EFFECT OF FOLIAR SILICIC ACID ON GROWTH, YIELD AND NUTRIENT UPTAKE BY SOYBEAN [*Glycine max* (L.)]

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BENGALURU- 560065

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Affectionately dedicated to my Family and Friends

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES
GKVK, BENGALURU- 560065

CERTIFICATE

This is to certify that the thesis entitled **"EFFECT OF FOLIAR SILICIC ACID ON GROWTH, YIELD AND NUTRIENT UPTAKE BY SOYBEAN [*Glycine max* (L.)]"** submitted by **Ms. SHWETHAKUMARI, U., ID No. PALB 5327** in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (Agriculture)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the University of Agricultural Sciences, Bengaluru, is a record of research work done by her during the period of her study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

Bengaluru
August, 2017

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3. **(B. C. MALLESHA)**

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Bengaluru

August, 2017 ***(Shwethakumari, V.)***

EFFECT OF FOLIAR SILICIC ACID ON GROWTH, YIELD AND NUTRIENT UPTAKE BY SOYBEAN [*Glycine max* (L.)]

SHWETHAKUMARI, U.

ABSTRACT

A field experiment was conducted at Z.A.R.S, U.A.S, GKVK, Bengaluru, during *kharif* - 2016 to study the effect of foliar silicic acid on growth, yield and nutrient uptake by soybean [*Glycine max* (L.)]. The study was conducted by using two soybean varieties (MAUS-2 and KBS-23) with seven treatments and three replications by adopting spilt plot design. The results revealed a significant effect on achieving higher plant height, number of leaves plant^{-1}, pod yield, seed yield, protein yield and oil yield with the foliar application of silicic acid @ 2ml L^{-1} for three times. Application of foliar silicic acid @ 4ml L^{-1} three times significantly increased number of branches plant^{-1}, number of pods plant^{-1}, number of seeds plant^{-1} and haulm yield over other treatments. Greater variation in Si content among various parts of soybean was observed with the foliar application of silicic acid recording higher in haulm (0.42-0.92 %) followed by husk (0.11-0.16 %) and seed (0.06 to 0.15 %). Application of foliar silicic acid significantly enhanced the major, secondary and micronutrients uptake by soybean over control. Irrespective of treatments, application of foliar silicic acid significantly increased the growth parameters of MAUS-2 variety, while increased the yield parameters of KBS-23 variety. Foliar application of boric acid @ 2ml L^{-1} and 4ml L^{-1} for three times also enhanced the growth and yield of soybean over control. Investigation concludes that foliar application of silicic acid @ 2ml L^{-1} for three times and 4ml L^{-1} for two or three times along with RDF was found to be effective in MAUS-2 and KBS-23 varieties, respectively.

August, 2017

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ಸೋಯಾಬೀನಿನ ಬೆಳವಣಿಗೆ, ಇಳುವರಿ ಮತ್ತು ಪೋಷಕಾಂಶಗಳ ಹೀರುವಿಕೆಯ ಮೇಲೆ ಸಿಲಿಸಿಕ್ ಆಮ್ಲದ ಪರಿಣಾಮ

ಶ್ವೇತಾಕುಮಾರಿ, ಯು.

ಸಾರಾಂಶ

ಸೋಯಾಬೀನಿನ ಬೆಳವಣಿಗೆ, ಇಳುವರಿ ಮತ್ತು ಪೋಷಕಾಂಶಗಳ ಹೀರುವಿಕೆಯ ಮೇಲೆ ಸಿಲಿಕಾನ್ ಮೂಲವಾಗಿ ಉಪಯೋಗಿಸಿದ ಸಿಲಿಸಿಕ್ ಆಮ್ಲದ ಪರಿಣಾಮದ ಕುರಿತು ಕ್ಷೇತ್ರ ಪ್ರಯೋಗವನ್ನು ಮುಂಗಾರಿನ ೨೦೧೬ರಲ್ಲಿ ವಲಯ ಕೃಷಿ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಜಿ.ಕೆ.ವಿ.ಕೆ, ಬೆಂಗಳೂರಿನಲ್ಲಿ ಕೈಗೊಳ್ಳಲಾಯಿತು. ಎರಡು ಸೋಯಾಬೀನ್ ತಳಿಗಳಲ್ಲಿ (ಎಮ್.ಎ.ಯು.ಎಸ್–೨ ಮತ್ತು ಕೆ.ಬಿ.ಎಸ್–೨೩) ಏಳು ಉಪಚಾರಗಳನ್ನೊಳಗೊಂಡ ಪ್ರಯೋಗವನ್ನು ವಿಭಜಿತ ತಾಕುವಿನ ಮಾದರಿಯಲ್ಲಿ ಮೂರು ಬಾರಿ ಪುನರಾವರ್ತಿಸಲಾಯಿತು. ಎಲೆಗಳ ಮೇಲೆ ಲೀಟರಿಗೆ ೨ ಮಿ.ಲೀ.ನಂತೆ ಸಿಲಿಸಿಕ್ ಆಮ್ಲವನ್ನು ಮೂರು ಬಾರಿ ಸಿಂಪಡಿಸಿದ್ದರಿಂದ ಸಸ್ಯದ ಎತ್ತರ, ಎಲೆಗಳ ಸಂಖ್ಯೆ, ಕಾಯಿ ಇಳುವರಿ, ಬೀಜ ಇಳುವರಿ, ಪ್ರೋಟೀನ್ ಇಳುವರಿ ಮತ್ತು ಎಣ್ಣೆ ಇಳುವರಿ ಅಧಿಕವಾಗಿರುವುದು ಕಂಡು ಬಂದಿದೆ. ಅದೇ ರೀತಿ, ಲೀಟರಿಗೆ ೪ ಮಿ.ಲೀ.ನಂತೆ ಸಿಲಿಸಿಕ್ ಆಮ್ಲ ಸಿಂಪಡಿಕೆಯಿಂದ ಪ್ರತೀ ಸಸ್ಯದಲ್ಲಿ ಹೆಚ್ಚಿನ ರೆಂಬೆಗಳು, ಕಾಯಿ, ಬೀಜ ಮತ್ತು ಒಣಗಿಡದ ಇಳುವರಿ ಅಧಿಕವಾಗಿರುವುದು ಕಂಡು ಬಂದಿದೆ. ಸಿಲಿಸಿಕ್ ಆಮ್ಲದ ಸಿಂಪಡಣೆಯಿಂದ ಸೋಯಾಬೀನಿನ ವಿವಿಧ ಭಾಗಗಳಲ್ಲಿ ಸಿಲಿಕಾನಿನ ಪ್ರಮಾಣವು ಅಧಿಕವಾಗಿ ಒಣಗಿಡದಲ್ಲಿ (೦.೪೨–೦.೯೨ %), ನಂತರ ಸಿಪ್ಪೆ (೦.೧೧–೦.೧೬ %) ಮತ್ತು ಬೀಜದಲ್ಲಿ (೦.೦೬–೦.೧೫ %) ಕಂಡು ಬಂದಿದೆ. ಅದೇ ರೀತಿ ಪ್ರಮುಖ ಮತ್ತು ಲಘು ಪೋಷಕಾಂಶಗಳ ಹೀರುವಿಕೆಯು ಸಿಲಿಸಿಕ್ ಆಮ್ಲದ ಪ್ರಯೋಗದಿಂದ ಅಧಿಕವಾಗಿರುವುದು ಕಂಡು ಬಂದಿದೆ. ಎರಡೂ ತಳಿಗಳನ್ನು ಪರಿಗಣಿಸಿದರೆ, ಸಿಲಿಸಿಕ್ ಆಮ್ಲದ ಸಿಂಪಡಣೆಯು ಎಮ್.ಎ.ಯು.ಎಸ್–೨ ತಳಿಯ ಬೆಳವಣಿಗೆಯನ್ನು ಹೆಚ್ಚಿಸಿದ್ದು ಕೆ.ಬಿ.ಎಸ್–೨೩ ತಳಿಯಲ್ಲಿ ಇಳುವರಿಯನ್ನು ಹೆಚ್ಚಿಸಿರುತ್ತದೆ. ಅದರಂತೆ ಬೋರಿಕ್ ಆಮ್ಲವು ಲೀಟರಿಗೆ ೨ ಮಿ.ಲೀ ಮತ್ತು ೪ ಮಿ.ಲೀ.ನಂತೆ ಮೂರು ಬಾರಿ ಸಿಂಪಡಿಸಿದ್ದರಿಂದ ಸೋಯಾಬೀನಿನ ಬೆಳವಣಿಗೆ ಮತ್ತು ಇಳುವರಿಯು ಅಧಿಕವಾಗಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಶಿಫಾರಸ್ಸಿನ ಪ್ರಮಾಣದ ರಸಗೊಬ್ಬರದ ಜೊತೆಗೆ ಸಿಲಿಸಿಕ್ ಆಮ್ಲ ಲೀಟರಿಗೆ ೨ ಮಿ.ಲೀ.ನಂತೆ ಮೂರು ಬಾರಿ ಮತ್ತು ೪ ಮಿ.ಲೀ.ನಂತೆ ಎರಡು ಬಾರಿ ಸಿಂಪಡಣೆಯು ಕ್ರಮವಾಗಿ ಎಮ್.ಎ.ಯು.ಎಸ್–೨ ಮತ್ತು ಕೆ.ಬಿ.ಎಸ್–೨೩ ತಳಿಗಳಲ್ಲಿ ಪರಿಣಾಮಕಾರಿ ಎಂದು ಕಂಡು ಬಂದಿದೆ.

ಆಗಸ್ಟ್, ೨೦೧೭
ಮಣ್ಣು ವಿಜ್ಞಾನ ಮತ್ತು ಕೃಷಿ ರಸಾಯನಶಾಸ್ತ್ರ ವಿಭಾಗ
ಕೃಷಿ ಮಹಾವಿದ್ಯಾಲಯ
ಗಾಂ.ಕೃ.ವಿ.ಕೇ. ಬೆಂಗಳೂರು–೬೫

ಪ್ರಧಾನ ಸಲಹೆಗಾರರ ಸಹಿ
(ಎನ್. ಬಿ. ಪ್ರಕಾಶ್)

Effect of foliar silicic acid and boric acid on growth and yield of soybean (*Glycine max*.[L.]).

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Introduction

Silicon play an important role in providing beneficial effects on growth and yield of crops. Different sources of foliar and soil applied silicon such as calcium silicate, diatomaceous earth, rice husk biochar, potassium silicate etc., are being widely used for different crops.

Oil seeds play a major role in resolving the edible oil deficit situation in India. Increasing gap between demand and production of edible oil in India certainly highlights the need to increase the oilseed production. This gap is mainly due to improper use of varieties, deficiency of nutrient and pest and disease attack. Among the major oilseeds satisfying domestic demand for edible oil, soybean has emerged as one of the important crop. Although the research on effect of Si and B nutrition in different oilseed crops is available, information on silicic acid and boric acid in soybean is limited. Hence, the present investigation was undertaken to know the effect of foliar silicic acid and boric acid on growth and yield of soybean.

Objective

✓ To know the effect of silicic acid and boric acid on growth and yield of different soybean varieties.

Material and Methods

Location : ZARS, UAS, GKVK, Bangalore
Season : Kharif-2016
Variety : 1) MAUS-2 (105 – 115 days)
2) KBS-23 (85 -90 days)
Spacing : 30 cm x 10 cm
No of treatments : 7
No of replication : 3
Design : Split plot
Plot size : 5 m x 3.6 m
Source
Silicic acid : OSAB, ReXil Agro BV
2.0% - soluble silicic acid,
0.8% - Boric acid
Boric acid : H_3BO_3

Treatment details :

T_1: RDF – water spray (control)*
T_2 : RDF + SA @ 2ml L^{-1} at 21 and 36 DAS
T_3 : RDF + SA @ 4ml L^{-1} at 21 and 36 DAS
T_4 : RDF + SA @ 2ml L^{-1} at 21, 36 and 51 DAS
T_5 : RDF + SA @ 4ml L^{-1} at 21, 36 and 51 DAS
T_6 : RDF + 0.8% BA @ 2ml L^{-1} at 21, 36 and 51 DAS
T_7 : RDF + 0.8% BA @ 4ml L^{-1} at 21, 36 and 51 DAS
(SA – Silicic acid, BA – Boric acid)

*RDF = 25kg N: 60kg P_2O_5: 25kg K_2O ha^{-1} (through Urea, SSP, MOP respectively). $ZnSO_4$ @12.5 kg ha^{-1} and FYM @ 6.25t ha^{-1} common to all treatment.

Table 1: Initial properties of soil

Parameters	Value
pH	5.26
EC (dSm^{-1})	0.08
Acetic acid Si (mg kg^{-1})	29.12
$CaCl_2$ Si (mg kg^{-1})	25.92

Results

Table 2 : Effect of foliar silicic acid and boric acid on growth parameters of soybean varieties.

	Plant height (cm)			No. of leaves $plant^{-1}$			No. of branches $plant^{-1}$			Chlorophyll content (SPAD)		
Treatment	MAUS 2	KBS 23	Mean	MAUS 2	KBS 23	Mean	MAUS 2	KBS 23	Mean	MAUS 2	KBS 23	Mean
T1 : RDF - Water spray (control)	34.69	24.53	29.61	13.87	11.40	12.63	1.80	2.40	2.10	39.64	31.95	35.80
T2 : RDF + SA @ 2ml L^{-1} at 21 and 36 DAS	36.77	24.87	30.82	12.70	12.93	12.82	1.80	2.20	2.00	41.21	32.55	36.88
T3: RDF + SA @ 4ml L^{-1} at 21 and 36 DAS	40.69	26.23	33.46	15.47	12.87	14.17	2.53	2.53	2.53	42.75	33.88	38.31
T4 : RDF + SA @ 2ml L^{-1} at 21, 36 and 51 DAS	37.37	28.50	32.93	17.73	13.93	15.83	2.53	2.60	2.57	41.30	33.17	37.23
T5 : RDF + SA @ 4ml L^{-1} at 21, 36 and 51 DAS	39.30	27.31	33.31	17.00	12.53	14.77	3.13	2.67	2.90	42.00	32.69	37.34
T6 : RDF + 0.8% BA @ 2ml L^{-1} at 21, 36 and 51 DAS	38.60	26.93	32.77	12.30	11.67	11.98	2.27	2.47	2.37	39.76	32.55	36.16
T7 : RDF + 0.8% BA @ 4ml L^{-1} at 21, 36 and 51 DAS	36.83	24.65	30.74	13.67	10.93	12.30	1.80	2.20	2.00	40.07	32.63	36.35
Mean	37.75	26.15		14.68	12.32		2.27	2.44		40.96	32.77	
	Plant height (cm)			No. of leaves $plant^{-1}$			No. of branches $plant^{-1}$			Chlorophyll content (SPAD)		
	V	T	T × V	V	T	T × V	V	T	T × V	V	T	T × V
SE±	0.90	1.81	2.56	0.40	0.83	1.17	0.05	0.21	0.30	0.17	0.69	0.98
C.D at 5%	5.45	NS	7.40	NS	2.39	3.38	NS	0.62	0.88	1.01	2.00	2.83

* SA – Silicic acid ; BA – Boric acid

- Significantly higher difference in mean of two varieties with respect to plant height (33.46 cm) and chlorophyll content (38.31) were noticed with the application of foliar SA @ 4ml L^{-1} for two times. Foliar SA @ 2ml L^{-1} and 4ml L^{-1} application for three times significantly increased number of leaves $plant^{-1}$ (15.83) and number of branches $plant^{-1}$ (2.90) (Table.2).
- Irrespective of the variety, foliar spray of SA @ 2ml L^{-1} for three times significantly enhanced pod yield (3296.23 kg ha^{-1}) and grain yield (2004.96 kg ha^{-1}) compared to other treatments. Whereas significant increase in haulm yield (1774.61 kg ha^{-1}) was noticed with the application of SA @ 4ml L^{-1} for three times (Fig.1).
- Among the varieties, application of foliar SA significantly increased growth parameter of MAUS-2, while increased the grain and haulm yield of KBS-23.
- Application of BA @ 4ml L^{-1} for three times significantly increased the mean haulm yield (kg ha^{-1}), pod yield (kg ha^{-1}) and grain yield (kg ha^{-1}) of soybean over control.

Fig 1: General view of field experimental plot

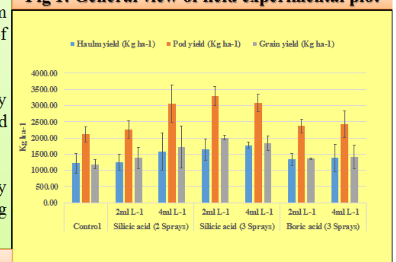

Fig-2: Effect foliar silicic acid and boric acid on yield of soybean varieties.

Discussion

- Application of foliar SA and BA significantly increased the growth parameters of MAUS-2 (long duration) and yield parameters of KBS-23 (short duration) in the present investigation. This may be attributed to better utilization of nutrients including silicon and boron by soybean during the crop growth.

Summary

- Foliar fertilization with the SA at two different doses (2ml L^{-1} and 4ml L^{-1}) at different intervals significantly enhanced the crop growth and yield of soybean.
- Among the treatments SA spray at 2ml L^{-1} with three times along with RDF was found to be effective in soybean.

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Advisory committee

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Dr. K. N. GEETHA
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I INTRODUCTION

Soybean [*Glycine max* (L.)] is a native of eastern Asia, widely grown for its edible bean, which has numerous uses. Currently in world, it is cultivated in an area of 967.7 lakh hectares with a production of 2400 lakh tonnes and productivity of 2441 kg ha^{-1}. In India, it is grown on an area of 95.68 lakh hectares with a production of 111.58 lakh tonnes and productivity of 1166 kg ha^{-1}. In Karnataka, an area of 1.58 lakh hectares is covered by soybean with production of 1.18 lakh tonnes and productivity of 746 kg ha^{-1}. Madhya Pradesh and Maharashtra are the major soybean cultivating states in India followed by Rajasthan, Andhra Pradesh and Karnataka (Rai *et al*., 2016).

Soybeans are the primary source of the world's supply of protein and vegetable oil, which contributes 25 per cent to the global oil consumption. The demand for increased production of soybeans is forecasted to mirror the world's population growth and demand for protein and edible oil. Increasing gap between demand and production of edible oil certainly highlights the need to increase the oilseed production. This gap is mainly due to challenges and threats to soybean production, which includes unpredictable weather, diseases, pests, weeds and variable soil quality and improper use of varieties (Lal, 2009; Strange and Scott, 2005; Hartman *et al*., 2011).

Soybean a grain legume is considered as a wonder crop due to its dual qualities *viz.*, high protein (40-43%) and oil content (20%). The soybean protein have five per cent lysine, which is deficit in most of cereals and enhancing the cereal flour with soybean improves the nutritive quality. Hence, this crop is aptly called as “Golden Bean” or “Miracle crop” of the 20^{th} century with its benefits. The seeds are used for direct human consumption, and as an oil and protein source (Weiss, 1983). Additionally, plant residues are extremely important as fodder for cattle in many regions of the world (Savage and Keenan, 1994).

Being a leguminous crop, soybean is able to fix atmospheric nitrogen in soil to an extent of 65 to 100 kg ha^{-1} depending on the soil type and climatic condition through rhizobial symbiosis (Srivastava *et al*., 1984). Despite the known ability of legumes to fix atmospheric nitrogen in symbiotic association with rhizobia, it has been demonstrated that supplementary fertilization can lead to improved performance of crop (Mallarino, 2005). Apart from soil applications, foliar spray of nutrients has been shown to be a practical means of replenishing the reservoir of nutrients in the leaves of legumes during pod development, since the efficiency of nutrient uptake by roots as well as symbiotic fixation activities are known to decline at this stage (Ashour and Thalooth, 1983). Fertilization with N, P, K and other micronutrient can effect yield and many physiological processes, which in turn could influence grain yield and protein concentration of soybean (Haq and Mallarino, 2005). Inspite of increase in area under soybean, the production and productivity remained low. Inclusion of beneficial element with recommended dose of fertilizer for providing balanced nutrition to the plants will help in augmenting the production and productivity of soybean crop. In that context, Si plays an important role in providing beneficial effects on growth and yield of crops. Different sources of foliar and soil applied silicon such as calcium silicate, diatomaceous earth, rice husk biochar, potassium silicate etc., are being widely used for different crops.

In recent years, foliar fertilization is gaining more importance due to availability of soluble fertilizers and it is of great significance in rainfed areas and under changing climatic conditions. Fertilizer applied to the crop at the time of sowing is not fully available to the plants as the crop approaches maturity, so supplemental foliar application is one of the techniques to increase yield of the crop. For the prophylactic effect to manifest, Si needs to be absorbed in the form of silicic acid [$Si(OH)_4$], where along with water, it follows the transpiration stream to finally deposit as silica (Canny, 1990; Sangster *et al*., 2001). Other researchers have found that foliar application of silicon (as silicates) compounds may be superior to root zone application for disease control (Bowen *et al*., 1992; Menzies *et al*., 1992).

Although the research on effect of Si nutrition in different oilseed crops is available, information on silicic acid is limited. Most of the work with foliar Si in soybean is focused to its role in plant protection. Though a crop of immense unexploited potential and tolerant to various biotic and abiotic stresses, information regarding Si accumulation or its role in growth of soybean is limited. Hence, the present investigation was undertaken with the following objectives.

1. To study the effect of silicic acid on growth and yield of soybean.
2. To determine the effect of silicic acid on nutrient content and uptake by soybean.
3. To know the effect of silicic acid on protein and oil content of soybean.

II REVIEW OF LITERATURE

The present study was undertaken to study the "Effect of foliar silicic acid on growth, yield and nutrient uptake by soybean "[*Glycine max* (L.)]" The reviews related to this investigation are presented under the following titles:

2.1 Role of silicon in crop performance

2.2 Role of silicon in bioavailability of nutrients in crops

2.3 Role of silicon in different leguminous crops

2.4 Foliar silicon and its performance in different crops

2.1 Role of silicon in crop performance

Although silicon is not recognized as an essential element for plant growth, its beneficial effect has widely been reported to increase the growth and biomass, yield and quality of a broad range of crops. It has been well documented that silicon (Si) is effective in enhancing the growth and yield of many agricultural and horticultural crops. The major crops that are widely reported to positively respond to Si fertilization include some monocotyledonous crops such as rice (*Oryza sativa*), wheat (*Triticum aestivum*), maize (*Zea mays*), barley (*Hordeum vulgare*), millet (*Setaria italica*), sorghum (*Sorghum bicolor*) and sugarcane (*Saccharum officinarum*) that actively absorb and accumulate high amount of Si in their organs. Some dicotyledonous crops such as cotton (*Gossypium sp.*), soybean (*Glycine max*) and some vegetable and fruit crops that are also able to accumulate Si.

Si fertilization after transplanting was found to increase the number of tillers and grains (Liang *et al*., 1994). Abro *et al.* (2009) conducted pot experiment to assess different levels of silicic acid on growth of wheat in silty loam soil. Silicic acid concentrations affected crop positively as well as negatively as all the varieties produced highest plant growth and yield at 0.25 per cent and 0.50 per cent silicic acid application while the lowest plant growth and yield was found under 0.75 per cent silicic acid.

Singh *et al*. (2005) conducted filed experiment to know the effect of levels (60, 120 and 180 kg Si ha^{-1}) and time of silicon application (full basal, 50% basal + 50% at tillering stage, 50% basal + 50% at panicle-initiation stage, 25% basal + 50% tillering + 25% at panicle-initiation stages and 0 basal + 50%, tillering + 50% panicle-initiation stages) including the control on growth and yield of rice. They noticed increase in plant height, dry-matter production, panicles m^{-2}, filled grains panicle^{-1}, test weight and yield of rice with the different levels of Si application. The maximum grain yield (6,588 kg ha^{-1}) was recorded with highest level of silicon, i.e. 180 kg Si ha^{-1} as calcium silicate and the maximum response was observed at 127 kg Si ha^{-1}. They opined that, among the application time, full basal application of silicon at the time of transplanting significantly increased the growth, yield attributes, yield and uptake of nutrients compared with the other time of silicon application. Singh *et al*. (2006) suggested that application of Si increased dry matter and yield of rice.

Application of calcium silicate as Si source significantly increased the grain and straw yield in all the soils from Karnataka (Narayanaswamy and Prakash, 2009). Among the soils studied, crop responded even up to 1448 kg ha^{-1} of applied Si in achieving higher grain yield over the control. However, there was a varied response in rice yield in different soil to the application of calcium silicate. They opined that these varied responses of soil to applied Si is due to variation in native plant available Si content of these soils. Soils having low to medium in available Si responded to applied Si fertilizers to greater extent than the soils having higher levels of available Si. Similar results were also noticed for organic soils of Florida (Korndorfer and Lepsch, 2001).

Yogendra *et al*. (2013) noticed that application of calcium silicate @ 2t ha^{-1} as a source of silicon increased grain and straw yield of wetland rice. Application nitrogen based on leaf colour chart with or without calcium silicate @ 2t ha^{-1} recorded on par grain yield over RDF. They concluded that the leaf colour chart would be helpful to avoid the under or over fertilization besides applying at appropriate time when the crop needs nitrogen so as to increase the productivity in rice.

Bhat *et al*. (2010) compared the effectiveness of basic slag with that of calcite as an ameliorant for rehabilitating acid soils using mustard followed by rice as test crops. They noticed that on an average, basic slag performed better than calcite in increasing yields of both mustard and rice. They opined that effectiveness of the basic slag improved when it was applied in combination with farmyard manure or poultry manure.

Wang *et al*. (2014) studied the beneficial effects of steel slag applied at various rates on rice growth, yield and soil properties in a subtropical paddy field of China. They noticed that steel-slag amendment had no positive effects on rice growth characteristics other than the shoot/root ratio, it significantly increased the grain yield and percentage of ripened grain.

Wang *et al*. (2015) noticed that yield of the first early rice crop was significantly higher when slag was applied at a rate of 8 Mg ha^{-1} than when lower rates were applied, and the yield of the late rice crop was significantly higher when slag added at a rate of 4 and 8 Mg ha^{-1}. They revealed that no significant rice yield response was observed when steel slag was applied at a rate of 2 Mg ha^{-1} only.

Sugarcane is considered a Si-accumulating plant, but in Brazil, where several soil types are used for cultivation, there is little information about silicon (Si) fertilization. Camargo *et al*. (2013) evaluated silicon availability, uptake and recovery index of Si from the applied silicate on tropical soils with and without silicate fertilization, in three crops. The experiment was performed with specific Si rates (0, 185, 370 and 555 kg ha^{-1} Si) in three soils (Quartzipsamment-Q, 6 % clay; Rhodic Hapludox - RH, 22 % clay; and Rhodic Acrudox - RA, 68 % clay). The silicon source was Ca-Mg silicate. They noticed that the silicon rates increased soil Si availability and Si uptake by sugarcane and had a strong residual effect. The silicate rates promoted an increase in soluble Si-acetic acid at harvest for all crops and in all soils, except RA.

Torkashvand (2011) investigated the possibility of using converter slag as an Fe fertilizer in some calcareous soils. They showed that application of 0.5 and 1 per cent converter slag to soil remarkably increased shoot dry matter of corn.

Sistani *et al*. (1997) conducted a greenhouse experiment to study the effect of Si from rice hull ash (RHA) on the growth of rice (*Oryza sativa* L.) seedlings. The RHA-treated seedlings produced more dry matter (18%) over the untreated seedlings. They opined that RHA application to rice nurseries seems to be an efficient way of recycling plant Si and have agronomic and environmental benefits, especially in developing countries.

Sandhya (2013) reported that increase in plant height was noticed with the application 100 per cent package of practice (POP)+ 300 kg (Diatomaceous earth) DE ha^{-1} compared to only 100 per cent POP and control. Among different levels of DE and POP, response of DE was more pronounced at lower level of POP. Application of 100 per cent POP along with 300 kg DE ha^{-1} recorded maximum number of tillers per plant, highest number of filled grains per panicle, maximum grain and straw yield over control.

Bradbury and Ahmad (1990) showed that decrease in whole plant dry weight was observed when *Prosopis juliflora* (Swartz) DC. was treated with saline irrigation water for 24 days which was partially alleviated by the addition of 0.47 mM SiO_2 to the irrigation water. The plants treated with high salinity and SiO_2 showed a greater distribution of dry material to the leaves at the expense of the stems and roots.

Gao *et al*. (2004) studied on influence of silicon (Si) on water use efficiency (WUE) in maize plants. Plants treated with 2 mM L^{-1} silicic acid (Si) had 20 per cent higher WUE than that of plants without Si application. Compared with treatment without Si, Si addition significantly increased WUE of plants and the degree of increase was more significant when the plants suffered from water stress. They reported that no significant effect of added silicon on fresh or dry weight of maize plants.

Amin *et al*. (2016) conducted a pot experiment to evaluate the growth of two maize hybrids under well watered and water deficit situations as affected by Si application. Silicon was added to soil @ 100 mg kg^{-1} as calcium silicate and plants were grown with two levels of soil water content *viz*. 100 per cent and 60 per cent of field capacity. They noticed that, drought - stressed hybrid P-33H25 and FH-810 plants with Si application significantly increased plant height (129.0 cm and 120.0 cm), stem diameter (1.23 cm and 1.22 cm), number of leaves (13.3 and 13.2), cob length (13.96 cm and 12.83 cm), number of grains per cob (235.1 and 215.4), 100 grain weight (19.7 g and 18.5 g), grain yield (46.2 g and 39.9 g) and biological yield (115.5 g and 102.3 g) along with improvement in photosynthetic rate and lowered transpiration rate, respectively. They concluded that silicon application to drought stressed maize plants improved the growth and yield which could be due to improved photosynthetic rate and lowered transpiration.

Jayawardana and Weerahewa (2016) conducted an experiment to investigate the effect of soil incorporation of raw rice hull (RRH) as a source of silicon in enhancing anthracnose disease resistance of chili pepper. They observed highest reduction of disease severity (61%) was in crops grown in soils amended with RRH compared to control plants and the disease reduction observed in fruits from plants provided with potassium silicate was only about 15 per cent, compared to that of Si-free plants. They opined that Si provided by RRH in the substrate would be the main factor influencing the disease reduction. Finally concluded that incorporation of rice hull (60% of the media) in the growing substrate would be an effective solution against anthracnose disease of chili pepper plants.

Liu *et al*. (2014) studied the potential of biochar soil amendment (BSA) to improve Si availability in paddy soils. They noticed that plant - available Si content of soil increased significantly and rice shoot Si was well correlated to the concurrent increase in soil pH under BSA treatment. They revealed that BSA improve Si availability and uptake by rice mainly through increasing soil pH of the acid and slightly acid rice soils.

Ratnayake *et al*. (2016) studied on application liquid potassium silicate (100, 200, 300 mg Si kg^{-1}) to the growing medium containing top soil, compost and sand on downy mildew disease intensity in bitter gourd. They revealed that Si treated plants exhibited less disease severity than that of control plants and 200 mg Si kg^{-1} treatment resulted in highly significant disease suppression (37 - 53% reduction against controls). Numbers of leaves, flowers or fruits in Si treated plants were significantly higher than control plants except in 300 ppm Si level. They concluded that structural changes created by Si is responsible for reducing the fungal disease severity in bitter gourd leaves.

2.2 Role of silicon in bioavailability of nutrients in crops

Gunes *et al*. (2007) investigated effect of silicon (Si) on the growth, uptake of Na, Cl, and B in spinach and tomato grown in sodic- B toxic soil. Si applied to the sodic- B toxic soil at 2.5 and 5.0 mM concentrations significantly increased the Si concentration in the plant species and counteracted the deleterious effects of high concentrations of Na, Cl and B on root and shoot growth by lowering the accumulation of these elements in the plants. Si alleviates sodicity and B toxicity by preventing both oxidative membrane damage and also translocation of Na, Cl and B from root to shoots and/or soil to plant, and lowering the phytotoxic effects of Na, Cl and B within plant tissues. It was concluded that tomato was more responsive to Si than spinach since it was more salt sensitive than spinach.

