOSTEN, P. AND KUTSCHERA, U., 1999, The micronutrient boron causes the development of adventitious roots in sunflower cuttings. *Ann. Bot.*, **84**: 337-342
- KALLOL BHATTACHARYYAA, JAJATI MANDALB, HIRAK BANERJEEC, AYON ALIPATRAD, KRISHNENDU RAYC AND AMIT PHONGLOSAA, 2014, Boron fertilization in sunflower (*Helianthus annuus* L.) in an *Inceptisol* of West Bengal, India. *Comm. Soil Sci. Plant Anal.*, **46**(4): 528-544.
- KAPILA SHEKHAWAT AND SHIVAY, Y. S., 2008, Effect of nitrogen sources, sulphur and boron levels on productivity, nutrient uptake and quality of sunflower (*Helianthus annuus*). *Indian J. Agron.*, **53**(2): 129-134.
- KARTHIKEYAN, K. AND SHUKLA, L. M., 2008, Effect of boron – sulphur interaction on their uptake and quality parameters of mustard (*Brassica juncea* L.) and sunflower (*Helianthus annuus* L.). *J. Indian Soc. Soil Sci.*, **56**(2): 225-230.
- KASRA MAROUFI, HOSSEIN ALIABADI FARAHANI AND OMID MORADI., 2011, Evaluation of nano priming on germination Percentage in green gram (*Vigna radiata* L.). *Adv. in Environ. Bio.* **5**(11): 3659-3663.
- KHAN, R., GURMANI, A. H., GURMANI, A. R. AND ZIA, M. S., 2006, Effect of boron application on rice yield under wheat rice system. *Int. J. Agri. Biol.*, **8**: 805808.

- KHANAL, A., SHAKYA, S. M., SRIVASTAVA, A. AND SHA, S. K., 2012, Seed yield and quality of broccoli as affected by different levels of nitrogen and boron in plain areas of Chitwan. *Int. J. Interdisciplinary and Multidisciplinary Studies*, **1**(5): 277-283.
- KHODAKOVSKAYA, M., DERVISHI, E., MAHMOOD, M., YANG XU, ZHONGRUI LI, WATANABE, F. AND BIRIS, A. S., 2009, Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. *ACS Nano*, **3**: 3221-3227.
- KONTHOUJA, N. D., LAIKANGBAM, N. K. S., MAIBAM SUMARJIT, S., SOIBAM BASANTA, S. AND KEISHAM KHAMBA, S., 2007, Influence of sulphur and boron fertilization on yield, quality, nutrient uptake and economics of soybean (*Glycine max*) under upland conditions. *J. Agric. Sci.*, **4**(4): 139-143.
- KUMAR, R., KUMAR, S. S. AND PANDEY, A. C., 2008, Effect of seed soaking in nitrogen, phosphorus, potassium and boron on growth yield of garden pea (*Pisum sativum* L.). *Ecol. Environ. Conserv.*, **14**: 383-386.
- LAWARE, S. L. AND RASKAR, S. V., 2014, Effect of zinc oxide nanoparticles on cytology and seed germination in onion. *Int. J. Curr. Microbiol. App. Sci.*, **3**: 467-473.
- LIN, D. AND XING, B., 2007. Phytotoxicity of nanoparticles: inhibition of seed germination and root growth. *Environ. Pollut.*, **150**: 243-250.
- LIU, X. M., ZHANG, F. D., ZHANG, S. Q., HE, X. S., FANG, R., FENG, Z. AND WANG, S., 2005. Effects of nano-ferric oxide on the growth and nutrients absorption of peanut. *Plant Nutrition and Fertilizer Sci.*, **11**: 14-18.
- LUIS, R., GREWAL, H. S., BELL, R. W. AND GRAHAM, R. D., 2012, Effects of boron toxicity on soil fertility and plant growth. *Plant & Soil*, **225**: 243-251.

