# BORON NUTRITION
# OF WET LAND RICE (*Oryza sativa* L.)

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**(2014-11-153)**

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**

**COLLEGE OF AGRICULTURE**

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**KERALA, INDIA**

**2016**

# BORON NUTRITION
# OF WET LAND RICE (*Oryza sativa* L.)

*by*

**RESHMA REMESH**

**(2014-11-153)**

**THESIS**

**Submitted in partial fulfilment of the**

**requirement for the degree of**

## MASTER OF SCIENCE IN AGRICULTURE

**Faculty of Agriculture**

**Kerala Agricultural University**

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**

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**KERALA, INDIA**

**2016**

# DECLARATION

I, hereby declare that this thesis entitled **“BORON NUTRITION OF WET LAND RICE (*Oryza sativa* L.)”** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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# CERTIFICATE

Certified that this thesis entitled **"BORON NUTRITION OF WET LAND RICE (*Oryza sativa* L.)"** is a record of research work done independently by Ms. Reshma Remesh under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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# ACKNOWLEDGEMENT

*I would like to use this opportunity to express my sincere gratitude to several people and organizations without whose support, implementation of this research work would not have been possible.*

*Prima facie, I am grateful to* **God, the Almighty** *for the unbound blessings which is the prime factor that led to the successful completion of this research work.*

*With immense pleasure I avail this opportunity to express my deep sense of gratitude and indebtness to my major advisor* **Dr. B. Rani***, Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for her expert guidance, practical suggestions, support, patience, affection, encouragement and above all, the extreme patience in understanding and wholehearted co-operation rendered throughout the course of this work and for the critical scrutiny of the manuscript. This work would not have been complete without her valuable help and support. So I express my sincere gratitude to my lord Shiva for giving me such a supportive guide.*

*I would express my sincere gratitude to* **Dr. Sumam George***, Professor and Head, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for her continuous and timely advice, constructive criticisms and guidance at all stages of research work.*

*I extend my profound gratitude to* **Dr. Usha Mathew***, Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani for her valuable suggestions and critical evaluation that greatly assisted the successful conduct of this research work.*

*I place on record my sincere thanks to* **Dr. Jacob John,** *Professor & Head, Cropping Systems Research Centre, Karamana, for his affection, guidance, mental* *support, kindness, care and help. Formally I am thankful to him for his guidance and suggestions rendered to me in formulating the thesis.*

*My sincere thanks also goes to* ***Dr. N. Saifudeen*** *and* ***Dr. Sumam Susan Varghese****, Retd. Professors and Heads, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani for their expert guidance in formulating and implementing this research project.*

*I accord my sincere thanks to* ***Dr. Vijayaraghavakumar****, Professor and Head, Department of Agricultural Statistics for his co-operation during the statistical analysis of the data.*

*I am thankful to* ***Kerala Agricultural University*** *for supporting me by way of the KAU postgraduate student fellowship, contingency fund and other necessary facilities for the successful implementation of this project.*

*I place on record my gratitude to* ***Dr. A. Sajeena*** *(Assistant Professor (Plant Pathology), CSRC Karamana),* ***Mr. Tomy Abraham*** *(Farm officer, CSRC Karamana) and* ***Mr. Hirosh Kumar K. S.*** *(Technical Officer, CSRC Karamana) for their valuable suggestions and support during the course of this work. I also express my heartfelt thanks to the non-teaching staff of CSRC Karamana-* ***Saji chettan, Arun Chettan, Aneesha Chechi, Arya Chechi, Karthika, Antu and Sreekkutty*** *for their kind support and help during the work.*

*I would express my sincere gratitude to my teachers* ***Dr. P. B Usha****,* ***Dr. Usha Kumari, Dr. Sudharmai Devi****,* ***Dr. K. C. Manorama Thampatti, Dr. B. Aparna, Dr. Gladis****,* ***Dr. Biju Joseph, Dr. Sam T Kurumthottical, Dr. Komala Amma, Dr. Shehana and Dr. Thomas George****, Department of Soil Science & Agricultural Chemistry and* ***Dr. Roy Stephan and Dr. Manju,*** *Departmment of Plant Physiology for their support and advice at all stages of research work. I also remember the help and support from* ***Biju chettan, Vijayakumar chettan, Aneesh chettan, Maya chechi and shyni chechi.***

*I would like to thank* **Dr. G. Byju,** *Principal Scientist, CTCRI, Sreekariyam for giving permission to use the Atomic Absorption Spectrometer during the course of my research work.*

*I am most indebted to my* **Achan, Amma** *and* **Remitha** *for their affection, continuous encouragement, unfailing support and blessings that have enabled me to complete this work successfully.*

*I express my sincere thanks to my classmates,* **Dhanya, Arya, Jaya, Dharmendra, Raghu**, **Dathan sir, Meera chechi and Visweshwaran sir** *for their support and valuable suggestions. I would like to express my gratitude to my seniors and juniors,especially* **Sreeja Chechi, Emil Chechi, Sachu Chechi, Arya Chechi, Sai Chettan Dhanesh, Dhanya K. R.** *and* **Rakhi.**

*Deep sense of gratitude are due to my beloved friends* **Amala, Mridu, Prasanth, Achuettan, Sreejithettan** *and* **Rakhi** *for all their love, continuous support, care, suggestions and advices for me during my research programme.*

*I am extremely thankful to my friends* **Nimisha, Nikitha, Reshma. S, Aby, Shwetha** *and* **Eldhose** *for their help, moral support and constant help throughout the period of my study.*

*I extend my thanks to the* **Library, College of Agriculture, Vellayani** *for the facilities rendered to me.*

*Thanks to all my* **batchmates** *for their constant support and encouragement.*

*I would like to take this opportunity to express my gratitude to each and every persons who helped me to made this effort fruitful.*

***Reshma Remesh***

## TABLE OF CONTENTS

| Sl. No. | CHAPTER | Page No. |
|---|---|---|
| 1 | INTRODUCTION | 1-3 |
| 2 | REVIEW OF LITERATURE | 4-23 |
| 3 | MATERIALS AND METHODS | 24-35 |
| 4 | RESULTS | 36-67 |
| 5 | DISCUSSION | 68-83 |
| 6 | SUMMARY | 84-88 |
| 7 | REFERENCES | 89-109 |
|  | ABSTRACT | 110-112 |
|  | APPENDIX | 113 |

# LIST OF TABLES

| Table No. | Title | Page No. |
|---|---|---|
| 1 | Analytical methods followed in soil analysis | 25 |
| 2 | Analytical methods followed in plant analysis | 34 |
| 3 | Physico-chemical properties of the soil of the experimental site | 37 |
| 4 | Effect of boron on plant growth parameters of rice | 39 |
| 5 | Effect of boron on yield attributes of rice | 41 |
| 6 | Effect of boron on grain and straw yields | 44 |
| 7 | Effect of boron on pest and disease scoring of rice | 44 |
| 8 | Effect of boron on economics of cultivation | 47 |
| 9 | Effect of boron on the content of boron in index leaf at critical stages | 47 |
| 10 | Effect of boron on the content and uptake of nitrogen in straw and grain | 51 |

| | | |
|---|---|---|
| 11 | Effect of boron on the content and uptake of phosphorus in straw and grain | 51 |
| 12 | Effect of boron on the content and uptake of potassium in straw and grain | 55 |
| 13 | Effect of boron on the content and uptake of calcium in straw and grain | 55 |
| 14 | Effect of boron on the content and uptake of magnesium in straw and grain | 58 |
| 15 | Effect of boron on the content and uptake of copper in straw and grain | 58 |
| 16 | Effect of boron on the content and uptake of zinc in straw and grain | 61 |
| 17 | Effect of boron on the content and uptake of boron in straw and grain | 61 |
| 18 | Effect of boron on the phenol content of plant at different stages | 64 |
| 19 | Effect of boron on soil reaction and electrical conductivity | 64 |
| 20 | Post harvest soil nutrient status | 66 |
| 21 | Effect of boron on seed germination after harvest | 67 |

# LIST OF FIGURES

| Fig. No. | Title | Between pages |
|---|---|---|
| 1 | Weather data for the cropping period: September-January 2015-'16 | 25-26 |
| 2 | Layout of the experimental field | 27-28 |
| 3 | Effect of B application on shoot length at harvest | 68-69 |
| 4 | Effect of B application of root length at harvest | 68-69 |
| 5 | Effect of B application on panicle weight | 70-71 |
| 6 | Effect of B application on percentage filled grains | 70-71 |
| 7 | Effect of B application on spikelet sterility | 71-72 |
| 8 | Effect of B application on thousand grain weight | 71-72 |
| 9 | Effect of B application on grain yield | 73-74 |
| 10 | Effect of B application on straw yield | 73-74 |
| 11 | Effect of B application on gross and net returns per hectare | 74-75 |
| 12 | Effect of B application on B:C ratio | 74-75 |

| | | |
|---|---|---|
| 13 | Effect of B application on B content of index leaf at critical stages | 76-77 |
| 14 | Effect of B application on N uptake by straw and grain | 76-77 |
| 15 | Effect of B application on P uptake by straw and grain | 78-79 |
| 16 | Effect of B application on K uptake by straw and grain | 78-79 |
| 17 | Effect of B application on Ca uptake by straw and grain | 79-80 |
| 18 | Effect of B application on Cu uptake by straw and grain | 79-80 |
| 19 | Effect of B application on Zn uptake by straw and grain | 81-82 |
| 20 | Effect of B application on B uptake by straw and grain | 81-82 |
| 21 | Effect of B application on phenol content of shoot at tillering and flowering stages | 82-83 |
| 22 | Effect of B application on phenol content of straw and grain at harvest | 82-83 |

## LIST OF PLATES

| Plate No. | Title | Between pages |
|---|---|---|
| 1 | General view of the experimental field | 27-28 |

# LIST OF APPENDIX

| Sl. No. | Title | Appendix No. |
|---|---|---|
| 1 | Weather data for the cropping period (September 2015- January 2016) | I |

## LIST OF SYMBOLS AND ABBREVIATIONS USED

| | | |
|---|---|---|
| % | - | Per cent |
| @ | - | At the rate of |
| $^{o}$C | - | Degree Celsius |
| ₹ | - | Indian rupee(s) |
| B | - | Boron |
| B:C | - | Benefit : cost |
| Ca | - | Calcium |
| CD | - | Critical difference |
| CEC | - | Cation exchange capacity |
| cm | - | Centimeter |
| c mol kg$^{-1}$ | - | Centi mol per kilogram |
| Cu | - | Copper |
| dS m$^{-1}$ | - | deci Siemens per meter |
| EC | - | Electrical conductivity |
| *et al.* | - | Co-workers/ co-authors |
| FYM | - | Farmyard manure |
| Fe | - | Iron |
| Fig. | - | Figure |
| g | - | Gram |
| g pot$^{-1}$ | - | Gram per pot |
| *i.e.* | - | that is |

| | | |
|---|---|---|
| K | - | Potassium |
| KAU | - | Kerala Agricultural University |
| kg ha$^{-1}$ | - | Kilogram per hectare |
| Mg | - | Magnesium |
| mg g$^{-1}$ | - | Milli gram per gram |
| M ha | - | Million hectare |
| mg kg$^{-1}$ | - | Milli gram per kilogram |
| Mg m$^{-3}$ | - | Mega gram per meter cube |
| mm | - | Millimeter |
| Mn | - | Manganese |
| Mo | - | Molybdenum |
| M t | - | Million tons |
| N | - | Nitrogen |
| No. | - | Number |
| NS | - | Non-significant |
| P | - | Phosphorus |
| pH | - | Negative logarithm of hydrogen ions |
| ppm | - | Parts per million |
| S | - | Sulphur |
| t ha$^{-1}$ | -- | Tonnes per hectare |
| *viz.* | - | Namely |
| Zn | - | Zinc |

# *Introduction*

# 1. INTRODUCTION

Rice (*Oryza sativa* L.), the predominant cereal crop of India, is the staple food of majority of the population of the country. India, one of the leading producers of rice in the globe, accounts for 19.7 per cent of the world rice production. About one-fourth of the total cropped area of the country is covered by rice, which feeds about 50 per cent of the Indian population. Rice also supplies a major proportion of human per capita energy and protein requirement, in addition to vitamins, minerals and fibre.