In rice, about 66 per cent of silicon in the whole plant and 70 to 75 per cent of silicon in the leaf blades were absorbed during the reproductive stage and 75 per cent of silicon in the panicle was absorbed during the ripening stage, 40 to 50 per cent of the silicon absorbed during the vegetative and reproductive stages was present in the leaf blades, whereas only 20 to 30 per cent of silicon absorbed during the ripening stage was present in the leaf blades. Dry weight of straw increased about 30-200 per cent when silicon was applied at reproductive stage. 1000- grain weight was hardly influenced with the application of Si, but there was an increase in filled spikelets and grain yield (Ma *et al*., 1989).

Singh *et al*. (2005) noticed that among the application time, full basal application of silicon as calcium silicate (180 kg Si ha^{-1}) at the time of transplanting significantly increased the uptake of nitrogen, phosphorus, potassium and silicon compared with the other time of silicon application.

Sopandie *et al*. (1995) investigated the effect of Si on the growth and ions uptake (K, Na, Ca, and Mg) in rice, bean and barley plants grown in saline conditions. They revealed that Si had the protective effect on salt injury only for rice plants. This alleviating effect of Si appeared to be associated with the interference of Si on the upward Na transport by reducing the content of Na in the shoots and retaining it in the roots. They concluded that addition of Si did not affect the content of K in all plants tested. Except for rice, Si had no or less effect on Ca and Mg uptake by bean and barley plants.

Guo *et al*. (2005) noticed that increasing Si concentration decreased the shoot and root As concentrations and total As uptake by rice seedlings. In addition, Si significantly decreased shoot P concentration and shoot P uptake. They concluded that addition of Si to the growth medium also inhibited the uptake of arsenate and phosphate by the rice seedlings.

Ma and Takahashi (1989) revealed that the content and the uptake of phosphorus decreased by the addition of silicic acid, and the effect was more pronounced at the vegetative stage than at the reproductive stage in rice plants. They found that rice plants that received silicic acid in advance absorbed less phosphorus compared with those which were not pretreated with silicic acid.

Ma and Takahashi (1990) conducted a pot experiment to measure the effect of silicon on phosphorus uptake and on the growth of rice at different P levels. Shoot dry weight with Si (+Si) in solution increased with increasing P level, suggesting that +Si raised the optimum P level in rice. The beneficial effect of Si on the growth of rice was clearly shown when P was low or high. This effect may have resulted from decreased Mn and Fe uptake.

Tamai and Ma (2003) reported that Si uptake by rice roots was much higher than that by other graminaceous species including wheat, triticale, sorghum, rye, maize and barley. Uptake of Si is unaffected by the presence of boron. They confirmed that rice roots have a different uptake system for silicic acid from other species.

Mitani and Ma (2005) noticed that the accumulation of silicon (Si) in the shoots varies considerably among plant species. They noticed that concentrations of Si in the root-cell symplast in rice, cucumber and tomato were higher than that in the external solution, although the concentration in rice was 3 and 5 fold higher than that in cucumber and tomato, while the Si concentration of xylem sap in rice was 20 and 100 fold higher than that in cucumber and tomato, respectively. They indicated that a higher density of transporter for radial transport and the presence of a transporter for xylem loading are responsible for the high Si accumulation in rice.

Ma *et al*. (2001) investigated the role of root hairs and lateral roots in the Si uptake using two mutants of rice, one defective in the formation of root hairs (RH2) and another in that of lateral roots (RM109). They showed that Si uptake of RM109 was much less than that of wild type (WT). The number of silica bodies formed on the third leaf in RH2 was similar to that in WT, but the number of silica bodies in RM109 was only 40% of that in WT. They opined that lateral roots contribute to the Si uptake in rice plant.

Pati *et al*. (2016) revealed that application of silicon (diatomaceous earth, DE) at 600 kg ha^{-1} in combination with full standard fertilizer practice (SFP) not only increased the growth and yield but also enhanced the concentration and uptake of the other nutrients. They suggested soil application of Si through DE at 600 kg ha^{-1} in combination with full SFP is very effective to obtain significantly greater rice yield.

Prakash *et al*. (2011) revealed that foliar spray of soluble silicic acid @ 2 and 4ml L^{-1} alone increased the per cent Si and its uptake in both straw as well as grain in both hilly and coastal zone. They noticed that highest per cent and uptake of Si was in plots treated with silicic acid @ 4ml L^{-1} with half dose of pesticide.

Nagula *et al*. (2016) noticed that the application of potassium silicate @ 0.5% + borax 0.5% spray three rounds at 15 days interval significantly recorded lower content of Fe and Mn in straw and grain, whereas the uptake recorded higher in the same treatment. They noticed that the application of potassium silicate @ 0.5 per cent + borax 0.5 per cent spray three rounds at 15 days interval significantly improved the content and uptake of silicon by plant, while improving the yield of rice. They opined that foliar application of potassium silicate was superior to the soil application of calcium silicate in terms of Si content in straw and grain and the uptake by plant.

2.3 Role of silicon in different leguminous crops

Gonzalo *et al*. (2013) studied the role of Si in the alleviation of iron deficiency symptoms and Fe distribution in iron deficient plants. The soybean and cucumber plants grown under hydroponic culture with the supply of 0, 0.5 and 1.0 mM Si. For soybean, addition of 0.5 mM of Si to the nutrient solution without iron, initially or continuously during the experiment, prevented the chlorophyll degradation, maintained the Fe content in leaves and thus slowed down the growth decrease due to the iron deficiency. Similarly, for cucumber, Si addition delayed the decrease of stem dry weight, stem length, node number and iron content in stems and roots.

Iwasaki *et al*. (2002) conducted solution-culture experiments to know the relationship between the Mn and Si concentrations in apoplastic washing fluids (AWF) and the severity of Mn toxicity symptoms in the leaves of the Mn - sensitive cowpea cultivar. They noticed that the expression of Mn toxicity symptoms was prevented when 1.44 mM L^{-1} Si was supplied together with 50 μM L^{-1} Mn. The severity of Mn toxicity symptoms and the guaiacol-peroxidase (POD) activity in AWF of these plants were not significantly correlated with the Mn concentrations in AWF, but were highly significantly correlated with the Si concentrations in AWF. They concluded that the decrease of Mn concentration in the apoplast caused by Si supply was insufficient to explain the enhanced Mn tolerance by Si supply.

Cruz *et al*. (2013) studied the effect of jasmonic acid (JA), Acibenzolar-S-Methyl (ASM) and calcium silicate (0 and 1.75 g kg^{-1} of soil) on the potentiation of soybean resistance to Asian soybean rust (ASR). The ASR severity was significantly reduced on plants sprayed with ASM or supplied with Si in comparison to plants sprayed with JA or deionized water. The Si concentration in leaf tissue of plants grown in soil amended with calcium silicate was significantly higher (2.6 g kg^{-1} of dry weight) compared to plants sprayed with ASM, JA and deionized water (0.60, 0.43 and 0.51 g kg^{-1} of dry weight, respectively). They opined that the increase in the Si concentration in leaf tissue of soybean plants grown in soil amended with calcium silicate contributed to reduce the Asian soybean rust (ASR) severity.

Miyake and Takahashi (1985) concluded that soybean plants cultured in solution with and without Si application (l00 ppm SiO_2) grew normal in the earlier growth stage. Later at flowering stage, newly developed leaves of the Si-free plants showed malformations such as curling and curving to the outside compared to Si-supplied plants. The growth and pollen fertility of the Si-free plants was markedly inferior to that of the Si-supplied plants. Further, they revealed that the mode of Si uptake of the soybean plant is not of the rejective type like in the tomato plant but of the intermediate type as in the case of cucumber plants which stand between the active uptake type and the rejective type.

Lee *et al*, (2010) found that application of Si as sodium metasilicate (Na_2SiO_3) to hydroponically grown soybean (*Glycine max* (L.) Merrill.) improved plant length and biomass by mitigating the adverse effect of salt stress on soybean, while NaCl significantly decreased these attributes.

Soybean plants grown in hydroponic culture containing either 0 or 2 mM Si (–Si and +Si, respectively) and noninoculated or *Cercospora sojina* inoculated. Severity of frogeye leaf spot was higher in cultivar Bossier plants than cultivar Conquista and also in the +Si plants compared with their –Si counterparts. The defense enzyme activities decreased in soybean plants supplied with Si, which compromised resistance to *C. sojina* infection (Nascimento *et al*., 2016).

Nelwamondo and Dakora (1999) reported that applying silicon in the form of metasilicic acid (H_4SiO_3) or silicic acid (H_4SiO_4) to *Bradyrhizobium* - infected, hydroponically grown cowpea seedlings resulted in a significant increase in the number of nodules, nodule dry matter and nitrogen fixed on a per plant basis. Total dry matter of plants increased with silicon supply and the differences were significant at the higher silicon concentrations. They opined that, though silicon is not essential for growth of cowpea it is important for nodule formation and nodule functioning in hydroponically grown plants.

Ghasemi *et al*. (2013) conducted an experiment to evaluate the effect of Si on growth and development of broad bean in a calcareous soil. They recorded that higher flower number, pod weight, seed number, plant fresh weight, plant dry weight and chlorophyll index were in application of 15 mg Si as sodium silicate among different treatments (0, 5, 10 and 15 mg Si Kg^{-1} soil).

Nelwamondo *et al*. (2001) revealed that provision of silicon (0, 0.048, 0.096, 0.24, 0.48, and 0.96 g L^{-1}) in the form of silicic acid (H_4SiO_4) to nodulated cowpea plants grown in liquid culture resulted in considerable changes in the internal organization of nodule structure. They noticed that compared to the control plants which received no added silicate, bacteroid numbers increased significantly at silicate concentrations of both 0.096 and 0.48 g L^{-1}. The number of symbiosomes also increased by 3.2 - fold at the silicate concentration of 0.96 g L^{-1} compared to the control. They opined that the positive effects of silicon on N_2 fixation might actually be due to an increased number of bacteroids and symbiosomes.

Silicon improved salt and drought induced physio-hormonal changes (gibberellins, jasmonic acid and salicylic acid) including shoot length, plant fresh weight and dry weight of soybean, that were reduced under NaCl (a salt stress inducer) and polyethylene glycol (PEG; a drought stress inducer) additions. The adverse effects of NaCl and PEG were alleviated with silicon addition at a rates of 100 and 200 mg L^{-1}. The effects of silicon were more pronounced under salt induced than drought-induced stress. Silicon affected the gibberellic acid biosynthesis pathway, increasing GA1 and GA4 content of soybean leaves with or without stress (salt, drought). Jasmonic acid concentrations in leaves increased under both salt and drought stress but declined with silicon additions. Free salicylic acid also increased under both salt and drought, but the increase was greater with silicon under salt stress and decreased under drought with silicon (Hamayun *et al*., 2010).

Shen *et al*. (2010) noticed that relative leaf water content in soybean seedling increased by 19 per cent with supplemental Si and 30 per cent under combined drought + Ultraviolet-B radiation (UV-B) stress. Silicon also had a positive effect on photosynthesis under stress, increasing photosynthesis to an extent of 21 per cent under UV-B, 18.3 per cent under drought and 21.5 per cent under drought + UV-B. Although UV-B light proved to be more stressful than drought, silicon additions ameliorated the biological and physiological damages caused by these environmental stresses.

Mali and Aery (2009) studied the effect of various concentrations of Si as sodium metasilicate (0, 50, 100, 200, 400, and 800 μg g^{-1}) on nodule growth and mineral nutrition of *Rhizobium* sp. U 15–inoculated cowpea. Lower additions of Si (50–100 μg g^{-1}) significantly increased nodule growth (nodule number, nodule fresh weight and dry weight), relative yield of root and shoot, nitrogen, phosphorus, and calcium concentrations. Plant Si concentrations increased with an increase in soil - applied Si. They concluded that Si at low concentrations is beneficial for nodule growth.

Mahmood *et al.* (2016) explored the eco-friendly approach of utilizing plant-growth promoting rhizobacteria (PGPR) inoculation and application of silicon (Si) to improve the physiology, growth, and yield of mungbean under saline conditions. They evaluated two PGPR strains and two Si levels (1 and 2kg ha^{-1}), in comparison with control treatments, under three different saline irrigation conditions (3.12, 5.46, and 7.81 dSm^{-1}). The noticed that salt stress substantially reduced stomatal conductance, transpiration rate, relative water content (RWC), total chlorophyll content, plant height, leaf area, dry biomass, seed yield, and salt tolerance index of mungbean. The PGPR strains and Si levels independently improved all the mentioned parameters. Furthermore, the combined application of the *B. drentensis* strain with 2 kg Si ha^{-1} resulted in the greatest enhancement of mungbean physiology, growth, and yield.

Kurdali *et al*. (2013) conducted pot experiment to know the effect of three fertilizer rates of Si (Si_{50}, Si_{100} and Si_{200}) and one fertilizer rate of K on plant growth, nitrogen uptake and N_2-fixation in water stressed (FC1) and well-watered (FC2) chickpea plants using ^{15}N and ^{13}C isotopes. They noticed that $Si_{100}K$+ (FC1) and $Si_{50}K$+ (FC2) treatments recorded high enough amounts of N_2-fixation, higher dry matter production and greater nitrogen yield and the per cent increments were 51 and 47 over their controls, respectively. They concluded that the synergistic effect of silicon and potassium fertilization with adequate irrigation improves growth and nitrogen fixation in chickpea plants.

Miao *et al*, (2010) noticed that application of Si (Na_2SiO_3) to K-deficient medium markedly alleviated K deficiency-induced inhibition of both root and shoot growth in soybean seedlings. Si significantly enhanced K accumulation in soybean plants exposed to K-deficient medium, thus alleviating K deficiency-induced membrane lipid peroxidation and oxidative stress by modulating antioxidant enzymes. They found that Si is not only involved in amelioration of nutrient toxicity, but can also improve nutrient use efficiency under nutrient-deficient conditions.

Owino-Gerroh *et al*. (2005) conducted a greenhouse experiment to know the effect of calcium silicate on P availability and the effect of *Rhizobium* inoculation on the growth of pigeonpea. Both Si and P applications significantly increased the growth of pigeonpea and the optimum fresh and dry shoot weights, plant-available water, shoot height, nitrogen (N) and P contents. They revealed that high levels of plant Mn concentrations were reduced by Si application.

Horst and Marschner (1978) studied the effect of silicon on manganese tolerance of bean plants (*Phaseolus vulgaris*) grown in water culture at different levels of manganese supply. They noticed that without silicon, growth depression and toxicity symptoms occurred already at $5 \text{ X } 10^{-4}$ mM Mn in the nutrient solution. After addition of Aerosil (0.75 ppm Si), the plants tolerated 5×10^{-3} mM Mn and at a higher silicon supply of 40 ppm, as much as 10^{-2} mM Mn in the nutrient solution without any growth depression. They opined that, this increase in manganese tolerance was not caused by a depressing effect of silicon on uptake or translocation of manganese but rather by an increase in the manganese tolerance of the leaf tissue.

Qados and Moftah (2015) conducted an experiment to evaluate the effects of silicon (Si) and nano-silicon (NSi) for ameliorating negative effects of salinity on germination, growth and yield of fababean. They noticed that salinity had deleterious effects on seed germination, plant growth and yield. Application of Si and NSi significantly enhanced the characteristics of seed germination and alleviated the harmful effect of salt stress on vegetative growth and relative water content (RWC), which caused significant increase in plant height, fresh and dry weights total yield. They concluded that the application of Si was beneficial in improving the salt tolerance of *Vicia faba* plants.

Shahzad *et al*. (2013) noticed that NaCl treatment with the addition of 1 mM silicon led to a significantly increased growth at NaCl concentrations above 50 mM compared with the corresponding NaCl treatment alone. The treatment of 75 and 100 mM NaCl + 1 mM silicon increased biomass to 14 per cent and 18 per cent compared with the salt treatment without silicon.

Yang *et al.* (1999) conducted an experiment to know the effect of Si on the toxicity of Al to mungbean seedlings. They noticed that Si at 1 mM in the solution only increased seedling height, epicotyl length, fresh weight, and chlorophyll content, but decreased dry weight and protein content of the roots under 5 mM Al stress, significantly. They revealed that Si addition at 10 mM showed similar toxic effects on mungbean seedling growth under 5 mM Al stress to that under no Al stress.

2.4 Foliar silicon and its performance in different crops

Few scientific studies have confirmed the benefits of Si amendments through foliar silicic acid applications. Prakash *et al*. (2011) conducted a field experiment to evaluate the effect of foliar soluble silicic acid on growth and yield parameters of wetland rice. The results revealed a significant effect on achieving higher grain and straw yield with foliar silicic acid (4ml L^{-1} along with half dose of recommended pesticide) over control. Similar results were also recorded in ragi (Sandhya, 2010) with foliar spray of silicic acid and significant reduction in neck blast was achieved with increased level of silicic acid. Also, application of calcium silicate and foliar silicic acid improved growth and yield parameters of maize (Venkataraju, 2013).

Rodrigues *et al.* (2009) studied the effect potassium silicate (KSi) sprays on intensity of soybean rust under field and greenhouse condition. In the field experiment-1, soybean plants were sprayed with KSi (pH 10.5) at rates of 8, 20, 40 and 60 g L^{-1}. In the field experiment 2, with the same treatments, the pH of the KSi solutions was 5.5. In experiment 3, the treatments were KSi (40 g L^{-1}, pH 10.5), potassium hydroxide (KOH) (6.5 g L^{-1}, pH 10.5), epoxiconazole + pyraclostrobin, and control. In experiment 4, the treatments were the same as in experiment 3, but the pH of the KSi and KOH solutions was adjusted to 5.5. Plants sprayed with water served as a control treatment for all field experiments. Here plants were artificially inoculated with *Phakopsora pachyrhizi* before the application of products. They concluded that, even though there was no relationship between Si concentration in leaf tissue and KSi rates, Si concentration increased by 67 per cent and 73 per cent, respectively above the control, when averaged across all KSi rates for experiments 1 and 2. Soybean rust severity at the highest KSi rate (pH 5.5) was 70 per cent less than the control. Further, in experiments 3 and 4, the highest disease severity was observed in the control treatment, which differed from other treatments. The application of KSi at pH of 10.5 (Exp. 3) and 5.5 (Exp. 4) decreased soybean rust severity by 36 per cent and 43 per cent, respectively, over the control. In greenhouse experiments, Si concentration in leaf tissue was higher with the application of KSi, regardless of the pH of the solutions, as compared with water spray. Soybean rust severity and the number of pustules were higher on leaves of plants sprayed with water, as well as on those sprayed with phosphoric acid + NaOH and phosphoric acid + KOH, when compared with the application of KSi.

Rodrigues *et al.* (2010) studied the effect potassium silicate (KSi) sprays on intensity of angular leaf spot in common bean. In field experiment 1, bean plants were sprayed with KSi (pH 10.5) at rates of 8, 20, 40, and 60 g L^{-1}. In field experiment 2, with the same treatments, the pH of the KSi solutions was 5.5. In experiment 3, the treatments were KSi (40 g L^{-1}, pH 5.5), potassium hydroxide (6.5 g L^{-1}, pH 5.5), tebuconazole (0.5 L ha^{-1}), and control. In experiment 4, the treatments were the same as in experiment 3, but the pH of the KSi and KOH solutions was 10.5. Plants sprayed with water served as a control treatment for all field experiments. Plants were artificially inoculated with

Pseudocercopora griseola before products application. They revealed that there was no relationship between KSi rates and Si concentration in leaf tissues, but Si concentration increased by 58 and 57 per cent, respectively, as the KSi rates increased from 0 to 60 g L^{-1} regardless of the pH. Further, noticed that disease severity decreased by 42 and 30 per cent, respectively, at the highest KSi rate with pH 5.5 and pH 10.5 over the control. They concluded that plant defoliation decreased with the application of KSi with pH 5.5 and 10.5 in 29 and 34 per cent, respectively, compared to the control, and yield increased by 30 and 43 per cent, respectively, as the KSi rates increased from 0 to 60 g $L^{-1}$with pH 5.5 and 10.5.

Crusciol *et al*. (2013) conducted an experiment to evaluate the effect of foliar application of Si, in the form of stabilized silicic acid on the nutrition and productivity of crops of soybean, common bean and peanut. They revealed that foliar application increased the Si content, providing an increase in the number of pods and a higher seed yield in all three crops. The increase was around 14, 15 and 9.6 per cent, respectively, for the soybean, common bean and peanut.

Pereira *et al*. (2009) conducted an experiment to know the effect of foliar application of this element on rust severity. Soybean plants (cultivar MG / BR-46 Conquest) were sprayed with water (control), potassium silicate (KSi) (pH 10.5), KSi (pH 5.5), and acibenzolar-S-methyl (ASM) 24 hours before inoculation. They reported that there was no significant difference between the treatments for the content of Si and potassium in leaf tissue and rust severity was significantly lower on plants sprayed with KSi, regardless of pH, and ASM compared to plants from control treatment. They noticed ASM significantly decreased rust severity by 65.5 per cent in comparison to control.

Among the different rates of foliar applications of silicon aqueous solution to paddy crop, 0.50 per cent silicon solution produced maximum grain diameter and grain protein, while silicon @ 1.00 per cent solution resulted maximum in number of productive tillers, straw yield, spike per panicle, 1000 grain weight, yield and grain starch (Ahmad *et al*., 2013).

Guevel *et al*. (2007) observed that root applications of 1.7 mM Si on wheat plant performed consistently the best in reducing disease severity as much as 80 per cent and foliar treatments with both Si and nutrient salt solutions led to a significant reduction of powdery mildew.

Rezende *et al*. (2009) revealed that foliar application of potassium silicate (PS) (40 g L^{-1}) decreased the intensity of brown spot of rice compared to root application of calcium silicate (CS) (1.25 g kg^{-1} of soil).

Liang *et al*. (2005) reported that foliar-applied Si can effectively control infections by P. *xanthii* only *via* the physical barrier of Si deposited on leaf surfaces, and /or osmotic effect of the silicate applied, but cannot enhance systemic acquired resistance induced by inoculation, while continuously root-applied Si can enhance defence resistance in response to infection by P. *xanthii* in cucumber.

Buck *et al*. (2008) stated that the greatest reduction on blast incidence was observed at 4 g Si L^{-1}, when potassium silicate (K_2SiO_3) was applied in different doses (0, 1, 2, 4, 8, or 16 g L^{-1} Si) to rice plants.

Menzies *et al*. (1992) reported that foliar sprays of more than 17.0 mM Si developed fewer powdery mildew colonies, when foliar sprays containing 1.7, 8.5, 17, and 34 mM Si of potassium silicate was sprayed on cucumber, muskmelon and zucchini squash.

Bowen *et al*. (1992) noticed that foliar sprays on grape at 17 mM Si substantially reduced the number of mildew colonies that developed on inoculated leaves due to a physical barrier to hyphal penetration and to a resistance response involving the lateral movement of Si and its deposition within the leaf at fungal penetration sites.

Maghsoudi *et al*. (2015) reported that foliar application of silicon increased the leaf relative water content, photosynthesis pigments, chlorophyll stability index (CSI) and membrane stability index (MSI) in all wheat cultivars, especially in Sirvan and Chamran (drought tolerant cultivars), under both stress and non-stress conditions. Si significantly decreased electrolyte leakage in all four cultivars, net photosynthesis, transpiration rate and stomatal conductance, intrinsic water use efficiency carboxylation efficiency under drought condition.

Syu *et al*. (2016) conducted an experiment to know the effects of Si foliar and soil applications on the growth and As accumulation in rice seedlings. They reported that there were no significant differences in Si concentrations in shoot among different Si foliar as sodium silicate, and it had no significant effect on the growth and As accumulation in rice seedlings. In contrast, soil applications of Si as sodium silicate caused a decrease in As accumulation in shoots grown in the tested soils, resulting from a high Si/As ratio in the soil pore water allowing enough Si out-compete the As for uptake by roots. They finally concluded that foliar applications of Si are not able to decrease As accumulation in rice seedlings, but the application of moderate amounts of Si into As - contaminated soil could effectively reduce As uptake by rice seedlings.

Lopes *et al*. (2013) reported that foliar application of silicate alone was not efficient for the control of coffee leaf rust under high disease incidence. In addition, there was no synergistic effect when the potassium silicate was combined with copper hydroxide. They opined that, application of potassium silicate to coffee plants is not an effective strategy to control coffee rust.

Hydroponic pot experiment was conducted to study the role of foliar application with 2.5 mM nano - silicon in alleviating Cd stress in rice seedlings (Wang *et al*., 2014) grown in solution added with or without 20 μM $CdCl_2$. They revealed that Cd treatment decreased the growth and the contents of Mg, Fe, Zn, chlorophyll a, and glutathione (GSH), accompanied by a significant increase in Cd accumulation. However, foliar application with nano - Si improved the growth, Mg, Fe, and Zn nutrition, and the contents of chlorophyll a of the rice seedlings under Cd stress and decreased Cd accumulation and translocation of Cd from root to shoot.

Liu *et al*. (2009) revealed that foliar application of Si sols significantly increased the dry weight of grains (without husk) and shoots in rice grown in Cd contaminated soil and decreased the Cd concentration in the grains and shoots. They opined that Si-sol should be foliar applied at the tillering - stage during rice growth for optimal effect and the mechanism of Si foliar application to alleviate the toxicity and accumulation of Cd in grains of rice may be related to the probable Cd sequestration in the shoot cell walls.

Neeru *et al*. (2016) revealed that foliar spray of Silixol to nursery seedlings enhanced uptake of essential nutrients (viz. P, Ca and K). In main fields, foliar sprays at three critical stages of rice (active tillering 25 DAT, panicle initiation 40 DAT and heading 60 DAT), improved root volume, number of tillers along with various yield attributing traits over control plants.

Hanumanthaiah *et al*. (2015) noticed that maximum N and P uptake by leaf lamina of banana was with soil application of calcium silicate @ 1000 g plant^{-1} + foliar application of potassium silicate @ 4 ml L^{-1} plant^{-1} at 30 days interval. The uptake and accumulation of silicon in leaf was more with foliar application of potassium silicate @ 4 ml L^{-1} at 15 days interval (2.63%).

Pilon *et al*. (2013) revealed that both soil application of soluble Si (50 mg dm^{-3} Si), and foliar application of soluble Si (three sprays of 1.425 mM Si water solution, prepared with a soluble concentrate stabilized silicic acid) resulted in higher Si accumulation in the whole potato plant. Foliar application of Si resulted in the greatest Si concentration in leaves, and soil application increased Si concentration in leaves, stems, and roots. Silicon application, regardless of the application method, increased leaf area, specific leaf area, and pigment concentration (chlorophyll a and carotenoids) as well as photosynthesis and transpiration rates of well - watered potato plants.

III MATERIAL AND METHODS

The present investigation was undertaken to study the "Effect of foliar silicic acid on growth, yield and nutrient uptake by soybean [*Glycine max* (L.)]". The details of the materials used and methods adopted are described in this chapter.

3.1 Location of the experimental site

The field experiment was conducted at ZARS, UAS, GKVK, Bengaluru during *kharif*-2016, situated in the Eastern Dry Zone of Karnataka at $12^0$58' N latitude $77^0$35' E longitude with an altitude of 930 m above mean sea level. The experimental details are presented below.

Experimental Details:

Location	:	ZARS, UAS, GKVK, Bengaluru -65
Season	:	*Kharif*-2016
Variety	:	1) MAUS-2 (105 - 115 days)
		2) KBS-23 (85 - 90 days)
Spacing	:	30 cm x 10 cm
No of treatments	:	7
No of replications	:	3
Design	:	Split plot
Main plot	:	Varieties
Sub plot	:	Treatments
Plot size	:	5 m × 3.6 m
Seed rate	:	62.5 kg ha^{-1}
NPK	:	RDF (25:60:25 kg of N: P_2O_5: K_2O ha^{-1} through Urea, SSP and MOP)
FYM and $ZnSO_4$	:	6.25 t ha^{-1} of FYM and 12.5 kg ha^{-1} of $ZnSO_4$ common to all treatments

Treatment details :

- T_1= RDF – water spray (control)
- T_2 = RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
- T_3 = RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
- T_4 = RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
- T_5 = RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
- T_6 = RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
- T_7 = RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

3.1.1 Soil characteristics of experimental site

Initial composite soil sample was collected from experimental site at 0-15 cm depth and analyzed for pH, EC, O.C, N, P, K, Ca, Mg, S, micronutrients and Available Si. The procedure employed for analysis are given in Table 1 and the results are presented in Table 2.

3.1.2 Climatic data of experimental area

The total rainfall was lower during the period of study (707.0 mm) compared to actual annual rainfall (916.0 mm**)**. Total rainfall during August to November was found to be 27.60 mm than the actual rainfall of 135.55 mm.

3.1.3 Variety

MAUS-2 and KBS-23 soybean varieties were used for the experimentation. Characteristics of both the varieties are given in Table 3.

3.2 Experimental details

A field experiment was conducted during *kharif*- 2016 by raising two selected varieties of soybean *viz.*, MAUS - 2 and KBS - 23, to study the effect of foliar silicic acid and boric acid on the growth and yield parameters of the crop. The experiment was laid out in split plot design and the field experiment layout is given in Fig: 1.   .

Table 1. Methods of soil and plant analysis

Sl. No.	Parameter	Procedure	Method and Reference
1	Particle size analysis	Soil was pre-digested with H_2O_2, dispersed with sodium hexa metaphosphate, sand with decantation procedure, silt and clay in the suspension was measured after pipetting with Robinson pipette	International pipette method, Jackson (1973)
2	Cation exchange capacity	Sample was leached with 1N (pH 7) ammonium acetate followed by washing with alcohol and ammonium in the leachate was determined by distillation method.	Distillation method Page *et al*. (1982)
3	Soil reaction	Soil: water suspension (1:2.5) was measured for pH using potentiometer after standardising with appropriate buffers.	Potentiometry, Jackson (1973)
4	Electrical conductivity	Soil: water extract (1:2.5) was measured for EC using conductivity bridge	Conductometry Jackson (1973)
5	Organic carbon	Soil was digested with $K_2Cr_2O_7$ and conc. H_2SO_4. The unutilized $K_2Cr_2O_7$ was back titrated against ferrous ammonium sulphate using diphenyl amine indicator.	Wet oxidation, Walkley and Black (1934)
6	Available nitrogen	Soil was oxidized and distilled with alkaline potassium permanganate and then titrated against standard acid using mixed indicator.	Subbaiah and Asija (1949)
7	Available phosphorus	Soil was extracted with Brays -I extractant and estimated by chloromolybdate acid method using spectrophotometer and intensity of blue color measured at 660 nm.	Bray & Kurtz (1945)
8	Available potassium	Extract the soil with 1 N (pH 7) ammonium acetate and estimate with flame photometer.	Flame photometry, Jackson (1973)
9	Available silicon	Soil was extracted with 0.1M calcium chloride, the Si was determined by using UV- visible spectrophotometer at 820 nm.	Haysom and Chapman (1975)
		Soil was extracted with 0.5 M acetic acid; the Si was determined by using UV- visible spectrophotometer at 630 nm.	Korndorfer *et al*. (2001)

Sl. No.	Parameter	Procedure	Method and Reference
10	Exchangeable calcium and magnesium	Extracted the soil with 1 N (pH 7) ammonium acetate and Ca and Mg were estimated by complexometric titration method.	Baruah and Barthakur (1997)
11	Available sulphur	Soil is extracted with 0.15% $CaCl_2$ and the extracted sulphate is treated with $BaCl_2$ in the presence of stabilising agent, turbidity is estimated using UV-visible spectrophotometer at 420 nm.	Williams and Steinberg (1959)
12	DTPA extractable micronutrients	Soil was extracted with DTPA and micronutrients were determined using atomic absorption spectrophotometer (AAS)	Lindsay and Norvell (1978)
13	Available boron	Soil was extracted with 0.1M Salicylic acid solution and boron was determined by UV-visible spectrophotometer at 420 nm.	Datta *et al*. (1998)
14	Total plant phosphorus	Phosphorus in di-acid digested plant sample was estimated by forming yellow colour phospho-venado-molybdate complex using spectrophotometer at 420 nm.	Yellow phospho-venado-molybdate complex method, Baruah and Barthakur (1997)
15	Total plant potassium	Potassium in di-acid digested plant sample was estimated with flame photometer	Flame photometry, Jackson (1973)
16	Total plant calcium and magnesium	Calcium and magnesium in di-acid digested plant sample was estimated by complexometric titration method.	Complexometric titration method, Baruah and Barthakur (1997)
17	Total plant sulphur	Sulphur in di-acid digested sample was quantified by using $BaCl_2$ to develop turbidity following estimation.	Turbidiometry method
18	Total plant micronutrients	Micronutrients in di-acid digested plant sample determined by using atomic absorption spectrophotometer (AAS)	Lindsay and Norvell (1978)

Table 2. Physico-chemical properties of the experimental soil of ZARS, GKVK.