- MA, Y., KUANG, L., HE, X., BAI, W., DING, Y., ZHANG, Z., ZHAO, Y. AND CHAI, Z., 2010. Effects of rare earth oxide nanoparticles on root elongation of plants. *Chemosphere*, **78**: 273-279.
- MAHAJAN, P., SHAILESH, K., DHOKE, R. K. AND ANAND, K., 2013, Effect of nanoparticles suspension on the growth of mung (*Vigna radiata*) seedlings by foliar spray method. *Nanotechnol.*, **3**: 4052-4081.
- MAHMOUD, M. R., 2014, Response of zaghoul date palms grown under minia region conditions to spraying wheat seed sprout extract and nano- boron. *Stem Cell*, **5**(4): 22-28.
- MAHNAZ VALADKHAN, KHOSRO MOHAMMADI AND MOHAMMAD TAHSIN KARIMI NEZHAD, 2015, Effect of priming and foliar application of nanoparticles on agronomic traits of chickpea. *Biological Forum*, **7**(2): 599-602.
- MALEWAR, G. U., SYED, I. I. AND INDULKAR, B. S., 1992, Effect of phosphorus with and without boron on the yield and uptake of boron and phosphorus in cotton-groundnut cropping sequence. *Ann. Agric. Res.*, **13**: 269-270.
- MALLA, R. M., PADMAJA, B., MALATHI, S. AND JALAPATHI, R. L., 2007, Effects of micronutrients on growth and yield of pigeonpea. *J. Semi-Arid Trop. Agric. Res.*, **5**: 1-3.
- MARTIN, T. N., PAVINATO, P. S., GLASENAPP, L. F., BERTONCELLI, P. AND ORTIZ, S., 2010, Phytomass partition of sunflower silage, under boron and calcium fertilization. 19th World Congress of Soil Science, soil solutions for a changing world, Brisbane, Australia. pp 191-194.
- MASUTHI, D. A., VYAKARANAHAL, B. S. AND DESHPANDE, V., 2009, Influence of pelleting with micronutrients and botanical on growth, seed yield and quality of vegetable cowpea. *Karnataka J. Agric. Sci.*, **22**: 898-900.

- MOHSEN JANMOHAMMADI, NASER SABAGHNIA, SHAHRYAR DASHTI AND MOJTABA NOURAEIN., 2016, Investigation of foliar application of nano micronutrient fertilizers and nano-titanium dioxide on some traits of barley. *Biologija.*, **62**(2):148–156.
- MONICA, R. C., LUCIA, G. CHIARA, G. AND ROBERTO, C., 2011, The effects of nano-TiO₂ on seed germination, development and mitosis of root tip cells of *Vicia narbonensis* L. and *Zea mays* L. *J. Nanopart Res.*, **13**: 2443–2449.
- MOORE, H. M., 1994, Effects of boron toxicity on mitosis and incorporation of tritiated thymidine into nuclei. *American J. Bot.*, **80**(2): 165-172.
- MORTEZA, E. P., MOAVENI, H., ALIABADI, F. AND MOHAMMAD, K., 2013, Study of photosynthetic pigments changes of maize (*Zea mays* L.) under nano TiO₂ spraying at various growth stages. *Springer Plus*, **2**: 247.
- MUHAMMAD TAHIR, SHARJEEL ASHRAF AND MUHAMMAD IBRAHIM, 2013, Effect of foliar application of boron on yield and quality of sunflower (*Helianthus annuus* L.). *Crop Envi.*, **4**(1): 23-27.
- MUNEEB MUNAWAR, MUHAMMAD IKRAM, MUDASSAR IQBAL, MUHAMMAD MUZAFFAR RAZA, SAJIDA HABIB, GHAZANFAR HAMMAD, MUHAMMAD NAJEEBULLAH, MUHAMMAD SALEEM AND RABIA, 2013, Effect of seed priming with Zn, B and Mn on seedling health in carrot (*Dacus carota* L.). *Int. J. Agri. crop sci.*, **5**(22): 2697-2702.
- MUNTHEAN, N., 2009, Biochemical response of plants to boron toxicity- a review. *Plant Soil Environ.*, **54**(3): 89-99.
- MURTHY, I.Y.L.N., 2006, Boron studies in major oilseed crops. *Indian J. Ferti.*, **1**(11): 11-20.
- MURTHY, I.Y.L.N., 2011, Recent advances in secondary and micronutrient management in safflower (*Carthamus tinctorius* L.). *J. Oilseeds Res.*, **28**(2): 94-104.