The growing population of India, estimated to reach around 1.4 billion by 2025, demands an annual food grain requirement of 380 M t (Yadav *et al.*, 2010). But, rice, with an area of 43.95 M ha, presently produces only 106.54 M t of grains with a productivity as low as 2.42 t $ha^{-1}$ (GOI, 2014a).

Rice in Kerala occupies an area of 1.99 lakh ha with a total production of 5.64 lakh t and a productivity of 2.83 t $ha^{-1}$ (GOI, 2014b). The production is only 1/5th of the present requirement of rice in the state *viz.,* 35-40 lakh t $year^{-1}$. This widening gap between demand and supply poses a threat to food grain security.

The major constraints limiting rice yield in Kerala are imbalanced fertilizer use and inefficient management of other inputs. The decrease in rice area and production and the gradual increase in productivity reflects an intensification of rice cultivation over the decades, to meet the food grain demand of the growing population. The productivity increase achieved over the decades by intensive cultivation and the use of high analysis fertilizers is far below the yield potential of the rice plant. The intensive and exploitative cultivation using high analysis NPK fertilizers and low organic manure addition, combined with nutrient loss through leaching have aggravated the deficiencies of secondary and micronutrients in rice growing areas, leading to a decline in production. Such secondary and micronutrient deficiencies limit the plant in gaining maximum benefit from the applied NPK fertilizers.

Micronutrients though required in minute quantities, play important roles in plant metabolism, and unless their requirements are satisfied, the full yield potential, of the crop cannot be tapped. Adequate supply of these micronutrients improves nutrient availability to plants, positively affecting cell physiology, which is reflected not only in yield, but also in the micronutrient content of the grains, leading to better quality of the crop and an improvement in human nutrition as well. Deficiency of micronutrients is recognized as one of the major reasons for declining rice productivity.

Boron is one of the most important micronutrients, having direct and indirect roles in plant growth and metabolism. The principal forms in which B is present in soils are $H_3BO_3$ and $B(OH)_4$. Soil B contents below 0.5 mg kg$^{-1}$ hot water soluble B is generally found to be deficient for most crops whereas values above 5.0 mg kg$^{-1}$ are found to be toxic (Rashid *et al.*, 2004). Moreover, deficiency of B in crops is more widespread than the deficiency of any other micronutrient in the world (Gupta, 1993). This deficiency is increasing due to intensive cropping and non-judicious use of high analysis fertilizers. Boron deficiency reportedly causes many anatomical, physiological and biochemical changes in plants (Blevins and Lukaszewski, 1998).

Boron, required for the rice crop during its entire growth cycle, is responsible for improved pollination and grain setting. Thus, this nutrient is very essential during the reproductive stage of the crop compared to the vegetative stage. Ahmad and Irshad (2011) reported that B application increases the tillering ability of the plant, plant height, panicle length, productivity of panicle, weight of thousand grains and rice yield in addition to increase in starch content and grain size. It is known that an improvement in starch content increases the cooking quality of rice.

According to the Kerala State Planning Board, around 70 per cent of Kerala soils are boron deficient (Kerala State Planning Board, 2013). Though, the deficiency of boron is being reported in soils and plant tissues from many parts of Kerala, a recommendation of boron to different crops has not yet been developed.

Application methods and rates of B for rice crop should be carefully defined due to narrow ranges between deficiency and toxicity. Since only small amounts are needed for correction of B deficiency, avoiding over application is important to prevent possible toxicity. Hence this project entitled "Boron nutrition of wet land rice (*Oryza sativa* L.)" was formulated to determine the optimum quantity and method of application of boron for wet land rice in order to achieve better grain yield and economic returns in the acid rice soils of Kerala. In this study, an attempt was made to evaluate the effect of B application on yield attributes, yield and nutrient uptake of rice for increased sustainable yield.

# *Review of Literature*

# 2. REVIEW OF LITERATURE

Mineral nutrition is essential for regulating physiological and biochemical processes occurring in plants. Deficiency of any nutrient may alter these processes and disturb plant growth and yield. Boron is one among the mineral nutrients that is required for completing the normal life cycle and is a component of plant cell walls and reproductive structures. The essentiality of B for growth and development of higher plants had been demonstrated by Warrington in 1923.

Boron deficiency is the most widespread micronutrient deficiency around the world and causes large scale losses in crop production both quantitatively and qualitatively (Shorrocks, 1997). Deficiency of B affects vegetative and reproductive growth of plants resulting in inhibition of cell enlargement, death of meristem and reduced fertility (Marschner, 1995).

In this chapter, an attempt is made to review the role of B in soil, soil parameters affecting B availability to plants, role of B in rice crop, B deficiency and toxicity, effect of B on plant growth parameters, yield attributes, effect on pest and disease resistance, nutrient availability, nutrient content and uptake by plants, phenol metabolism, soil acidity, seed germination and method of B application.

## 2.1 Boron in Soil

Boron exists in five major forms in the soil, (1) in primary minerals (2) in secondary minerals (3) as adsorbed B (4) in soil solution (5) and in organic matter (Argust, 1998).

Boron exists as borosilicate in rocks, which is hard to weather and not easily available to plants (Zerrari *et al.*, 1999). The principal B sources in soil solution are $H_3BO_3$ and $B(OH)_4$. Generally, boric acid is seen in soil solution, and above pH 9.2 $B(OH)_4$ is the major form of B (Keren and Bingham, 1985).

Plant available B content in soils of cropping areas ranges between 0.05 and 5 mg $kg^{-1}$, major part of which is derived from sediments and plant materials. However, a slightly higher content may lead to toxicity problems to plants, since there exist only a narrow range between deficiency and toxicity of B (Gupta, 1993). Soil B contents below 0.5 mg $kg^{-1}$ (hot water soluble B) is generally found to be deficient for most of the crops and values above 5.0 mg $kg^{-1}$ tend to be toxic (Rashid *et al.,* 2004).

Hou *et al.* (1994) claimed that the plant available forms of B consist of both inorganic and organic compounds formed as a result of decomposition of vegetation and organisms.

Santhosh (2013) reported that soils from southern and northern coastal sandy plains are deficient in B (<0.5 mg $kg^{-1}$) while acid saline soils of pokkali and kaipad have registered higher levels of available B (>3 mg $kg^{-1}$). For light textured Entisols, the optimum doses of B application range between 0.5 and 1.0 kg B $ha^{-1}$ (Singh, 2006).

## 2.2 Soil Factors Affecting B Availability to Plants

### *2.2.1 Soil pH*

As in the case of all other nutrients, the availability is decreased when the pH is increased (Gupta, 1993). The decrease in B availability with increase in pH is because of its higher fixation. Peterson and Newman (1976) reported that maximum B fixation is found to occur at pH of 6 to 9.

### *2.2.2 Soil Texture*

According to Zhu *et al.* (1999) and Fleming (1980), coarse textured soils are susceptible to leaching losses of B and so sandy soils are said to be B deficient soils unlike silty and clayey soils, which are not that much deficient as that of sandy soils.

### *2.2.3 Organic Matter*

Soil B is positively influenced by organic carbon content (Zhu *et al.* 1999). Yermiyahu *et al.* (2001) reported that the major source of available B in soil is the organic matter, which supplies B for crop use and also helps in adsorbing B.

### *2.2.4 Soil Moisture*

According to Evans and Sparks (1983), drying of soil depresses water uptake by plants and therefore decreases B availability to plant roots due to lack of B absorption through mass flow. Under conditions of moisture stress, B deficiency is also induced by low plant transpiration (Fleming, 1980).

### *2.2.5 Liming*

Liming leads to B deficiency as it increase the soil pH (Evans and Sparks, 1983). Goldberg and Chuming (2007) claimed that heavy liming of acid soils results in the formation of insoluble calcium metaborate that reduce the B availability.

## 2.3 Role of B in Rice

Loomis and Durst (1992) reported that 90 per cent of B in plants is localized in the cell walls. Boron is important in cell walls due to its influence on cell wall formation (Bolanos *et al.*, 2004). Boron is also involved in cell division (Marchner 1995; Gunes *et al.*, 2003) cell wall synthesis, cell wall rigidity, synthesis of boron-pectin compounds (Hu *et al.*, 1996; Matoh, 1997; Bellaloui and Brown, 1998; Goldbach *et al.*, 2001), and plasma membrane integrity (Cakmak *et al.*, 1995; Marschner, 1995; Brown *et al.*, 2002).

Though B has no direct effect on photosynthesis, it has many indirect effects, like the decrease in photosynthetic area of plants or the stomatal conductance to $CO_2$ (Dell and Huang, 1997). Deficiency and toxicity of B result in lower chlorophyll levels thereby reducing the rate of photosynthesis (Bolanos *et al.*, 2004).

Boron has been functional in carbohydrate metabolism (Gunes *et al.*, 2003) and translocation of sugar (Marchner, 1995; Parr and Loughman, 1983), which is facilitated by the synthesis of borate-sugar compounds as reported by Katyal and Singh (1983) and Marcus-Wyner and Rains (1982).

Involvement of B in several physiological, biochemical, and molecular processes in plants have also been reported. Boron influences the metabolisms of several bio-molecules (Goldbach *et al.*, 2001; Marchner 1995), lignification, respiration, (Parr and Loughman, 1983), ascorbate metabolism (Lukaszewski and Blevins, 1996), and oxygen activation (Marschner, 1995).

Boron plays an important role in plant reproduction as it can induce the pollen tube germination (Bolanos *et al.*, 2004). It is responsible for improved pollination and grain setting in different rice cultivars (Aslam *et al.*, 2002; Rehman *et al.*, 2012; Zhang *et al.*, 1994), proving its essentiality in the reproductive stage compared to the vegetative stage of the crop. The involvement of B in stimulating the growth of pollen tube is understood and the B in the plant can be directly correlated with the reproductive and yield components (O'Neill *et al.*, 2004; Bergmann, 1984). It is actively involved in disease resistance (Bonilla *et al.*, 2009; Pandey and Gupta, 2013) and hormonal production (Gunes *et al.*, 2003). Boron is also essential for a wide range of morphological alterations, tissue differentiation, metabolite transfer, and pollen germination which influence yield and productivity in rice (Rao *et al.*, 2013).

Earlier studies show that B is required for plant growth and development (Pilbeam and Kirkby, 1983; Marschner, 1995), promoting crop quality (Dordas, 2006; Dordas *et al.*, 2007) and formation of quality contributing factors of seed (Bellaloui *et al.*, 2010). Although the structural and metabolic role of B (Pilbeam and Kirkby, 1983; Marschner, 1995; Brown *et al.*, 2002) were well documented, the absolute function of B in growth (Cakmak and Romheld, 1997) and seed constitution (Bellaloui *et al.*, 2010) is not completely revealed.

## 2.4 Boron Deficiency

Boron deficiency is considered as the most serious micronutrient deficiency spreading widely across the world as per the reports of Brown *et al.* (2002) and Blevins and Lukaszewski (1998). According to Alloway (2008) B deficiency is said to be the second most important micronutrient deficiency in the world.

Deficiency of B is an important agricultural constraint encountered in over 80 countries (Shorrocks, 1997) and is usually prevalent in crops cultivated in soils with higher carbonates and lower organic matter (Lindsay, 1991; Rashid, 1996).

Rashid and Ryan (2008) reported that the rice and wheat cultivating soils of Pakistan are deficient in B, and its application increased both rice and wheat yields. According to Goldberg (1997) and Rashid *et al.* (2009) the probable causes of B deficiency are observed to be low soil pH, deficiency of water, washing of B by rain water, and B fixation. A gradual reduction in the subsoil B concentration occurs in areas receiving higher rainfall because of leaching (Roessner *et al*, 2006).

Boron deficiency may lead to poor development of cell wall structures because of the deterioration of plasticity of cell walls resulting in the lower enlargement rates of newly formed cells. The cell wall malformation of B deficient roots may also result in abnormal shape and size of the newly formed cells (Hu and Brown, 1994).

Boron deficiency may also persuade leaf structural changes such as the structural and functional abnormalities of stomata and guard cells (Sharma and Sharma, 1987; Blevins and Lukaszewski, 1998; Sheng *et al.*, 2009).