Sl. No.	Properties/ Parameters		Values
1	Particle size distribution	Sand (%)	71.07
		Silt %)	15.21
		Clay (%)	13.72
2	Textural class		Sandy loam
3	pH (1 :2.5 water)		5.26
4	EC (d Sm^{-1}) (1:2.5 water)		0.08
5	CEC (cmol [p+] kg^{-1})		23
6	OC (g kg^{-1})		4.7
7	Avail. N (kg ha^{-1})		156.8
8	Avail. P_2O_5 (kg ha^{-1})		463.63
9	Avail.K_2O (kg ha^{-1})		185.47
10	Exch. Ca (cmol [p+] kg^{-1})		1.62
11	Exch. Mg (cmol [p+] kg^{-1})		1.45
12	Avail. S (mg kg^{-1})		8.54
13	Boron (mg kg^{-1})		1.71
14	Zn (mg kg^{-1})		3.81
15	Fe (mg kg^{-1})		15.42
16	Cu (mg kg^{-1})		1.77
17	Mn (mg kg^{-1})		26.55
18	Acetic acid Si (mg kg^{-1})		29.12
19	Calcium chloride Si (mg kg^{-1})		25.92

Table 3. Characteristics of soybean varieties

Parameter	MAUS - 2	KBS – 23
Plant type	Erect, medium tall, Determinate	Erect, medium tall, Semi-determinate
Crop duration	105 – 115 days	85 -90 days
Colour of flower	White	Purple
Parentage	Selection from SH – 84 - 14	JS – 335 × KHSb - 2
Pubescence	Gray pubescence	Tawny pubescence
Hilum colour	Brown	Black
Average seed yield (t ha^{-1})	2.0 – 2.2	2.2 – 2.5

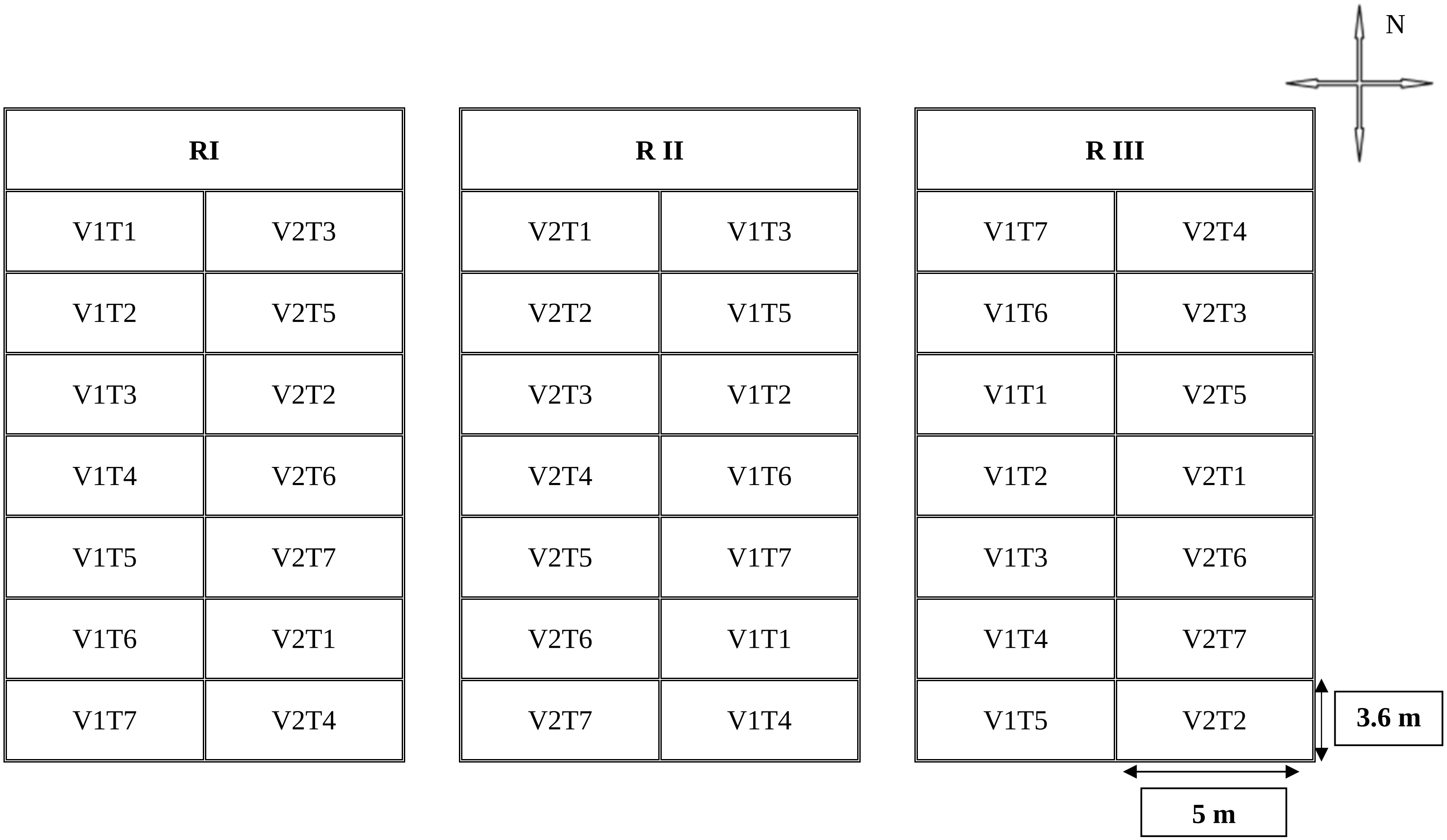

Fig. 1: The plan and layout of experimental plot indicating the pattern allocation for main and sub plots

Plate 1: General view of field experimental plot

Plate 2: Lay out of experimental plot and 30 days crop after imposition of treatments

3.3 Cultural practices

The details regarding various cultural operations carried out during the course of investigation are furnished below.

3.3.1 Land preparation

The land was ploughed with mould board plough and cultivator was passed twice to get good tilth. Later, the land was converted into required sized plots and levelling was ensured within each plot. Channels were prepared to drain out excess water during heavy rains.

3.3.2 Fertilizer application

Recommended dose of fertilizer application was given at the rate of 25:60:25 kg of N: P_2O_5: K_2O ha^{-1} as urea, SSP and MOP, respectively and $ZnSO_4$ (12.5 kg ha^{-1}) were applied to the soil. FYM (6.25 t ha^{-1}) application was done 15 days prior to the land preparation.

3.3.3 Seeds and sowing

MAUS-2 and KBS 23 seeds were used for sowing with recommended seed rate of 62.5 kg ha^{-1}. The small furrows were opened at a row spacing of 30 cm, and three seeds were placed at 10 cm distance within the rows to a depth of 5 cm and later soil was covered. To overcome the seedling disease, seeds are treated with SAAF (Mancozeb + Bavistin) at 6g kg^{-1}. Seeds treated with *Rhizobium* at a rate of 500 g ha^{-1}one week after the treatment with SAAF. Sowing was done on 13th August, 2016.

3.4 Foliar silicon

3.4.1 Source of Silicon

Concentrated soluble silicic acid obtained from OSAB, ReXil Agro BV, Chennai, was used for spraying. pH and composition of the formulation is given in the Table 4.

Table 4. Composition and pH of foliar silicic acid material

Composition	Content (%)
Si as soluble H_4SiO_4 (%)	2.0
K as KCl (%)	1.2
B as H_3BO_3 (%)	0.8
HCl (%)	1.0
Demi water (%)	47.0
PEG* $_{400}$ (%)	48.0
pH	
pH of raw material	0.88
pH of 2ml L^{-1} solution	6.8
pH of 4ml L^{-1} solution	6.0

*****PEG – Poly Ethylene Glycol

3.4.2 Spraying of foliar Si and Boric acid

Foliar Si was given as silicic acid @ 2ml L^{-1} and 4ml L^{-1} at an interval of 21, 36 and / or 51 DAS. Soluble silicic acid also contains 0.8 per cent of boron as boric acid. To nullify the effect of boron treatments with boric acid was considered. Hence, 0.8 per cent of boron as boric acid foliar spray @ 2ml L^{-1} and 4ml L^{-1} were also performed at an interval of 21, 36 and 51 DAS. Control plots received only water spray. For spraying, clean tap water of negligible Si content was used @ 250 L ha^{-1} for the first and second spraying and 500 L ha^{-1} for third spraying. Spraying was done with a backpack sprayer of 20 L capacity in the early morning during less wind to avoid drifting of spray droplet to adjoining plots.

3.5 After care

3.5.1 Thinning

Thinning was done 15 days after sowing to maintain the optimum plant population in each plot.

3.5.2 Earthing up and weeding

Earthing up was done manually at 30 days after sowing followed by hand weeding at 30 and 45 days after sowing.

3.5.3 Plant protection measures

Plant protection sprays with Monocrotophos @ 2 ml L^{-1} was given two times at 25 and 45 days after sowing to control leaf webber and leaf minor.

3.5.4 Irrigation

To compensate with the low rainfall, protective irrigations were given at critical crop growth stages of crop.

3.5.5 Harvesting and threshing

The crop was harvested when leaves started to drop and pods were completely matured. The plants were harvested at 83 DAS (KBS-23) and 105 DAS (MAUS-2) separately from the net plot by cutting the stalks to ground level with sickle and hand. Threshing was exercised after drying of the produce and pod weight and seed weight per plot was recorded.

3.6 Growth parameter observations

3.6.1 Growth components

All the observations were recorded treatment wise in the gross plot. Randomly five plants were selected in the gross plot area and were marked suitably for recording observations at 30, 45, 60 DAS and at the time of harvesting.

3.6.1.1 Plant height

Plant height was taken at 30, 45, 60 DAS and at the time of harvest. Plant height was measured from ground level to tip of the main shoot and mean of five observations were reported.

3.6.1.2 Number of leaves

The number of fully opened trifoliate green leaves per plant were recorded at 30, 45 and 60 DAS and mean of five observations were reported.

3.6.1.3 Number of branches

The number of branches per plant were recorded in selected five plants at 45, 60 DAS and at harvest and mean of five observations were reported.

3.6.1.4 Chlorophyll content

Chlorophyll content was measured by SPAD meter (SPAD-502, 1989 Minolta Co., Ltd) in 3rd and 4th leaf of plant at 30, 45 and 60 DAS. A mean of 10 values per plant was taken as measures SPAD value.

Plate 3: Foliar application of silicic acid and boric acid at 21 and 36 days after sowing

3.7 Yield and yield attributes

Randomly selected five plants were utilized for recording the observations on yield attributes such as number of pods $plant^{-1}$, seed yield $plant^{-1}$, number of seeds pod^{-1} and test weight.

3.7.1 Number of pods $plant^{-1}$

The pods from the randomly selected plants were counted. Mean of five observations were reported in grams.

3.7.2 Number of seeds pod^{-1}

Pods from the randomly selected plants were utilized for counting the seeds. Mean of five observations were reported in grams.

3.7.3 Number of seeds $plant^{-1}$

All pods from five plants were threshed, cleaned and were utilized for counting seeds. Mean of five observations were reported in grams.

3.7.4 Test weight (100 seed weight in g)

The weight of hundred seeds was recorded from the samples drawn from the produce obtained in each of the net plot and expressed as gram per hundred seeds.

3.7.5 Grain yield and pod yield (kg ha^{-1})

After harvest, pods were separated from the plants then the pods were dried, seeds were threshed, cleaned and weighed. Using net plot yield, seed yield and pod yield in kg per hectare was computed and presented.

3.7.6 Haulm yield (kg ha^{-1})

Haulm weights were recorded from the plants collected at R7 stage (when one normal pod on the main stem is mature in colour) after air drying and oven dried at 60 ^{0}C to constant weight (Moreira *et al*., 2016).

3.7.7 Harvest Index

Harvest index is the ratio of the economic yield to the total biological yield as suggested by Donald (1962). It was obtained as follows.

$$\text{Harvest index} = \frac{\text{Grain yield in kg ha}^{-1}}{\text{(Pod yield+ haulm yield) in kg ha}^{-1}}$$

3.8 Quality parameters

3.8.1 Protein content (%)

The protein content in the seeds was analysed by indirect method. First, the per cent nitrogen content of the sample was estimated by microkjeldahl method. Then the nitrogen content was multiplied by a factor 6.25 to get the protein content of the sample and expressed in percentage.

3.8.2 Protein yield (kg ha^{-1})

Protein yield was worked out on the basis of seed protein content and seed yield of soybean and expressed in kg ha^{-1}.

$$\text{Protein yield (kg ha}^{-1}) = \frac{\text{Seed protein content (\%)}}{100} \times \text{Seed yield (kg ha}^{-1})$$

3.8.3 Oil content (%)

The oil content of soybean seeds was estimated by Soxhlet method at COA, Hassan. 5g of powdered seed sample was taken in thimble and placed in previously weighed flask with stones (W_1). Later 100ml of petroleum ether (boiling range of 40-60 ^{0}C) was added to these flasks and kept in soxtherm. Then, run the instrument for one and half hour. After complete extraction, flasks were kept in hot air oven @ 105 ^{0}C for 30 min and weight (W_2) of flask was recorded after cooling.

$$\text{Oil content (\%)} = \frac{W_2 \text{ g (flask + stones + oil)} - W_1 \text{ g (flask + stones)}}{\text{Weight of seed sample (g)}} \times 100$$

3.8.4 Oil yield (kg ha^{-1})

Oil yield was worked out on the basis of seed oil content and seed yield of soybean.

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

3.9 Chemical analysis

3.9.1 Soil sample analysis

Representative soil samples from each experimental plot was drawn from the top 15 cm at harvest. Soil samples thus collected were air dried in shade, powdered and passed through 2 mm sieve and analysed for pH, EC, phosphorus, boron and silicon by adopting appropriate procedure presented in the Table 1.

3.10 Analytical methods for soil samples

3.10.1 Extraction and estimation of plant available silicon in soils by 0.01M $CaCl_2$ extractant

Two gram of soil was taken in a 50ml centrifuge tube and 20 ml of 0.01M $CaCl_2$ was added. After continuous end to end shaking in a mechanical shaker for sixteen hours, the solution was centrifuged at 2000 rpm for 10 minutes and then filtered.

Silicon in the extracting solution was determined by transferring 1 ml of filtrate into plastic centrifuge tube and then added 2.5 ml of 0.5 M sulfuric acid and 2.5 ml of ammonium molybdate solution (pH 7). After 5 minutes, 1.25 ml of tartaric acid solution was added. After allowing for additional two minutes, 0.25 ml reducing agent (ANSA) was added. After 30 minutes following addition of the reducing agent, absorbance was measured at 820 nm using UV visible spectrophotometer (SHIMADZU Pharma spec, UV-1700 series) with auto sample changer (ASC-5). Simultaneously Si standards (0, 0.5, 1, 2, 3, 4, 5 and 6 mg L^{-1}) prepared in the same matrix were also measured using UV visible spectrophotometer (Haysom and Chapmen, 1975).

3.10.2 Extraction and estimation of plant available Si in soils using 0.5 M acetic acid extractant

Available silicon in soil was extracted using 0.5 M acetic acid with the soil to extractant ratio of 1:2.5 as outlined by Korndorfer *et al*. (2001). After shaking continuously for a period of one hour, solution was centrifuged at 3000 rpm for 3 minutes and then filtered. The filtrate was then used for silicon determination. Silicon in the extracting solution was determined by adopting the procedure of Narayanaswamy and Prakash (2009).

An aliquot of 0.25 ml filtrate was taken into a plastic centrifuge tube and then added with 10.5 ml of distilled water, plus 0.25 ml of 1:1 hydrochloric acid, and 0.5 ml of 10 per cent ammonium molybdate solution. After allowing for 5 minutes, 0.5 ml of 20 per cent tartaric acid solution was added. After allowing for additional two minutes, 0.5 ml reducing agent (1-amino-2-napthol-4-sulfonic acid - ANSA) was added. After 5 minutes, but not later than 30 minutes following addition of the reducing agent, absorbance was measured at 630nm using UV-visible spectrophotometer (SHIMADZU Pharma spec, UV-1700 series) with auto sample changer (ASC-5). Simultaneously Si standards (0.2, 0.4, 0.8, 1.2 and 1.6 mg L^{-1}) prepared in the same matrix were also measured using UV-visible spectrophotometer.

3.11 Determination of Si in plant samples

3.11.1.1 Digestion of plant samples

0.1 g of the powdered plant sample was pre- digested with 7 ml HNO_3 (70 %), 2 ml H_2O_2 (30 %) and 1 ml HF (40 %) and later digested using a microwave digester (Milestone- START D) at 150 ^{0}C with following steps: 1200 w for 15 minutes, 1200 w for 10 minutes and venting for 10 minutes. The digested sample was stored in clean plastic tubes of 50 ml capacity, after making up the volume using 4 % boric acid solution (Ma and Takahashi, 2002).

3.11.1.2 Estimation of Si in digested plant sample

Silicon in the digested plant sample was determined by the colorimetric molybdenum blue method at 600 nm (Ma *et al*., 2002). 0.5 ml aliquot was taken to a plastic centrifuge tube, added 3.75 ml of 0.2 N HCl, and 0.5 ml of 10 % ammonium molybdate. After one minute 0.5 ml of 20 % tartaric acid and 0.5 ml of reducing agent (Amino naphtholsulphonic acid - ANSA) was added. The volume was made up to 12.5 ml with distilled water. After one hour, the absorbance was measured at 600 nm with a UV- visible spectrophotometer (SHIMADZU Pharma spec, UV-1700 series) with auto sample changer (ASC-5).

Standards (0, 0.2, 0.4, 0.8 and 1.2 ppm Si) were prepared by following the same procedure.

3.11.2 Determination of nutrients in the plant samples

Plant samples collected at R7 stage of the crop were analysed for P, K, Ca, Mg, S, Fe, Mn, Cu, and Zn content.

For analysis, five plants were randomly selected from each plot at R7 stage (when one normal pod on the main stem is mature in colour) of crop. They were thoroughly washed with deionised water and oven dried at 60 ^{o}C to obtain constant weight, cut to pieces, powdered and used for analysis.

3.11.2.1 Digestion of plant sample

Powdered haulm, pod and seed samples (0.3 gram) each were treated with 10 ml of concentrated HNO_3 and kept for pre digestion overnight. The samples were then digested with 10 ml of di-acid mixture (HNO_3 in $HClO_4$ in 9:4 ratio) in hot plate at 180-200 ^{0}C until a white residue was left. The residue was cooled and diluted to 100ml using distilled water, filtered and used for further estimation. The whole digestion procedure was carried out in the department of Soil Science and agricultural chemistry, UAS, GKVK, Bengaluru.

3.12 Analysis of soil and plant samples

The different methods used for the analysis of soil and plant samples for major and micronutrients are presented in Table 2.

3.13 Nutrient uptake studies

Major, micro nutrient and silicon concentration in plant samples were used to work out the uptake of crop. The uptake of these nutrients were obtained by multiplying the dry weight of respective plant parts with percentage of corresponding nutrients and expressed as kg ha^{-1}.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)} \times \text{Dry matter weight (kg ha}^{-1}\text{)}}{100}$$

3.14 Statistical analysis

The data obtained from field observations and chemical analysis of soil and plant samples were subjected to statistical scrutiny to find out the influence of silicic acid treatments on the growth, yield and nutrient uptake of soybean. Experiment has been laid out as per the split plot design. The main factors and sub factors and combination effects were tested at 5 % level of significance.

IV EXPERIMENTAL RESULTS

The present investigation entitled “Effect of foliar silicic acid on growth, yield and nutrient uptake by soybean [*Glycine max* (L.)]” was conducted during *kharif* 2016 at ZARS, UAS, GKVK, Bengaluru. The results of the investigation are presented in this chapter under the following headings.

4.1 Effect of foliar application of silicic acid and boric acid on growth parameters of soybean

The data on growth parameters *viz*., plant height, number of leaves, number of branches and chlorophyll content as influenced by the foliar application of silicic acid and boric acid are presented in Tables 5 and 6.

4.1.1 Plant height (cm)

The effect of foliar application of silicic acid and boric acid on plant height at different growth stages of crop is presented in Table 5.

4.1.1.1 30 Days after sowing

Significant difference with respect to varieties was observed with the foliar application of silicic acid and boric acid for plant height. Irrespective of different treatments, MAUS-2 recorded higher plant height (16.16 cm) than KBS-23 (10.71 cm).

Irrespective of the varieties, treatment with the foliar application of silicic acid @ 4ml L^{-1} for two times significantly enhanced the plant height (14.17 cm) compared to other treatments. The lower value was recorded in control with water spray (12.84 cm). Foliar application of boric acid at different doses also enhanced the plant height over control.

Plant height ranged from 10.32 to 17.67 cm in different varieties and treatments combinations. Maximum plant height was recorded with the foliar application of silicic acid @ 4ml L^{-1} for two times in MAUS-2 variety and the least was recorded with water spray in KBS-23 variety.

4.1.1.2 45 Days after sowing

The data presented in the Table.5 revealed that, significantly higher plant height (29.02 cm) was noticed with the foliar application of silicic acid and boric acid in MAUS-2 variety compared to KBS-23 variety (23.87 cm).

There was a significant increase in plant height (27.49 cm) with the foliar application of silicic acid @ 4ml L^{-1} for three times followed by treatment with foliar application of silicic acid @ 2ml L^{-1} for two times (26.99 cm).

Among the different varieties and treatments combinations, application of foliar silicic acid @ 2ml L^{-1} for two times in MAUS-2 variety recorded higher plant height (30.47 cm) at 45 days after sowing. The plant height ranged from 22.63 to 30.47 cm. The lower plant height was recorded in treatment receiving foliar application of boric acid alone and the least was recorded with the water application in KBS-23 variety**.**

4.1.1.3 60 Days after sowing

The effect of different levels of foliar application of silicic acid and boric acid significantly enhanced the plant height among the varieties at 60 days after sowing. Maximum plant height was recorded in MAUS-2 (37.00 cm) compared to KBS-23 (25.93 cm).

Among the different treatments, the maximum height (34.17 cm) was recorded by the treatment receiving foliar application of silicic acid @ 2ml L^{-1} for three times and minimum (29.40 cm) by control. Application of boric acid also enhanced the crop growth compared to control.

The maximum plant height (40.20 cm) was recorded with the application of foliar silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety and least was recorded with water spray in KBS-23 variety (24.20 cm).

4.1.1.4 At harvest

Significant positive effect of foliar application of silicic acid and boric acid was observed on plant height among the varieties at harvest. The higher plant height was recorded in MAUS-2 (38.22 cm) than in KBS-23 (26.15 cm).

Though foliar application of silicic acid and boric acid had no significant effect on plant height at harvest, combination of varieties and treatments had a significant effect (Table 5). The plant height ranged from 24.53 cm to 40.70 cm, recording higher with the foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety and lower with water application in KBS-23 variety.

4.1.2 Number of leaves plant^{-1}

The data on effect of foliar application of silicic acid and boric acid on number of leaves plant^{-1} is presented in Table 5.

4.1.2.1 30 days after sowing

There was no significant effect of foliar application of silicic acid and boric acid on varieties with respect to number of leaves plant^{-1} at 30 days after sowing.

Treatments and the combination effect was found to be significant on number of leaves plant^{-1}. Irrespective of varieties used in the study, maximum number of leaves (3.70) was recorded with the foliar application of silicic acid @ 2ml L^{-1} for two times. Lower with both foliar application of boric acid @ 2ml L^{-1} and 4ml L^{-1} for three times (3.37).

Among the varieties and treatments combinations, foliar application of silicic acid @ 4ml L^{-1} for three times in KBS-23 variety recorded higher number of leaves plant^{-1} (3.93) and least was observed both in boric acid application at 2ml L^{-1} and 4ml L^{-1} three times in MAUS-2 variety (3.27).

Table 5. Effect of foliar application of silicic acid and boric acid on growth parameters at different stages of soybean

	Plant height (cm)				Number of leaves		
	30 DAS	45 DAS	60 DAS	At harvest	30 DAS	45 DAS	60 DAS
Varieties							
V1	16.16	29.02	37.00	38.22	3.44	9.05	14.68
V2	10.71	23.87	25.93	26.15	3.66	9.87	12.32
SEm±	0.15	0.38	0.62	0.90	0.06	0.44	0.40
C.D at 0.05	0.93	2.31	3.74	3.45	NS	NS	NS
Treatments							
T1	12.84	25.43	29.40	29.61	3.67	8.93	12.63
T2	13.58	26.99	30.65	30.82	3.70	9.97	12.82
T3	14.17	26.85	30.08	33.46	3.60	10.27	14.17
T4	13.33	26.46	34.17	34.46	3.47	9.63	15.83
T5	13.69	27.49	32.83	33.31	3.67	9.90	14.77
T6	13.28	26.30	32.57	32.77	3.37	8.70	11.98
T7	13.18	25.60	30.55	30.74	3.37	8.80	12.30
SEm±	0.43	0.67	1.36	1.81	0.11	0.63	0.83
C.D at 0.05	1.23	1.92	3.93	NS	0.31	NS	2.39
Interaction							
T1VI	15.35	28.23	34.60	34.69	3.53	9.00	13.87
T2V1	16.21	30.47	36.63	36.77	3.67	9.80	12.70
T3V1	17.67	29.10	34.00	40.69	3.60	10.33	15.47
T4V1	15.81	28.69	40.20	40.70	3.33	9.00	17.73
T5V1	16.39	29.87	38.57	39.30	3.40	9.00	17.00
T6V1	15.75	28.43	38.33	38.60	3.27	8.20	12.30
T7V1	15.95	28.33	36.67	36.83	3.27	8.00	13.67
T1V2	10.32	22.63	24.20	24.53	3.80	8.87	11.40
T2V2	10.95	23.51	24.67	24.87	3.73	10.13	12.93
T3V2	10.67	24.59	26.17	26.23	3.60	10.20	12.87
T4V2	10.85	24.24	28.13	28.50	3.60	10.27	13.93
T5V2	10.99	25.11	27.10	27.31	3.93	10.80	12.53
T6V2	10.80	24.17	26.80	26.93	3.47	9.20	11.67
T7V2	10.40	22.87	24.43	24.65	3.47	9.60	10.93
SEm±	0.60	0.94	1.93	2.56	0.15	0.88	1.17
C.D at 0.05	1.17	2.72	5.56	7.18	0.44	2.55	3.38

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

4.1.2.2 45 days after sowing

Both varietal as well as treatment effect was found to be non-significant on number of leaves plant^{-1} with the foliar application of silicic acid and boric acid. Among varieties and treatment combinations, significant positive interaction was observed for number of leaves plant^{-1} recording higher number of leaves plant^{-}1(10.80) with the foliar application of silicic acid @ 4ml L^{-1} for three in KBS-23 and lower with the foliar application of boric acid @ 4ml L^{-1} three times in MAUS-2 variety (8.00).

4.1.2.3 60 days after sowing

The data presented in Table 5, revealed significant increase in number of leaves per plant^{-1} in both treatment and combinations, recording maximum (15.83) with the foliar application of silicic acid @ 2ml L^{-1} for three times. There was no significant effect of foliar application of silicic acid and boric acid on number of leaves plant^{-1} among varieties at 60 DAS.

Among the different varieties and treatments combinations, MAUS-2 variety with the foliar application silicic acid @ 2ml L^{-1} for three times recorded higher number of leaves plant^{-1} (17.73) and least (10.93) was observed in KBS-23 with the foliar application of boric acid @ 4ml L^{-1} for three times.

4.1.3 Number of branches plant^{-1}

The effect of foliar application silicic acid and boric acid on number of branches plant^{-1} in different varieties are given in Table 6.

4.1.3.1 45 Days after sowing

Number of branches plant^{-1} differed significantly among varieties with the foliar application of silicic acid and boric acid, recording higher in KBS-23 (2.28) than MAUS-2 (1.29).

Treatments had no significant effect on number of branches plant^{-1}. Varieties and treatments combinations differed significantly for number of branches plant^{-1} with the foliar application of silicic acid. The number of branches $plant^{-1}$ ranged from 0.87 to 2.47. Maximum number of branches $plant^{-1}$ (2.47) was recorded both with the foliar application of silicic acid @ 2ml L^{-1} and 4ml L^{-1} for three times in KBS-23 variety and minimum (0.87) with foliar application of boric acid 2ml L^{-1} for three times in MAUS-2 variety.

4.1.3.2 60 Days after sowing

Though foliar application of silicic acid and boric acid was found to be non-significant on number of branches $plant^{-1}$ among varieties at 60 DAS, individual treatments had a significant effect. Application of foliar silicic acid at 4ml L^{-1} for three times recorded maximum number of branches $plant^{-1}$ (2.90) and minimum (2.00) with both foliar application of silicic acid @ 2ml L^{-1} for two times and boric acid @ 4ml L^{-1} for three times.

Among different varieties and treatment combinations, treatment with the foliar application of silicic acid @ 4ml L^{-1} for three times in MAUS-2 variety recorded higher number of branches $plant^{-1}$ (3.13) at 60 DAS. The lower number of branches $plant^{-1}$ (1.80) was recorded in the treatments receiving water application, foliar application of silicic acid @ 2ml L^{-1} for two times and boric acid @ 4ml L^{-1} for three times in MAUS-2 variety.

4.1.4 Chlorophyll content (SPAD)

The data presented in Table 6, revealed the effect of foliar application of silicic acid and boric acid on chlorophyll content at different growth stages of crop.

4.1.4.1 30 Days after sowing

The application of different levels of silicic acid and boric acid had a significant effect on the chlorophyll content recording higher in KBS-23 (34.86) than MAUS-2 (33.77). However, application of foliar silicic acid effect was found to be non-significant on the chlorophyll content among treatments and the combination of varieties and treatments.