- NABLE, R. O., BANUELOS, G. S. AND PAULL, J. G., 1997, Boron toxicity. *Plant Soil*, **193**(12): 181-198.
- NIELSON, F. H., 2008, Is boron nutritionally relevant? *Nutrition reviews*. **66**: 183-191.
- NIRANJAN, S. S., PRAKASH BASAVEGOUDA, YELLADHALLI, N. A. AND CHANDRAKANTH, H. T., 2005, Effect of micronutrient seed treatment on growth and yield of groundnut. *Seed Res.*, **33**(2): 138-141.
- NOOR UN NISA MEMON, MOULA BUX GANDAHI, VAJANTI MALA PAHOJA AND NASIM SHARIF., 2013, Response of seed priming with boron on germination and seedling sprouts of broccoli. *Int. J. Agric. Sci. and Res.*, **3**(2): 183-194.
- O'NEILL, M. A., ISHII, T., ALBERSHEIM, P. AND DARVILL, A. G., 2004, RhamnogalacturonanII: structure and function of borate cross-linked cell wall pectic polysaccharide. *Annual review of plant bio.*, **55**: 109-139.
- OYINLOLA, E. Y., 2007, Effect of boron fertilizer on yield and oil content of three sunflower cultivars in the Nigerian Savana. *J. Agron.*, **6**: 421-426.
- PATIL, S. B., VYAKARANAHAL, B. S., DESHPANDE, V. K. AND SHEKHARGOUDA, M., 2006, Effect of boron and zinc application on seed yield and quality of sunflower restorer line, RHA-857. *Karnataka J. Agric. Sci.*, **19**(3): 708-710.
- PIPER, C. S., 1966, Soil and plant analysis. Academic press, New York (USA), pp. 4777.
- PRAMOD, M., DHOKE, S. K. AND KHANNA, A. S., 2011, Effect of nano-ZnO particle suspension on growth of mung (*Vigna radiata*) and gram (*Cicer arietinum*) seedlings using plant agar method. *J. Nanotech.*, **34**: 1-7.

- PRAPATSORN, B., PRABHAT, K., BOONTHIDA, K., SUNANDAN, B. AND JOYDEEP, D., 2011, Effects of zinc oxide nanoparticles on roots of rice (*Oryza sativa* L.). Paper presented In : *Int. Conf. Environ. Bio sci., IPCBEE*. Singapore.
- PRASAD, T. N. V. K. V., SUDHAKAR, P., SREENIVASULU, Y., LATHA, P., MUNASWAMY, V., RAJA REDDY, K., SREEPRASAD, T. S., SAJANLAL, P. R. AND PRADEEP, T., 2012, Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *J. Plant Nutri.*, **35**: 905-927.
- PRATHIMA, A. S., 2015, Boron nutrition in sunflower (*Helianthus annuus* L.). M.Sc. Thesis, University. Agric. Sci., Bengaluru.
- PRATHIMA, A. S., ROHINI N METI, SHIVARAMU, H. S., 2016, Influence of boron seed treatment on seed germination, seedling length and seedling vigor in sunflower (*Helianthus annuus* L.). *Int. J. Sci. and Nature*, **7**(2):273-276.
- RADEVA, K., 1991, Supply of boron on yield and seed quality in sunflower. *Ann. Plant Physiol.*, **6**: 43-45.
- RAMULU, N., KRISHNA MURTHY, JAYADEVA, H. M., VENKATESHA, M. M. AND RAVI KUMAR, H. S., 2011, Seed yield and nutrients uptake of sunflower (*Helianthus annuus* L.) as influenced by different levels of nutrients under irrigated condition of eastern dry zone of Karnataka, India. *Plant Archives*, **11**(2): 1061-1066.
- RANI, P. L. AND REDDY, T. M. M., 1993, Effect of nitrogen and boron on yield components, yield and oil content of sunflower (*Helianthus annuus* L.). *J. Res. Andhra Pradesh Agric. Univ.*, **21**(1): 39-41.
- RATHORE, P. S. 2001, Technique and management of field crop production. *Agro Bios. India*, 215-220.