Development of roots is more affected by B deficiency compared to that of the shoot (Marschner, 1995; Dell and Huang, 1997). It has been proposed that inhibition of root elongation is caused by the accumulation of excessive levels of endogenous indole acetic acid (IAA) in the meristematic regions of B deficient roots (Dugger, 1983). According to Loomis and Durst (1992), the root tips where B deficiency occurs, develop an abnormal thickening of the radial cell walls. Boron depletion results in suppression of root growth and development in higher plants (Dugger, 1983; Shelp, 1993; Marschner, 1995).

Kastori and Sakac (1995) observed that B deficiency affects photosynthesis, reduce the photosynthetic oxygen evolution and efficiency of photosystem-II. Even though, Goldbach and Wimmer (2007) reported that the involvement of B in photosynthesis is not known and so effects of B deficiency on photosynthesis are less important.

Boron maintains the water balance of the plant body and thereby regulates the related functions and metabolism. Boron deficient plants lack the required moisture content, stomatal conductance and turgidity leading to lower growth of the plant (Sharma and Ramchandra, 1990).

It has been observed that reproductive growth, especially flowering, fruit and seed set and seed yield, is more sensitive to B deficiency than vegetative growth in all crops (Longbin *et al.,* 2000; Noppakoonwong *et al.,* 1997). As the severity of B deficiency increases, plant reproduction will be inhibited, resulting in lower yield of the plant (Nabi *et al.,* 2006; Huang *et al.,* 2000).

Cereals along with other grasses are considered less sensitive to B deficiency than dicotyledons. Critical deficiency concentrations in Graminaceous species are within the range of 5–10 mg B $kg^{-1}$ dry weight, compared with 4–14 times as much B required for maximum growth and yield in dicotyledonous species (Marschner, 1995).

However, rice is considered to be tolerant to B deficiency, it leads to remarkable reduction in rice yield (Cakmak and Romheld, 1997; Rashid *et al.*, 2004; 2009). The deficiency symptoms of B in rice are thin stems, fewer tillers, and lack of viable seeds. Boron deficient plant parts become brittle compared to the sufficient parts, which are flaccid (Dunn *et al.*, 2005). The deficiency also leads to white and rolled tips of emerging leaves, decreased plant height, necrosis and inability to form panicles (Dobermann and Fairhurst, 2000).

Boron deficiency during the panicle initiation stage may inhibit panicle production (Dobberman and Fairhurst, 2000). Limiting B in the growing media reduce the number of panicles and increase the spikelet sterility (Uraguchi and Fujiwara, 2011).

Pollen tube growth and anther developments are seriously affected by B deprivation in rice (Rawson, 1996). Under the deficiency of B, pollen tubes may break as it is primarily involved in maintaining the integrity of pollen tube cell walls (Brown *et al.*, 2002). Since growth of pollen tubes require rapid synthesis of cell wall and plasma membrane (Taiz and Zeiger, 2010), B deficiency inhibits pollen tube growth and fertilization thus causing failure of grain setting (Rerkasem *et al.*, 1993).

The rates of germination of pollen collected from rice cultivated under B deprived conditions were lower than those of pollen from rice cultivated under the conditions of B sufficiency (Lordkaew *et al.*, 2012).

The study conducted in wheat by Rerkasem and Jumjod (1997a), reveals that low B leads to lesser number and half the size of pollen grains as compared to the normal and a change in shape is also observed. Because of the inhibitory effect on the growth and development of reproductive structures like anther and pollen, B deficiency is recognized as one of the factors resulting in sterility in several plants (Cheng and Rerkasem, 1993). Sharma (2006) claimed that B deficiency is the main reason for causing male sterility and reproductive abnormalities (Sharma, 2006). Rawson (1996) claimed that the spikelet sterility occurs because of the lack of adequate translocation of B to flowers during the 6–10 days of pollen formation. Boron deficiency has been reported to increase panicle sterility in wheat (Rerkasem and Jamjod 1997a) and rice (Rashid *et al.*, 2004).

Reproductive organs are more sensitive to B deficiency (Brown *et al.*, 2002; Dell *et al.*, 2002; Uraguchi and Fujiwara, 2011) and any deficiency of B during the reproductive stage may cause pollen abortion (Dell *et al.*, 2002; Dordas, 2006) in rice resulting in the development of sterile panicles (Rashid *et al.*, 2004). Huang *et al.* (2005) reported that B is required at a higher quantity for reproductive growth compared to that of vegetative growth and any deficiency at flowering stage may result in sterility and floral abnormalities.

Deficiency of B causes severe reduction in crop yield, due to severe disturbances in metabolic processes involving B, such as nucleic acid, carbohydrate, protein and indole acetic acid metabolisms, cell wall synthesis, membrane integrity and function, and phenol metabolism (Dell and Huang, 1997; Tanaka and Fujiwar, 2008).

Yield depression due to B deficiency among different rice varieties was reported to range from 9 to 32 per cent for grain, and from 2 to 44 per cent for straw (Rashid *et al.*, 2002) in Pakistan. Insufficient B nutrition destroys the grain quality of rice, making it cheaper in the market (Rashid *et al.*, 2004).

Since genotypic variation in responses to low B has been reported for many crop species, rice varieties also differ widely in their B responses (Rerkasem and Jamjod, 1997b).

## 2.5 Boron Toxicity

Boron has a remarkable influence in plants from the stand point of both nutrition and toxicity (Das, 2003). The soils formed from marine or volcanic sediments have higher concentrations of B, and hence plants grown in these soils were found to accumulate B to levels that are phytotoxic (Chesworth, 1991).

The unique feature of essential micronutrients is that the range between deficiency and toxicity is narrow. When only a portion of one ppm is the optimum requirement, more than that quantity may cause toxicity problems in plant body (Muntean, 2009). Reduced crop quality and yield in soils containing toxic levels of B is a worldwide problem in food production, especially in arid areas (Nable *et al.,* 1997). It has long been known that the optimum B level for one species could be either toxic or insufficient for other species (Blevins and Lukaszewski, 1998).

The critical toxicity level of B in rice plants at maturity is 100 mg $kg^{-1}$ (FFTC, 2001). The typical visible symptom of B toxicity is leaf burn in the form of chlorotic and/or necrotic patches, often at the margins and tips of older leaves (Benett, 1993).

Excess levels of B in soil will inhibit the root development and reduce the capability of plant to uptake the required nutrients and water from soil solution, at the same time, leaf necrosis will reduce photosynthesis and ultimately, the ability to translocate photosynthates to developing plant parts and storage organs (Reid, 2007).

In soils where B is found toxic, B concentrations are maximum in subsoil (Yau and Ryan, 2008) which may suppress the root growth deep into the soil profile (Holloway and Alston, 1992). As a result of restriction in the effective rooting depth of crops, higher levels of soil B may reduce grain yield by reducing water use (Holloway and Alston, 1992).

The decrease in dry matter yield of rice at higher B levels may be ascribed to B toxicity because a slight increase in B levels markedly increased the B concentration in shoots (Rashid *et al.*, 2004; Sakal *et al.*, 1993).

### 2.6 Effect of Boron on Plant Growth Parameters of Rice

According to Ashraf *et al.* (2004) and Rahmatullah *et al.* (2006), B application induces plant growth due to its involvement in formation of cell wall and improved growth parameters like tillering capacity, shoot and root length and shoot and root weight as reported by Ehsan-ul-Haq *et al.* (2009).

Height of rice plant is reported to respond significantly to B application (Khan *et al.,* 2006) and increased from 101.9 to 111.5 cm. The greatest plant height was registered by cumulative application of 2 kg B ha$^{-1}$ (111.5 cm) and was on par with single application of 2 kg B ha$^{-1}$ (111.2 cm), and the lowest height was given by the no B check.

Increase of rice plant height due to B application is an effect of enhancement of growth rate and improved development of root and shoot (Khan *et al.,* 2006; Shah *et al.,* 2011). Inhibition of shoot elongation of rice following an increase in the media B concentration from a certain optimum B level was also reported by Ochiai *et al.* (2008).

` Bohnsack and Albert (1977) reported that B is involved in meristematic development of plants, which might be the reason for increase in number of tillers and height of rice plant with the application of B. Boron nutrition was found to increase the division and enlargement of cells (Shelp, 1993; Mouhtaridou *et al.,* 2004), leading to better vegetative growth. Boron is also involved in the regulation and metabolism of several phytohormones and other bio—molecules making it essential for the growth of new cells and tissues (Ahmad *et al.,* 2009). Improvement in tillering is also reported to be because of the enhancement in the growth and metabolisms occurring in plant body as a result of B nutrition (Goldbach *et al.,* 2001).

Boron application is reported to increase the ability of plant to produce more number of leaves and tillers (Khan *et al.,* 2006). Rehman *et al.* (2012) reported a substantial improvement in emergence of leaves and tillers in rice when the paddy seeds were primed in 0.001 per cent solution.

Numerous studies have shown that the elongation rate of the most actively growing leaf decreases in response to a decrease or interruption in the external B supply (Kirk and Loneragan, 1988; Bell *et al.*, 1990; Hu and Brown, 1994; Huang *et al.*, 1996). Furthermore, cell size is generally smaller in B deficient leaves than B adequate leaves (Hu and Brown, 1994).

An increase of 5.76 to 10.75 g pot$^{-1}$ in average shoot yield was observed due to application of B @ 1.5 mg kg$^{-1}$ in B deficient soils while in B sufficient soil, an addition of 1 mg B kg$^{-1}$ soil produced shoot yield increase of 9.99 to 10.29 g plot$^{-1}$ when B was applied in soils still higher in B, the yield was found to decrease (Debnath and Ghosh, 2011).

## 2.7 Effect of Boron on Yield and Yield Attributes of Rice

Boron is essential for the development of reproductive structures and reproduction and so B nutrition improve the yield contributing factors, leading to higher yields (Dear and Lipsett, 1987; Noppakoonwong *et al.*, 1997). Chaudhry *et al.*, (1977) found that rice yield is increased when B is applied in soils where it is found deficient.

Application of B @ 1 kg ha$^{-1}$ significantly increased number of tillers plant$^{-1}$, plant height, panicle length, number of grains per panicle, thousand grain weight and paddy yield (Ahmad and Irshad, 2011). Significant improvement in yield attributes of rice (cv. IR-36) like plant height, panicle length, percentage of filled grains, grain weight (Mandal *et al.*, 1987), panicle weight, thousand grain weight and resultant yield due to B nutrition were also reported by Shafiq and Maqsood (2010).

Mehdi *et al.* (2006) claimed that residual B improved several yield attributes such as crop yields, plant height and tillering intensity of rice under saline sodic conditions.

A field experiment conducted in low land lateritic soils of Central Palakkad Plains revealed that B is involved in increasing the yield parameters such as number of productive tillers and grains per panicle, weight of thousand grains and the yield (Santhosh, 2013). He also showed that borax application @ 5.5 kg ha$^{-1}$ resulted in yield improvement to the tune of 1.0 t ha$^{-1}$.

Boron nutrition in different rice varieties revealed that B plays an important role in improving the pollination and grain setting, thereby increase the number of grains per panicle, and lower the spikelet sterility (Aslam *et al.,* 2002). Rashid *et al.* (2004) reported 14-25 per cent yield increase in rice over control by analyzing the role of B in different rice varieties and this increase in crop yield was due to the improved tillering and reduced spikelet sterility as a result of B application.

Several reports show that B application at the heading or flowering stage in rice results in increased number of grains per panicle and grain yield (Lin and Zhu, 2000; Ramanthan *et al.*, 2002). Due to B application, improvement in rice yield by decreasing the panicle sterility has also been reported (Rehman *et al*., 2014; Jana *et al.*, 2005; Rashid *et al.*, 2006).

In soils where B is deficient, the rice plant grows unevenly and exhibit positive response to an optimum dose of B @ 0.75 kg ha$^{-1}$ as reported by Rashid *et al.* (2004). Compared to the control, rice yield was increased by 5-26 per cent by the application of B (Rashid *et al*., 2002). An increase of 34.6 and 19 per cent respectively in paddy grain yield due to B application @ 2 kg ha$^{-1}$ in Mirpur and Satgara soils respectively was reported by Ali *et al.* (1996).