Table 6. Effect of foliar application of silicic acid and boric acid on growth parameters at different stages of soybean

	Number of branches		Chlorophyll content (SPAD)		
	45 DAS	**60 DAS**	**30 DAS**	**45 DAS**	**60 DAS**
Varieties					
V1	1.29	2.27	33.77	37.74	40.96
V2	2.28	2.44	34.86	41.29	32.77
SEm±	0.18	0.05	0.07	0.36	0.17
C.D at 0.05	0.10	NS	0.45	2.17	1.01
Treatments					
T1	2.00	2.10	33.40	38.32	35.80
T2	1.63	2.00	35.24	39.83	36.88
T3	1.87	2.53	35.18	40.52	38.31
T4	1.83	2.57	34.17	40.05	37.23
T5	2.07	2.90	34.12	40.07	37.34
T6	1.53	2.37	34.10	39.31	36.16
T7	1.53	2.00	33.99	38.51	36.35
SEm±	0.26	0.21	0.81	0.79	0.69
C.D at 0.05	NS	0.62	NS	NS	NS
Interaction					
T1VI	1.60	1.80	32.49	36.27	39.64
T2V1	1.27	1.80	35.34	37.93	41.21
T3V1	1.47	2.53	34.98	39.04	42.75
T4V1	1.20	2.53	34.17	38.18	41.30
T5V1	1.67	3.13	33.01	38.93	42.00
T6V1	0.87	2.27	33.64	37.28	39.76
T7V1	0.93	1.80	32.77	36.54	40.07
T1V2	2.40	2.40	34.30	40.37	31.95
T2V2	2.00	2.20	35.13	41.73	32.55
T3V2	2.27	2.53	35.39	42.01	33.88
T4V2	2.47	2.60	34.17	41.91	33.17
T5V2	2.47	2.67	35.23	41.22	32.69
T6V2	2.20	2.47	34.55	41.34	32.55
T7V2	2.13	2.20	35.21	40.48	32.63
SEm±	0.37	0.3	1.14	1.12	0.98
C.D at 0.05	1.06	0.88	NS	3.22	2.83

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

4.1.4.2 45 Days after sowing

Significant positive effect with foliar application of silicic acid and boric acid was observed for the chlorophyll content among the varieties, recording higher value in KBS-23 (41.29) and lower in MAUS-2 (37.74). No significant difference was observed for the foliar application of silicic acid among the treatments for chlorophyll content.

Among different varieties and treatments combinations, maximum chlorophyll content (42.01) was observed in KBS-23 variety with the foliar application of silicic acid @ 4ml L^{-1} for two times followed by foliar application of silicic acid @ 2ml L^{-1} for three times (41.91) and lower value (36.27) was recorded in MAUS-2 variety with water application.

4.1.4.3 60 Days after sowing

Chlorophyll content differed significantly between the varieties irrespective of the treatments for the foliar application of silicic acid and boric acid, recording higher in MAUS-2 (40.96) and lower in KBS-23 (32.77).

No significant difference was observed among the treatments for the foliar application of silicic acid and boric acid. Significant increase in chlorophyll content was observed among the varieties and treatment combinations showing higher chlorophyll content (42.75) with the foliar application of silicic acid @ 4ml L^{-1} for two times in MAUS-2 variety and least was recorded with water application in KBS-23 variety (31.95).

4.2 Effect of foliar application of silicic acid and boric acid on yield attributes of soybean

The data on the effect of foliar application of silicic acid and boric acid on yield parameters *viz*., number of pods $plant^{-1}$, number of seeds pod^{-1}, number of seed $plant^{-1}$ and test weight of seeds are given in Table 7.

4.2.1 Number of pods plant^{-1}

Perusal of the data presented in the Table 7, revealed that there was a significant increase in number of pods plant^{-1} among the varieties with the foliar application of silicic acid and boric acid. Higher number of pods plant^{-1} recorded in KBS-23 (27.11) compared to MAUS-2 (26.42).

Among the different treatments, foliar application of silicic acid significantly enhanced the number of pods plant^{-1}, recording higher (32.13) with foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for three times (30.93). Lower number of pods plant^{-1} was observed with foliar application of boric acid except for foliar application of silicic acid @ 2ml L^{-1} for two times and least in control (21.95).

There was no significant effect on the number of pods plant^{-1} among the varieties and treatments combinations with the application of foliar silicic acid.

4.2.2 Number of seeds pod^{-1}

There was a significant difference in number of seeds pod^{-1} with the foliar application of silicic acid and boric acid among the varieties. Maximum number of seeds pod^{-1} was observed in KBS-23 (2.11) than in MAUS-2 (1.57).

Number of seeds pod^{-1} differed significantly with the foliar application of silicic acid, recording higher (1.92) with the foliar application of boric acid @ 4ml L^{-1} for three times and least with the foliar application of boric acid @ 2ml L^{-1} for three times (1.80).

The data pertaining to number of seeds pod^{-1} (Table.7) for the varieties and treatments combinations differed significantly. Among the varieties and treatment combinations, treatment with the foliar application of boric acid @ 4ml L^{-1} for three times in KBS-23 variety recorded higher number of seeds pod^{-1} (2.20). Least was observed with the foliar application of silicic acid @ 4ml L^{-1} for two times (1.47) in MAUS-2 variety.

Table 7. Effect of foliar application of silicic acid and boric acid on yield attributes of soybean

	Number of pods $plant^{-1}$	Number of seeds pod^{-1}	Number of seeds $plant^{-1}$	Test weight (g)
Varieties				
V1	26.42	1.57	44.58	14.26
V2	27.11	2.11	56.64	11.27
SEm±	0.31	0.00	1.22	0.09
C.D at 0.05	1.86	0.01	7.40	0.52
Treatments				
T1	21.95	1.81	42.53	12.22
T2	22.53	1.82	42.23	12.75
T3	27.83	1.82	51.78	13.34
T4	30.93	1.86	57.97	12.82
T5	32.13	1.86	64.33	12.88
T6	24.92	1.80	45.67	13.02
T7	27.07	1.92	49.73	12.31
SEm±	1.29	0.04	2.74	0.18
C.D at 0.05	3.73	0.10	7.19	NS
Interaction				
T1VI	18.50	1.54	32.40	13.25
T2V1	22.80	1.51	38.20	14.25
T3V1	23.60	1.47	35.30	14.99
T4V1	33.07	1.69	58.47	14.59
T5V1	31.60	1.64	60.67	14.54
T6V1	27.10	1.52	43.67	14.66
T7V1	28.27	1.64	43.33	13.54
T1V2	25.40	2.07	52.67	11.18
T2V2	22.27	2.13	46.27	11.24
T3V2	32.07	2.17	68.27	11.69
T4V2	28.80	2.03	57.47	11.06
T5V2	32.67	2.08	68.00	11.22
T6V2	22.73	2.09	47.67	11.39
T7V2	25.87	2.20	56.13	11.08
SEm±	1.82	0.05	3.87	0.26
C.D at 0.05	NS	0.14	11.19	0.74

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

4.2.3 Number of seeds plant^{-1}

Perusal of data presented in the Table 7, revealed that there was a significant difference with respect to number of seeds plant^{-1}, recording higher in KBS-23 (56.64) than MAUS-2 (44.58).

Among the different treatments, foliar application of silicic acid @ 4ml L^{-1} (64.33) for three times significantly enhanced the number of seeds plant^{-1} which was on par with the foliar application of silicic acid @ 2ml L^{-1} for three times (57.97) compared to other treatments and lower (42.23) with the foliar application of silicic acid @ 2ml L^{-1} for two times. Foliar application of boric acid alone also increased number of seeds plant^{-1} compared to control.

Number of seeds plant^{-1} for varieties and treatments combinations differed significantly with the foliar application of silicic acid and boric acid. The number of seeds plant^{-1} varied from 32.40 to 68.27, recording higher with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety and lower with water application in MAUS-2 variety.

4.2.4 Test weight (g)

Though test weight among treatments not differed significantly for the foliar application of silicic acid and boric acid, varieties and the combination of varieties and treatments differed significantly recording higher in MAUS-2 (14.26 g) than KBS-23 (11.27 g). Among the different combination of varieties and treatments, the test weight ranged from 11.06 to 14.99 g, recording higher with the foliar application of silicic acid @ 4ml L^{-1} for two times in MAUS-2 variety and lower with the foliar application of silicic acid @ 2ml L^{-1} for three times in KBS-23 variety.

4.3 Effect of foliar application of silicic acid and boric acid on yield and quality of soybean

The results of foliar application of silicic acid and boric acid on yield of soybean viz., haulm yield, pod yield and grain yield, harvest index, oil content, protein content, oil yield and protein yield are presented in Table 8.

4.3.1 Haulm yield (kg ha^{-1})

Haulm yield differed significantly between the varieties with the foliar application of silicic acid and boric acid. Among the varieties, KBS-23 recorded higher haulm yield (1565.81 kg ha^{-1}) than MAUS-2 (1342.46 kg ha^{-1}).

Among the treatments, foliar application of silicic acid at 4 ml L^{-1} for three times recorded significantly higher haulm yield (1774.61 kg ha^{-1}). While, lower haulm yield was recorded for the foliar application of boric acid @ 2ml L^{-1} for three times other than the treatment which received foliar application silicic acid @ 2ml L^{-1} for two times. Least was recorded in control (1221.60 kg ha^{-1}).

The different combination of varieties and treatments differed significantly for haulm yield with the foliar application of silicic acid. Maximum haulm yield (1977.00 kg ha^{-1}) was observed with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety, which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety (1870.80 kg ha^{-1}) followed by foliar application of silicic acid application @ 4ml L^{-1} for three times in KBS-23 variety (1843.67 kg ha^{-1}). Least was recorded with water application in MAUS-2 variety (1008.53 kg ha^{-1}).

4.3.2 Pod yield (kg ha^{-1})

Perusal of data presented in Table 8, revealed that there was a significant effect of foliar application of silicic acid and boric acid on the pod yield, recording maximum in KBS-23 (2783.20 kg ha^{-1}) than MAUS-2 (2532.55 kg ha^{-1}).

Significantly higher pod yield (3296.23 kg ha^{-1}) was observed with the foliar application of silicic acid @ 2ml L^{-1} for three times followed by foliar application of silicic acid @ 4ml L^{-1} for three times (3085.93 kg ha^{-1}). Foliar application of boric acid also enhanced the pod yield compared to control (2112.24 kg ha^{-1}).

Among the varieties and treatments combinations, the pod yield ranged from 1949.90 to 3507.48 kg ha^{-1}. The higher pod yield was observed with the foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety, which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for two times (3459.11 kg ha^{-1}) and three times (3279.29 kg ha^{-1}) in KBS-23 variety. Least was recorded with water application in MAUS-2 variety.

4.3.3 Seed yield (kg ha^{-1})

The foliar application of silicic acid and boric acid significantly differed the seed yield among the varieties. Between the two varieties used, KBS-23 recorded significantly higher seed yield (1720.78 kg ha^{-1}) than the MAUS-2 (1395.27 kg ha^{-1}).

Seed yield differed significantly with the foliar application of silicic acid and boric acid. Among the treatments, foliar application of silicic acid @ 2ml L^{-1} for three times recorded higher seed yield (2004.96 kg ha^{-1}) followed by foliar application of silicic acid @ 4ml L^{-1} for three times (1841.94 kg ha^{-1}). Lower seed yield was observed for the treatment that received foliar application of boric acid @ 2ml L^{-1} for three times (1357.59 kg ha^{-1}) and least in control (1184.84 kg ha^{-1}).

The effect of foliar application of silicic acid and boric acid on seed yield of different varieties and treatments differed significantly. Maximum seed yield was observed with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety (2176.67 kg ha^{-1}) which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety (2054.24 kg ha^{-1}) and least with water spray in MAUS-2 variety (1083.37 kg ha^{-1}).

4.3.4 Harvest index (H.I)

There was no significant effect of foliar application of silicic acid among varieties on harvest index (Table 8). However, treatments and combination of treatments were found to be significant. The higher harvest index (0.41) was recorded with the foliar application of silicic acid @ 2ml L^{-1} for three times over both control and foliar application of silicic acid @ 4ml L^{-1} for two times (0.36).

Among the varieties and treatments combinations, harvest index ranged from 0.33 to 0.44, recording higher with the foliar application of silicic @ 2ml L^{-1} for three times in KBS-23 variety, which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety (0.42). Least was observed with the foliar application of silicic acid @ 4ml L^{-1} for two times.

4.3.5 Protein content (%)

The data pertaining to the foliar application of silicic acid and boric acid on the protein content of soybean seeds is given in Table 8.

Protein content differed significantly with the foliar application of silicic acid and boric acid. Among the varieties, KBS-23 recorded maximum protein content (34.83 %) than MAUS-2 (30.75 %).

There was a significant effect on protein content with the foliar application of silicic acid for the treatments. Maximum protein content (35.15 %) was recorded in treatment with the foliar application of silicic acid @ 4ml L^{-1} for three times followed by treatment with foliar application of silicic acid 4ml L^{-1} for two times (34.27 %). Least was recorded with the foliar application of boric acid @ 4ml L^{-1} for three times (29.90 %).

The combination of varieties and treatments varied significantly for the foliar silicic acid, recording maximum protein content (39.67 %) with foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety, which was found to be on par with the foliar application of silicic acid @ 4ml L^{-1} for two times (37.63 %) and three times (37.33 %) in KBS-23 variety. Least with the foliar application of boric acid @ 4ml L^{-1} for three times in MAUS-2 variety (28.29 %).

4.3.6 Protein yield (kg ha^{-1})

The effect of foliar application of silicic acid and boric acid on the protein yield is presented in Table 8.

Table 8. Effect of foliar application of silicic acid and boric acid on yield and quality of soybean

	Haulm yield (kg ha^{-1})	Pod yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Harvest Index	Protein content (%)	Protein yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Varieties								
V1	1342.26	2532.55	1395.27	0.36	30.75	432.52	19.89	278.83
V2	1565.81	2783.20	1720.78	0.39	34.83	601.32	16.88	288.57
SEm±	18.09	27.10	26.34	0.01	0.39	10.71	0.04	5.28
C.D at 0.05	109.76	164.40	159.82	NS	2.36	65.00	0.21	NS
Treatments								
T1	1221.60	2112.24	1184.84	0.36	31.06	367.53	18.27	215.88
T2	1247.30	2267.45	1384.57	0.39	34.56	490.47	17.20	233.30
T3	1573.55	3055.52	1717.18	0.36	34.27	589.07	18.24	300.68
T4	1641.40	3296.23	2004.96	0.41	33.54	672.18	18.43	370.53
T5	1774.61	3085.93	1841.94	0.38	35.15	649.61	18.51	338.46
T6	1339.28	2366.51	1357.59	0.37	31.06	421.69	19.21	261.16
T7	1380.52	2421.24	1415.13	0.37	29.90	427.91	18.85	265.91
SEm±	36.38	62.95	43.69	0.01	0.83	19.54	0.23	8.90
C.D at 0.05	105.07	181.81	126.19	0.02	2.41	56.43	0.66	25.71
Interaction								
T1VI	1008.53	1949.90	1083.37	0.36	32.08	348.67	18.69	202.25
T2V1	1078.94	2075.96	1153.75	0.36	29.46	341.30	19.06	218.70
T3V1	1170.09	2651.92	1257.69	0.33	30.92	388.40	20.95	263.49
T4V1	1870.80	3507.48	2054.24	0.38	32.38	666.20	20.46	420.42
T5V1	1705.54	2892.58	1686.14	0.37	32.96	554.17	20.17	340.34
T6V1	1474.88	2523.47	1372.51	0.34	29.17	400.89	20.65	283.74
T7V1	1087.03	2126.54	1159.20	0.36	28.29	328.03	19.25	222.92
T1V2	1434.67	2274.59	1286.30	0.35	30.04	386.39	17.84	229.51
T2V2	1415.67	2458.94	1615.38	0.42	39.67	639.65	15.34	247.90
T3V2	1977.00	3459.11	2176.67	0.40	37.63	789.73	15.52	337.87
T4V2	1412.00	3084.98	1955.67	0.44	34.71	678.16	16.39	320.63
T5V2	1843.67	3279.29	1997.73	0.39	37.33	745.05	16.85	336.57
T6V2	1203.67	2209.56	1342.67	0.39	32.96	442.49	17.77	238.58
T7V2	1674.00	2715.95	1671.06	0.38	31.50	527.79	18.45	308.90
SEm±	51.45	89.02	61.79	0.01	1.18	27.63	0.32	12.59
C.D at 0.05	148.59	257.12	178.45	0.03	3.40	79.81	0.94	36.36

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

Perusal of the data reveals that there was a significant difference on protein yield among the varieties with foliar application of silicic acid and boric acid, recording higher in KBS-23 (601.32 kg ha^{-1}) and lower in MAUS-2 (432.52 kg ha^{-1}).

Protein yield differed significantly with the foliar application of silicic acid. The maximum protein yield (672.18 kg ha^{-1}) was recorded in treatment with the foliar application of silicic acid @ 2ml L^{-1} for three times, which was found to be on par with the foliar application of silicic acid @ 4ml L^{-1} for three times (649.61 kg ha^{-1}) and the least was recorded in control (367.53 kg ha^{-1}).

Among different varieties and treatments combinations, maximum protein yield (789.73 kg ha^{-1}) was recorded with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety, which was on par with the foliar application of silicic acid @ 4ml L^{-1} for three times (745.05 kg ha-1). Lower protein yield (328.03 kg h-1) was recorded with the foliar application of boric acid @ 4ml L-1 for three times.

4.3.7 Oil content (%)

Data on oil content of soybean seeds as influenced by the foliar application of silicic acid and boric acid is presented in the Table 8.

Oil content differed significantly with the foliar application of silicic acid and boric acid among the varieties used. Higher oil content was observed in MAUS-2 (19.89 %) than KBS-23 (16.88 %).

Among the different treatments, foliar application of boric acid significantly enhanced the oil content of soybean. Application of silicic acid also significantly enhanced the oil content of seed over control. Higher oil content (19.21 %) was recorded with the foliar application of boric acid @ 2ml L^{-1} for three times, which was found to be on par with foliar application of boric acid @ 4ml L^{-1} three times (18.85 %). Least was observed with foliar application of silicic acid @2ml L^{-1} for two times (17.20 %).

Foliar application of silicic acid as well as boric acid significantly enhanced the oil content of soybean. The oil content of seed ranged from 15.34 to 20.95 per cent.

Higher oil content in seed was recorded with the foliar application of silicic acid @ 2ml L^{-1} for two times in MAUS-2 variety, which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for three times (20.46 %) followed by foliar application of silicic acid @ 4ml L^{-1} for three times (20.17 %) and with foliar application of boric acid @ 2ml L^{-1} for three times (20.65 %) in MAUS-2 variety. Least was recorded in KBS-23 variety with foliar application of silicic acid @ 2ml L^{-1} for two times.

4.3.8 Oil yield (kg ha^{-1})

The effect of foliar application of silicic acid and boric acid on oil yield (kg ha^{-1}) of soybean is given in Table 8.

The data presented in Table 8, revealed that there was no significant difference for oil yield among varieties with the application of foliar silicic acid and boric acid at different growth stages of crop. However, significant increase in the oil yield was observed among the treatments, recording higher (370.53 kg ha^{-1}) with the foliar application of silicic acid @ 2m L^{-1} for three times followed by foliar application of silicic acid @ 4ml L^{-1} for three times (338.46 kg ha^{-1}). Least was observed in control (215.88 kg ha^{-1}).

Among the varieties and treatments combinations, foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety recorded higher oil yield (420.42 kg ha^{-1}) followed by foliar application of silicic acid @ 4ml L^{-1} for three times in MAUS-2 variety (340.34 kg ha^{-1}) and least was with water application in MAUS-2 variety (202.25 kg ha^{-1}).

4.4 Effect of foliar application of silicic acid and boric acid on Si content (%) and its uptake (kg ha^{-1}) of soybean

Data on the effect of foliar application of silicic acid and boric acid on Si content and its uptake by different parts of soybean are given in Table 9.

4.4.1 Silicon content and uptake by haulm

Application of foliar silicic acid and boric acid significantly enhanced the silicon content and uptake by the haulm of varieties used. Higher Si content (0.77 %) and uptake (10.46 kg ha^{-1}) by haulm was observed in MAUS-2 than its content (0.53 %) and uptake in KBS-23 (8.16 kg ha^{-1}).

Among treatments, Si content and uptake significantly differed with the application of foliar silicic acid and boric acid. The content in haulm ranged from 0.53 to 0.74 %. Maximum Si content was recorded in treatment with the foliar application of silicic acid at 2ml L^{-1} for two times and lower with the foliar application of boric acid at 2ml L^{-1} for three times. Maximum silicon uptake (12.16 kg ha^{-1}) was observed with the foliar application of silicic acid @ 4ml L^{-1} for three times followed by treatment with the foliar application of silicic acid @ 2ml L^{-1} for three times (11.44 kg ha^{-1}) and the least in foliar application of boric acid @ 2ml L^{-1} for three times (7.20 kg ha^{-1}).

Among the different varieties and treatments combinations, maximum silicon content in haulm (0.92 %) was observed with the foliar application of silicic acid @ 4ml L^{-1} for three times in MAUS-2 variety and lower (0.42 %) with the foliar application of boric acid @ 2ml L^{-1} for three times in KBS-23 variety. Silicon uptake by haulm varied from 5.12 to 15.72 kg ha^{-1}. Higher Si uptake was observed with the foliar application of silicic acid @ 4ml L^{-1} for three times in MAUS-2 variety, which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times in the same variety (15.54 kg ha^{-1}). Least was recorded with the foliar application of boric acid @ 2ml L^{-1} for three times in KBS-23 variety.

4.4.2 Silicon content and uptake by husk

Silicon content and uptake by pod as influenced by the foliar application of silicic acid and boric acid is presented in the Table 9.

No significant difference was observed with the foliar application of silicic acid and boric acid on the Si content and uptake by husk. However, treatments and combination of treatments differed significantly for the foliar applied silicic acid on Si

Table 9. Effect of foliar application of silicic acid and boric acid on Si content (%) and its uptake (kg ha^{-1}) by soybean

	Content (%)			Uptake (kg ha^{-1})		
	Haulm	**Husk**	**Seed**	**Haulm**	**Husk**	**Seed**
Varieties						
V1	0.77	0.13	0.11	10.46	1.54	1.44
V2	0.53	0.13	0.09	8.16	1.35	1.56
SEm±	0.004	0.002	0.002	0.14	0.04	0.05
C.D at 0.05	0.22	NS	0.009	0.87	NS	NS
Treatments						
T1	0.69	0.13	0.11	8.37	1.19	1.29
T2	0.74	0.12	0.12	9.05	1.02	1.61
T3	0.64	0.14	0.09	9.46	1.92	1.60
T4	0.63	0.14	0.10	11.44	1.86	1.95
T5	0.69	0.14	0.10	12.16	1.68	1.82
T6	0.53	0.12	0.07	7.20	1.19	0.99
T7	0.61	0.13	0.09	7.48	1.26	1.22
SEm±	0.02	0.004	0.003	0.37	0.07	0.08
C.D at 0.05	0.04	0.01	0.01	1.06	0.19	0.22
Interaction						
T1VI	0.65	0.11	0.14	6.51	0.95	1.54
T2V1	0.82	0.13	0.15	8.85	1.16	1.68
T3V1	0.80	0.16	0.07	9.30	2.25	0.90
T4V1	0.83	0.15	0.09	15.54	2.17	1.77
T5V1	0.92	0.14	0.11	15.72	1.67	1.88
T6V1	0.63	0.11	0.09	9.28	1.32	1.21
T7V1	0.74	0.13	0.10	8.01	1.26	1.10
T1V2	0.73	0.14	0.08	10.22	1.42	1.04
T2V2	0.65	0.11	0.10	9.25	0.88	1.53
T3V2	0.49	0.12	0.11	9.62	1.59	2.31
T4V2	0.44	0.14	0.11	7.34	1.55	2.14
T5V2	0.47	0.13	0.09	8.59	1.69	1.77
T6V2	0.42	0.12	0.06	5.12	1.06	0.77
T7V2	0.48	0.12	0.08	6.94	1.25	1.34
SEm±	0.02	0.006	0.004	0.52	0.09	0.11
C.D at 0.05	0.06	0.016	0.01	1.52	0.27	0.31

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

content and uptake by the husk. Maximum Si content in husk (0.14 %) was observed with both foliar application of silicic acid @ 4ml L^{-1} two times, 2ml L^{-1} and 4ml L^{-1} three times, which was found to be on par with both foliar application of boric acid @ 4ml L^{-1} three times and only water application (0.13 %). Silicon uptake by husk was higher (1.92 kg ha^{-1}) with the foliar application of silicic acid @ 4ml L^{-1} for two times, which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for three times (1.86 kg ha^{-1}). Least Si uptake with the foliar application of silicic acid @ 2ml L^{-1} for two times (1.02 kg ha^{-1}).

The varieties and treatments combinations differed significantly for Si content and its uptake by husk. The Si content ranged from 0.11 to 0.16 per cent in soybean husks. Maximum uptake (2.25 kg ha^{-1}) was recorded with the foliar application of silicic acid @ 4ml L^{-1} for two times in MAUS-2 variety, which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times (2.17 kg ha^{-1}). Least (0.88 kg ha^{-1}) with the foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety.

4.4.3 Silicon content and uptake by seed

The data regarding Si content and uptake by seed as a result of foliar application of silicic acid and boric acid is given in Table 9.

Silicon content in seed differed significantly with the foliar applied silicic acid and boric acid, recording higher in MAUS-2 (0.11 %) than KBS-23 (0.09 %). No significant difference was observed for the Si uptake by seed among the varieties with the foliar application of silicic acid and boric acid.

Si content and uptake by seed differed significantly with the application of foliar silicic acid. Si content ranged from 0.07 to 0.12 per cent. Higher Si content was observed with the foliar application of silicic acid @ 2ml L^{-1} for two times, which was found to be on par with water spray. Lower Si content in seed was observed with the foliar application of boric acid @ 2ml L^{-1} for three times. Si uptake by seed varied from 0.99 to 1.95 kg ha^{-1}, recording higher with the foliar application of silicic acid @ 2ml L^{-1} for three times which was found to be on par with the foliar application of silicic acid @ 4ml L^{-1} for three times, and lower with the application of boric acid @ 2ml L^{-1} for three times.

Application of silicic acid significantly enhanced the Si content and uptake by seed among the varieties and treatments combinations. Maximum Si content of seed (0.15 %) was observed with the foliar application of silicic acid @ 2ml L^{-1} for two times in MAUS-2 variety, which was found to be on par with water application in MAUS-2 variety (0.14). Higher Si uptake by seed (2.31 kg ha^{-1}) was recorded with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety. Lower Si content in soybean seed (0.06 %) was observed in KBS-23 variety receiving foliar application of boric acid @ 2ml L^{-1} for three times. Whereas, lower uptake by seed (0.77 kg ha^{-1}) was observed in KBS-23 variety with the foliar application of boric acid @ 2ml L^{-1} for three times.

4.5 Effect of foliar application of silicic acid and boric acid on nutrient content (%) of soybean

4.5.1 Nitrogen content

Data on N content of soybean seed as influenced by the foliar application of silicic acid and boric acid is presented in Table 10.

4.5.1.1 Seed

Nitrogen content in seed differed significantly among the varieties with the foliar application of silicic acid and boric acid. Higher N content in seed was observed in KBS-23 (5.57 %) than MAUS-2 (4.92 %).

Irrespective of the varieties, foliar application of silicic acid significantly increased the N content in seed. Higher N content (5.62 %) in seed was observed with the foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with the foliar application of silicic acid @ 2ml $L^{-1}$and 4ml L^{-1} for two times and 2ml L^{-1} for three times recording 5.53, 5.48 and 5.37 per cent respectively. Application of boric acid did not show any significant difference for N content in seed over control.

Among the varieties and treatments combinations, effect of foliar application of silicic acid and boric acid significantly enhanced the N content in seeds, recording highest (6.35 %) with the foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety and lower (4.53 %) with the foliar application of boric acid @ 4ml L^{-1} for three times in MAUS-2 variety.

4.5.2 Phosphorus content

Data presented in the Table 10, revealed the effect of foliar application of silicic acid and boric acid on P content in haulm, husk and seed.

4.5.2.1 Haulm

Among the varieties irrespective of treatments, there was no significant effect of foliar application of silicic acid and boric acid on P content in haulm. Treatments differed significantly irrespective of varieties for P content in haulm with the foliar application of silicic acid. Maximum P content in haulm (0.105 %) was observed with the foliar application of silicic acid @ 2ml L^{-1} for two times, which was found to be on par with water application, foliar application of silicic acid @ 4ml L^{-1} for two times followed by foliar application of silicic acid @ 2ml L^{-1} for three times and foliar application of boric acid @ 2ml L^{-1} for three times. Least was observed with foliar application of boric acid @ 4ml L^{-1} for three times (0.077 %).

Varieties and treatments combinations found to differ significantly with the foliar application of silicic acid and boric acid for P content in haulm. Higher P content in haulm (0.124 %) was recorded with the water application in KBS-23 variety, which was found to be on par with the treatment receiving foliar application of boric acid @ 2ml L^{-1} for three times in MAUS-2 variety (0.112 %). Least (0.056 %) was recorded in foliar application of boric acid @ 4ml L^{-1} three times in KBS-23 variety.

4.5.2.2 Husk (without seed)

There was no significant difference among the varieties for the P content in husk with the foliar application of silicic acid and boric acid at different growth stages of crop.

Table 10. Effect of foliar application of silicic acid and boric acid on N, P and K content (%) of soybean

	Nitrogen (%)	Phosphorus (%)			Potassium (%)		
	Seed	Haulm	Husk	Seed	Haulm	Husk	Seed
Varieties							
V1	4.92	0.093	0.063	0.51	0.56	1.11	1.68
V2	5.57	0.091	0.061	0.51	0.52	0.97	1.64
SEm±	0.06	0.002	0.003	0.01	0.02	0.01	0.01
C.D at 0.05	0.38	NS	NS	NS	NS	0.08	0.03
Treatments							
T1	4.97	0.093	0.058	0.51	0.55	0.99	1.68
T2	5.53	0.105	0.042	0.50	0.57	0.90	1.66
T3	5.48	0.101	0.063	0.50	0.46	1.25	1.62
T4	5.37	0.091	0.061	0.49	0.51	0.94	1.63
T5	5.62	0.078	0.068	0.49	0.53	1.09	1.63
T6	4.97	0.100	0.071	0.52	0.58	1.10	1.69
T7	4.78	0.077	0.070	0.52	0.57	1.02	1.70
SEm±	0.13	0.01	0.01	0.02	0.03	0.09	0.03
C.D at 0.05	0.39	0.02	0.01	NS	0.10	0.27	0.08
Interaction							
T1VI	5.13	0.062	0.073	0.51	0.55	1.06	1.69
T2V1	4.71	0.105	0.042	0.50	0.61	0.97	1.69
T3V1	4.95	0.094	0.066	0.50	0.48	1.34	1.64
T4V1	5.18	0.090	0.061	0.47	0.53	0.96	1.65
T5V1	5.27	0.093	0.067	0.50	0.56	1.22	1.66
T6V1	4.67	0.112	0.068	0.52	0.64	1.12	1.69
T7V1	4.53	0.099	0.063	0.54	0.53	1.12	1.74
T1V2	4.81	0.124	0.043	0.52	0.55	0.91	1.67
T2V2	6.35	0.105	0.041	0.51	0.53	0.83	1.63
T3V2	6.02	0.107	0.060	0.49	0.44	1.15	1.60
T4V2	5.55	0.092	0.060	0.51	0.49	0.92	1.62
T5V2	5.97	0.062	0.070	0.49	0.49	0.95	1.61
T6V2	5.27	0.088	0.074	0.51	0.51	1.08	1.68
T7V2	5.04	0.056	0.078	0.51	0.61	0.92	1.67
SEm±	0.19	0.01	0.007	0.03	0.05	0.13	0.04
C.D at 0.05	0.54	0.02	0.02	0.07	0.14	0.38	NS

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

Significant difference was observed for the treatments and the combination of varieties and treatments with the foliar applied silicic acid and boric acid. Higher P content in husk (0.071 %) was recorded with the foliar application of boric acid @ 2ml L^{-1} for three times, which was found to be on par with both foliar application of boric acid (0.070 %) and silicic acid (0.068 %) @ 4ml L^{-1} for three times. Least (0.042 %) was with the foliar application of silicic acid @ 2ml L^{-1} for two times.