- REDDY, S. S., YADAHALLI, Y. H., KUMAR, V. K. K., KUMARA, O. AND BORAIAH, B., 2002, Effect of fertilizer, gypsum and boron on dry matter accumulation, yield and nutrient content in sunflower hybrids. *Karnataka J. Agric. Sci.*, **15**(3): 569-572.
- REDDY, S. S., YADAHALLI, Y. H., KUMAR, V. K. K., KUMARA, O. AND NAIK, A. H. K., 2003, Effect of fertilizer, gypsum and boron application on yield and economics of sunflower hybrids. *Crop Res.*, **23**(3): 450-453.
- REID, R., 2007, Update on boron toxicity and tolerance in plants. *Adv. Plant Animal Boron Nutri.*, 83-90.
- REYHANEH AZIMI, GHOLAMALI HESHMATI AND REZA KAVANDI HABIB., 2016, Evaluation of SiO₂ nanoparticle effects on seed germination in *Astragalus squarrosus*. *J. Rangeland Sci.*, **6**(2): 1-9.
- REYHANEH, A., HASSAN, F. AND MOHAMMAD, K. H., 2013, Can bulk and nanosized titanium dioxide particles improve seed germination features of wheatgrass (*Agropyron desertorum*). *Not. Sci. Biol.*, **5**(3): 325-331.
- SALAMA, H. M. H., 2012, Effects of silver nanoparticles in common bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.). *Int. Res. J. Biotech.*, **3**(10): 190-197.
- SCHONFELD, M. A., JOHNSON, R. C., CARVER, B. F. AND MORNHINWEG, D. W., 1988, Water relations in winter wheat as drought resistance indicator. *Crop Sci.*, **28**: 526-531.
- SEDGI, M., HADI, M., GHOLI, S. AND TOLUIE, 2013, Effect of nano zinc oxide on the germination parameters of soybean seeds under drought stress. *Ann. West Univ. Bio.*, Timișoara, **16**(2): 73-78.
- SEEMA CHOUDHARY AND BHOGAL, N. S., 2013, Response of mustard cultivars to boron application. *Ann. Plant Soil Res.*, **15**(2): 131-133.

- SHARMA, P., BHATT, D., ZAIDI, M. G., SARADHI, P. P., KHANNA, P. K. AND ARORA, S., 2012, Silver nanoparticle mediated enhancement in growth and antioxidant status of *Brassica juncea*. *Appl. Biochem. Biotechnol.*, **167**:2225–2233.
- SHAILESH K. DHOKE, PRAMOD MAHAJAN, RAJASHRI KAMBLE AND ANAND KHANNA., 2013, Effect of nanoparticles suspension on the growth of mung (*Vigna radiata*) seedlings by foliar spray method. *Nanotechnology Development*. **3**:159-178.
- SHAW, A. K., GHOSHA, S., HAZEM, M., KALAJIB, BOSAC, K., BRESTICD, M., MAREK ZIVCAKD AND SHAW, Z. H., 2014, Nano-CuO stress induced modulation of antioxidative defense and photosynthetic performance of Syrian barley (*Hordeum vulgare* L.). *Environ. Exp. Bot.*, **5**: 1-10.
- SHEYKHBAGLOU, R., SEDGHI, M., TAJBAKSH SHISHEVAN, M. AND SHARIFI, S. R., 2010, Effects of nanoiron oxide particles on agronomic traits of soybean. *Notulae Sci Bio.*, **2**: 112-113.
- SKARPA, 2008, Effect of boron foliar application at critical growth stages on sunflower (*Helianthus annuus* L.) yield and quality. *J. Elem. Sci.*, **4**:449–459.
- SOHRAB DAVARPANAH, ALI TEHRANIFAR, GHOLAMHOSSEIN DVARYNEJAD, JAVIER ABADIA AND REZA KHORASANI, 2016, Effect of foliar application of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. *Ardestani*) fruit yield and quality. *Scientia Horticulturae*, **210**: 1-8.
- SONIA AND THUKRAL, A. K., 2014, Effects of macro and nano-cobalt oxide particles on barley seedlings and remediation of cobalt chloride toxicity using sodium hypochlorite. *Int. J. Plant Soil Sci.*, **3**(6): 751-762.