Hussain and Yasin (2003) found an increase of 13 per cent in wheat yield compared to control when B was applied @ 1 kg ha$^{-1}$; while for paddy, the yield increase over control with the same level of B was found to be 16 per cent.

Higher and sustainable rice production is also reported to be achieved when B was applied on foliage @ 1.0 per cent aqueous solution (Ahmad *et al*., 2012).

In addition to grain yield, Rashid and Yasin (2004) reported positive responses to B for straw yield, panicle fertility and weight of individual kernels as well as several key quality characteristics of the rice grain. A pot study by the same group of researchers found variation in positive responses to B application among rice varieties that ranged from 10 to 46 per cent in grain yield and 2 to 77 per cent in straw yield in a calcareous soil (pH 8) containing 0.08 mg hot water soluble (HWS) B kg$^{-1}$ (Rashid *et al.*, 2002).

Increases in grain yield of rice were reported to be accompanied by decreases in spikelet sterility and increases in straw dry weight and the weight of 1000 grains (Rashid and Yasin 2004; Shah *et al.*, 2011).

Rahmatullah *et al.* (2006) observed that B application improved the size, weight and number of spikelets in the rice panicle. The weight of single rice grain is relatively constant; as the rigid rice hull limits grain size and spikelet fertility is regulated by assimilate availability (Yoshida, 1981). Stresses such as salinity (Zaibunnisa *et al.*, 2002), cold and heat (Dingkuhn *et al.,* 1995; Yoshida, 1981) have been reported to affect rice by causing spikelet sterility as well as depressing the extent to which the grains are filled. Low water status of panicle during anthesis has also been suggested as one of the reasons of panicle sterility in rice (Farooq *et al.,* 2011). Supply of adequate quantity B helps to balance the partitioning of assimilates to the developing grains (Dixit *et al.,* 2002) and increase the grain size.

Rashid *et al.* (2004) observed that because of B nutrition, grain yield and several quality parameters such as cooking quality, milling and head rice recovery were improved.

Foliar application of 0.5 per cent borax 3 rounds at 15 days interval significantly improved the yield and yield attributes of rice (Nagula, 2014). The application of B through various sources either in soil or on foliage was found to stimulate plant growth and increase the rice yield (Sakal *et al.*, 2002).

## 2.8 Effect of Boron on Pest and Disease Resistance

Boron has a direct function in cell wall structure and stability and has a beneficial effect on reducing disease severity. The reason for providing disease resistance to crops by B might be due to its role in cell wall structure, cell membrane permeability and stability, or the metabolism of phenolics or lignin (Brown *et al.*, 2002; Blevins and Lukaszewski, 1998).

Boron promotes stability and rigidity of cell wall and therefore supports the shape and strength of the plant cell and thus contributes to disease resistance (Brown *et al.*, 2002; Marschner, 1995).

Boron has been shown to reduce disease caused by *Blumeria graminis* (D. C.) in wheat (Marschner, 1995). It was also observed that in B deficient wheat plants, the disease severity was several folds higher than that in B sufficient plants, with the fungus spreading more rapidly when B was deficient in plants (Schutte, 1967).

## 2.9 Effect of Boron on Nutrient Availability

Improvement in nutrient availability due to B application has been reported by many scientists. Foliar application of 0.5 per cent borax 3 rounds at 15 days intervals has been reported to improve the available nutrient status of soil significantly (Nagula, 2014).

Barman *et al.* (2014) reported that application of B (20 mg $kg^{-1}$) and lime (1/3 LR) significantly increased N, P, K content in soil. Singh *et al.* (1990) observed that increase in the supply of B significantly decrease the uptake of P and K and reported that application of higher concentrations of B had an antagonistic effect on nutrient absorption as a result of B toxicity on root cells, leading to imbalanced nutrient absorption mechanism.

Application of B (20 mg $kg^{-1}$) and lime (1/3 LR) was found to significantly increase Ca, Mg and S content in soil (Barman *et al.*, 2014).

Oyewole and Aduayi (1992) observed a negative relation between leaf Mg and Ca, concluded that this relationship was obtained when leaf Ca and Mg increased with increasing B levels in soil.

Singh *et al.* (1990) observed that increase in the supply of B significantly decrease the absorption of Ca and Mg and reported that application of higher concentrations of B had a nagative effect on nutrient absorption as a result of B toxicity, leading to imbalanced absorption of nutrients. The results of experiments conducted by Ramon *et al.* (1990) reported that B deficiency affects calcium translocation and the further formation of an insoluble material in the cell wall. It is observed that B toxicity can be alleviated by the application of calcium in soil.

Application of B (20 mg kg$^{-1}$) and lime (1/3 LR) significantly increased Zn content in soil while the availability of Cu, Fe and Mn in soil was reduced (Barman *et al.,* 2014). Singh *et al.* (1990) observed that increase in the concentration of B application markedly reduced the uptake of manganese while that of zinc, copper and iron was enhanced. They also reported that higher concentrations of B application have an antagonistic effect on nutrient uptake, which might be because of the imbalanced absorption of nutrients.

Availability of B is depressed under low soil water conditions, as water is required for both the release of B from organic compounds and its extraction from soil by the plants (Tisdale *et al.,* 1985). Li *et al.* (2001) claimed that the B found in cell wall of the plants cannot be considered as a storage pool for further use of the plants. The concentration of plant available B is regulated by soil reaction, texture, clay mineralogy, organic matter, etc. (Goldberg, 1993). Generally, the plant takes B in molecular form as boric acid by the process of diffusion (Bingham *et al.*, 1981).

## 2.10 Effect of Boron on Plant Nutrient Content and Uptake

Santra *et al.* (1989) claimed that B functions both inside the plant body and in the external nutrient media, thus it influence the uptake of nutrients. In contrast to this, Amagishi and Yamamoto (1994) and Furlani *et al.* (2001) demonstrated that increasing external B concentrations did not interfere with the uptake of other nutrients. Nagula (2014) reported that foliar application of 0.5 per cent borax 3 rounds at 15 days interval significantly improved the nutrient uptake by rice plant.

Ghatak *et al.* (2006) concluded that application of B had no significant effect on N, P and K concentrations and uptake. But Roth-Bejerano and Itai, (1981) reported that B deficiency can depress the rate of phosphate uptake and it can be quickly restored within one hour by the supply of B to those plants. In rice, the concentration of K in new leaves significantly decreased with B addition at tillering, while at flowering stage, leaf K increased with B addition (Yu and Bell, 1998).

Boron influences the nitrogen metabolism and calcium uptake (Bonilla *et al.*, 2009; Pandey and Gupta, 2013). However the deficiency of B may cause reduction in nitrate contents of the leaves, it will not affect the nitrate reductase activity and the contents of other nutrients *viz.*, phosphorus, potassium, calcium and magnesium (Camacho-Cristobal *et al.*, 2005).

The concentration of Ca in new leaves of rice plant significantly increased while that of S decreased with B addition at tillering, whereas at flowering, the opposite effect occurred, i.e., leaf Ca decreased with B addition (Yu and Bell, 1998).

A concentration of Mo in new leaves of rice was found to increase significantly with B addition while a decrease was observed in Cu and Fe at tillering stage (Yu and Bell, 1998).

Debnath and Ghosh (2012) reported that B content in rice shoot increased with increase in B application levels. Boron content in the plant body is found increasing from lower to upper portions (Shuman, 1994) and B nutrition increased its concentration in plant tissues to a greater extent compared to that in grains (Kauser *et al.,* 1988). Higher meristematic B requirement may arise due to reduced phloem transport from shoots to other plant parts, resulting in greater accumulation of B in leaves (Rerkasem, 1996). Increase in the content of B in both leaves and grain as the level of B in the growing media increased reveals that, if available, plants continue to translocate it to the grains (Cheng and Rerkasem, 1993; Gunes and Alpaslan, 2000).

Plant B uptake has a direct relation with the concentration of boric acid in soil solution as it is found that B content of leaves increased linearly with increase in B concentration of the nutrient solution (Tariq *et al*., 2005)**.**

Brown and Shelp (1997) observed that plants exhibit positive response to concentrations of B in soil solution by absorbing it through roots and carried through xylem to upper parts of shoots. Yang *et al.* (2000) claimed that residual B can increase the leaf and grain B content in rice plant.

Antagonistic interaction between nutrient elements can also be very useful in reducing toxic level of B. Boron toxicity can be decreased with P x B interaction (Gunes *et al*., 1999), also high level of N decreases the B concentration (Alpaslan *et al.,* 1996). Under certain situations, B toxicity in plants can be alleviated by the application of zinc in soil or on foliage of affected plants (Graham *et al*., 1986; Swietlik, 1995).

Singh *et al.* (1990) observed that higher concentrations of B application have antagonistic effect on nutrient uptake in wheat plants. When B is applied in higher concentrations than the normal, it can alleviate aluminium toxicity, by enhancing the growth of plant roots (Blevins, 1995).

Application of zinc and B @ 10 and 2 kg $ha^{-1}$ along with the recommended doses of nitrogen and phosphorus to rice crop is reported to improve nutrient contents in grains (Bhutto *et al.*, 2013).

## 2.11 Effect of Boron on Phenol Metabolism

Boron is related to alterations in the content of phenolic compounds and their metabolism (Ruiz *et al.*, 1998). The accumulation of phenolic compounds in B deficient tissues occurs as a result of increased synthesis and inhibited utilization of them in cell wall synthesis.

Cakmak and Romheld (1997) observed an accumulation of huge quantity of hazardous phenolic compounds in the tissues of B deficient plants (Cakmak and Romheld, 1997). The defence capacity of cells against toxic $O_2$ species is reduced because of reduction in contents of ascorbic acid and $H_2O_2$ scavenging enzymes. Hence, it is suggested that B deficiency renders membrane leakiness and structural alteration in plasma membranes (Cakmak, 1994).

As a result of accumulation of phenolic compounds, oxidative enzymes and peroxidase activities rise in B deficient tissues (Cakmak and Romheld 1997). Oxidation of phenolic compounds has also been observed under certain foliar levels of B in tobacco plants (Ruiz *et al.*, 1998). The phenol metabolism also involves oxidative enzymes like PPO that catalyze the oxidation of phenols to quinones (Thipyapong *et al.*, 1995). In addition, PPO is considered as a pathogenesis related protein and a proteinase inhibitor, and has been reported to have a defensive role against herbivores or pathogens (Lamb *et al.*, 1989).

Boron nutrition plays a direct role in phenyl propanoid metabolism (Brown *et al.*, 2002). Because of the higher rate of formation and inhibited use of phenolic compounds in the cell wall formation, they were accumulated in the B deficient tissues (Marschner, 1995; Cakmak and Romheld, 1997). On the contrary, the higher concentration of internal phenolic compounds can be correlated with the allocation of organic carbon to secondary metabolites for increasing the plant defence capacity (Wittstock and Gershenzon, 2002) or to any physiological mechanism which is presently unknown.

Marcus-Wyner and Rains (1982) reported that auxins and phenols get accumulated in the necrotic areas of leaves as a result of B deficiency. Boron plays a role in complexing the phenolic compounds of plant body, reducing its toxicity and so a lack of this nutrient leads to cell damage (Marschner, 1986).

In B deficient plants, it is reported that a higher quantity of phenolic compounds is accumulated (Cakmak and Romheld, 1997).

### 2.12 Effect of Boron on Soil Acidity

Su *et al.* (1994) suggested that with increase in pH, adsorption of B also increased because of the higher quantity of lime application in the soil. The higher rate of B adsorption by oxides and clay minerals occurs in the pH range of 7 to 9 (Goldberg and Glaubig, 1986). Santhosh (2013) found that B availability increases with increase in soil acidity and electrical conductivity.

### 2.13 Effect of Boron on Seed Germination

Low B concentrations deteriorate the ability of seeds to germinate (Bell *et al.*, 1989) thus affect the crop establishment as reported by Rerkasem *et al.* (1997). Boron treatments were found to improve seed germination potential and vigor (Bonilla *et al.*, 2004). Priming of paddy seeds in B solutions improves the seed germination thereby leads to better crop stand (Farooq *et al.*, 2016).

Boron plays critical roles in the development of radical and plumule and thus improve their lengths when the seeds were primed in B solutions (Bohnsack and Albert, 1977).