Among the different varieties and treatments combinations, foliar application of boric acid @ 4ml L^{-1} for three times in KBS-23 variety recorded higher P content in husk (0.078 %) followed by foliar application of boric acid @ 2ml L^{-1} for three times (0.074 %) and the least (0.041 %) in KBS-23 variety with the foliar application of silicic acid @ 2ml L^{-1} for two times.

4.5.2.3 Seed

The content of P in Seed did not differ significantly for the foliar applied silicic acid and boric acid among both the varieties and the treatments. However, treatment combinations differed significantly. The seed P ranged from 0.47 to 0.54 per cent. Higher was observed with the foliar application of boric acid @ 4ml L^{-1} for three times in MAUS-2 variety and lower with the foliar application of silicic acid @ 2ml L^{-1} for three times in the same variety.

4.5.3 Potassium content

Data presented in Table 10, revealed the effect of foliar silicic acid and boric acid on potassium content of haulm, husk and seed.

4.5.3.1 Haulm

Application of foliar silicic acid and boric acid had no significant effect on K content in haulm. However, treatments and combination of varieties and treatments had significant effect. Higher K content in haulm (0.58 %) was recorded with the foliar application of boric acid @ 2ml L^{-1} for three times and lower with the foliar application of silicic acid @ 4ml L^{-1} for two times (0.46 %). Among the different varieties and treatments combinations, MAUS-2 variety with the foliar application of boric acid @ 2ml L^{-1} for three times recorded higher K content in haulm (0.64 %) and the least (0.44 %) with the foliar application of silicic acid 4ml L^{-1} for two times in KBS-23 variety.

4.5.3.2 Husk

Among the varieties, foliar application of silicic acid and boric acid on K content of husk differed significantly. Higher potassium content was recorded in MAUS-2 (1.11 %) than KBS-23 (0.97 %).

Potassium content in husk differed significantly with the application of foliar silicic acid among the treatments. Higher K content in husk (1.25 %) was recorded with the foliar application of silicic acid @ 4ml L^{-1} for two times and least (0.90) with the foliar application of silicic acid @ 2ml L^{-1} for two times.

The K content in husk differed significantly among the combination of varieties and treatments with the foliar application of silicic acid. Maximum K content in husk (1.34 %) was recorded in MAUS-2 variety with the foliar application of silicic acid @ 4ml L^{-1} for two times and least (0.83 %) with the foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety.

4.5.3.3 Seed

Perusal of data presented in Table 10, revealed that there was significant difference on K content in seed among the varieties with the foliar application of silicic acid and boric acid. Higher K content was recorded in MAUS-2 (1.68 %) than KBS-23 (1.64 %).

Irrespective of the varieties, foliar application of silicic acid significantly differed for K content in seed. Higher K content in seed (1.70 %) was recorded with the foliar application of boric acid @ 4ml L^{-1} three times, which was found to be on par with other treatments except for treatment receiving foliar application of silicic acid @ 4ml L^{-1} for two times (1.62 %). Combination of varieties and treatments did not differ significantly with the foliar application of silicic acid.

4.5.4 Calcium content

Data presented in Table 11, revealed the effect of foliar application of silicic acid and boric acid on Ca content in haulm, husk and seed.

4.5.4.1 Haulm

Calcium content in haulm did not differ significantly among the varieties with the foliar application of silicic acid and boric acid. Between the treatments, Ca content in haulm decreased significantly, recording higher (1.92 %) with the foliar application of boric acid @ 2ml L^{-1} three times and lower (1.64 %) with the foliar application of silicic acid @ 2m L^{-1} for three times.

The combination of varieties and treatments differed significantly with the foliar application of silicic acid. The Ca content in haulm ranged from 1.48 to 1.95 per cent. Higher Ca content in haulm (1.95 %) was observed with both water application and boric acid application @ 2ml L^{-1} for three times in KBS-23 variety and lower (1.48 %) with the foliar application of silicic acid @ 2ml L^{-1} for three times in the same variety.

4.5.4.2 Husk

Effect of foliar application of silicic acid and boric acid on Ca content in husk differed significantly among varieties. Maximum calcium content in husk was observed in variety MAUS-2 (1.34 %) than KBS-23 (1.05 %).

Significant difference with the foliar application of silicic acid and boric acid for Ca content in husk was observed among the treatments, recording higher (1.27 %) with the foliar application of boric acid at 2ml L^{-1} for three time, which was found to be on par with other treatments except for foliar application of silicic acid @ 4ml L^{-1} for two times (1.11 %).

Among the varieties and treatments combinations, maximum Ca content in husk (1.45 %) was recorded in MAUS-2 variety with water spray, which was found to be on par with foliar application of silicic aid @ 2ml L^{-1} for two times (1.43 %), silicic acid application @ 2ml L^{-1} (1.33 %) and 4ml L^{-1} (1.30 %) for three times followed by boric acid application @ 2ml L^{-1} (1.40 %) and 4ml L^{-1} (1.26 %) for three times in the same variety. Least was recorded in KBS-23 with water application (0.98 %).

4.5.4.3 Seed

There was no significant effect of foliar application of silicic acid and boric acid on Ca content in seed among the varieties and the treatments.

Combination of varieties and treatments differed significantly for Ca content in seed. The Ca content ranged from 0.37 to 0.48 per cent. Higher content was recorded with the foliar application of silicic acid @ 2ml L^{-1} for two times in MAUS-2 variety and lower with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety.

4.5.5 Magnesium content

The data on effect of foliar application of silicic acid and boric acid on Mg content in haulm, husk and seed are presented in Table 11.

4.5.5.1 Haulm

Perusal of data presented in Table 11, revealed that there was significant difference in Mg content of haulm was observed among the varieties. Higher Mg content was observed in KBS-23 (0.83 %) than MAUS-2 (0.74 %). However, no significant difference was observed among the treatments for Mg content in haulm with the foliar application of silicic acid and boric acid.

Magnesium content in haulm differed significantly with the foliar application of silicic acid and boric acid for different varieties and treatments combinations. The Mg content in haulm varied from 0.67 to 0.97 per cent. Higher Mg content in haulm was observed both in KBS-23 variety with the foliar application of silicic acid @ 4ml L^{-1} for two times and 2ml L^{-1} for three times and lower in MAUS-2 variety with water spray.

Table 11. Effect of foliar application of silicic acid and boric acid on Ca, Mg and S content (%) of soybean

	Calcium (%)			Magnesium (%)			Sulphur (%)		
	Haulm	Husk	Seed	Haulm	Husk	Seed	Haulm	Husk	Seed
Varieties									
V1	1.71	1.34	0.42	0.74	0.83	0.30	0.15	0.14	0.48
V2	1.82	1.05	0.40	0.83	0.75	0.32	0.17	0.19	0.31
SEm±	0.06	0.02	0.01	0.04	0.02	0.01	0.004	0.02	0.00
C.D at 0.05	NS	0.13	NS	0.24	NS	NS	NS	0.06	0.02
Treatments									
T1	1.82	1.22	0.40	0.74	0.83	0.35	0.13	0.09	0.26
T2	1.74	1.24	0.44	0.74	0.75	0.31	0.11	0.14	0.40
T3	1.73	1.11	0.39	0.83	0.75	0.25	0.15	0.16	0.38
T4	1.64	1.17	0.43	0.86	0.81	0.25	0.17	0.16	0.50
T5	1.72	1.14	0.39	0.74	0.79	0.32	0.19	0.19	0.44
T6	1.92	1.27	0.42	0.77	0.77	0.33	0.19	0.17	0.32
T7	1.78	1.21	0.40	0.79	0.82	0.36	0.19	0.23	0.50
SEm±	0.08	0.06	0.02	0.06	0.03	0.02	0.01	0.01	0.03
C.D at 0.05	0.23	0.16	NS	NS	NS	0.06	0.03	0.03	0.10
Interaction									
T1VI	1.69	1.45	0.41	0.67	0.80	0.31	0.10	0.07	0.37
T2V1	1.71	1.43	0.48	0.69	0.76	0.30	0.11	0.11	0.42
T3V1	1.56	1.21	0.40	0.69	0.76	0.23	0.11	0.14	0.34
T4V1	1.79	1.33	0.45	0.75	0.91	0.25	0.15	0.14	0.67
T5V1	1.63	1.30	0.38	0.77	0.88	0.29	0.19	0.18	0.57
T6V1	1.89	1.40	0.41	0.80	0.85	0.32	0.18	0.16	0.40
T7V1	1.71	1.26	0.41	0.78	0.84	0.39	0.21	0.16	0.60
T1V2	1.95	0.98	0.40	0.81	0.85	0.39	0.15	0.10	0.15
T2V2	1.76	1.06	0.40	0.79	0.73	0.32	0.11	0.16	0.37
T3V2	1.91	1.01	0.37	0.97	0.74	0.27	0.18	0.19	0.42
T4V2	1.48	1.01	0.42	0.97	0.72	0.26	0.20	0.17	0.33
T5V2	1.82	0.99	0.41	0.70	0.69	0.34	0.18	0.19	0.31
T6V2	1.95	1.14	0.44	0.75	0.70	0.34	0.21	0.19	0.23
T7V2	1.84	1.17	0.39	0.80	0.80	0.33	0.17	0.30	0.38
SEm±	0.11	0.08	0.03	0.09	0.04	0.03	0.02	0.02	0.05
C.D at 0.05	0.33	0.23	0.09	0.26	0.13	0.09	0.04	0.047	0.14

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

4.5.5.2 Husk

Both varieties and treatments had no significant effect on Mg content in husk with the foliar application of silicic acid. Varieties and treatments combinations differed significantly for Mg content in husk with the foliar application of silicic acid. The Mg content in husk ranged from 0.69 to 0.91 per cent, recording higher with foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety and lower in KBS-23 variety with foliar application of silicic acid @ 4ml L^{-1} for three times.

4.5.5.3 Seed

Magnesium content in seed did not differ significantly with the foliar application of silicic acid and boric acid among the varieties.

Treatments differed significantly with the foliar application of silicic acid for Mg content in seeds. All the treatments are found to be on par with each other except for both with foliar application of silicic acid @ 4ml L^{-1} for two times and 2ml L^{-1} for three times (0.25 %). The Mg content in seed ranged from 0.23 to 0.39 per cent. Maximum Mg content in seed was observed both with foliar application of boric acid @ 4ml L^{-1} for three times in MAUS-2 variety and water spray in KBS-23 variety. Lower was observed with foliar application of silicic acid @ 4ml L^{-1} for two times in MAUS-2 variety.

4.5.6 Sulphur content

Data presented in Table 11, revealed the effect of foliar application of silicic acid and boric acid on S content of haulm, husk and seed.

4.5.6.1 Haulm

The content of S in haulm did not differed significantly for the foliar application of silicic acid and boric acid among the varieties. Among the different treatments, foliar application of silicic acid @ 4ml L^{-1} followed by application of boric acid @ 2ml L^{-1} and 4ml L^{-1} for three times recorded significantly higher S content in haulm (0.19 %), which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times

(0.17 %). Least was observed with foliar application of silicic acid 2ml L^{-1} for two times (0.11 %).

Varieties and treatments combinations differed significantly for the foliar application of silicic acid, recording higher S content of haulm (0.21 %) both in MAUS-2 variety with the foliar application of boric acid @ 4ml L^{-1} for three times and in KBS-23 variety with the foliar application of boric acid @ 2ml L^{-1} for three times and lower in MAUS-2 variety with water application (0.10 %).

4.5.6.2 Husk

Among the varieties, S content of husk differed significantly with the foliar application of silicic acid and boric acid. Higher S content was observed in KBS-23 (0.19 %) than MAUS-2 (0.14 %).

Foliar application of silicic acid significantly increased the S content in husks among the treatments. However, higher S content (0.23 %) was observed with the foliar application of boric acid @ 4ml L^{-1} for three times than other treatments. Least was observed in control (0.09 %).

Combination of varieties and treatments differed significantly, recording higher S content in husk (0.30 %) with the foliar application of boric acid @ 4ml L^{-1} for three times in KBS-23 variety and lower in MAUS-2 variety with water spray (0.07 %).

4.5.6.3 Seed

Perusal of data presented in Table 11, revealed the effect of foliar application of silicic acid and boric acid on the S content of soybean seed. MAUS-2 (0.48 %) significantly recorded higher S content than the KBS-23 (0.31 %).

Application of foliar silicic acid significantly enhanced the S content in seeds recording higher (0.50 %) with both foliar application of silicic acid @ 2ml L^{-1} and boric acid application @ 4ml L^{-1} for three times followed by silicic acid application @ 4ml L^{-1} for three times (0.44 %). Least was recorded in control (0.26 %).

Combination of varieties and treatments differed significantly for the foliar application of silicic acid. The data revealed that, higher S content in seed (0.67 %) was observed with the foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety, which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for three times (0.57 %) followed by foliar application of boric acid @ 4ml L^{-1} for three times (0.60 %) in the same variety. Lower S content in seed was recorded in KBS-23 variety with water spray (0.15 %).

4.5.7 Iron content (mg kg^{-1})

Data presented in Table 12, revealed the effect of foliar application of silicic acid and boric acid on Fe content (mg kg^{-1}) in haulm, husk and seeds of soybean.

4.5.7.1 Haulm

Iron content in haulm did not differ significantly with the foliar application of silicic acid and boric acid among the varieties. However, treatments differed significantly for foliar application of silicic acid. Higher Fe content in haulm (331.28 mg kg^{-1}) was recorded with the foliar application of silicic acid @ 2ml L^{-1} for three times, which was found to be on par with control (330.44 mg kg^{-1}) followed by foliar silicic acid application @ 2ml L^{-1} for two times (324.00 mg kg^{-1}) and boric acid application @ 2ml L^{-1} for three times (305.78 mg kg^{-1}). Least was recorded with the foliar application of silicic acid @ 4ml L^{-1} for two times (294.61 mg kg^{-1}).

Among the different varieties and treatments combinations, Fe content in haulm varied from 283.78 to 375.56 mg kg^{-1}. Higher Fe content was observed in MAUS-2 variety with water spray. Application of foliar silicic acid significantly decreased the Fe content in haulm except for the treatment receiving both with foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety (355.67 mg ka^{-1}) and 2ml L^{-1} silicic acid application for two times in KBS-23 variety.

4.5.7.2 Husk

There was no significant effect of the foliar application of silicic acid and boric acid on Fe content in husk. Among the different treatments, application of foliar silicic acid significantly enhanced the Fe content in husk over control except for the treatment which received foliar application of silicic acid @ 4ml L^{-1} for two times (155.15 mg ka^{-1}). However, higher Fe content in husk (323.78 mg kg^{-1}) was observed with foliar application of boric acid @ 2ml L^{-1} for three times. Whereas, application of 4ml L^{-1} boric acid for three times recorded lesser Fe content in husk (170.11 mg kg^{-1})

The Fe content of husk varied from 164.22 to 344.78 mg kg^{-1}. Higher Fe content was observed in KBS-23 variety with foliar application of silicic acid @ 2ml L^{-1} for two times, which was found to be on par with foliar application of boric acid @ 2ml L^{-1} for three times in both MAUS-2 (328.00 mg kg^{-1}) and KBS-23 variety (319.56 mg kg^{-1}). Lower Fe content in husk was observed in KBS-23 variety with foliar application of silicic acid @ 4ml L^{-1} for two times.

4.5.7.3 Seed

Iron content in seed did not differ significantly with the foliar application of silicic acid and boric acid among the varieties. Among the treatments, foliar application of silicic acid significantly decreased the Fe content in seed over control. Higher Fe content in seed was observed in control (295.44 mg kg^{-1}) followed by foliar application of boric acid @ 4ml L^{-1} for three times (228.89 mg kg^{-1}) and lower with the foliar application of silicic acid @ 4ml L^{-1} for two times (185.17 mg kg^{-1}).

Among different varieties and treatments combinations, higher Fe content in seed (334.33 mg kg^{-1}) was recorded in MAUS-2 variety with water spray, which was found to be on par with foliar application of boric acid @ 2ml L^{-1} for three times in the same variety (298.11 mg kg^{-1}). Least Fe content in seed was recorded in MAUS-2 variety with silicic acid application @ 4ml L^{-1} for two times (184.89 mg kg^{-1}).

4.5.8 Zinc content (mg kg^{-1})

Data presented in Table 12, revealed the effect of foliar application of silicic acid and boric acid on Zn content in haulm, husk and seed.

4.5.8.1 Haulm

Perusal of data presented in Table 12, revealed that there was significant difference for Zn content in haulm among the varieties. Higher Zn content in haulm was observed in MAUS-2 (71.94 mg kg^{-1}) than KBS-23 (52.68 mg kg^{-1}).

Significant increase in Zn content in haulm was observed with the foliar application silicic acid over control except for the treatment which received foliar silicic acid application @ 4ml L^{-1} for two times (45.50 mg kg^{-1}). Higher Zn content in haulm (75.56 mg kg^{-1}) was observed with foliar application of boric acid @ 2ml L^{-1} for three times, which was found to be on par with both foliar application of boric acid (72.56 mg kg^{-1}) and silicic acid @ 4ml L^{-1} for three times (66.00 mg kg^{-1}).

Zinc content in haulm differed significantly among the varieties and treatments combinations with the foliar application of silicic acid. Zn content in haulm ranged from 44.33 to 90.00 mg kg^{-1}. Higher Zn content in haulm was observed with foliar application of boric acid @ 2ml L^{-1} for three times and lower with silicic acid application @ 4ml L^{-1} for two times in MAUS-2 variety.

4.5.8.2 Husk

The variety MAUS-2 recorded significantly higher Zn content (49.83 mg kg^{-1}) in husk over KBS-23 (33.65 mg kg^{-1}) with the foliar application of silicic acid. However, no significant difference was observed among the treatments for Zn content in husk.

Varieties and treatments combinations differed significantly with the foliar application of silicic acid. Higher Zn content in husk was recorded with foliar application of silicic acid @ 2ml L^{-1} for two times (54.56 mg kg^{-1}) followed by boric acid application @ 2ml L^{-1} (52.33 mg kg^{-1}) in MAUS-2 variety. Lower Zn content was observed in both foliar application of silicic acid application @ 2ml L^{-1} for two times and silicic acid application @ 4ml L^{-1} for three times in KBS-23 variety (31.78 mg kg^{-1}).

4.5.8.3 Seed

No significant difference was observed for Zn content among the varieties and treatments with the foliar application of silicic acid and boric acid. Among the varieties and treatments combinations, higher Zn content in seed (101.11 mg kg^{-1}) was observed in MAUS-2 variety with foliar application of boric acid @ 4ml L^{-1} for three times followed by foliar application of silicic acid @ 2ml L^{-1} for two times in the same variety (93.67 mg kg^{-1}), which was found to be on par with control (91.89 mg kg^{-1}), foliar silicic acid application @ 2ml L^{-1} (93.67 mg kg^{-1}) and 4ml L^{-1} (90.67 mg kg^{-1}) for two times and boric acid application @ 2ml L^{-1} for three times (93.56 mg kg^{-1}) in MAUS-2 variety followed by boric acid application @ 4ml L^{-1} for three times (90.11 mg kg^{-1}) in KBS-23 variety. Lower Zn content in seed was observed in KBS-23 variety with water spray (83.56 mg kg^{-1}).

4.5.9 Manganese content (mg kg^{-1})

Effect of foliar application of silicic acid and boric acid on Mn content in haulm, husk and seed of soybean are presented in Table 12.

4.5.9.1 Haulm

Manganese content in haulm did not differ significantly with the foliar application of silicic acid and boric acid between the varieties.

Among the treatments, foliar application of silicic acid significantly decreased the Mn content in haulm over control. Higher Mn content was observed in control (120.83 mg kg^{-1}), which was found to be on par with foliar application of boric acid at 4ml L^{-1} three times (114.06 mg kg^{-1}). Lowest Mn content was recorded with foliar application of silicic acid @ 4ml L^{-1} for two times (90.06 mg kg^{-1}).

Varieties and treatment combinations differed significantly for foliar application of silicic acid. Mn content in haulm varied from 84.00 to 127.44 mg kg^{-1}. Higher Mn content in haulm was observed with foliar application of boric acid @ 4ml L^{-1} for three times, which was found to be on par with control, foliar application of silicic acid @ 2ml L^{-1} for two and three times followed by boric acid application @ 2ml L^{-1} for three times in MAUS-2 variety and control in KBS-23 variety. Lower Mn content haulm (84.00 mg kg^{-1}) was observed with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety.

4.5.9.2 Husk

There was no significant difference among the varieties for Mn content in husk with the foliar application of silicic acid and boric acid.

Among the treatments, Mn content in husk varied from 40.61 to 61.39 mg kg^{-1}. Application of silicic acid significantly increased Mn content in husk over control (39.11 mg kg^{-1}). Higher Mn content was observed with foliar application of boric acid @ 2ml L^{-1} for three times.

The combination of varieties and treatments differed significantly with the application of foliar silicic acid for Mn content in husk. The Mn content in husk ranged from 30.33 to 72.56 mg kg^{-1}. Higher Mn content in husk was recorded in MAUS-2 variety with foliar application of boric acid @ 2ml L^{-1} for three times, which was found to be on par with silicic acid application @ 2ml L^{-1} and 4ml L^{-1} two times followed by silicic acid application @ 4ml L^{-1} for three times in the same variety. Lower Mn content in husk was recorded in KBS-23 variety with the silicic acid application @ 2ml L^{-1} for three times.

4.5.9.3 Seed

Application of foliar silicic acid and boric acid did not differ significantly for Mn content in seed. Irrespective of the varieties, application of foliar silicic acid significantly decreased the Mn content in seed. Higher Mn content in seed was recorded in control (57.78 mg kg^{-1}) followed by treatment with foliar application of silicic acid @ 2ml L^{-1} for two times (43.50 mg kg^{-1}) and least was with foliar application of boric acid @ 4ml L^{-1} for three times (38.78 g kg^{-1}).

Table 12. Effect of foliar application of silicic acid and boric acid on micronutrient content of soybean

	Iron (mg kg^{-1})			Zinc (mg kg^{-1})			Manganese (mg kg^{-1})			Copper (mg kg^{-1})		
	Haulm	Husk	Seed	Haulm	Husk	Seed	Haulm	Husk	Seed	Haulm	Husk	Seed
Varieties												
V1	305.73	216.29	237.00	71.94	49.83	90.92	110.86	58.27	43.32	11.73	21.79	33.65
V2	319.02	219.24	226.21	52.68	33.65	86.43	99.63	40.67	41.89	16.70	23.83	31.08
SEm±	5.03	2.22	9.23	1.98	2.29	1.66	3.74	4.61	1.82	0.28	1.02	0.68
C.D at 0.05	NS	NS	NS	12.03	13.90	NS	NS	NS	NS	1.68	NS	NS
Treatments												
T1	330.44	195.83	295.44	58.33	39.00	87.72	120.83	39.11	57.78	13.61	19.72	32.33
T2	324.00	257.56	220.11	62.11	43.17	91.50	100.89	56.56	43.50	12.00	22.22	31.39
T3	294.61	155.17	185.17	45.50	45.39	87.06	90.06	53.78	39.50	11.67	21.78	31.28
T4	331.78	214.39	219.67	56.11	41.28	86.33	106.72	40.61	37.56	14.44	22.28	31.39
T5	303.89	207.50	206.44	66.00	39.83	82.00	101.56	53.06	39.00	14.78	28.28	31.11
T6	305.78	323.78	265.50	75.56	44.94	90.50	102.61	61.39	42.11	15.11	24.22	35.33
T7	296.11	170.11	228.89	72.56	38.56	95.61	114.06	41.78	38.78	17.89	21.17	33.72
SEm±	9.51	8.04	8.92	4.25	2.74	3.17	5.89	5.12	2.89	1.09	1.48	0.99
C.D at 0.05	27.46	23.23	25.75	12.31	NS	NS	17.00	14.77	8.35	3.15	4.28	2.86
Interaction												
T1VI	285.33	185.78	334.33	68.44	52.11	91.89	123.67	45.22	72.56	11.56	20.11	33.89
T2V1	307.00	170.33	229.11	69.67	54.56	93.67	104.44	71.00	44.89	10.00	21.33	33.78
T3V1	302.33	169.56	184.89	44.33	51.00	90.67	96.11	59.44	37.67	9.78	20.33	31.44
T4V1	355.67	235.89	210.56	58.78	47.22	87.00	117.22	50.89	35.44	13.33	23.78	32.22
T5V1	283.78	248.44	185.78	83.11	47.89	78.56	99.78	63.33	30.44	12.22	21.33	31.44
T6V1	310.11	328.00	298.11	90.00	52.33	93.56	107.33	72.56	42.44	12.89	24.22	36.33
T7V1	295.89	176.00	216.22	89.22	43.67	101.11	127.44	45.44	39.78	12.33	21.44	36.44
T1V2	375.56	205.89	256.56	48.22	25.89	83.56	118.00	33.00	43.00	15.67	19.33	30.78
T2V2	341.00	344.78	211.11	54.56	31.78	89.33	97.33	42.11	42.11	14.00	23.11	29.00
T3V2	286.89	140.78	185.44	46.67	39.78	83.44	84.00	48.11	41.33	13.56	23.22	31.11
T4V2	307.89	192.89	228.78	53.44	35.33	85.67	96.22	30.33	39.67	15.56	20.78	30.56
T5V2	324.00	166.56	227.11	48.89	31.78	85.44	103.33	42.78	47.56	17.33	35.22	30.78
T6V2	301.44	319.56	232.89	61.11	37.56	87.44	97.89	50.22	41.78	17.33	24.22	34.33
T7V2	296.33	164.22	241.56	55.89	33.44	90.11	100.67	38.11	37.78	23.44	20.89	31.00
SEm±	13.44	11.37	12.61	6.03	3.88	4.49	8.33	7.23	4.09	1.54	2.16	1.4
C.D at 0.05	38.83	32.85	36.42	17.41	11.2	12.96	24.05	20.89	11.81	4.46	6.00	4.65

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

Among the varieties and treatments combinations, Mn content in seed varied from 30.44 to 72.56 mg kg-^{1}. Higher Mn content in seed was recorded in MAUS-2 variety with water application and lower in the same variety with the foliar application of silicic acid @ 4ml L^{-1} for three times.

4.5.10 Copper content (mg kg^{-1})

Effect of foliar application of silicic acid and boric acid on copper content in haulm, husk and seed are presented in Table 12.

4.5.10.1 Haulm

Effect of foliar application of silicic acid and boric acid on Cu content of haulm differed significantly among the varieties. Higher Cu content in haulm was observed in KBS-23 (16.70 mg kg^{-1}) than MAUS-2 (11.73 mg kg^{-1}).

Among the treatments, foliar application of boric acid @ 4ml L^{-1} for three times recorded higher Cu content in haulm (17.89 mg kg^{-1}) followed by 2ml L^{-1} boric acid application for three times (15.11 mg kg^{-1}), which was found to be on par with both foliar application of silicic acid (14.78 mg kg^{-1}) and boric acid application @ 4ml L^{-1} for three times (17.89 mg kg^{-1}). Lower Cu content in haulm (11.67 mg kg^{-1}) was recorded with the foliar application of silicic acid @ 4ml L^{-1} two times.

Foliar application of boric acid @ 4ml L^{-1} for three times in KBS-23 variety recorded significantly higher Cu content in haulm (23.44mg kg^{-1}) over foliar application of silicic acid @ 4ml L^{-1} for two times in MAUS-2 variety (9.78 mg kg^{-1}). Foliar application of silicic acid increased the Cu content in haulm over control.

4.5.10.2 Husk

No significant difference was observed with the foliar application of silicic acid and boric acid among the varieties for Cu content in husk. Irrespective of the variety, application of silicic acid significantly enhanced the copper content in husk over control. Higher Cu content in husk (28.28 mg kg^{-1}) was observed with foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} three times (24.22 mg kg^{-1}). Least Cu content in husk was observed in control (19.72 %).

Cu content in husk significantly varied from 19.33 to 35.22 mg kg^{-1} among the combination of varieties and treatments. Higher Cu content was observed in MAUS-2 with foliar silicic acid application @ 4ml L^{-1} for three times and lower with water spray in the same variety.

4.5.10.3 Seed

Application of foliar silicic acid and boric acid did not differ significantly on Cu content of seed. In general, foliar applied boric acid enhanced the Cu content in seed. Higher Cu content in seed (35.33 mg kg^{-1}) was observed with the foliar application of boric acid @ 2ml L^{-1} for three times, which was found to be on par with boric acid application @ 4ml L^{-1} for three times (33.72 mg kg^{-1}). Application of foliar silicic acid decreased the Cu content in seed over control.

Application of foliar silicic acid varied significantly among the varieties and treatments combinations for Cu content in seed. Maximum Cu content in seed was recorded in MAUS-2 variety with foliar boric acid application @ 4ml L^{-1} for three times (36.44 mg kg^{-1}) followed by boric acid application @ 2ml L^{-1} for three times in the same variety (36.33 mg kg^{-1}). Lower Cu content in seed (29.00 mg kg^{-1}) was observed with foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety.

4.6 Effect of foliar application of silicic acid and boric acid on nutrient uptake (kg ha^{-1}) by soybean

4.6.1 Nitrogen uptake

Data on effect of foliar application of silicic acid and boric acid on N uptake by seed is given in Table 13.

4.6.1.1 Seed

Application of foliar silicic acid and boric acid significantly influenced the N uptake by the seeds. Higher N uptake by seed was recorded in KBS-23 (96.20 kg ha^{-1}) than MAUS-2 (69.20 kg ha^{-1}).

Irrespective of variety used, foliar application of silicic acid significantly increased the N uptake by seed over control. Maximum N uptake by seed (107.55 kg ha^{-1}) was recorded with the foliar application of silicic acid @ 2ml L^{-1} for three times followed by treatment with the foliar application of silicic acid @ 4ml L^{-1} for three times (103.94 kg ha^{-1}) and least in control (58.81 kg ha^{-1}).

Significant difference was observed for N uptake by seed among varieties and treatments combinations with the foliar application of silicic acid. The N uptake by seed ranged from 52.49 to 131.19 kg ha^{-1}. Higher N uptake by seed was observed in KBS-23 variety with the foliar application of silicic acid @ 4m L^{-1} for two times and lower in MAUS-2 variety with foliar application of boric acid @ 4ml L^{-1} for three times.

4.6.2 Phosphorus uptake

Data presented in Table 13, revealed the effect of foliar application of silicic acid and boric acid on P uptake by haulm, husk and seed of soybean.

4.6.2.1 Haulm

Effect of foliar application of silicic acid and boric acid did not differ significantly among the varieties for P uptake by haulm. Irrespective of the variety used, both with foliar application of silicic acid @ 2ml L^{-1} for three times and with 4ml L^{-1} for two times significantly recorded higher P uptake by haulm (1.62 kg ha^{-1}) compared to other treatments, which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for three times (1.38 kg ha^{-1}).

Combination of varieties and treatments differed significantly with the foliar application of silicic acid for P uptake by haulm. The P uptake by haulm ranged from 0.62 to 2.12 kg ha^{-1}. Higher P uptake by haulm was observed in KBS-23 variety with foliar application of silicic acid @ 4ml L^{-1} for two times and lower MAUS-2 variety with water spray.

4.6.2.2 Husk

No significant difference was observed with the foliar application of silicic acid on P uptake by husk among the varieties. Irrespective of the variety, foliar application of silicic acid significantly increased the P uptake by husk. Higher P uptake was observed both with the foliar application of silicic acid @ 4ml L^{-1} for two times and three times (0.85 kg ha^{-1}) followed by treatment with the foliar application of silicic acid @ 2ml L^{-1} (0.79 kg ha^{-1}) and boric acid @ 2ml L^{-1} (0.72 kg ha^{-1}) for three times. Least was observed with the foliar spray of silicic acid @ 2ml L^{-1} for two times.