- SRIVATHSAN, J., SIVAKAMI, V., RAMACHANDRAN, B., HARIKRISHNA, K. S., VETRISELVI, S. AND MUKESH, K. D. J., 2012, Synthesis of silver nanoparticles and its effects on soil bacteria. *J. Microbiol. Biotech. Res.* **2**(6): 871-874.
- SUBBIAH, B. V. AND ASIJA, G. L., 1956, A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci.*, **25**: 259-260.
- SUSHEELA, C., 1996, Studies on the effect of phosphorus and boron on the yield and seed setting of sunflower (*Helianthus annuus* L.). M.Sc. Thesis, Tamil Nadu Agric. Univ., Coimbatore.
- TAMAK, J. C., SHARMA, H. C. AND SINGH, K. P., 1997, Effect of phosphorous, sulphur and boron on seed yield and quality of sunflower (*Helianthus annuus* L.). *Indian J. Agron.*, **42**(1): 169-172.
- TAPAN, A., KUNDU, S. AND SUBBA, R. A., 2013, Impact of SiO₂ and Mo nano particles on seed germination of rice (*Oryza Sativa* L.). *Int. J. Agric. Food Sci. Technol.*, **4**(8): 809-816.
- TARAFDAR, J. C., AGARWAL, A., RALIYA, R., KUMAR, P., BURMAN, U. AND KAUL, R. K. 2012a, ZnO nanoparticles induced synthesis of polysaccharides and phosphatates by *Aspergillus* fungi. *Advanced Science, Engineering and Medicine.* **4**:1-5.
- TARAFDAR, J. C., XIANG, Y., WANG, W. N., DONG, Q. AND BISWAS, P. 2012b, Standardization of size, shape and concentration of nanoparticle for plant application. *Appl. Biol. Res.*, **14**: 138-144.
- TEJESWARA RAO, K. AND SUBBIAH, G., 2006, Response of Indian mustard (*Brassica juncea* L.) Czern and coss to foliar application of zinc, boron and molybdenum. *J. Seeds Res.*, **23**(2): 336-339.