Boron is important for division and enlargement of cells (Shelp, 1993). The study conducted by Bohnsack and Albert (1977) revealed that root development of seedlings was inhibited when B was removed from the medium and it was observed to be recovered 12 to 18 hours after the application of B to the media.

## 2.14 Method of Boron Application

Boron can be applied either as soil or as foliar application. Application of B in soil may lead to its loss through leaching or by fixation and there is also chances for it to get accumulated in the surface soil in toxic levels. Foliar application also has a risk of leaf burn when the level of application exceeds (Fageria *et al.*, 2009).

Rengel *et al.* (1999) reported that either soil or foliar B application enhance the nutritional quality of rice. Boron, which is immobile in plant tissues, sprayed directly towards developing tissues such as flower buds and flowers ensure adequate supply at critical stages of development (Brown and Shelp, 1997). Rao *et al.* (2013) reported that soil application of B leads to fixation and unavailability to plants.

Dunn *et al.,* (2005) carried out a field experiment to reveal the response of various modes of B application in rice yield and concluded that rice with soil applied B recorded remarkably higher yields compared to that with foliar applied B and without B.

# *Materials and Methods*

# 3. MATERIALS AND METHODS

An investigation entitled “Boron nutrition of wet land rice (*Oryza sativa* L.)” was carried out at Cropping Systems Research Centre, Karamana during 2015-2016 to standardise the amount and method of application of B in wet land rice. The analytical work was conducted at Cropping Systems Research Centre, Karamana and at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani.

The details of the experiment, materials used and methods adopted are discussed in this chapter.

## 3.1 EXPERIMENTAL SITE

The field experiment was conducted at Cropping Systems Research Centre, Karamana to standardise the dose and method of application of B in wet land rice. Geographically the field is located at 8º 28′ 25″ N latitude and 76º 57′ 41″ E longitude at an elevation of 3.3 m above mean sea level.

### 3.1.1 Collection and Initial Analysis of Soil Samples

Soil samples were collected from the field for complete physical and chemical analysis of the soil of the experimental site. Samples were taken at 15 cm depth, from different points of each plot, and composite sample was prepared by quartering method. The samples were air dried, ground, passed through 2 mm sieve and stored air tight.

The samples were analysed for bulk density, particle density, porosity, texture, pH, EC, CEC, and soil available nutrient status (N, P, K, Ca, Mg, Cu, Zn and B). The standard procedures adopted are delineated in Table 1.

### 3.1.2 Climate and Season

The experiment was conducted during the rabi season (September to January), 2015-’16 at the experimental site which enjoys a humid tropical climate.

Table 1. Analytical methods followed in soil analysis

| Sl. No. | Parameter | Method | Reference |
|---|---|---|---|
| 1 | Bulk density | Undisturbed core sample | Black *et al.* (1965) |
| 2 | Particle density | Pycnometer method | Black *et al.* (1965) |
| 3 | Porosity | | Black *et al.* (1965) |
| 4 | Textural analysis | International pipette method | Robinson (1922) |
| 5 | pH | pH meter | Jackson (1958) |
| 6 | EC | Conductivity meter | Jackson (1958) |
| 7 | CEC | Neutral normal ammonium acetate method | Jackson (1973) |
| 8 | Organic Carbon | Walkley and Black rapid titration method | Walkley and Black (1934) |
| 9 | Available N | Alkaline permanganate method | Subbaiah and Asija (1956) |
| 10 | Available P | Bray extraction and photoelectric colorimetry | Jackson (1958) |
| 11 | Available K | Flame photometry | Pratt (1965) |
| 12 | Available Ca | Versanate titration method | Hesse (1971) |
| 13 | Available Mg | Versanate titration method | Hesse (1971) |
| 14 | Available Cu | Atomic absorption spectroscopy | Emmel *et al.* (1977) |
| 15 | Available Zn | Atomic absorption spectroscopy | Emmel *et al.* (1977) |
| 16 | Available B | Photoelectric colorimetry | Gupta (1967) |

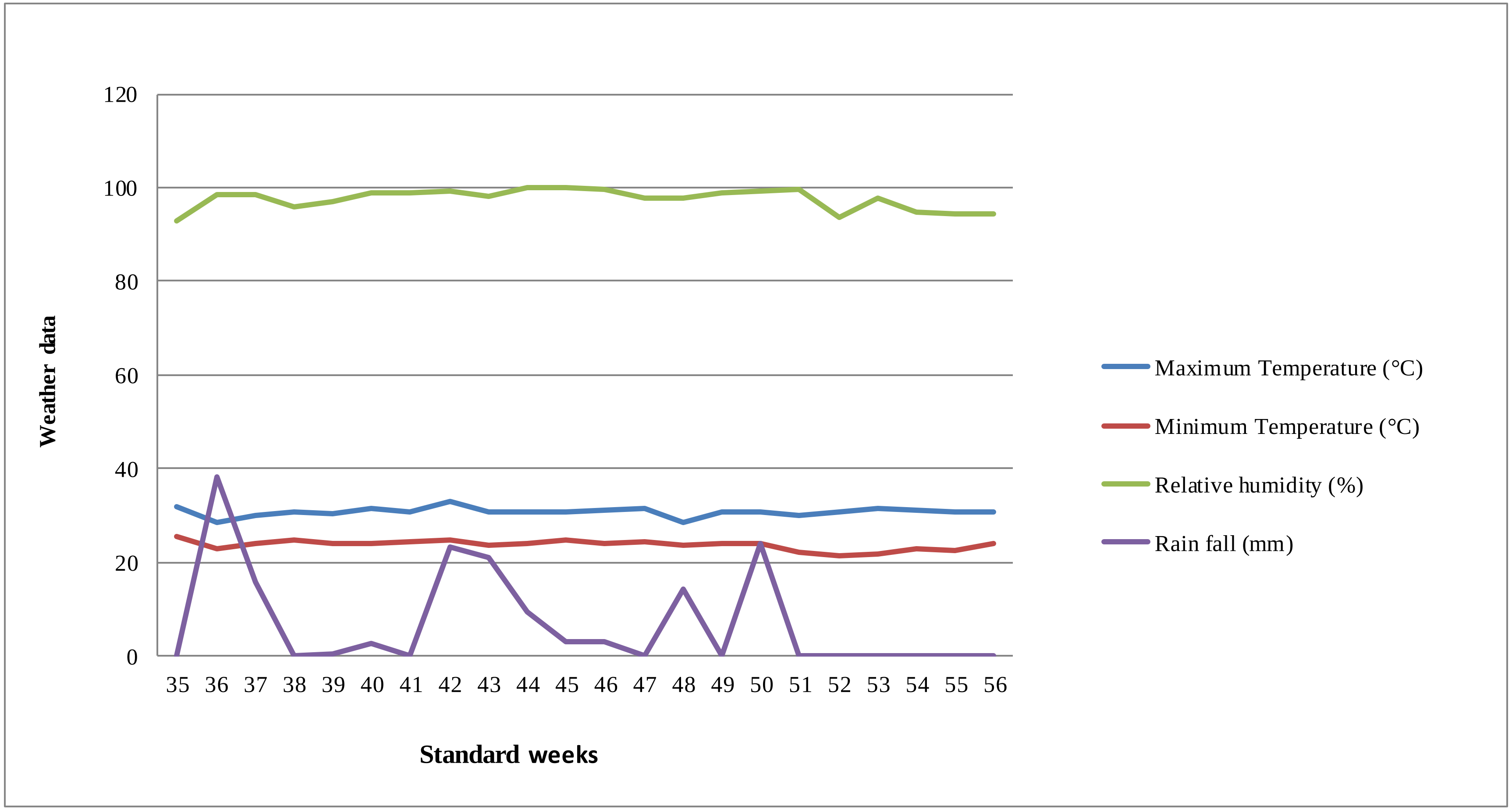


Fig. 1. Weather data for the cropping period: September-January 2015-‘16

The maximum and minimum temperatures recorded during the cropping period ranged from 32.95 to 28.44°C and 25.62 to 21.33°C respectively with a total rainfall of 155.19 mm. The data on weather parameters during the cropping period is illustrated in Fig. 1.

## 3.2 MATERIALS

### 3.2.1 Crop and Variety

The experiment was conducted with the medium duration (120 days) rice variety Uma (MO 16) which is non-lodging and resistant to brown plant hopper. Paddy seeds available at Cropping Systems Research Centre, Karamana were used for sowing.

### 3.2.2 Manures and Fertilizers

The fertilizer sources used were urea (46 per cent N), rajphos (20 per cent $P_2O_5$) and muriate of potash (60 per cent $K_2O$) for meeting the NPK requirements of the crop. Boron was given to the crop through borax (11.3 per cent B). Farmyard manure was applied @ 5 t $ha^{-1}$ and lime was applied as per soil pH based *ad hoc* recommendations for lime application according to the Package of Practices recommendations of Kerala Agricultural University (KAU, 2011).

## 3.3 METHODS

### 3.3.1 Design and Layout

The experiment consisted of nine treatments which were replicated thrice. Details of experiment are given below.

| | |
|---|---|
| Variety | : Uma |
| Design | : Randomized block design |
| Replications | : 3 |
| Plot size | : 5 m x 4 m |

Spacing : 20 cm x 10 cm

Season : Rabi 2015-‘16

Number of treatments: 9

$T_1$ - Soil application of 0.25 kg B $ha^{-1}$
$T_2$ - Soil application of 0.5 kg B $ha^{-1}$
$T_3$ - Soil application of 0.75kg B $ha^{-1}$
$T_4$ - Soil application of 1.0 kg B $ha^{-1}$
$T_5$ - Foliar spray of 250 ppm B
$T_6$ - Foliar spray of 500 ppm B
$T_7$ - Foliar spray of 750 ppm B
$T_8$ - Foliar spray of 1000 ppm B
$T_9$ - No B control

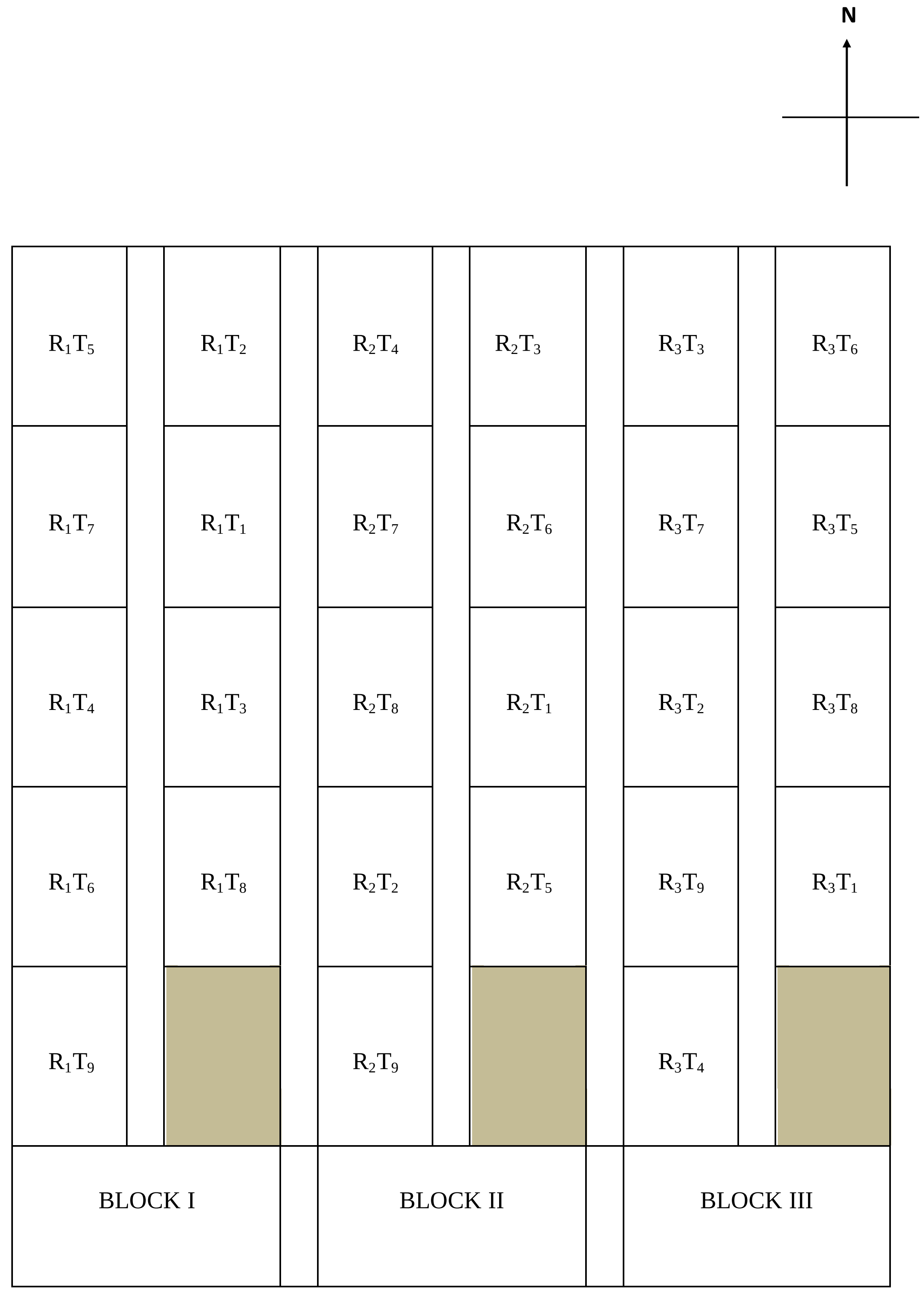
Boron was applied in two equal split doses at active tillering and flowering stages. The layout of the field experiment is shown in Fig. 2.