Foliar application of silicic acid significantly differ for the P uptake by husk among different varieties and treatments combinations. The P uptake by husk ranged from 0.34 to 0.92 kg ha^{-1}. Higher P uptake was observed with the foliar application of silicic acid @ 4ml L^{-1} for three times and lower with the foliar application of silicic acid @ 2ml L^{-1} for two times in KBS-23 variety.

4.6.2.3 Seed

Perusal of data presented in Table 13, revealed that significant effect of foliar application of silicic acid and boric acid on P uptake by seed. Among the varieties, higher P uptake was noticed in KBS-23 (8.66 kg ha^{-1}) than MAUS-2 (7.04 kg ha^{-1}).

Among the treatments, higher P uptake by seed (9.82 kg ha^{-1}) was observed with the foliar application of silicic acid @ 2ml L^{-1} for three times followed by foliar application of silicic acid 4ml L^{-1} for three times (9.08 kg ha^{-1}). Least P uptake by seed was observed in control (6.13 kg ha^{-1}).

Phosphorus uptake by seed varied from 5.53 to 10.68 kg ha^{-1} among the varieties and treatments combinations. Higher P uptake was observed in KBS-23 with the foliar application of silicic acid @ 4ml L^{-1} for two times, which was found to be on par with both foliar application of silicic acid @ 2ml L^{-1} (9.94 kg ha^{-1}) and 4ml L^{-1} (9.76 kg ha^{-1})

Table 13. Effect of foliar application of silicic acid and boric acid on N, P and K uptake (kg ha^{-1}) by soybean

	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})			Potassium (kg ha^{-1})		
	Seed	Haulm	Husk	Seed	Haulm	Husk	Seed
Varieties							
V1	69.20	1.27	0.72	7.04	7.50	12.75	23.39
V2	96.90	1.41	0.66	8.66	8.02	10.36	28.12
SEm±	1.97	0.06	0.04	0.20	0.21	0.39	0.28
C.D at 0.05	11.97	NS	NS	1.23	NS	2.37	1.73
Treatments							
T1	58.81	1.19	0.53	6.13	6.69	9.00	19.84
T2	78.48	1.31	0.37	7.02	6.99	7.95	22.95
T3	96.67	1.62	0.85	8.50	7.15	16.92	27.73
T4	107.55	1.62	0.79	9.82	9.03	12.13	32.70
T5	103.94	1.38	0.85	9.08	9.39	13.42	30.12
T6	67.47	1.34	0.72	7.03	7.79	11.18	22.94
T7	68.47	0.94	0.71	7.35	7.30	10.28	24.02
SEm±	3.35	0.16	0.06	0.41	0.50	1.25	0.88
C.D at 0.05	9.69	0.28	0.18	1.17	1.44	3.61	2.53
Interaction							
T1VI	55.79	0.62	0.63	5.53	5.54	9.12	18.20
T2V1	54.61	1.13	0.39	5.84	6.52	8.98	19.46
T3V1	62.14	1.11	0.92	6.33	5.67	18.83	20.69
T4V1	106.59	1.68	0.88	9.70	9.89	13.83	33.78
T5V1	88.67	1.61	0.81	8.41	9.68	14.70	28.13
T6V1	64.14	1.64	0.79	7.22	9.38	12.90	23.25
T7V1	52.49	1.07	0.61	6.26	5.81	10.89	20.21
T1V2	61.82	1.75	0.43	6.73	7.83	8.88	21.47
T2V2	102.34	1.48	0.34	8.20	7.46	6.91	26.44
T3V2	131.19	2.12	0.78	10.68	8.62	15.01	34.77
T4V2	108.50	1.55	0.70	9.94	8.18	10.42	31.61
T5V2	119.21	1.14	0.89	9.76	9.10	12.14	32.10
T6V2	70.80	1.05	0.64	6.84	6.19	9.46	22.63
T7V2	84.45	0.81	0.80	8.45	8.80	9.67	27.82
SEm±	4.74	0.14	0.09	0.58	0.700	1.77	1.24
C.D at 0.05	13.70	0.40	0.26	1.66	2.030	5.11	3.58

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

for three times in the same variety. Lower P uptake by seed was observed in MAUS-2 variety with water spray.

4.6.3 Potassium uptake

The data pertaining to effect of foliar application of silicic acid and boric acid on K uptake by haulm, husk and seed are given in Table 13.

4.6.3.1 Haulm

No significant difference was observed for K uptake in haulm among the varieties with the foliar application of silicic acid and boric acid. Irrespective of varieties, application of silicic acid at higher concentration significantly enhanced the K uptake by haulm. Higher K uptake by haulm (9.39 kg ha^{-1}) was observed with foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for three times (9.03 kg ha^{-1}) and least was recorded in control (6.69 kg ha^{-1}).

Among different varieties and treatments combinations, foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety recorded significantly higher K uptake by haulm (9.89 kg ha^{-1}) followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for three times (9.68 kg ha^{-1}) in the same variety than other treatments. Least K uptake by haulm (5.54 kg ha^{-1}) was observed in MAUS-2 variety with water spray.

4.6.3.2 Husk

Potassium uptake by husk differed significantly with the foliar application of silicic acid and boric acid among the varieties. Maximum K uptake by husk was recorded in MAUS-2 (12.75 kg ha^{-1}) than KBS-23 (10.36 kg ha^{-1}).

In general, foliar application of silicic acid at 4ml L^{-1} for two times significantly increased the K uptake by husk (16.92 kg ha^{-1}) which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for three times (13.42 kg h^{-1}) and lower with silicic acid application @ 2ml L^{-1} for two times (7.95 kg ha^{-1}).

Among different varieties and treatments combinations, foliar application of silicic acid at different intervals significantly enhanced K uptake by husk except for foliar application of silicic acid @ 2ml L^{-1} for two times in both MAUS-2 and KBS-23 variety over control. Higher K uptake by seed (18.83 kg ha^{-1}) was recorded in MAUS-2 variety with the foliar application of silicic acid @ 4ml L^{-1} for two times, which was found to be on par with both foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety (15.01 kg ha^{-1}) and foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety (13.83 mg kg^{-1}) compared to other treatments.

4.6.3.3 Seed

Potassium uptake by seed differed significantly with the foliar application of silicic acid and boric acid among the varieties, recording high K uptake by KBS-23 (28.12 kg ha^{-1}) than MAUS-2 (23.39 kg ha^{-1}).

Irrespective of variety used, foliar application of silicic acid at 2ml L^{-1} for three times significantly recorded higher K uptake (32.70 kg ha^{-1}) by seed over control (19.84 kg ha^{-1}).

Application of silicic acid differed significantly for K uptake by seed among different varieties and treatments combinations. The K uptake by seed ranged from 18.20 to 34.77 kg ha^{-1}, recording higher in KBS-23 variety with foliar application of silicic acid @ 4ml L^{-1} for two times and lower in MAUS-2 variety with water spray.

4.6.4 Calcium uptake

Data on the effect of foliar application of silicic acid and boric acid on Ca uptake by haulm, husk and seed are presented in Table 14.

4.6.4.1 Haulm

Irrespective of treatments, foliar application of silicic acid and boric acid did not differ significantly for Ca uptake by haulm among the varieties. Among the different treatments, foliar application of silicic acid at 4ml L^{-1} for three times recorded higher Ca uptake by haulm (30.64 kg ha^{-1}), which was found to be on par with both foliar application of silicic acid @ 2ml L^{-1} for two times (29.09 kg ha^{-1}) and three times (27.91 kg ha^{-1}). Least Ca uptake by haulm (21.72 kg ha^{-1}) was observed with foliar application of silicic acid @ 2ml L^{-1} for two times. Application of boric acid also enhanced the Ca uptake by haulm over control.

Effect of foliar application of silicic acid differed significantly for Ca uptake by haulm among varieties and treatments combinations. Higher Ca uptake by haulm (37.81 kg ha^{-1}) was observed in KBS-23 with foliar application of silicic acid @ 4ml L^{-1} for two times, which was found to be on par with both foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety (33.44 kg ha^{-1}) and with foliar application of silicic acid @ 4ml L^{-1} for three times in KBS-23 variety (33.48 kg ha^{-1}). Lower uptake was recorded in MAUS-2 variety with water application (17.06 kg ha^{-1}).

4.6.4.2 Husk

Significant differences for Ca uptake by husk was observed among the varieties with the foliar application of silicic acid and silicic acid. Higher Ca uptake by husk was observed in MAUS-2 (15.13 kg ha^{-1}) than KBS-23 (11.13 kg ha^{-1}).

Among the treatments, Ca uptake by husk ranged from 11.08 to 15.46 kg ha^{-1}. Maximum Ca uptake by husk was recorded with foliar application of silicic acid @ 2ml L^{-1} for three times. Application of boric acid also enhanced the Ca uptake by husk.

Among the different varieties and treatments combinations, foliar application of silicic acid differed significantly for Ca uptake by husk. Higher Ca uptake by husk (19.40 kg ha^{-1}) was recorded in MAUS -2 variety and least was in KBS-23 variety with foliar application of silicic acid @ 2ml L^{-1} for two times (8.96 kg ha^{-1}).

4.6.4.3 Seed

Calcium uptake by seed differed significantly with the foliar application of silicic acid and boric acid among varieties. Maximum Ca uptake by seed was observed in KBS-23 (6.90 kg ha^{-1}) than MAUS-2 (5.86 kg ha^{-1}).

Table 14. Effect of foliar application of silicic acid and boric acid on Ca, Mg and S uptake (kg ha^{-1}) by soybean

	Calcium (kg ha^{-1})			Magnesium (kg ha^{-1})			Sulphur (kg ha^{-1})		
	Haulm	**Husk**	**Seed**	**Haulm**	**Husk**	**Seed**	**Haulm**	**Husk**	**Seed**
Varieties									
V1	23.01	15.13	5.86	3.32	9.43	4.08	2.06	1.59	6.99
V2	28.35	11.13	6.90	13.10	7.92	5.41	2.69	2.00	5.57
SEm±	1.01	0.34	0.06	0.80	0.32	0.10	0.07	0.13	0.06
C.D at 0.05	NS	2.03	0.37	4.88	NS	0.60	0.41	NS	0.36
Treatments									
T1	22.29	11.12	4.82	6.85	7.67	4.18	1.55	0.80	2.97
T2	21.72	11.08	5.93	6.80	6.58	4.35	1.39	1.21	5.46
T3	27.91	14.91	6.59	10.99	9.96	4.40	2.45	2.18	6.69
T4	29.09	15.46	8.67	10.53	10.63	5.04	3.03	2.00	10.04
T5	30.64	14.18	7.27	8.67	9.76	5.83	3.29	2.31	7.89
T6	25.68	12.96	5.76	6.50	7.91	4.45	2.58	1.70	4.25
T7	22.42	12.20	5.62	7.12	8.21	5.00	2.35	2.36	6.65
SEm±	1.35	0.74	0.42	3.61	0.36	0.31	0.16	0.14	0.53
C.D at 0.05	3.89	2.15	1.22	NS	1.05	0.91	0.40	0.4	1.54
Interaction									
T1VI	17.06	12.54	4.54	2.25	6.96	3.30	1.04	0.60	4.05
T2V1	18.45	13.21	5.45	2.49	7.03	3.50	1.20	1.03	4.97
T3V1	18.02	16.88	5.01	2.68	10.49	2.92	1.30	1.93	4.22
T4V1	33.44	19.40	9.14	4.69	13.12	5.05	2.75	2.01	13.67
T5V1	27.80	15.73	6.37	4.38	10.60	4.90	3.23	2.19	9.60
T6V1	27.89	16.00	5.66	3.94	9.75	4.36	2.66	1.76	5.37
T7V1	18.44	12.18	4.81	2.82	8.09	4.55	2.24	1.58	7.02
T1V2	27.52	9.69	5.10	11.45	8.38	5.07	2.06	1.00	1.88
T2V2	24.99	8.96	6.40	11.11	6.13	5.20	1.59	1.39	5.95
T3V2	37.81	12.95	8.16	19.30	9.44	5.88	3.59	2.43	9.15
T4V2	24.74	11.52	8.19	16.38	8.14	5.03	3.32	1.99	6.41
T5V2	33.48	12.63	8.16	12.97	8.91	6.75	3.34	2.43	6.19
T6V2	23.48	9.92	5.85	9.05	6.07	4.53	2.50	1.64	3.13
T7V2	26.40	12.22	6.43	11.42	8.33	5.45	2.46	3.14	6.27
SEm±	1.91	1.05	0.60	5.11	0.52	0.44	0.23	0.20	0.75
C.D at 0.05	5.51	3.04	1.72	14.76	1.49	1.28	0.65	0.57	2.17

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

Irrespective of varieties, application of foliar silicic acid at 2ml L^{-1} for three times significantly enhanced the Ca uptake by seed (8.67 kg ha^{-1}) over control. Among the varieties and treatments combinations, Ca uptake by seed varied from 4.54 to 9.14 kg ha^{-1}. Higher Ca uptake was recorded with foliar application of silicic acid @ 2ml L^{-1} for three times and lower with water spray in MAUS-2 variety.

4.6.5 Magnesium uptake

Data presented in Table 14, revealed the effect of foliar application of silicic acid and boric acid on Mg uptake by haulm, husk and seed.

4.6.5.1 Haulm

Significant variation in Mg uptake by haulm was observed with the foliar application of silicic acid and boric acid among the varieties. Higher Mg uptake by haulm was recorded in KBS-23 (13.10 kg ha^{-1}) than MAUS-2 (3.32 kg ha^{-1}).

No significant difference was observed among the treatments with the foliar application of silicic acid. varieties and treatment combinations differed significantly for Mg uptake by husk with the foliar application of silicic acid. Mg uptake by husk ranged from 2.25 to 19.30 kg ha^{-1}, recording higher with foliar application silicic acid @ 4ml L^{-1} for two times in KBS-23 variety and lower in MAUS-2 variety with water spray.

4.6.5.2 Husk

Magnesium uptake by husk did not differ significantly among the varieties with the foliar application of silicic acid and boric acid. Regardless of the variety, foliar application of silicic acid significantly enhanced the Mg uptake by husk. Higher Mg uptake by husk (10.63 kg ha^{-1}) was observed with foliar application of silicic acid @ 2ml L^{-1} for three times, which was found to be on par with both foliar application of silicic acid @ 4ml L^{-1} for two times (9.96 kg ha^{-1}) and three times (9.76 kg ha^{-1}). Lower Mg uptake by husk (6.58 kg ha^{-1}) was observed with foliar application of silicic acid @ 2ml L^{-1} for two times.

The varieties and treatments combinations showed significant difference for Mg uptake by husk with the foliar application of silicic acid. Foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety recorded highest Mg uptake by husk (13.12 Kg ha^{-1}) followed by foliar application of silicic acid @ 4ml L^{-1} for three times in MAUS-2 variety (10.60 kg ha^{-1}) and least was recorded in KBS-23 variety with foliar application of boric acid @ 2ml L^{-1} for three times (6.07 kg ha^{-1}).

4.6.5.3 Seed

Effect of foliar application of silicic acid and boric acid on Mg uptake by seed differed significantly among the varieties. Highest Mg uptake was observed in KBS-23 (5.41 kg ha^{-1}) than MAUS-2 (4.08 kg ha^{-1}).

Irrespective of the varieties used, foliar application of silicic acid @ 4ml L^{-1} for three times (5.83 kg ha^{-1}) significantly enhanced the Mg uptake by seed over control (4.18 kg ha^{-1}), which was found to be on par with both foliar application of foliar application of silicic acid @ 2ml L^{-1} for three times (5.04 kg ha^{-1}) and with foliar application of boric acid @ 4ml L^{-1} for three times (5.00 kg ha^{-1}). Foliar application of boric acid also enhanced the Mg uptake by seed over control.

Mg uptake by seed differed significantly among the varieties and treatments combinations. Highest Mg uptake was observed with the foliar application of silicic acid @ 4ml L^{-1} for three times (6.75 kg ha^{-1}) followed by foliar application of silicic acid @ 4ml L^{-1} for two times (5.88 kg ha^{-1}) in KBS-23 variety. Lowest was observed in MAUS-2 variety with foliar application of silicic acid @ 4ml L^{-1} for two times (2.92 kg ha^{-1}).

4.6.6 Sulphur uptake (kg ha^{-1})

Effect of foliar application of silicic acid and boric acid on S uptake by haulm, husk and seed are presented in Table 14.

4.7.6.1 Haulm

Perusal of data presented in Table 14, revealed that foliar application of silicic acid and boric acid differed significantly for S uptake by haulm between the varieties. Maximum S uptake was recorded in KBS-23 (2.69 kg ha^{-1}) than MAUS-2 (2.06 kg ha^{-1}).

Sulphur content in haulm differed significantly among the treatments with the foliar application of silicic acid, recording higher S uptake by haulm (3.29 kg ha^{-1}) with foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times (3.03 kg ha^{-1}) and lower was recorded with foliar application of silicic acid @ 2ml L^{-1} for two times (1.39 kg ha^{-1}). Foliar application of boric acid also enhanced the S uptake by haulm.

Among different varieties and treatments combinations, S uptake by haulm ranged from 1.04 to 3.59 kg ha^{-1}, recording higher with foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety and lower in MAUS-2 variety with water spray.

4.6.6.2 Husk

There was no significant difference among the varieties for S uptake by husk with the application of foliar silicic acid and boric acid. Among the treatments, significantly higher S uptake (2.36 kg ha^{-1}) was recorded with foliar application of boric acid @ 4ml L^{-1} for three times, which was found to be on par with both foliar application of silicic acid @ 4ml L^{-1} for two times (2.18 kg ha^{-1}) and foliar application of silicic acid @ 2ml L^{-1} for three times (2.00 kg ha^{-1}) followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for three times (2.31 kg ha^{-1}). Least S uptake by husk (0.80 kg ha^{-1}) was recorded in control.

Among the varieties and treatments combinations, foliar application of boric acid @ 4ml L^{-1} for three times in KBSS-23 variety recorded significantly higher S uptake by husk (3.14 kg ha^{-1}) followed by both foliar application of silicic acid @ 4ml L^{-1} for two and three times in the same variety (2.43 kg ha^{-1}). Least was observed in control (0.60 kg ha^{-1}).

4.6.6.3 Seed

Sulphur content in seed differed significantly with foliar application of silicic acid and boric acid among the varieties, recording higher S uptake by seed in MAUS-2 (6.99 kg ha^{-1}) than KBS-23 (5.57 kg ha^{-1}).

Irrespective of the varieties, application of silicic acid significantly enhanced the S uptake in seed. Foliar application of silicic acid @ 2ml L^{-1} for three times recorded higher S uptake by seed (10.04 kg ha^{-1}) followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for three times (7.89 kg ha^{-1}) and least was recorded in control (2.97 kg ha^{-1}).

Sulphur uptake by seed varied significantly among the varieties and treatments combinations. The S uptake by seed ranged from 1.88 to 13.67 kg ha^{-1}. Higher S uptake by seed was observed in MAUS-2 variety with foliar application of silicic acid @ 2ml L^{-1} for three times and lower in KBS-23 variety with water application.

4.6.7 Iron uptake

Effect of foliar application of silicic acid and boric acid on Fe uptake by haulm, husk and seed are presented in Table 15.

4.6.7.1 Haulm

Among the varieties, application of foliar silicic acid and boric acid significantly increased the Fe uptake by haulm in KBS-23 (497.12 g ha^{-1}) than MAUS-2 (414.04 g ha^{-1}).

Irrespective of variety, foliar application of silicic acid significantly increased the Fe uptake by haulm. Highest Fe uptake by haulm (589.57 g ha^{-1}) was recorded with foliar application of silicic acid @ 2ml L^{-1} for three times followed by treatment with the foliar application of silicic acid @ 4ml L^{-1} for three times (541.62 g ha^{-1}). Least Fe uptake by haulm (374.21 g ha^{-1}) was observed with foliar application of boric acid at ml L^{-1} for three times.

Varieties and treatment combinations differed significantly for Fe uptake by haulm with the foliar application of silicic acid. The Fe uptake by haulm ranged from 287.85 g ha^{-1} to 663.61 g ha^{-1}, recording highest with foliar application of silicic acid @ 2ml L^{-1} for three times and lowest with water spray in MAUS-2 variety.

4.6.7.2 Husk

Iron uptake by husk differed significantly with the foliar application of silicic acid and boric acid among the varieties. Maximum Fe uptake by husk was observed in MAUS-2 (248.91 g ha^{-1}) than KBS-23 (221.49 g ha^{-1}).

Application of silicic acid differed significantly for Fe uptake by husk among the treatments, recording higher (326.52 g ha^{-1}) with foliar application of boric acid @ 2ml L^{-1} for three times and lower (170.81 g ha^{-1}) with foliar application of boric acid @ 4ml L^{-1} for three times.

Among the varieties and treatments combinations, Fe uptake by husk differed significantly with the application of silicic acid. Higher Fe uptake by husk was recorded with foliar application of boric acid @ 2ml L^{-1} for three times in MAUS-2 variety (377.55 g ha^{-1}), which was found to be on par with the foliar application of silicic acid @ 2ml L^{-1} for three times (341.51 g ha^{-1}) in the same variety. Least Fe uptake by husk (157.03g ha^{-1}) was observed in KBS-23 variety with foliar application of silicic acid @ 2ml L^{-1} for two times.

4.6.7.3 Seed

Effect of foliar application of silicic acid and boric acid differed significantly among the varieties for Fe uptake by seed. Higher Fe uptake by seed was recorded in KBS-23 (384.89 g ha^{-1}) than MAUS-2 (323.79 g ha^{-1}).

Irrespective of the variety, treatments differed significantly for Fe uptake by seed, recording maximum Fe uptake by seed (439.94 g ha^{-1}) with the foliar application of silicic acid @ 2ml L^{-1} for three times and minimum with silicic acid application @ 2ml L^{-1} for two times (305.17 g ha^{-1}).

Perusal of data presented in Table 15, revealed that application of silicic acid significantly differed the Fe uptake by seed. Higher Fe uptake by seed (453.89 g ha^{-1}) was observed with foliar silicic acid application @ 4ml L^{-1} for three times in KBS-23 variety followed by treatment with foliar silicic acid application @ 2ml L^{-1} for three times in the same variety (448.06 g ha^{-1}). Lower Fe uptake by seed (234.04 g ha^{-1}) was observed in MAUS-2 variety with the foliar application of silicic acid application @ 4ml L^{-1} for two times.

4.6.8 Zinc uptake

Effect of foliar application of silicic acid and boric acid on Zn uptake by haulm, husk and seed are given in Table 15.

4.6.8.1 Haulm

Zinc uptake by haulm did not differ significantly with the foliar application of silicic acid among the varieties. In general, foliar application of silicic acid at 4ml L^{-1} for three times significantly increase the Zn uptake by haulm (116.67 g ha^{-1}), which was found to be on par with 2ml L^{-1} boric acid application (103.01 g ha^{-1}) and 2ml L^{-1} silicic acid application (99.70 g ha^{-1}) three times over control (68.87 g ha^{-1}). Among the varieties and treatments combination, foliar application of silicic acid @ 4ml L^{-1} for three times in MAUS-2 variety recorded higher (143.08 g ha^{-1}), which was found to be on par with foliar application of boric acid @ 2ml L^{-1} for three times (132.35 g ha^{-1}) in the same variety. Silicic acid application @ 4ml L^{-1} for two times in MAUS-2 variety recorded lower Zn uptake by haulm (51.64 g ha^{-1}).

4.6.8.2 Husk

No significant difference was observed for Zn uptake by husk among the varieties with the foliar application of silicic acid and boric acid. Application of silicic acid at different interval significantly increased the Zn uptake by husk, recording higher with foliar application of silicic acid @ 4ml L^{-1} for two times (61.05 g ha^{-1}), which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for three times (54.63 g ha^{-1}). Least Zn uptake by husk (35.41 g ha^{-1}) recorded in control.

Table 15. Effect of foliar application of silicic acid and boric acid on micronutrients uptake (g ha^{-1}) by two soybean

	Iron (g ha^{-1})			Zinc (g ha^{-1})			Mn (g ha^{-1})			Cu (g ha^{-1})		
	Haulm	**Husk**	**Seed**	**Haulm**	**Husk**	**Seed**	**Haulm**	**Husk**	**Seed**	**Haulm**	**Husk**	**Seed**
Varieties												
V1	414.04	248.91	323.79	96.78	55.88	125.84	143.97	66.37	58.36	15.99	24.84	46.73
V2	497.12	221.49	384.89	81.59	36.10	148.58	154.95	43.04	72.22	25.92	25.71	53.36
SEm±	9.28	3.76	9.24	3.68	3.36	1.70	9.50	5.54	2.68	0.33	1.29	1.31
C.D at 0.05	56.32	22.82	56.09	NS	NS	10.29	NS	NS	NS	2.03	NS	NS
Treatments												
T1	408.75	181.36	347.63	68.87	35.41	103.40	137.23	36.33	67.14	16.91	18.20	38.37
T2	406.55	222.88	305.17	76.01	38.67	126.57	125.29	50.24	60.48	15.34	19.44	42.89
T3	459.82	208.50	319.04	71.89	61.05	147.54	132.53	72.43	68.80	19.11	29.20	53.73
T4	589.57	279.51	439.94	99.70	54.63	172.90	189.62	54.02	75.16	25.47	28.89	63.00
T5	541.62	256.82	383.46	116.67	49.00	152.36	180.98	65.14	73.36	26.44	35.54	57.41
T6	408.55	326.52	357.81	103.01	46.19	123.60	138.87	63.00	57.26	19.83	24.36	47.89
T7	374.21	170.81	327.32	88.15	36.96	134.09	141.69	41.75	54.83	23.57	21.30	47.05
SEm±	14.66	10.65	14.90	6.81	3.64	7.78	10.45	5.44	5.56	1.74	2.07	2.54
C.D at 0.05	42.35	30.76	43.02	19.67	10.54	22.47	30.19	15.71	16.06	5.03	5.97	7.33
Interaction												
T1VI	287.85	159.99	365.09	69.32	45.20	99.45	108.93	39.88	79.06	11.61	17.40	37.15
T2V1	330.36	157.03	269.75	74.78	50.40	108.55	112.79	65.91	52.73	10.86	19.66	39.00
T3V1	352.64	236.22	234.04	51.64	70.60	113.44	98.37	82.63	47.12	11.39	28.37	39.57
T4V1	663.61	341.51	431.82	109.81	68.97	178.33	217.90	73.72	72.66	24.93	34.17	66.24
T5V1	485.94	299.89	313.03	143.08	57.44	133.87	171.32	75.94	52.12	20.91	25.62	53.34
T6V1	454.28	377.55	402.76	132.35	59.73	129.79	159.49	82.89	58.37	18.88	27.93	49.64
T7V1	323.59	170.16	250.02	96.50	38.79	117.46	138.97	43.62	46.44	13.33	20.74	42.20
T1V2	529.64	202.73	330.17	68.42	25.62	107.36	165.53	32.79	55.21	22.20	19.00	39.60
T2V2	482.74	288.73	340.59	77.23	26.93	144.59	137.79	34.58	68.22	19.82	19.22	46.78
T3V2	567.00	180.78	404.05	92.14	51.49	181.64	166.69	62.24	90.47	26.83	30.02	67.89
T4V2	515.53	217.50	448.06	89.58	40.29	167.47	161.34	34.32	77.65	26.01	23.60	59.75
T5V2	597.31	213.76	453.89	90.26	40.56	170.85	190.63	54.35	94.59	31.98	45.46	61.48
T6V2	362.83	275.49	312.86	73.66	32.66	117.41	118.25	43.11	56.15	20.79	20.79	46.13
T7V2	424.82	171.47	404.63	79.80	35.13	150.72	144.41	39.88	63.22	33.82	21.87	51.91
SEm±	20.73	15.06	21.07	9.63	5.15	11.00	14.78	7.69	7.86	2.46	2.92	3.59
C.D at 0.05	59.89	43.50	60.85	27.82	14.88	31.78	42.70	22.22	22.71	7.12	8.44	10.36

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

Varieties and treatment combinations differed significantly for Zn uptake by husk with the foliar application of silicic acid. Among the combinations, foliar silicic acid application @ 4ml L^{-1} for two times in MAUS-2 variety recorded higher Zn uptake by husk (70.60 g ha^{-1}) and lower was observed with water application in KBS-23 variety (25.62 g ha^{-1}).

4.6.8.3 Seed

Among the varieties, Zn uptake by seed differed significantly with the foliar application of silicic acid and boric acid. Higher Zn uptake by seed was observed in KBS-23 (148.58 g ha^{-1}) than MAUS-2 (125.84 g ha^{-1}).

Irrespective of the variety, foliar application of silicic acid significantly increased the Zn uptake by seed over control (103.40 g ha^{-1}). Maximum Zn uptake by seed (172.90 g ha^{-1}) was recorded with foliar silicic acid application @ 2ml L^{-1} for three times followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for three times (152.36 g ha^{-1}). Application of boric acid also enhanced the Zn uptake by seed over control.

Among different varieties and treatments combinations, application of foliar silicic acid differed significantly for the Zn uptake by seed. The Zn uptake by seed ranged from 99.45 to 181.64 g ha^{-1}, recording higher with the foliar application of silicic acid @ 4ml L^{-1} for two times in KBS-23 variety and lower in MAUS-2 variety with water spray.

4.6.9 Manganese uptake

The data pertaining to Mn uptake by haulm, husk and seed with the foliar application of silicic acid and boric acid are presented in Table 15.

4.6.9.1 Haulm

There was no significant difference was observed among the varieties for Mn uptake by haulm with the foliar application of silicic acid and boric acid. In general, foliar application of silicic acid significantly increased the Mn uptake by haulm. Higher Mn uptake by haulm (189.62 g ha^{-1}) was observed with foliar application of silicic acid

@ 2ml L^{-1} for three times, which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for three times (180.98 g ha^{-1}) and lower was recorded with foliar application of silicic acid @ 2ml L^{-1} for two times (125.29 g ha^{-1}).

Among different varieties and treatments combinations, application of silicic acid significantly enhanced the Mn uptake by haulm. The Mn uptake by haulm ranged from 98.37 to 217.90 g ha^{-1}. Higher Mn uptake was observed in MAUS-2 variety with the foliar application of silicic acid @ 2ml L^{-1} for three times, which was found to be on par with the foliar application of silicic acid @ 4ml L^{-1} for three times in KBS-23 variety (190.63 g ha^{-1}). Least was in MAUS-2 variety with foliar application of silicic acid @ 4ml L^{-1} for two times.

4.6.9.2 Husk

Manganese uptake by husk did not differ significantly among the varieties with the foliar application of silicic acid and boric acid. Irrespective of the varieties, application of silicic acid significantly increased the Mn uptake by husk. Higher Mn uptake by husk (72.43 g ha^{-1}) was recorded with foliar application of silicic acid @ 4ml L^{-1} for two times followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for three times (65.14 g ha^{-1}). Application of boric acid also increased the Mn uptake by haulm over control (36.33 g ha^{-1}).

Among the varieties and treatments combinations, Mn uptake by husk varied from 32.79 to 82.89 kg ha^{-1}, recording higher in MAUS-2 variety with foliar application of boric acid @ 2ml L^{-1} for three times, which was found to be on par with all treatments (except control) in MAUS-2 variety and 4ml L^{-1} silicic acid application for two times in KBS-23 variety. Lower was in KBS-23 variety with water application.

4.6.9.3 Seed

Manganese uptake by seed did not differ significantly with the foliar application of silicic acid and boric acid. Among the treatments, application of silicic acid increased Mn uptake by seeds, recording higher value (75.16 g ha^{-1}) with foliar application of silicic acid @ 2ml L^{-1} for three times. While foliar application of boric acid decreased Mn uptake by seed.