- TOUCHTON, J. T. AND BOSWELL, B. C., 1990, Effects of boron application on soybean yield, chemical composition, and related characteristics. *American Soc. Agron.*, **77**: 4-7.
- VENKATAKRISHNAN, A. S. AND BALASUBRAMANIAM, N., 1996, Yield maximization in sunflower. *Madras Agri. J.*, **83**(12): 791-792.
- VIJENDRA, K. M. AND ASHOK, K., 2009, Impact of metal nanoparticles on the plant growth promoting rhizobacteria. *Digest J. Nanomaterials Biostructures*, **4**(3): 587–592.
- VINOTH KUMAR, K. AND UDAYASOORIAN, C., 2014, Toxicity potential of different metal oxides nanoparticles on germination of maize plant. *Global J. Res. Analys.*, **3**(1): 22– 31.
- VITTI, A., NUZZACI, M., SCOPA, A., TATARANNI, G., TAMBURRINO, I. AND SOFO, A., 2014. Hormonal response and root architecture in *Arabidopsis thaliana* subjected to heavy metals. *Int. J. Plant Biol.*, **5**:5226-5232.
- VYAKARANAHAL, B. S., 2001, Investigations on seed set, seed yield and quality of parental lines and hybrids of sunflower (*Helianthus annuus* L.). Ph.D, Thesis, Univ. Agric. Sci., Dharwad.
- WALKELY, A. J. AND BLACK, T. A., 1934, Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci.*, **37**: 29-38.
- WANG, Y. G., LI, Y. S., KIM, H., WALKER, S. L., ABRIOLA, L. M. AND PENNELL, K. D., 2010, Transport and retention of fullerene nanoparticles in natural soils. *J. Environ. Qual.*, **39**: 1925-1933.
- WATSON, D. J., 1952, The physiological basis of variation in yield. *Advn. Agron.*, **4**:101-105.

- WENCHAO, D., YUANYUAN, S., RONG, I., JIANGUO, Z., JICHUN, W. AND HONGYAN, G., 2010, TiO₂ and ZnO nanoparticles negatively affect wheat growth and soil enzyme activities in agricultural soil. *J. Environ. Monit.*, **13**: 822.
- YANG, K., LIN, D. H. AND XING, B. S., 2009, Interactions of humic acid with nano sized inorganic oxides. *Langmuir.*, **25**: 3571-3576.
- ZHAO, L., HERNANDEZ VIEZCAS, J. A., PERALTA VIDEA, J. R., BANDYOPADHYAY, S. AND PENG, B., 2013, ZnO nanoparticles fate in soil and zinc bioaccumulation in corn plants (*Zea mays* L.) influenced by alginate. *Environ. Sci. Processes Impacts*, **15**: 260-266.
- ZHAO, L., YOUPING, S., JOSE, A., HERNANDEZ-VIEZCAS, JIE, H., MAJUMDAR, S., GENHUA, N., DUARTE-GARDEA, M., JOSE, R., PERALTA-VIDEA, JORGE, L. AND GARDEA-TORRESDEY, 2015, Monitoring the environmental effects of CeO₂ and ZnO nanoparticles through the life cycle of corn (*Zea mays*) plants and in Situ μ -XRF mapping of nutrients in kernels. *Environ. Sci. Technol.*, **49**: 2921-2928.
- ZHENG, L., HONG, F., LU, S. AND LIU, C., 2005, Effect of nano-TiO₂ on strength of naturally aged seeds and growth of spinach. *Biol. Trace Elem. Res.*, **104**: 83-91.

APPENDIX

Cost of inputs used and price of output (*Kharif* -2016)

Seed material	Cost (Rs.)	Fertilizers	Cost (Rs.)
KBSH - 53	Rs. 210/kg of seeds	FYM	Rs. 1250/t
Plant Protection		Urea	Rs. 544/qt
Quinolphos	Rs. 315/lt	SSP	Rs. 743/qt
Phorate	Rs. 74kg	MOP	Rs. 1583/qt
Confidor	Rs. 2625/lt	DAP	Rs. 1808/qt
Gouch	Rs. 236/50ml	Nano boron nitride	Rs.4065 / 25 g
Metalaxyl	Rs. 342/100g	Borax	Rs. 100/kg
Mancozeb	Rs. 278/kg	Labour Wages	
Tilt	Rs. 735/500ml	Men	Rs. 220/day
Bavistin	Rs. 500/ kg	Women	Rs. 220/day
Out put		Cultivator	Rs. 300/ day
Grain Produce		Disc Plough	Rs. 350/hr
Sunflower	Rs. 3800/qt	Irrigation charges	Rs. 175/day
Herbicide		Transportation	Rs. 200/hr
Lasso	Rs. 498/lt		