### 3.3.2 Nursery

Pre-germinated seeds of rice (variety Uma) were sown in the nursery area prepared by ploughing and levelling. Healthy seedlings were raised as per the Package of Practices (POP) recommendations of KAU (2011) for transplanting in the main field.

### 3.3.3 Main Field

The experimental field was ploughed well to remove weeds and puddled to a uniform tilth. Nine plots of 5m x 4m were prepared in all the three replications by forming bunds of 30 cm width. Irrigation and drainage channels of width 30 cm each were also provided in between the plots to maintain the water level as per requirement.



| | | | | | |
|---|---|---|---|---|---|
| $R_1T_5$ | $R_1T_2$ | $R_2T_4$ | $R_2T_3$ | $R_3T_3$ | $R_3T_6$ |
| $R_1T_7$ | $R_1T_1$ | $R_2T_7$ | $R_2T_6$ | $R_3T_7$ | $R_3T_5$ |
| $R_1T_4$ | $R_1T_3$ | $R_2T_8$ | $R_2T_1$ | $R_3T_2$ | $R_3T_8$ |
| $R_1T_6$ | $R_1T_8$ | $R_2T_2$ | $R_2T_5$ | $R_3T_9$ | $R_3T_1$ |
| $R_1T_9$ | | $R_2T_9$ | | $R_3T_4$ | |
| BLOCK I | | BLOCK II | | BLOCK III | |

Fig. 2. Layout of the experimental field

Plate 1. General view of the experimental field

### 3.3.4 Transplanting

In order to wash out the excess acidity, liming was given during the first ploughing followed by irrigation and drainage of the field. Twenty days old seedlings were transplanted @ 2-3 seedlings per hill, at 3-4 cm depth, and at a spacing of 20 cm x 10 cm.

### 3.3.5 Fertilizer Application

Fertilizers were applied as per Package of Practices (POP) recommendations of KAU (2011). Liming was given @ 350 kg $ha^{-1}$ as per pH based *ad hoc* recommendations for lime application according to the Package of Practices (POP) recommendations of Kerala Agricultural University (KAU, 2011). The nutrient recommendation for high yielding varieties raised in wet lands is 90:45:45 kg NPK per ha. Half the dose of N and K and full dose of P was applied as basal. The remaining dose of nitrogen and potassium was applied at panicle initiation stage. The requirements of N, P, and K were met through urea, rajphos and muriate of potash respectively. As per the treatments, B was applied as borax in two equal splits *viz.*, at active tillering and flowering stages by soil and foliar methods.

### 3.3.6 Water Management

A water level of 1.5 cm was maintained during transplanting and it was increased to about 5 cm which was maintained throughout the growth period with occasional drainage. The experimental area was drained 10 days prior to harvest.

### 3.3.7 Weed Management

Two hand weedings at 20 and 40 DAT were given so as to maintain the field weed free up to 45 DAT.

### 3.3.8 Harvest

The crop was harvested from individual plots leaving two border rows from all sides wth the net plot area harvested separately. After threshing and winnowing, the grain and straw yields were recorded separately from individual plots.

## 3.4 OBSERVATIONS

The details of different observations taken during the experiment are presented below.

### 3.4.1 Plant Biometric Observations

#### *3.4.1.1 Number of Tillers*

Six hills were randomly selected and tagged from the net plot area of each plot as sample plants. The number of tillers per hill was counted from these six hills at active tillering and harvest stages and the average at each stage were calculated.

#### *3.4.1.2 Number of Productive Tillers*

The number of productive tillers per hill was counted from the six sample plants in each plot at harvest stage and the average was recorded.

#### *3.4.1.3 Spikelet Sterility*

The number of filled and unfilled grains was counted from 10 panicles in each plot, mean taken and the spikelet sterility was computed using the equation given below.

$$\text{Spikelet sterility (\%)} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

#### *3.4.1.4 Shoot Length at Harvest*

Shoot length was measured at harvest stage from base of the stem to the tip of the youngest leaf from the six sample plants of each plot, using a meter scale, average worked out and expressed in cm.

#### *3.4.1.5 Root Length after Harvest*

Root length was measured after harvest from the six sample plants of each plot using a meter scale, average worked out and expressed in cm.

### 3.4.2 Yield and Yield Attributes

#### *3.4.2.1 Panicle Length*

Panicle length was measured from neck of the panicle to tip using a meter scale from the ten randomly selected panicles of each plot, average calculated and expressed in cm.

#### *3.4.2.2 Panicle Weight*

Panicle weight was taken from ten randomly selected panicles of each plot, average calculated and expressed in g.

#### *3.4.2.3 Number of Spikelets per Panicle*

The number of spikelets per panicle was counted from randomly selected ten panicles of each plot and the average was recorded.

#### *3.4.2.4 Percentage Filled Grains*

The number of filled and unfilled grains from ten randomly selected panicles of every plot was counted, mean taken and the percentage filled grains was computed using the equation given below.

$$\text{Percentage filled grains} = \frac{\text{Number of filled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

#### *3.4.2.5 Thousand Grain Weight*

Thousand grain weight from all the plots was calculated separately and expressed in g.

### *3.4.2.6 Grain and Straw Yield*

The crop from each plot was harvested and threshed separately and the weight of grain and straw was recorded. The grain yield and straw yield were then expressed in t ha$^{-1}$.

## **3.4.3 Scoring of Pests and Diseases**

### *3.4.3.1 Scoring of Pests*

#### *a. Leaf Folder*

The number of total and leaf folder attacked leaves was counted from ten randomly selected hills from each plot and the percentage of attack was calculated from the average value.

$$\text{Percentage of pest infestation (\%)} = \frac{\text{Number of leaf folder attacked leaves/hill}}{\text{Total number of leaves per hill}} \times 100$$

Scoring was done based on the following scale developed by International Rice Research Institute (2002).

| Scale | Damaged plants |
|---|---|
| 0 | No damage |
| 1 | 1-10 % |
| 3 | 11-20 % |
| 5 | 21-35 % |
| 7 | 36-50 % |
| 9 | 51-100 % |

### *3.4.3.2 Scoring of Diseases*

#### *a. Brown Spot*

Ten leaves each were collected from ten randomly selected hills of each plot and percentage of affected leaf area was recorded by using the standard area diagram for assessment of brown spot of rice. Based on the percentage of affected leaf area, scoring was done (IRRI, 2002) and expressed in terms of Percentage of Disease Incidence (PDI).

$$\text{PDI} = \frac{\text{Sum of grades}}{\text{Total number of sample leaves x maximum grade}} \times 100$$

| Scale | Affected leaf area |
|---|---|
| 0 | No incidence |
| 1 | Less than 1% |
| 2 | 1-3% |
| 3 | 4-5% |
| 4 | 6-10 % |
| 5 | 11-15% |
| 6 | 16-25% |
| 7 | 26-50% |
| 8 | 51-75% |
| 9 | 76-100% |

### 3.4.4 Seed Germination after Harvest

Seeds collected from each treatment plot were tested for germination percentage in petri plates and the number of seeds germinated in each plate was recorded and expressed in percentage.

## 3.5 CHEMICAL ANALYSIS

### 3.5.1 Soil Analysis

Soil samples were collected from the harvested field for analysing the nutrient status of the soil after the crop. Soil samples were taken at 15 cm depth, from different spots in each plot, and composite samples were prepared by quartering method. The samples were air dried, ground, passed through 2 mm sieve, and stored air tight.

The processed samples were analysed for pH, EC, CEC, and soil available nutrient status (N, P, K, Ca, Mg, Cu, Zn and B). The standard procedures adopted are detailed in Table 1.

### 3.5.1.1 Estimation of Boron in Soil Samples

Hot water extraction method by Gupta (1967) was adopted for the estimation of B in the soil samples.

Air dried and sieved soil sample (20 g) was taken in a 250 ml conical flask and boiled on a hot plate for 5 minutes after adding 0.5 g activated charcoal and 40 ml distilled water. This was filtered immediately through a Whatman no. 42 filter paper and cooled to room temperature. The aliquot (1 ml) was transferred to 10 ml polypropylene tube and 2 ml each of buffer and azomthine-H reagent were added. After 30 minutes, the absorbance was read on a spectrophotmeter (104) at 420 nm after standardisation using B solutions (0.1, 0.2, 0.4, 0.6, 0.8, and 1 ppm) with the above procedure.

### 3.5.2 Plant Analysis

Plant samples were collected at different growth stages for analysis. Index leaf samples at critical growth stages were collected from all the treatment plots for analysis of B content. Shoot samples at tillering and flowering stages were collected from all the treatment plots for the analysis of phenols in shoot. Grain and straw samples were collected after harvest from the treatment plots for the analysis of nutrients (N, P, K Ca, Mg, Cu, Zn, and B) and phenols at harvest stage. The leaf and shoot samples collected were washed with water in order to minimise the soil contamination. All the plant samples were dried in oven at 70˚C, ground and used for analysis. The standard procedures for plant analysis are given in table 2.

Table 2. Analytical methods followed in plant analysis

| Sl. No. | Parameter | Method | Reference |
|---|---|---|---|
| 1 | Total N | Kjeldahl method | Jackson (1958) |
| 2 | Total P | Vanado molybdate yellow colour method | Piper (1966) |
| 3 | Total K | Flame photometry | Jackson (1958) |
| 4 | Total Ca | Versanate titration method | Hesse (1971) |
| 5 | Total Mg | Versanate titration method | Hesse (1971) |
| 6 | Total Cu | Atomic Absorption Spectroscopy | Emmel *et al.* (1977) |
| 7 | Total Zn | Atomic Absorption Spectroscopy | Emmel *et al.* (1977) |
| 8 | Total B | Azomethine-H colorimetric method | Wolf (1971) |

### 3.5.2.1 Estimation of Boron in Plant Samples

Dried plant sample (0.5 g) was mixed well with 0.1 g calcium oxide powder and transferred to a porcelain crucible placed in a muffle furnace. The furnace temperature was raised gradually to a maximum of 550˚C and the sample was ignited completely, and then cooled with water. 3 ml dilute HCl (1:1) was added and heated for 20 minutes on a water bath. The contents were transferred to a 25 ml standard flask and volume was made up with distilled water.

The made up digest (1 ml) was transferred into polypropylene tube to which were added 2 ml each of buffer and azomethine-H reagent. Absorbance was read at 420 nm on a spectrometer after 30 minutes. Standard B solutions (0.1, 0.2, 0.4, 0.6, 0.8, and 1 ppm) were also read using the same procedure.