Among the different varieties and treatments combinations, maximum Mn uptake by seed (94.59 g ha^{-1}) was recorded in KBS-23 variety with the foliar application of silicic acid @ 4ml L^{-1} for three times followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for two times (90.47 g ha^{-1}) in the same variety. Minimum Mn uptake by seed (46.44 g ha^{-1}) was observed in MAUS-2 variety with the foliar boric acid application @ 4ml L^{-1} for three times.

4.6.10 Copper uptake

Data presented in Table 15, revealed the effect of foliar application of silicic acid and boric acid on Cu uptake by haulm, husk and seed.

4.6.10.1 Haulm

Haulm Cu uptake differed significantly with the foliar application of silicic acid and boric acid among the varieties. Higher Cu uptake was recorded in KBS-23 (25.92 g ha^{-1}) than MAUS-2 (15.99 g ha^{-1}).

Irrespective of the variety, application of foliar silicic acid significantly increased the Cu uptake by haulm. Higher Cu uptake by haulm (26.44 g ha^{-1}) was observed with foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with both foliar application of silicic acid @ 2ml L^{-1} for three times (25.47 g ha^{-1}) and boric acid application @ 4ml L^{-1} for three times (23.57 g ha^{-1}). Least Cu uptake by haulm (15.34 g ha^{-1}) was recorded with the foliar application of silicic acid @ 2ml L^{-1} for two times. Application of boric acid @ 4ml L^{-1} for three times enhanced the Cu uptake by haulm.

Effect of foliar application of silicic acid and boric acid differ significantly among the different varieties and treatments combinations. The Cu uptake by haulm ranged from 10.86 to 33.82 g ha^{-1}, recording higher in KBS-23 variety with foliar application of boric acid @ 4ml L^{-1} for three times and lower in KBS-23 variety with water spray.

4.6.10.2 Husk

There was no significant difference among the varieties for Cu uptake by husk with the foliar application of silicic acid and boric acid. Irrespective of variety, foliar application of silicic acid significantly increased the Cu uptake by husk. Higher Cu uptake by husk (35.54 g ha^{-1}) was recorded with foliar application of silicic acid @ 4ml L^{-1} for three times followed by treatment with foliar application of silicic acid @ 4ml L^{-1} for two times (29.20 g ha^{-1}) and least was observed in control (18.20 g ha^{-1}).

Among the different varieties and treatments combinations, application of foliar silicic acid differed significantly for Cu uptake by husk. Higher Cu uptake by husk (45.46 g ha^{-1}) was recorded in KBS-23 variety with foliar application of silicic acid @ 4ml L^{-1} for three times and lower in MAUS-2 variety with water spray (17.40 g ha^{-1}).

4.6.10.3 Seed

Copper uptake by seed did not differ significantly with the foliar application of silicic acid and boric acid between the varieties. In general, foliar application of silicic acid increased the Cu uptake by seed. Highest Cu uptake by seed (63.00 g ha^{-1}) was recorded with the foliar application of silicic acid @ 2ml L^{-1} for three times, which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for three times (57.41 g ha^{-1}) and least in control (38.37 g ha^{-1}).

Copper content in seed differed significantly among the varieties and treatments combinations with the foliar application of silicic acid. The Cu uptake by seed ranged from 37.15 to 67.89 g ha^{-1}. Higher Cu uptake was observed in KBS-23 with the foliar application of silicic acid @ 4ml L^{-1} for two times, which was found to be on par with foliar application of silicic acid @ 2ml L^{-1} for three times in MAUS-2 variety (66.24 g ha^{-1}) followed by foliar silicic acid application @ 2ml L^{-1} (59.75 g ha^{-1}) and 4ml L^{-1} (61.48 g ha^{-1}) for three times in KBS-23 variety. Lower Cu uptake by seed was recorded in MAUS-2 variety with water application.

4.7 Effect of foliar application of silicic acid and boric acid on the chemical properties of post-harvest soil

Effect of foliar application of silicic acid and boric acid on the chemical properties *viz*., pH, available phosphorus, available boron and available silicon content of post-harvest soil are presented in Table 16-17.

4.7.1 Soil pH

Effect of foliar application of silicic acid and boric acid on pH of post-harvest soil is presented in Table 16.

Though foliar application of silicic acid and boric acid had no significant effect on pH of post-harvest soil among the varieties and the treatments, combination of treatments had significant effect. The pH post-harvest soil ranged from 5.59 to 6.00 recording higher value both with foliar silicic acid application @ 2ml L^{-1} for two times and foliar silicic acid application @ 4ml L^{-1} for three times in MAUS-2 variety, which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for two applications in the same variety (5.89). Lower pH value was recorded in KBS-23 variety with foliar application of boric acid @ 4ml L^{-1} for three times

4.7.2 Available phosphorus (kg ha^{-1})

The data on effect of foliar application of silicic acid and boric acid on available P_2O_5 of post-harvest soil is presented in the Table 16.

Among the varieties, significant difference on available P_2O_5 content of post-harvest soil was observed with the application of foliar silicic acid, recording higher in KBS-23 (456.81 kg ha^{-1}) and lower in MAUS-2 (412.00 kg ha^{-1}).

Among the treatments, significantly higher available P_2O_5 content (466.28 kg ha^{-1}) of soil was observed in treatment receiving foliar application of silicic acid at 4ml L^{-1} for three times followed by treatment receiving foliar application of silicic acid @ 2ml L^{-1} for three times (452.75 kg ha^{-1}). Lower was observed in application silicic acid application 2ml L^{-1} for two times (410.24 kg ha^{-1}). Foliar application of boric acid also recorded lower P_2O_5 content compared to control.

Table 16. Effect of foliar application of silicic acid and boric acid on chemical properties of post-harvest soil

	pH	P_2O_5 (kg ha^{-1})	B (mg kg^{-1})
Varieties			
V1	5.86	412.00	1.44
V2	5.73	456.81	1.68
SEm±	0.04	1.57	0.02
C.D at 0.05	NS	9.51	NS
Treatments			
T1	5.69	448.78	1.61
T2	5.91	410.24	1.57
T3	5.85	430.69	1.54
T4	5.69	452.75	1.55
T5	5.90	466.28	1.57
T6	5.78	411.33	1.56
T7	5.73	420.76	1.52
SEm±	0.09	3.30	0.06
C.D at 0.05	NS	9.52	NS
Interaction			
T1VI	5.62	405.24	1.51
T2V1	6.00	387.16	1.47
T3V1	5.89	401.90	1.44
T4V1	5.76	455.64	1.42
T5V1	6.00	443.71	1.41
T6V1	5.85	381.25	1.43
T7V1	5.88	409.09	1.37
T1V2	5.76	492.31	1.70
T2V2	5.82	433.32	1.67
T3V2	5.81	459.48	1.64
T4V2	5.62	449.87	1.67
T5V2	5.80	488.85	1.72
T6V2	5.72	441.40	1.69
T7V2	5.59	432.43	1.66
SEm±	0.13	4.66	0.08
C.D at 0.05	0.37	13.46	0.24

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

Among different varieties and treatments combinations, higher available P_2O_5 content was observed in KBS-23 variety with water application (492.31 kg ha^{-1}), which was found to be on par with foliar application of silicic acid @ 4ml L^{-1} for three times (488.85 kg ha^{-1}) in the same variety. Least P_2O_5 content in soil was observed in MAUS-2 variety with boric acid application @ 2ml L^{-1} for three times (381.25 kg ha^{-1}).

4.7.3 Available boron (mg kg^{-1})

The data pertaining to the effect of foliar application of silicic acid and boric acid on the available boron in post-harvest soil is presented in the Table 16.

Though combination of varieties and treatments was found to be significant with the foliar application silicic acid on the available boron content in soil, no significant difference was observed for the varieties and the treatments. The available boron content ranged from 1.37 to 1.72 mg kg^{-1}. Maximum available boron was recorded in KBS-23 variety with foliar application of silicic acid @ 4ml L^{-1} for three times, which was found to be on par with water application in the same variety (1.70 mg kg^{-1}) and minimum in MAUS-2 variety with foliar application of boric acid @ 4ml L^{-1} for three times.

4.7.4 Available silicon (kg^{-1} ha^{-1})

The data pertaining to effect of foliar application of silicic acid and boric acid on available silicon in post-harvest soil is presented in Table 17.

4.1.4.1 Acetic acid silicon (AA Si)

No significant difference was observed for AA Si among the varieties and the treatments with the foliar application of silicic acid and boric acid.

Among different varieties and treatments combinations, maximum soil available AA Si was observed in MAUS-2 variety with the foliar application of silicic acid @ 2ml L^{-1} for two times (105.65 kg ha^{-1}). Least available AA Si was recorded in KBS-23 variety with foliar application of silicic acid application @ 4ml L^{-1} for three times (82.41 kg ha^{-1}).

Table 17. Effect of foliar application of silicic acid and boric acid on plant available Si ((kg ha^{-1}) of post-harvest soil

	AA Si (kg ha^{-1})	$CaCl_2$ Si (kg ha^{-1})
Varieties		
V1	97.25	76.69
V2	87.85	78.38
SEm±	5.63	1.24
C.D at 0.05	NS	NS
Treatments		
T1	92.69	74.50
T2	98.51	74.68
T3	96.02	82.81
T4	90.65	75.73
T5	92.19	78.59
T6	85.65	75.56
T7	92.14	80.86
SEm±	4.52	3.42
C.D at 0.05	NS	NS
Interaction		
T1VI	100.61	75.95
T2V1	105.65	74.42
T3V1	104.77	85.99
T4V1	91.05	70.49
T5V1	101.97	77.59
T6V1	86.34	77.41
T7V1	90.39	74.96
T1V2	84.77	73.04
T2V2	91.37	74.95
T3V2	87.27	79.63
T4V2	90.25	80.98
T5V2	82.41	79.59
T6V2	84.95	73.71
T7V2	93.89	86.77
SEm±	6.39	4.84
C.D at 0.05	18.44	13.31

V1 : MAUS-2 ; **V2** : KBS-23 ; **RDF** : Recommended dose of fertilizer ; **DAS** : Days after sowing ; **NS** : Non significant

T1 : RDF – Water spray (control)
T2 : RDF + Silicic acid @ 2ml L^{-1} at 21 and 36 DAS
T3 : RDF + Silicic acid @ 4ml L^{-1} at 21 and 36 DAS
T4 : RDF + Silicic acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T5 : RDF + Silicic acid @ 4ml L^{-1} at 21, 36 and 51 DAS
T6 : RDF + 0.8% Boric acid @ 2ml L^{-1} at 21, 36 and 51 DAS
T7 : RDF + 0.8% Boric acid @ 4ml L^{-1} at 21, 36 and 51 DAS

4.1.4.2 Calcium chloride silicon (CC Si)

No significant difference was observed for AA Si between the varieties and among the treatments with the foliar application of silicic acid and boric acid.   .

Combination of varieties and treatments differed significantly for available CC Si with the foliar application of silicic acid, recording maximum (86.77 kg ha^{-1}) in KBS-23 variety with the foliar application of boric acid @ 4ml L^{-1} for three times. Lower plant available CC Si (70.49 kg ha^{-1}) was recorded in MAUS-2 variety with the foliar application of silicic acid @ 2ml L^{-1} for three times.

Plate 4: Variations in different treatment with the application of silicon and boron

V DISCUSSION

The results of the investigation on "Effect of foliar silicic acid on growth, yield and nutrient uptake by soybean [*Glycine max* (L.)]" are discussed in this chapter under following headings.

5.1 Influence of foliar application of silicic acid on growth, yield and quality of soybean

5.2 Effect of foliar application on nutrient content and uptake by soybean

5.3 Effect of foliar application of silicic acid on chemical properties of post-harvest soil.

5.1 Influence of foliar application of silicic acid and boric acid on growth, yield and quality of soybean

5.1.1 Effect of foliar application of silicic acid and boric acid on growth parameters of soybean

Perusal of data presented in Table 5 - 6, revealed that there was a greater variation in the growth parameters of soybean with the application of foliar silicic acid and boric acid.

In general, application of 2ml L^{-1} and 4ml L^{-1} foliar silicic acid for three times significantly enhanced number of leaves $plant^{-1}$ and number of branches $plant^{-1}$ respectively at 60 DAS over control. Though varieties had no significant effect on plant height and chlorophyll content, soybean responded well for foliar silicic acid during early stages (30, 45 and 60 DAS). Improvement of growth parameters could be due to foliar available Si, which might have consequently increased the photosynthesis of plants. Inclusion of Si has widely been reported to increase the growth of many plant species. Lee *et al.* (2010) reported the application of Si as sodium metasilicate (Na_2SiO_3) to hydroponically grown soybean improved plant length and biomass. Similar results for crop growth was also noticed in rice (Nagula *et al*., 2016; Prakash *et al*., 2011), ragi (Sandhya, 2010), maize (Venkataraju, 2013) through foliar applied silicon and broad bean (Ghasemi *et al*., 2013) through soil Si application. Chlorophyll plays an important role in the photosynthesis and is responsible for light harvesting. Increase in chlorophyll content of soybean might be due to the application of foliar silicic acid, which improved net photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, and the contents of photosynthetic pigments. Addition of 0.5 mM of Si to the nutrient solution without iron, initially or continuously during the experiment, prevented the chlorophyll degradation of soybean (Gonzalo *et al*. 2013). Similar results were reported for chlorophyll content with the application of Si in different crops, such as strawberry (Wang *et al*., 1998), cucumber (Feng *et al*., 2010), wheat (Maghsoudi *et al*., 2015; Gong *et al*., 2005) sorghum (Yin *et al*., 2014) and potato (Pilon *et al*., 2013).

In the present study foliar application of silicic acid might have helped in alleviating plant disease, pest damage and various forms of environmental stress due to higher accumulation of Si in the plant tissues, which act as a physical barrier. Similar results were reported in soybean rust (Rodrigues *et al.,* 2009; Pereira *et al*. 2009), brown spot of rice (Rezende *et al*., 2009) rice blast (Buck *et al*., 2008) with the foliar application of KSi. Cruz *et al*. (2013) reported that increased Si concentration in leaf tissue of soybean plants grown in soil amended with calcium silicate contributed to reduce the Asian soybean rust (ASR) severity.

Overall improvement in growth parameters was observed in MAUS-2 variety than KBS-23 variety with the foliar application of silicic acid. The total amount of rainfall received during the cropping season was 27.60 mm than the actual rainfall of 135.55 mm. Although provided with protective irrigation, the crop affected during critical growth stages due to increased aerial temperature and humidity. The variety MAUS-2 being a long duration compared to KBS-23 variety responded well to foliar application of silicic acid. This might have attributed to prevention of membrane damage and increased leaf relative water content with the application of foliar silicic acid. Similar results noticed in sunflower (Gunes *et al*., 2008) and wheat (Gong *et al*. 2005; Tuna *et al*., 2008). However, there was a low performance with the foliar application of boric acid on growth parameters of soybean other than control.

5.1.2 Effect of foliar application of silicic acid and boric acid on yield attributes and yield of soybean

There was a significant effect of foliar application of silicic acid and boric acid on yield attributes and yield of soybean (Table 7-8).

Foliar application of silicic acid at three different intervals (21, 36 and 51 DAS) and at two levels (2ml L^{-1} and 4ml L^{-1}) significantly increased the number of pods $plant^{-1}$ and number of seeds $plant^{-1}$ over control. However, 100 seed weight had no significant effect with the foliar application of silicic acid. Though number of seeds pod^{-1} significantly increased with the foliar spray of boric acid @ 4ml L^{-1} for three times over boric acid spray @ 2ml L^{-1} for three times, no significant difference was observed among silicic acid and boric acid spray. In the present investigation, application of foliar silicic acid influenced the crop growth by providing Si directly to the foliage and enhanced the number of pod $plant^{-1}$, and thereby increased the seeds $plant^{-1}$. Among the varieties, KBS-23 responded well for foliar application of silicic acid on yield parameters. Irrespective of varieties, haulm yield increased significantly with the application of silicic acid @ 4ml L^{-1} for three times (Table 8, Fig. 2). While application of 2ml L^{-1} for three times of silicic acid enhanced the seed yield and pod yield over control. In the present investigation, there was no severe incidence of plant diseases or pests during the cropping season. One of the most important role of Si is to stimulate the plants defense abilities against abiotic and biotic stresses. Si deposited on the leaf tissue surface has been proposed to be responsible for the protective effect of silicon against biotic stress. The effect of foliar KSi in reducing diseases unquestionably contributes to increased yield (Rodrigues *et al.*, 2009). Similarly, beneficial effect of Si on soybean yield have been reported by Cruz *et al*. (2013); Lee *et al.* (2010) and in some of leguminous crops like cowpea (Nelwamondo and Dakora, 1999) through metasilicic acid application to hydroponically grown plants and in broad bean (Ghasemi *et al.*, 2013) through sodium silicate application to soil. However, there was a low performance with foliar spray of boric acid on yield of soybean over control.

In the present investigation, longer duration variety MAUS-2 performed better with foliar application of silicic acid @ 2ml L^{-1} for three times and shorter duration variety KBS-23 performed better with the foliar spray of silicic acid @ 4ml L^{-1} for two times with regard to yield parameters of soybean. In general, the yield and its attributes were higher in KBS-23 with foliar silicic acid than MAUS-2 variety, which might be due to efficient partitioning of photosynthates and better utilization of absorbed nutrients with the application of foliar silicic acid. Though varieties had no significant effect on harvest index with foliar application of silicic acid, significant increase was observed with the foliar spray of silicic acid @ 2ml L^{-1} for three times.

5.1.3 Effect of foliar application of silicic acid and boric acid on quality of soybean

Application of foliar silicic acid significantly enhanced the protein content, protein yield, oil content and oil yield of soybean in the present investigation. Among the different treatments, foliar application of silicic acid @ 4ml L^{-1} for three times significantly increased the protein content over both water spray and foliar application of boric acid @ 2ml L^{-1} and 4ml L^{-1} for three times (Fig. 3). Application of silicic acid at higher concentration might have involved in the biosynthesis of cell wall components there by enhanced the protein content of soybean. Higher protein yield was observed in treatment with the foliar application of silicic acid @ 2ml L^{-1} three times (Fig.4) over control, which can be attributed to higher seed yield recorded in the same treatment. In that context, Schwarz, (1973) reported that Si influences cell wall components, such as pectic acid and protein. Similarly, increase in protein content was also noticed in wheat (Gong *et al*., 2005) with the application of sodium silicate and in paddy (Ahmad *et al*., 2013) with foliar application of silicon aqueous solution.

Oil content and oil yield significantly differed with the foliar application of silicic acid. Irrespective of the variety, maximum oil content (Fig.5) was recorded with foliar application of boric acid (2ml L^{-1} or 3ml L^{-1} for three times), and the oil yield was higher with the foliar application of silicic acid @ 2ml L^{-1} three times in MAUS-2 and 4ml L^{-1} for two times in KBS-23 compared to other treatments (Fig.6). This may be due to higher seed yield recorded in the present investigation with the application of silicic acid @ 2ml

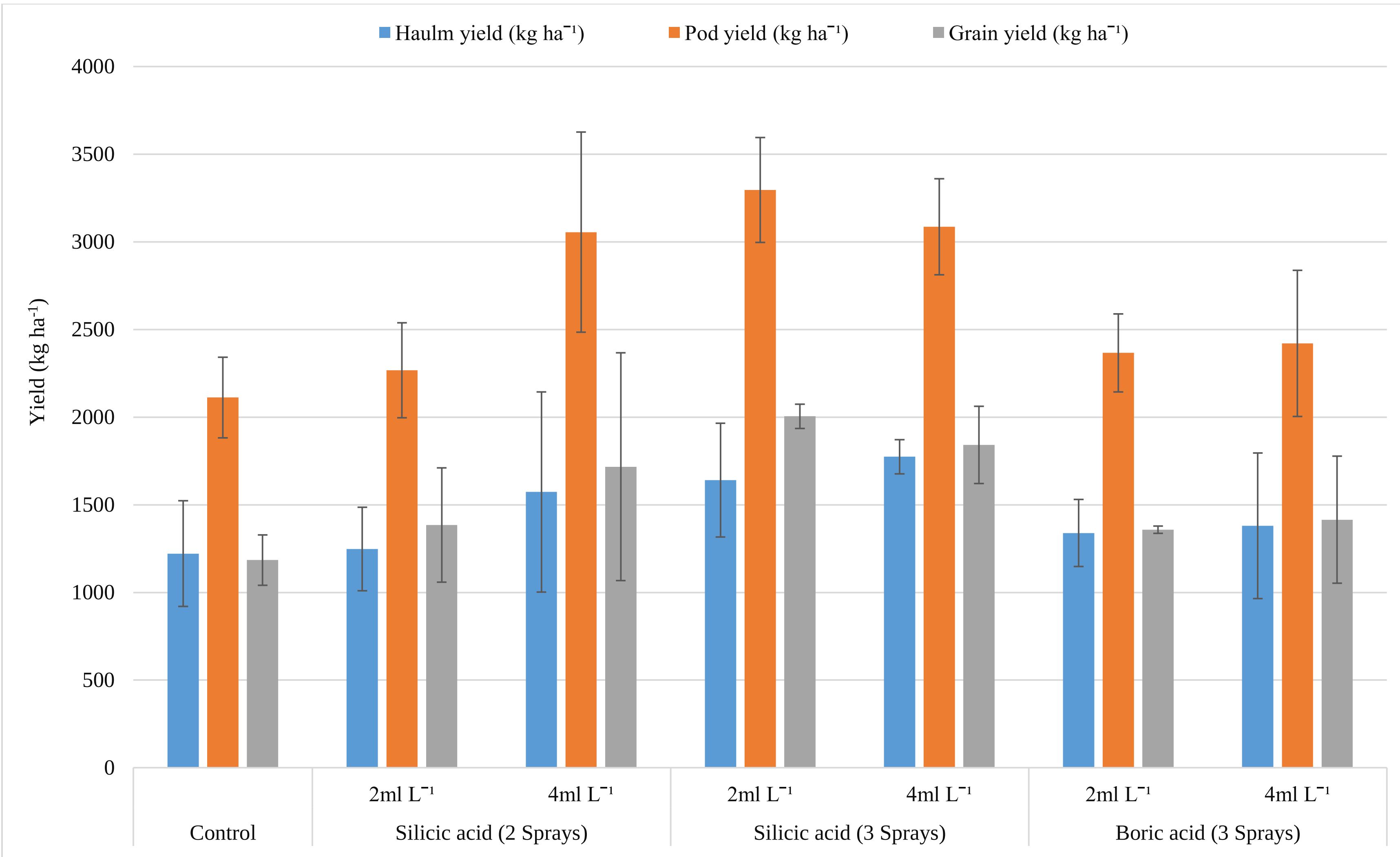

Fig. 2. Effect foliar silicic acid and boric acid on yield (kg ha^{-1}) of soybean

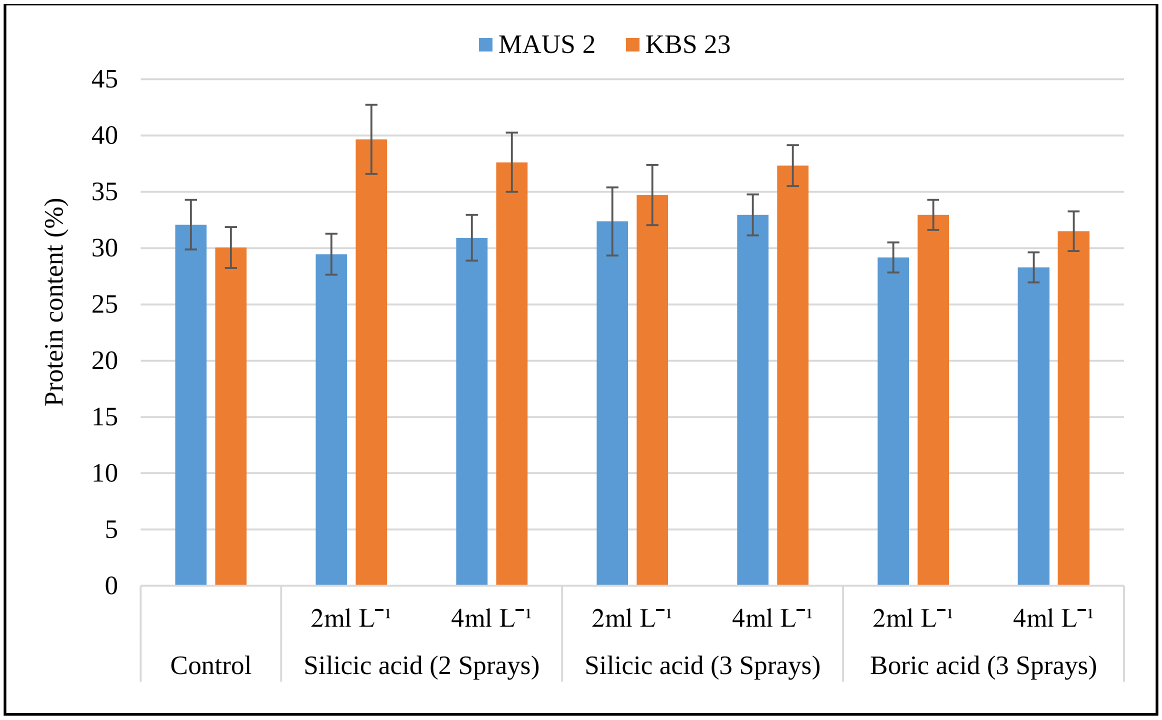

Fig. 3. Effect of foliar silicic acid and boric acid on protein content (%) of soybean

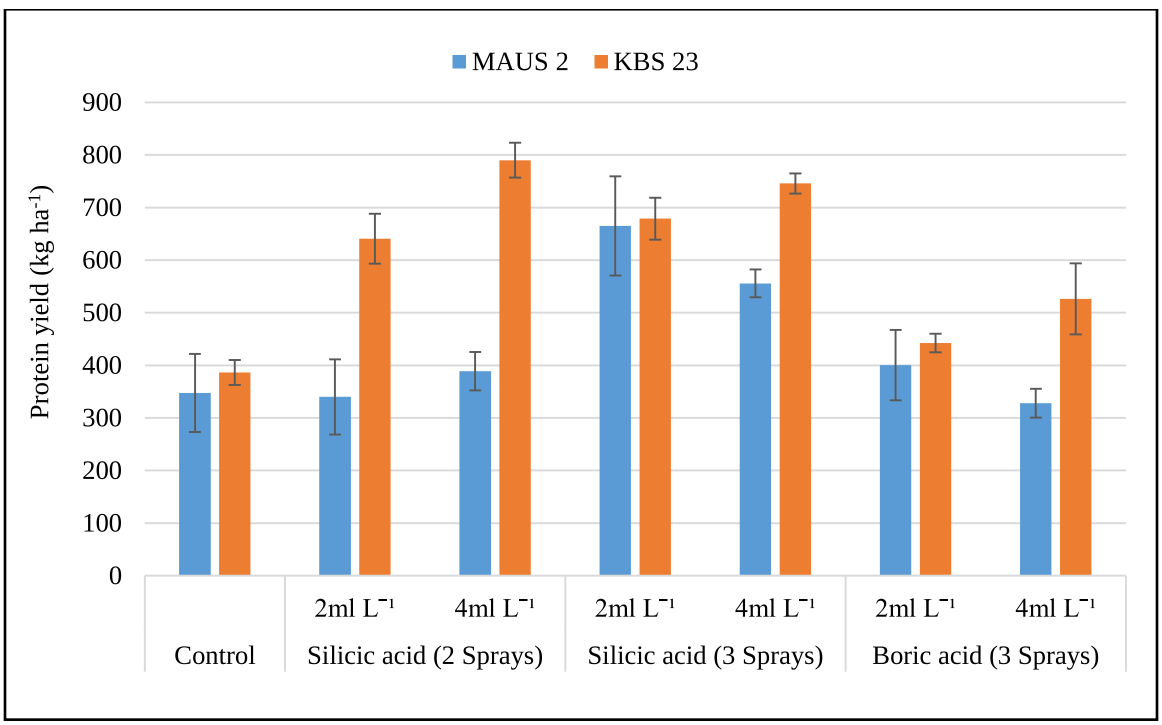

Fig. 4. Effect of foliar silicic acid and boric acid on protein yield (kg ha^{-1}) of soybean

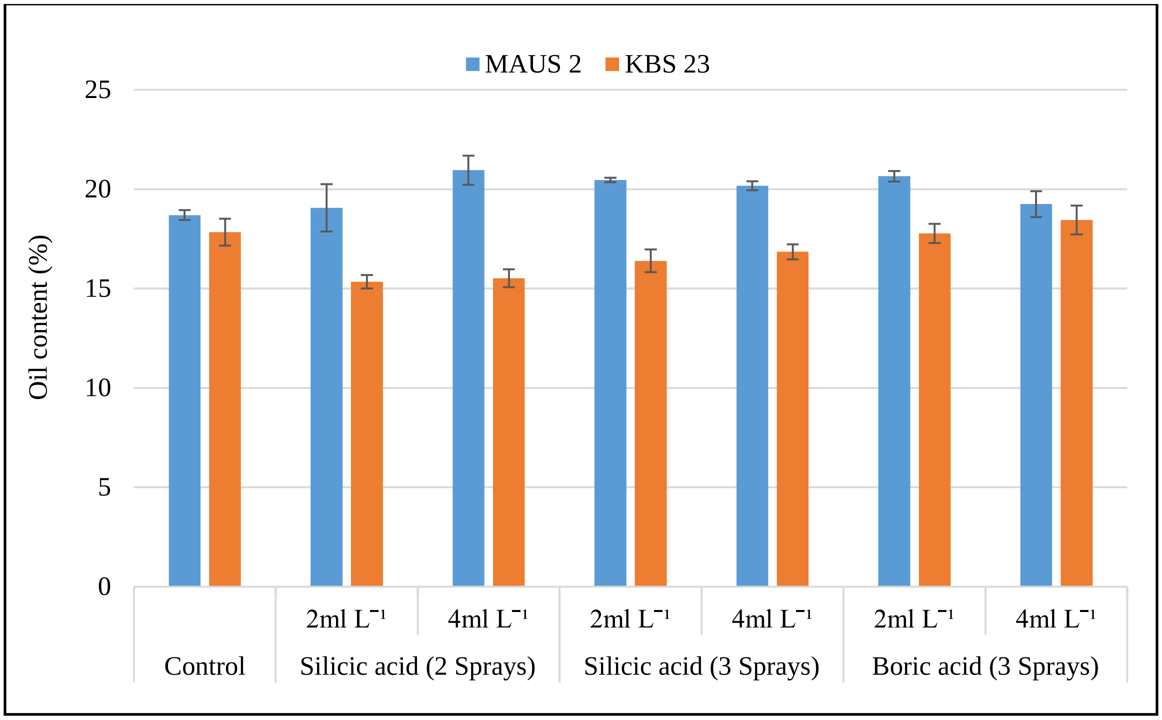

Fig. 5. Effect of foliar silicic acid and boric acid on oil content (%) of soybean

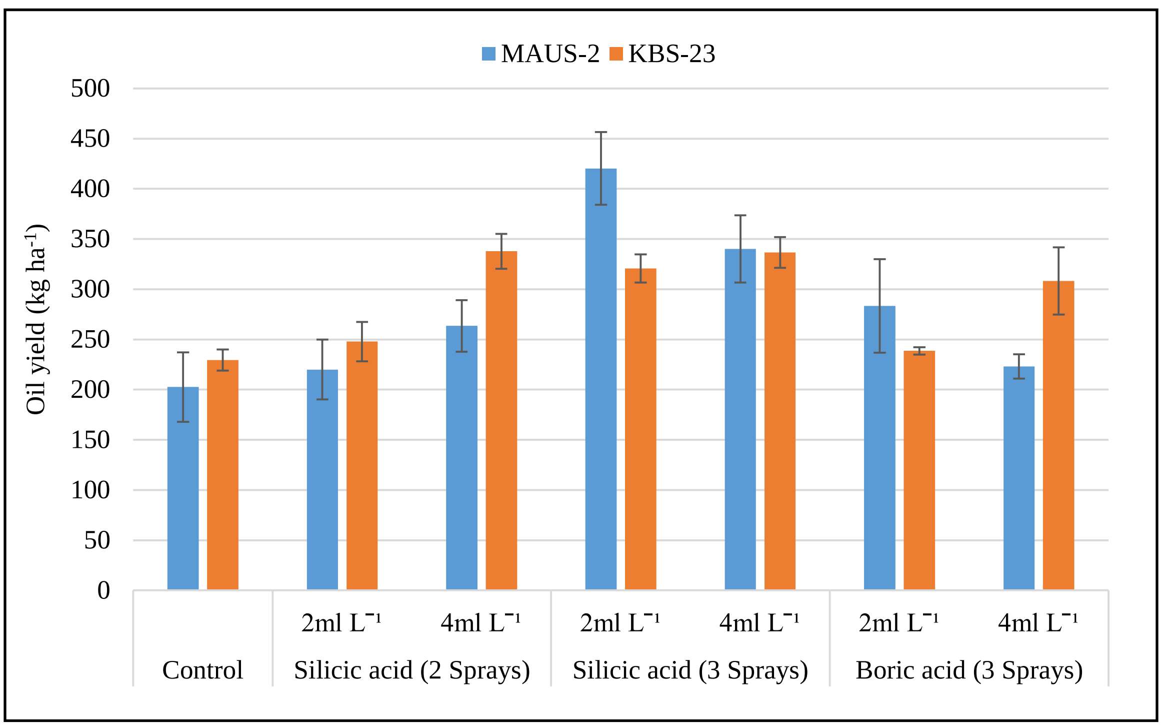

Fig. 6. Effect of foliar silicic acid and boric acid on oil yield (kg ha^{-1}) of soybean

L^{-1} for three times in MAUS-2 and 4ml L^{-1} for two times in KBS-23. Foliar application of boric acid might have enhanced the nucleic acid metabolism in plants, which resulted in higher oil content in seeds. Among the varieties, higher oil content and oil yield was recorded in MAUS-2 and KBS-23 respectively, whereas KBS-23 recorded significantly higher protein content and protein yield than MAUS-2. Though, significant difference was noticed in oil content among the varieties, the oil yield due to application of foliar silicic acid and boric acid was found non-significant. Data pertaining to beneficial effects of foliar applied silicon on oil content is limited and its mode of action is still unknown.