### 3.5.2.2 Determination of Phenol in Plant Samples

Small cut pieces of dried plant tissue (0.5 g) was ground with a pestle and mortar using 80 per cent ethanol with ten times the volume and the homogenate was centrifuged at 10,000 rpm for 20 minutes. The residue was re-extracted with 80 per cent ethanol five times the volume, centrifuged and pooled. The supernatant was evaporated to dryness by heating on a water bath and the residue was dissolved in 5ml distilled water. The aliquot (0.5 ml) was pipetted out into test tube, and 2.5 ml distilled water and 2 ml Folin-ciocalteau reagent were added. Two milli litres of 20 per cent sodium carbonate solution was also added after 3 minutes, mixed well and placed in a boiling water bath for 1 min. The contents were cooled and absorbance was read in a spectrophotometer at 650 nm. A standard curve was prepared with different concentrations of catechol (Ismail *et al.*, 2010).

### 3.5.2.3 Nutrient uptake

Dry weights of straw and grain were taken after drying the samples in a hot air oven at 70° C for computing the nutrient uptake separately. Nutrient uptake was calculated by using the following formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Concentration of nutrient (\%) x Dry matter production}}{100}$$

## 3.6 ECONOMICS OF CULTIVATION

Based on the cost of cultivation and prevailing minimum support price (Govt. MSP) of the produce, the economics of cultivation was worked out and expressed in terms of benefit-cost ratio.

$$\text{B:C ratio} = \frac{\text{Gross income}}{\text{Total expenditure}}$$

## 3.7 STATISTICAL ANALYSIS

The data recorded during the field experiment as well as the chemical analysis were subjected to analysis of variance for RBD (Cochran and Cox, 1965) using MS Office Excel.

# *Results*

# 4. RESULTS

The results obtained from the field experiment conducted at Cropping Systems Research Centre, Karamana during the rabi season of 2016 to standardize the dose and method of application of B to wet land rice are presented in this chapter.

## 4.1 SITE CHARACTERIZATION

The basic physico-chemical properties of the soil of the experimental site are presented in Table 3. The bulk density and particle density of the soil were found to be 1.23 Mg $m^{-3}$ and 2.58 Mg $m^{-3}$ respectively with a porosity of 52.32 per cent. The texture of the soil was observed to be sandy clay with a textural composition of 48.08 percent sand, 2.72 per cent silt and 49.20 per cent clay. The soil reaction was strongly acid (pH-5.15) and the electrical conductivity was normal (0.19 dS $m^{-1}$). Chemical analysis of the soil revealed that the cation exchange capacity (8.62 c mol $kg^{-1}$) was low and the organic carbon content (0.85 per cent) was medium in status. The available nitrogen (376 kg $ha^{-1}$) and potassium contents (179 kg $ha^{-1}$) were found to be in the medium range and the available phosphorus (48 kg $ha^{-1}$) was in the higher range. The soil was high in secondary nutrients *viz*., calcium (315 mg $kg^{-1}$), magnesium (260 mg $kg^{-1}$) and sulphur (14 mg $kg^{-1}$). Among the micronutrients, copper and zinc were found to be sufficient and the B content of the soil was found to be deficient.

## 4.2 EFFECT OF BORON APPLICATION ON PLANT GROWTH PARAMETERS OF WET LAND RICE

The effect of different levels and methods of boron application on plant growth parameters like shoot length, root length, number of total and productive tillers per hill and spikelet sterility are presented in Table 4.

Table 3. Physico-chemical properties of the soil of the experimental site

| Sl. No. | Physico-chemical properties | Status | Rating |
|---|---|---|---|
| I. Physical properties | | | |
| 1 | Bulk density (Mg m$^{-3}$) | 1.23 | |
| 2 | Particle density (Mg m$^{-3}$) | 2.58 | |
| 3 | Porosity (%) | 52.32 | |
| II. Mechanical composition | | | |
| 1 | Sand (%) | 48.08 | |
| 2 | Silt (%) | 2.72 | |
| 3 | Clay (%) | 49.2 | |
| 4 | Texture | Sandy clay | |
| III. Chemical properties | | | |
| 1 | pH | 5.15 | Strongly acid |
| 2 | EC (dS m$^{-1}$) | 0.19 | Normal |
| 3 | CEC (c mol kg$^{-1}$) | 8.62 | Low |
| 4 | Organic carbon (%) | 0.85 | Medium |
| 5 | Available N (kg ha$^{-1}$) | 376 | Medium |
| 6 | Available P (kg ha$^{-1}$) | 48 | High |
| 7 | Available K (kg ha$^{-1}$) | 179 | Medium |
| 8 | Available Ca (mg kg$^{-1}$) | 315 | High |
| 9 | Available Mg (mg kg$^{-1}$) | 260 | High |
| 10 | Available S (mg kg$^{-1}$) | 14 | High |
| 11 | Available Cu (mg kg$^{-1}$) | 3.8 | Sufficient |
| 12 | Available Zn (mg kg$^{-1}$) | 9.8 | Sufficient |
| 13 | Available B (mg kg$^{-1}$) | 0.5 | Deficient |

Shoot length of rice at harvest was significantly influenced by both soil and foliar application of boron. Shoot lengths for soil treatments $T_1$, $T_2$ and $T_3$ (96.36 cm, 96.21 cm and 96.17 respectively) were on par with control (95.46 cm) though numerical increases were obtained for the B applied treatments. Significantly lower (93.16 cm) shoot length was recorded by the treatment receiving B application @ 1.0 kg $ha^{-1}$ ($T_4$) compared to all other soil treatment levels and the control. Among the foliar treatments, $T_5$ *viz.,* foliar B application @ 250 ppm recorded significantly higher shoot length (97.81 cm) compared to higher concentrations of foliar spray and the no B control which were on par.

The effect of different treatments on root length was significant. Among the soil treatments, the highest root length of 19.26 cm was given by $T_2$ which received 0.5 kg B $ha^{-1}$ and was on par with $T_3$ (19.13 cm) and $T_1$ (18.92 cm). The treatments $T_1$, $T_2$ and $T_3$ recorded significantly higher root lengths compared to the control plot (17.15 cm) which was on par with $T_4$ (17.8 cm). Among the foliar treatments, the treatment receiving 250 ppm B spray ($T_5$) recorded significantly higher root length (18.41 cm) compared to higher concentrations which were on par with the no B control.

The total number of tillers and the number of productive tillers per hill were not significantly influenced by the treatments. The values ranged from 7.16 to 8.61 for total number of tillers and 6.92 to 8.27 for the number of productive tillers per hill. Though the treatment effects were not significant, it was seen that application of B up to 0.75 kg $ha^{-1}$ gave an increasing trend for these parameters compared to control.

### 4.3 EFFECT OF BORON ON YIELD ATTRIBUTES OF RICE

Table 5 presents the influence of different levels and methods of boron application on yield attributes of wet land rice *viz.,* weight per panicle, percentage

Table 4. Effect of boron on plant growth parameters of rice

| Treatments | Shoot length at harvest (cm) | Root length after harvest (cm) | Number of tillers per hill | Productive tillers per hill |
|---|---|---|---|---|
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 96.36 | 18.92 | 8.52 | 8.21 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 96.21 | 19.26 | 8.61 | 8.27 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 96.17 | 19.13 | 8.23 | 8.16 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 93.16 | 17.80 | 8.15 | 7.81 |
| $T_5$- Foliar spray of 250 ppm B | 97.81 | 18.41 | 8.04 | 7.59 |
| $T_6$- Foliar spray of 500 ppm B | 94.63 | 16.64 | 7.82 | 7.48 |
| $T_7$- Foliar spray of 750 ppm B | 95.13 | 16.75 | 7.94 | 7.43 |
| $T_8$- Foliar spray of 1000 ppm B | 94.18 | 16.18 | 7.16 | 6.92 |
| $T_9$- Control – No boron | 95.46 | 17.15 | 8.16 | 7.82 |
| CD (0.05) | 2.186 | 1.233 | NS | NS |

filled grains, thousand grain weight, panicle length and number of spikelets per panicle.

The weight per panicle was significantly influenced by boron application. Among the soil treatments significantly higher panicle weight compared to control was obtained for $T_4$ (2.71 g) which was on par with $T_3$ (2.24 g). The lower levels of soil B application *viz.*, $T_1$, $T_2$ and $T_3$ were on par with the no B control. Among foliar treatments, 250 ppm B recorded significantly higher value (2.51 g) compared to control but higher levels of foliar B application ($T_6$ to $T_8$) resulted in weight of panicle on par with control.

Observations on the percentage of filled grains revealed that the treatment effect was significant in case of both soil and foliar application methods. Application of 1.0 kg B ha$^{-1}$ ($T_4$) and 0.75 kg B ha$^{-1}$ ($T_3$) in the soil resulted in significantly higher percentage filled gains (83.67 and 82.27 per cent respectively) compared to control. Treatment $T_4$ was on par with $T_3$ but significantly superior to $T_1$ and $T_2$ in percentage filled gains. The foliar treatment of 250 ppm B spray in two splits resulted in significantly higher value (83.20 per cent) compared to $T_7$, $T_8$ and the control.

Spikelet sterility showed significant difference among the different treatments. Supplying boron through soil @ 0.5 to 1.0 kg ha$^{-1}$ ($T_2$ to $T_4$), significantly reduced the percentage of sterile spikelets compared to control. The highest soil B treatment $T_4$ recorded the lowest spikelet sterility of 16.33 per cent which was significantly lower than the lower levels of B application *viz.*,$T_2$ (19.37 per cent) and $T_1$ (20.30 per cent) but on par with $T_3$. The lowest soil B level, $T_1$ produced sterile spikelets on par with the no B control (21.93 per cent). Among the foliar treatments, the lower levels $T_5$ (250 ppm B) and $T_6$ (500 ppm B) were on par and gave significantly lower spikelet sterility (16.80 per cent and 18.90 per cent respectively) than the no B control. Higher foliar B concentrations *viz.*, $T_7$ and $T_8$

Table 5. Effect of boron on yield attributes of rice

| Treatments | Panicle length (cm) | Weight per panicle (g) | Number of spikelets per panicle | Percentage filled grains | Spikelet sterility (%) | Thousand grain weight (g) |
|---|---|---|---|---|---|---|
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 19.89 | 1.64 | 118.43 | 79.70 | 20.30 | 24.43 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 20.09 | 1.89 | 124.02 | 80.63 | 19.37 | 25.16 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 20.32 | 2.24 | 126.94 | 82.27 | 17.73 | 24.53 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 20.59 | 2.71 | 130.42 | 83.67 | 16.33 | 24.48 |
| $T_5$- Foliar spray of 250 ppm B | 20.30 | 2.51 | 129.71 | 83.20 | 16.80 | 23.46 |
| $T_6$- Foliar spray of 500 ppm B | 19.99 | 2.26 | 122.09 | 81.10 | 18.90 | 23.46 |
| $T_7$- Foliar spray of 750 ppm B | 20.03 | 2.27 | 117.63 | 80.40 | 19.60 | 23.43 |
| $T_8$- Foliar spray of 1000 ppm B | 19.93 | 2.18 | 119.27 | 79.70 | 20.30 | 23.37 |
| $T_9$- Control – No boron | 19.86 | 1.98 | 116.82 | 78.07 | 21.93 | 22.78 |
| CD (0.05) | NS | 0.511 | NS | 2.640 | 2.640 | 1.138 |

produced sterile spikelets significantly higher than $T_5$ and on par with $T_6$ and the no boron control.

Thousand grain weight showed significant differences among the treatments with all the four levels of soil application from 0.25 to 1.0 kg B ha$^{-1}$ being on par and registering significantly higher values (24.43, 25.16, 24.53 and 24.48 g respectively) compared to the no boron control (22.78 g). The treatment effect was not significant among foliar treatments which were on par with control. The lowest value (22.78 g) among all the treatments was noticed for the no boron control.

Though panicle length and number of spikelets per panicle were not significantly affected by boron application, there was an increase in values as the level of soil applied B increased and a general decrease in values as the concentration of foliar spray increased.

## 4.4 EFFECT OF BORON ON GRAIN AND STRAW YIELDS

The influence of levels and methods of boron application on grain and straw yields is presented in Table 6.