5.2 Effect of foliar application silicic acid and boric acid on nutrient content and uptake by soybean

5.2.1 Silicon content and its uptake

There was a greater variation in silicon content among the various plant parts of soybean with the application of silicic acid and boric acid (Table 9 & Fig. 7 - 9). The highest silicon content was noticed in haulm (0.42-0.92 %) followed by husk (0.11-0.16 %) and seed (0.06 to 0.15 %). Among the treatments, higher silicon content in haulm (0.92 %) and seed (0.15 %) was observed in treatment with foliar application of silicic acid @ 4ml L^{-1} for two times and 2ml L^{-1} for two times, respectively over other treatments. Though husk Si content among the varieties had no significant effect with the foliar application of silicic acid, higher Si content in haulm and seed was observed in MAUS-2 than KBS-23. This might be due to longer duration of MAUS-2, which responded better for absorption and accumulation of foliar applied Si than shorter duration variety (KBS-23). Accumulation of Si content varied greatly between species, ranging from 0.1 per cent to 10 per cent on dry weight basis (Ma and Takahashi, 2002). Among the higher plants, only species from Graminaceae and Cyperaceae families are known to be Si-accumulators (Takahashi *et al*., 1990). Little information is available in the literature about Si-transport properties in dicots including soybean.

There was a significant increase in silicon uptake in all parts of soybean among the different varieties (Table 9) with the application of silicic acid compared to other treatments. The uptake of Si in haulm, husk and seed ranged from 5.12 to 15.72 kg ha^{-1}, 0.88-2.25 kg ha^{-1} and 0.77-2.31 kg ha^{-1} respectively. Irrespective of the varieties, treatment with foliar silicic acid application increased the Si uptake in haulm followed by husk and seed. Higher Si uptake by haulm was recorded in MAUS-2 than KBS-23. However, no significant difference was observed for Si uptake by husk and seed among the varieties. Similar results were noticed for increased Si content in ragi (Sandhya, 2010) and rice (Prakash *et al*., 2011) with the foliar application of silicic acid and rice (Nagula *et al.,* 2016) with the application of potassium silicate. Similar results were also noticed for soybean plants grown in soil amended with calcium silicate as Si source (Cruz *et al*., 2013).

The occurrence of Si within the plants is a result of its uptake, in the form of soluble $Si(OH)_4$ or $Si(OH)_3O^-$ and its complete polymerization at final location. Silicon applied to leaves may deposit on the surface of leaves and play a similar role to that of Si taken up from the roots.

5.2.2 Nitrogen content and its uptake

Application of foliar silicic acid and boric acid influenced significantly on nitrogen content of soybean seed (Table 12).

Irrespective of the varieties, foliar application of silicic acid significantly increased the N content in seed of soybean. Application of silicic acid @ 4ml L^{-1} for three times recorded higher N content in seed over both control and foliar spray of boric acid @ 2ml L^{-1} and 4ml L^{-1} for three times. Foliar application of silicic acid @ 2ml L^{-1} for three times increased the N uptake by seed over control. Miyake and Takahashi (1985) reported that N content of leaves, stems and roots of soybean was consistently higher when Si was provided. Foliar application of silicic acid at 2ml L^{-1} for three times significantly increased the N uptake by seed over control. In general, higher N content and uptake was recorded in KBS-23 variety than MAUS-2 variety (Table 13). Li *et al*. (1999) reported that Si application greatly increased the concentration of N and P in corn plants. Savant *et al*. (1997) noticed a positive interaction between Si and N in rice for higher per cent Si and its uptake in straw as well as grain yield. Application of only boric acid at both the levels recorded lower seed yield in the present investigation. The lower

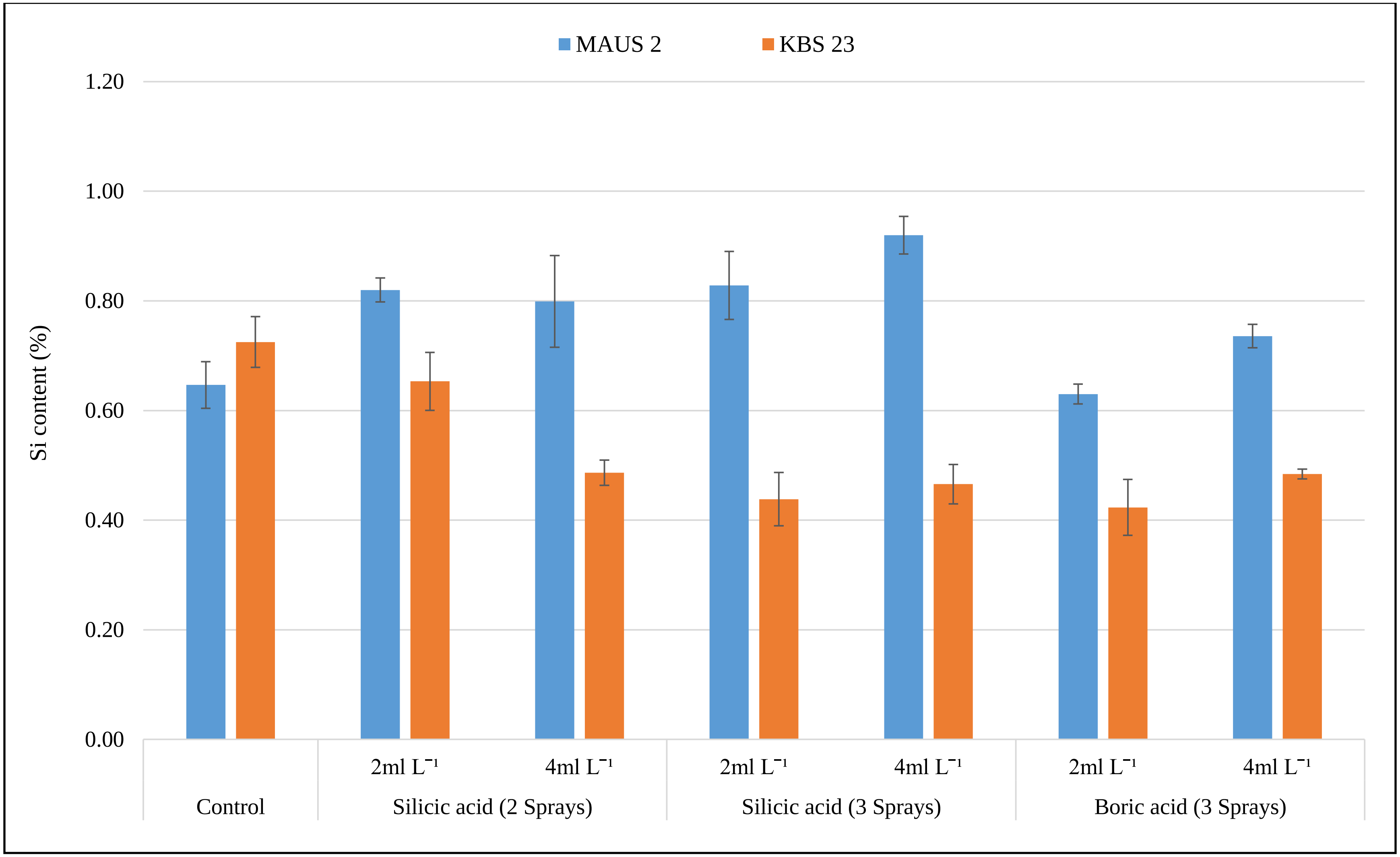

Fig. 7. Effect of foliar silicic acid and boric acid on Si content (%) in haulm of soybean

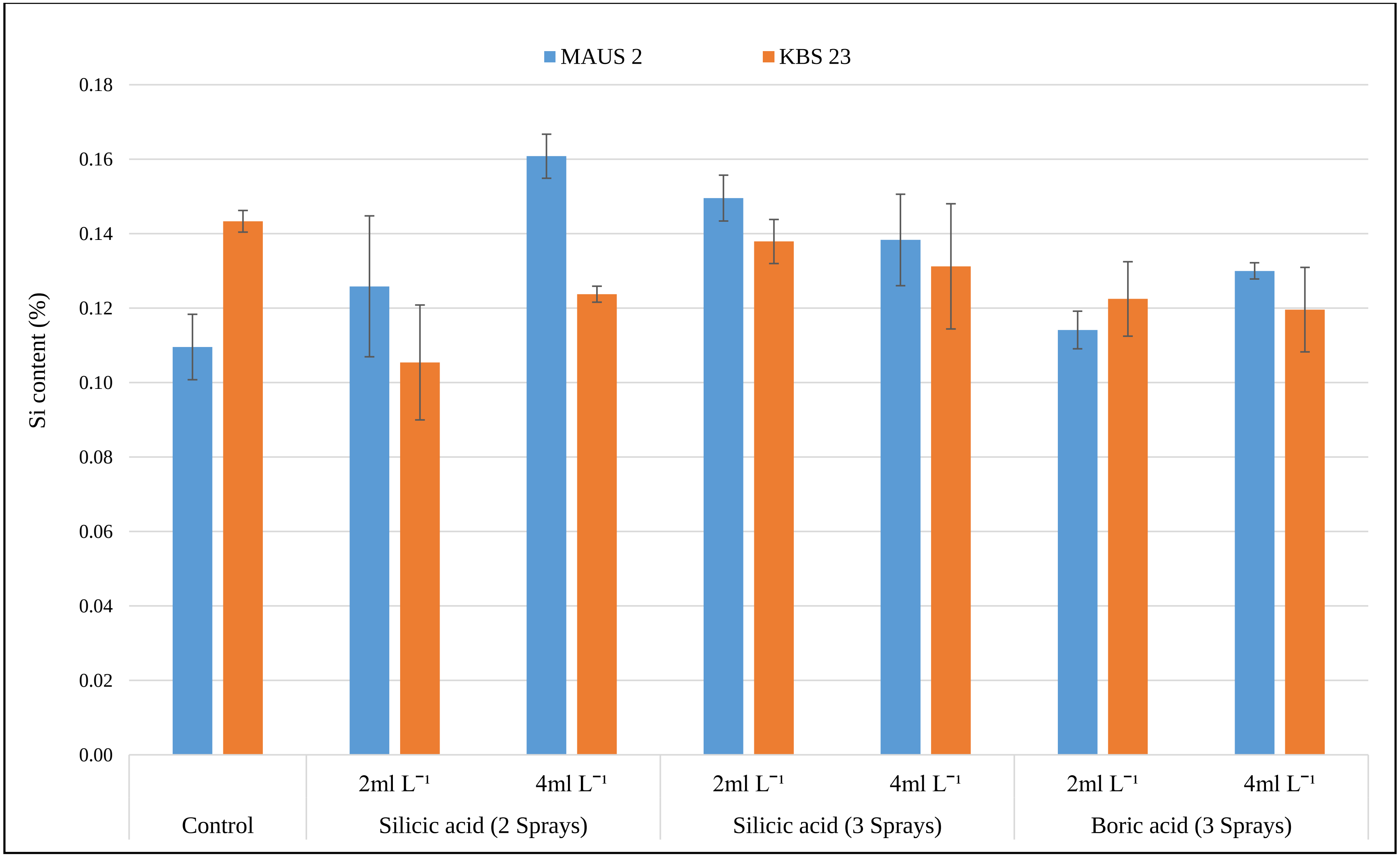

Fig. 8. Effect of foliar silicic acid and boric acid on Si content (%) in husk of soybean

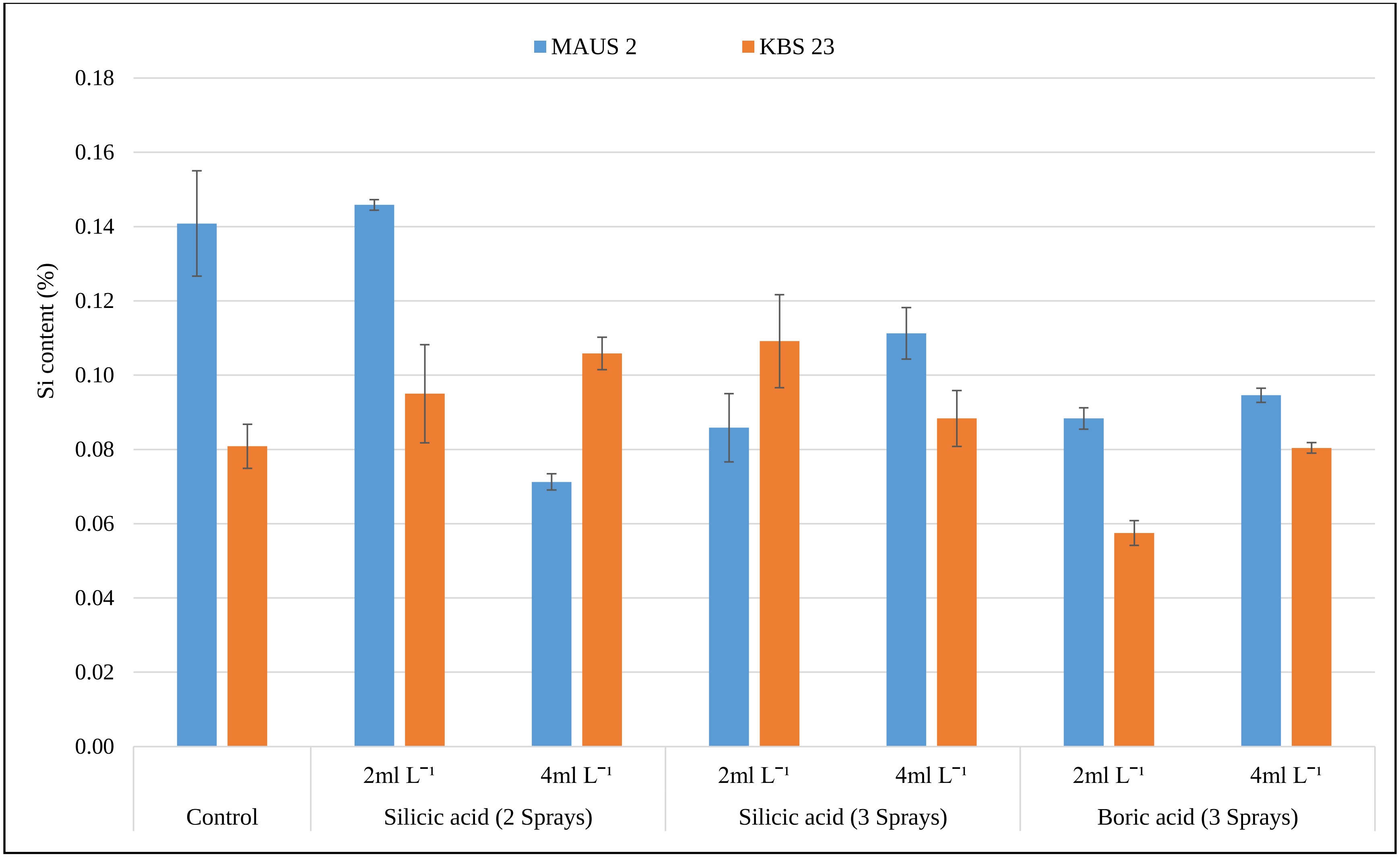

Fig. 9. Effect of foliar silicic acid and boric acid on Si content (%) in seed of soybean

uptake of N by seed with the foliar application of boric acid may be attributed to lower seed yield and lower N content of seeds.

5.2.3 Phosphorus content and its uptake

Perusal of data presented in Table 10, revealed that irrespective of the varieties (MAUS-2 and KBS-23), foliar application of silicic acid @ 4ml L^{-1} for two or three times significantly decreased the P content in haulm. However, foliar application of silicic acid @ 4ml L^{-1} either two or three times significantly increased the P content in husk compared to foliar application of silicic acid @ 2ml L^{-1}. However, there was no significant difference in P content in seed with the foliar application of silicic acid at different rates and intervals among both the varieties. Though no significant difference was observed for the P content and uptake among varieties by haulm, husk and seed, application of foliar silicic acid both @ 2ml L^{-1} and 4ml L^{-1} three times and two times respectively, enhanced the P uptake by haulm over control (Table 13). Application of foliar silicic acid @ 4ml L^{-1} for both two and three times recorded higher P uptake by husk and seed with foliar application of silicic acid @ 2ml L^{-1} for three times. In general, higher P uptake was observed in seed followed by haulm and husk. Increased concentration of Si might have reduced the P concentration in haulm and husk of soybean similar to that noticed in rice (Ma and Takahashi, 1989; Guo *et al*., 2005). Although foliar application of boric acid recorded higher P content in husk and seed compared to other treatments, there was no significant difference among the rates of application. The decrease in P content in haulm and seed of soybean with the foliar application of silicic acid may be attributed to dilution effect as noticed in rice (Snyder *et al*., 1986; Yogendra *et al*., 2014; Nagula *et al.,* 2016) and other crops with silicon application over control.

Ma and Takahashi (1990) conducted a pot experiment to measure the effect of silicon on P uptake and on growth of rice at different P levels. They opined that addition of Si raised the optimum P level in rice. Zhang *et al*. (1996) noticed increase in uptake of NPK by rice with the application of calcium silicate to soil.

5.2.4 Potassium content and its uptake

The results presented in Table 10, revealed that there was decrease in K content of haulm and seed of soybean with the foliar application of silicic acid while, increased the K content in husk. Though varieties had no significant effect on K content in haulm, higher content was recorded in MAUS-2 variety than KBS-23 variety. Application of silicic acid increased K uptake by haulm, husk and seed over control. In general, higher K uptake (Table 13) was observed in seed followed by husk and haulm. It has been reported that most of the absorbed K accumulates in shoot and a little portion is transferred to rice grains (Fageria *et al*., 2011). Increase in K content and uptake by seed in the present investigation may be attributed to presence of 1.2 % K as KCl in silicic acid. No significant difference was observed for K content in haulm, husk and seed and uptake in haulm and husk with water spray and application of foliar boric acid @ 2ml L^{-1} and 4ml L^{-1} for three times.. Similar to P, decrease in K content in haulm and seed with the foliar application of silicic acid may be due to dilution effect as noticed in rice (Snyder *et al*., 1986; Yogendra *et al*., 2014; Nagula *et al.*, 2016) and other crops. In an investigation to know the effect of Si on the growth and ions uptake (K, Na, Ca, and Mg) in rice, bean and barley plants grown in saline conditions, Sopandie *et al*. (1995) reported that addition of Si had no effect on the content of K in all plants tested.

5.2.5 Calcium content and its uptake

The perusal of data presented in Table 11, revealed that application of silicic acid decreased the Ca content in haulm and husk. No significant differences were noticed for Ca content in seed. Haulm recorded higher content of Ca than husk and seed. Application of silicic acid @ 4ml L^{-1} for three times recorded higher Ca uptake (Table 14) in haulm. Whereas, higher Ca uptake by husk and seed were noticed with the application of silicic acid @ 2ml L^{-1} for three times. Among the varieties, there was no significant difference for Ca uptake by haulm. However, MAUS-2 variety recorded significantly higher Ca uptake in husk and seed. Similar results were also observed with the application of Si on Ca uptake in rice, bean and barley plants grown in saline conditions (Sopandie *et al*., 1995). Except for rice, Si had no or less effect on Ca uptake in bean and barley plants.

5.2.6 Magnesium content and its uptake

Though foliar application of silicic acid had no significant difference on Mg content in haulm and husk, foliar application of silicic acid @ 2ml L^{-1} for two times and 4ml L^{-1} for three times decreased the content in seed. In general, higher Mg content was observed in MAUS-2 variety than KBS-23 variety. Highest Mg uptake in haulm, husk and seed was observed with the foliar spray of silicic acid @ 4ml L^{-1} for two times, 2ml L^{-1} for two times and 4ml L^{-1} for three times, respectively. Irrespective of the treatments, maximum Mg uptake by haulm and seed was observed in KBS-23 variety. Similar to P, K and Ca decrease in Mg content with the foliar application of silicic acid may be due to dilution effect as noticed in rice (Snyder *et al*., 1986; Yogendra *et al*., 2014; Nagula *et al.*, 2016) and other crops. In an investigation to know the effect of Si on the growth and ions uptake (K, Na, Ca, and Mg) in rice, bean and barley plants grown in saline conditions, Sopandie *et al*. (1995) reported that except for rice, Si had no or less effect on Ca and Mg uptake in bean and barley plants. Similarly, He and Wang (1999) reported that application of silicon fertilizer could enhance the uptake of N, P, K, Ca and Mg in wheat.

5.2.5 Sulphur content and its uptake

Application of silicic acid and boric acid significantly increased the S content and uptake in soybean plant, recording higher in seed followed by haulm and husk. Application of foliar silicic acid @ 2ml L^{-1} and 4ml L^{-1} for three times increased the S uptake by seed and haulm respectively. Though foliar Si enhanced the S uptake by husk, higher uptake was observed with the foliar spray of boric acid @ 4ml L^{-1} for three times over control. Application of boric acid @ 2ml L^{-1} and 4ml L^{-1} for three different intervals also enhanced the S uptake over control. Similarly, Venkataraju, (2013) reported that the application of foliar silicic acid enhanced the S uptake by maize.

Sulphur is constituent of S containing amino acids and plays a major role in oil seed crops by synthesizing fatty acids, increasing oil quality. Application of silicic acid and boric acid might have increased the content and uptake of S by soybean.

5.2.5 Micronutrients and its uptake

The data presented in Table 12 revealed that, irrespective of the varieties, application of foliar silicic acid decreased the Fe content in haulm and seed except husk. Similar results were also noticed with the application of boric acid. However, application of silicic acid increased the Fe uptake by haulm, husk and seed. Increased Zn content in haulm was observed with the foliar application of silicic acid and the uptake was recorded to be higher in seed followed by haulm and husk. Decrease in Mn content of haulm and seed was observed with foliar application of silicic acid. However, application of silicic acid increased the uptake of Mn by soybean plant parts recording higher in haulm and seed followed by husk. Foliar application of silicic acid as well as boric acid increased the Cu content in haulm and husk over control and had no difference on Cu content in seed with the foliar application of silicic acid. Increase in Cu uptake was observed with the foliar silicic acid application in seed followed by husk and haulm (Table 15).

Decrease in Mn content with the addition of calcium silicate was noticed in pigeonpea (Owino-Gerroh *et al*., 2005). Addition of Si decreased the concentration of Mn in apoplast of cowpea (Iwasaki *et al*., 2002). Similarly, foliar application of potassium silicate decreased the Fe and Mn content in straw and grain of rice (Nagula *et al*., 2016). Hai-Hong *et al*. (2012) noticed a significant increase in Zn concentration in shoots with the application of 0.5 mM Si to rice. Gonzalo *et al*. (2013) reported that the addition of 0.5 mM of Si to the nutrient solution without iron, maintained the Fe content in leaves. Decrease in micronutrient content might be due to reduced absorption and this coupled with the dilution effect attributed to high dry matter production. However, uptake of these micronutrient were higher in haulm, husk as well as seed of soybean with the foliar application of silicic acid over control.

5.3 Effect of foliar application of silicic acid and boric acid on chemical properties of soil

The perusal of data presented in Table 16, revealed that no significant differences was observed among treatments with the foliar application of silicic acid and boric acid on pH and boron content in post-harvest soil. Application of silicic acid at higher concentration significantly increased the available P_2O_5 content. Available P_2O_5 content was higher with the foliar application of silicic acid @ 4mlL^{-1} three times compared to other treatments. Although, Owino-Gerroh and Gascho (2004) reported the application of soluble silicon in acid soil could decrease adsorption of P in soils and increase the amount of bio available phosphorus, but mechanism involved with foliar application of silicic acid on available P_2O_5 content in soil has never been studied in the past.

In general, plant available Si content as extracted by $CaCl_2$ (CC Si) and acetic acid (AA Si) of post-harvest soils with the application of foliar silicic acid on soybean increased in all treatments compared to initial soil (Table 17). During the cropping period soil pH was slightly increased, which may be attributed to higher dissolution of soil Si and thereby higher plant available Si. Korndorfer *et al*. (2005) reported that slightly higher soil pH promotes the transformation of polysilicic acid into monosilicic acid. Oliveira *et al*. (2005) recorded similar results in sandy soil cultivated with dry land rice and indicated that with increase in soil pH from 4.5 to 6, there was a linear increase in available silicon.

Future line of work:

The study supports the potential role of Si in crops production of soybean. Further studies are needed to

- know the effect of silicic acid for disease resistance in soybean and other leguminous crops
- There is a need to study the performance of soybean for silicic acid application under drought condition.

VI SUMMARY

In the present study entitled "Effect of foliar silicic acid on growth, yield and nutrient uptake by soybean [*Glycine max* (L.)]", effect on growth, yield, quality and nutrient uptake by soybean was explored.

The field experiment consisted of two levels of Si application as silicic acid and B application as boric acid (2ml L^{-1} and 4ml L^{-1}) at three intervals (21, 36 and/or 51 DAS) on two varieties of soybean (MAUS-2 and KBS-23). Different growth and yield parameters were recorded. Nutrient content and uptake by soybean and other quality parameters were assessed. The salient findings of this study are summarized here.

Effect of silicic acid on growth and yield of soybean.

- ✓ Foliar application of silicic acid @ 2ml L^{-1} for three times significantly increased the plant height, number of leaves plant^{-1}, pod yield and seed yield.
- ✓ Silicic acid application @ 4ml L^{-1} for three times significantly increased number of branches plant^{-1}, number of pods plant^{-1}, number of seeds plant^{-1} and haulm yield over other treatments.
- ✓ Enhancement in growth of soybean was observed with the application of silicic acid during early growth stages.
- ✓ Silicic acid application in shorter duration KBS-23 enhanced the yield attributes like haulm, pod and seed yield.
- ✓ Boric acid treatment also enhanced the growth and yield of soybean over control.
- ✓ Foliar application of silicic acid @ 2ml L^{-1} for three times responded better in longer duration variety, MAUS-2.
- ✓ In shorter duration variety KBS-23 was found to respond better with two time application of silicic acid @ 4ml L^{-1}.

Effect of silicic acid on nutrient content and uptake by soybean.

- ✓ There was a greater variation in Si content among different parts of soybean. The Si content ranged between 0.06 to 0.92 per cent in soybean.
- ✓ The highest Si content was found in haulm (0.42-0.92 %) followed by husk (0.11-0.16 %) and seed (0.06 to 0.15 %).
- ✓ Higher Si content in haulm (0.92 %) and seed (0.15 %) was observed in treatment with foliar application of silicic acid @ 4ml L^{-1} three times and 2ml L^{-1} for two times, respectively over other treatments.
- ✓ The uptake of Si by haulm, husk and seed ranged from 5.12 to 15.72 kg ha^{-1}, 0.88-2.25 kg ha^{-1} and 0.77-2.31 kg ha^{-1} respectively.
- ✓ Foliar application of silicic acid @ 4ml L^{-1} and 2ml L^{-1} for three times recorded higher N content and uptake in seed over control. Overall, higher N uptake was recorded in MAUS-2 variety than KBS-23 variety.
- ✓ Silicic acid application @ 4ml L^{-1} for two or three times significantly decreased the P content in haulm but increased the P content in husk. In general, higher P uptake was observed in seed followed by haulm and husk with the application of silicic acid.
- ✓ Silicic acid was found to decrease K content in haulm and seed but increase K content in husks. Foliar application of silicic acid increased the K uptake in seed followed by husk and haulm.
- ✓ Application of silicic acid decreased the Ca content in haulm and husk and seed. Silicic acid applied @ 4ml L^{-1} three times recorded higher Ca uptake in haulm, followed by silicic acid applied @ 2ml L^{-1} for three times in husk and seed .
- ✓ Silicic acid application had no effect on Mg in soybean. However, an increased in Mg content in seed was found with application of boric acid @ 4ml L^{-1} for three times. Higher Mg uptake in haulm was observed with the foliar application of silicic acid @ 4ml L^{-1} two times. In husk and seed silicic acid applied @ 2ml L^{-1} and 4ml L^{-1} for three times, respectively recorded higher Mg uptake.

- ✓ Silicic acid and boric acid application significantly increased the S content and uptake in seeds followed by haulm and husk. Application of silicic acid @ 4ml L^{-1} and 2ml L^{-1} three times increased the S uptake by haulm and seed of soybean respectively.
- ✓ Silicic acid application was found to increase Zn and Cu content and decrease Fe and Mn content in haulm. Whereas, Fe, Mn and Cu content of husk was found to increase with silicic acid application, but reduced the Fe and Mn content seed. Zinc and Cu content in seed did not differ significantly.

Effect of silicic acid on protein and oil content of soybean.

- ✓ Application of foliar silicic acid significantly enhanced the protein and oil content of soybean.
- ✓ Foliar application of silicic acid @ 4ml L^{-1} three times significantly increased the protein content. Higher protein yield observed in treatment with the foliar application of silicic acid 2ml L^{-1} three times.
- ✓ Maximum oil content recorded with foliar application of boric acid.
- ✓ Higher oil yield was with the foliar application of silicic acid at 2ml L^{-1} three times.
- ✓ Higher oil content recorded in MAUS-2 variety. Whereas, higher protein content was recorded in KBS-23 variety.

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