The data on grain yield (Table 6) indicated that all the soil and foliar treatments recorded significantly higher values as compared to the no boron control. The highest grain yield among the soil treatments was given by the treatment $T_4$ (5502.85 kg ha$^{-1}$) which was on par with $T_3$ (5443.93 kg ha$^{-1}$). The yields obtained by all the foliar treatments were on par and significantly higher than that of the control. Among the foliar treatments, 250 ppm B spray in two splits resulted in the highest grain yield (5195.20 kg ha$^{-1}$) followed by 500 ppm B spray (5176.12 kg ha$^{-1}$). The treatments had significant effect on straw yield (Table 6). Among the soil treatments, significantly higher straw yield (7014.52 kg ha$^{-1}$) was registered by $T_4$ receiving 1 kg B ha$^{-1}$, compared to the no B control. The treatment $T_4$ was on par with $T_3$ (6359.44 kg ha$^{-1}$) and $T_2$ (6221.76 kg ha$^{-1}$). $T_1$ recorded the lowest straw yield (5210.16 kg ha$^{-1}$) which was on par with control (5513.06 kg ha$^{-1}$). Among the foliar treatments, $T_5$ to $T_7$ registered straw yields significantly higher than control. Foliar application of 250 ppm B resulted in the highest straw yield (6853.65 kg ha$^{-1}$) which was on par with $T_6$, $T_7$ and $T_8$. The lowest straw yields were recorded for $T_1$ receiving 0.25 kg B ha$^{-1}$ as soil application and the no boron control ($T_9$). There was an increase in straw yield as the level of B application to soil increased, whereas with increase in concentration of B spray to foliage, a decreasing trend was noticed in yield.

In general there is an increase in straw and grain yields as the level of soil B application increases and though there is a decrease in these values as the concentration of foliar spray increased the yields were higher than control.

## 4.5 EFFECT OF BORON ON INCIDENCE OF PESTS AND DISEASES

### 4.5.1 Pest Scoring

Data presented in Table 7 show that boron application did not significantly affect pest infestation irrespective of the mode of application.

### 4.5.2 Percentage of Disease Incidence (PDI)

Boron treatments significantly influenced the percentage of disease incidence (Table 7) with the no boron control recording the highest PDI (12.22 per cent) compared to the B applied treatments. Among the soil treatments the highest PDI (10.74 per cent) was recorded by the lowest level of B application *viz.*, $T_1$ which was on par with $T_2$ (10.37 per cent) and the control. The lowest disease incidence (8.88 per cent each) was noticed in the higher levels ($T_3$ and $T_4$) of soil B application. Among the foliar treatments, the highest value (11.11 per cent) was registered by the lowest B level ($T_5$), which was on par with the higher levels of foliar application and the control. The highest level of boron spray (1000 ppm) resulted in the lowest disease incidence (9.63 per cent) which was on par with rest of the foliar treatments and significantly lower than control.

Table 6. Effect of boron on grain and straw yields (on dry weight basis)

| Treatments | Grain yield (kg $ha^{-1}$) | Straw yield (kg $ha^{-1}$) |
|---|---|---|
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 5074.45 | 5210.16 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 5199.26 | 6221.76 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 5443.93 | 6359.44 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 5502.85 | 7014.52 |
| $T_5$- Foliar spray of 250 ppm B | 5195.20 | 6853.65 |
| $T_6$- Foliar spray of 500 ppm B | 5176.12 | 6713.06 |
| $T_7$- Foliar spray of 750 ppm B | 5104.94 | 6731.91 |
| $T_8$- Foliar spray of 1000 ppm B | 5124.27 | 6386.98 |
| $T_9$- Control – No boron | 4667.60 | 5513.06 |
| CD (0.05) | 291.283 | 1085.851 |

Table 7. Effect of boron on incidence of pest and disease in rice

| Treatments | Pest scoring | Percentage of Disease Incidence (PDI) |
|---|---|---|
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 3.00 | 10.74 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 3.67 | 10.37 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 3.00 | 8.88 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 3.00 | 8.88 |
| $T_5$- Foliar spray of 250 ppm B | 3.00 | 11.11 |
| $T_6$- Foliar spray of 500 ppm B | 3.00 | 10.00 |
| $T_7$- Foliar spray of 750 ppm B | 3.00 | 10.74 |
| $T_8$- Foliar spray of 1000 ppm B | 3.00 | 9.63 |
| $T_9$- Control – No boron | 3.00 | 12.22 |
| CD (0.05) | * | 1.77 |

(* Data not statistically analyzed)

## 4.6 EFFECT OF BORON ON ECONOMICS OF CULTIVATION

The effect of B application on cost of cultivation, gross returns, net returns and benefit-cost ratio are presented in Table 8.

The different treatments had no significant effect on cost of cultivation of paddy (Table 8). The cost of cultivation ranged from ₹ 102367 to ₹ 102708 for the soil treatments and ₹ 102310 to ₹ 102480 for foliar treatments. Compared to all the treatments the no boron control had the lowest cost of cultivation.

Data on gross returns of paddy from one hectare (Table 8) showed that different levels of B application either in the soil or as foliar spray significantly increased the gross returns. Soil B application at levels $T_2$ to $T_4$ gave gross returns significantly greater than control. Application of B @ 1.0 kg ha$^{-1}$ resulted in the highest gross returns (₹ 156135) which was on par with the application of 0.75 kg B ha$^{-1}$ (₹ 151564). With respect to foliar treatments, all foliar levels gave gross returns significantly higher than the no B control with $T_5$ recording the highest gross returns (₹ 148563) which was on par with rest of the foliar application levels.

The net returns per hectare presented in Table 8 also shows that all B application treatments (except $T_1$) gave net returns significantly higher than the no B control ($T_9$). Among the soil treatments, the treatment $T_4$ gave the highest net returns (₹ 53427) which was on par with $T_3$ (₹ 48970). Among foliar treatments, B spray of 250 ppm in two splits resulted in the highest net returns (₹ 46253) which was on par up to the highest foliar treatment. The no boron control gave significantly reduced net returns. The net returns was found to increase with incremental additions of B through soil but as foliar concentration increased the net returns was found to decrease.

The benefit-cost ratio of the various treatments was found to differ significantly (Table 8), with all the treatments except $T_1$ giving B:C ratio significantly higher than control. The highest computed B:C ratio among soil treatments was 1.52, recorded by treatment $T_4$ which was on par with $T_3$ (1.48). The lowest ratio (1.35) was recorded by $T_1$ which was on par with $T_2$ (1.42) and the no B control (1.29). Among the foliar treatments, 250 ppm B spray in two splits resulted in the highest B:C ratio (1.45) which was found to be on par with rest of the foliar treatments. The B:C was also found to increase with increased addition of B to soil but decreased with increasing concentration of B in spray fluid.

## 4.7 EFFECT OF BORON ON THE BORON CONTENT OF INDEX LEAF AT CRITICAL STAGES

The effect of different levels and methods of application of boron on the boron content of index leaf at critical stages *viz.*, active tillering, panicle initiation and flowering stages is indicated in Table 9.

Boron contents at active tillering stage indicate that all the soil and foliar treatments resulted in significantly higher values compared to the no B control. Soil application of B @ 1.0 kg ha$^{-1}$ recorded the highest boron content (10.07 mg kg$^{-1}$) compared to the rest of the soil treatments and control and the values decreased towards the lowest level ($T_1$). The treatment $T_1$ which registered the lowest B content was on par with $T_2$. Among the foliar treatments, 250 ppm B spray recorded the highest boron content (13.03 mg kg$^{-1}$) and thereafter a decreasing trend was observed towards the higher levels of sprays though values were greater than control. 1000 ppm B spray recorded the lowest B content which was on par with 750 ppm spray.

At panicle initiation stage also, the boron content of index leaf was significantly higher for all the soil and foliar treatments compared to control. Soil application of B @ 1.0 kg ha$^{-1}$ recorded the highest boron content (11.26 mg kg$^{-1}$) which was on par with 0.75 to 0.5 kg B ha$^{-1}$. Foliar application of B at all concentrations ($T_5$ to $T_8$) registered significantly higher boron contents than the control. 250 ppm B application through foliage resulted in the highest boron content

Table 8. Effect of boron on economics of cultivation

| Treatments | Cost of cultivation (₹ $ha^{-1}$) | Gross returns (₹ $ha^{-1}$) | Net returns (₹ $ha^{-1}$) | B:C ratio |
|---|---|---|---|---|
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 102367 | 137689 | 35322 | 1.35 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 102481 | 145493 | 43012 | 1.42 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 102594 | 151564 | 48970 | 1.48 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 102708 | 156135 | 53427 | 1.52 |
| $T_5$- Foliar spray of 250 ppm B | 102310 | 148563 | 46253 | 1.45 |
| $T_6$- Foliar spray of 500 ppm B | 102367 | 147440 | 45073 | 1.44 |
| $T_7$- Foliar spray of 750 ppm B | 102424 | 145968 | 43545 | 1.43 |
| $T_8$- Foliar spray of 1000 ppm B | 102480 | 144669 | 42188 | 1.41 |
| $T_9$- Control – No boron | 100949 | 130252 | 29303 | 1.29 |
| CD (0.05) | NS | 9155.787 | 9155.787 | 0.090 |

Table 9. Effect of boron on the content of boron in index leaf at critical stages

| Treatments | B content (mg $kg^{-1}$) | | |
|---|---|---|---|
| | Active tillering stage | Panicle initiation stage | Flowering stage |
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 5.92 | 8.98 | 12.54 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 6.81 | 10.07 | 18.17 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 8.69 | 11.16 | 18.66 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 10.07 | 11.26 | 13.63 |
| $T_5$- Foliar spray of 250 ppm B | 13.03 | 15.11 | 24.29 |
| $T_6$- Foliar spray of 500 ppm B | 11.45 | 14.32 | 20.14 |
| $T_7$- Foliar spray of 750 ppm B | 9.38 | 12.05 | 18.07 |
| $T_8$- Foliar spray of 1000 ppm B | 9.18 | 11.26 | 6.81 |
| $T_9$- Control – No boron | 4.74 | 4.84 | 5.04 |
| CD (0.05) | 0.937 | 1.538 | 1.867 |

(15.11 mg $kg^{-1}$) which was on par with 500 ppm spray while higher levels of foliar spray decreased the boron content significantly. The control plot (4.84 mg $kg^{-1}$) gave the lowest boron content of index leaf at panicle initiation stage.

Boron content of index leaf at flowering stage was significantly influenced by both the soil and foliar boron treatments. All the levels of soil and foliar application of boron registered significantly higher boron contents compared to the no boron control. The highest content (18.66 mg $kg^{-1}$) was given by the application of B @ 0.75 kg $ha^{-1}$ which was on par with 0.5 kg B application in soil. Application of B @ 1.0 kg $ha^{-1}$ resulted in a decrease in B content. The lowest content among soil treatments recorded by $T_1$ (12.54 mg $kg^{-1}$) was also significantly superior to the control (5.04 mg $kg^{-1}$). The lowest level of foliar spray (250 ppm) gave the highest boron content (24.29 mg $kg^{-1}$) among the foliar treatments and a further increase in the concentration of spray fluid resulted in lower boron contents. Foliar spray of 1000 ppm B recorded the lowest B content of index leaf among foliar treatments which was on par with control.

## 4.8 EFFECT OF BORON ON THE CONTENT AND UPTAKE OF NUTRIENTS IN STRAW AND GRAIN

### 4.8.1 Nitrogen

The effect of boron application at different levels through soil and foliar methods on the content and uptake of nitrogen in both straw and grain is given in Table 10.

The data presented shows that B treatments could not exert any significant influence on straw nitrogen content.

The treatment effect though significant in the case of grain nitrogen content, was not consistent. All the treatments gave N content on par with control. Among soil treatments, application of B @ 0.75 kg $ha^{-1}$ recorded the highest grain nitrogen content (1.16 per cent) which was on par with the application of 0.25 kg B ha$^{-1}$ (1.04 per cent) and the no B control (1.06 per cent). The lowest value was noticed in $T_2$ (0.91 per cent) which was on par with $T_4$ (0.96 per cent) and $T_1$ (1.04 per cent). Among the foliar treatments, a spray of 750 ppm B (1.16 per cent) registered the highest grain nitrogen content which was on par with the spray of 250 ppm B (1.13 per cent) and the control (1.06 per cent). Foliar spray of 1000 ppm B resulted in the lowest grain nitrogen content (0.98 per cent) which was on par with $T_6$ (1.01 per cent) and the no B control.

Nitrogen uptake by straw was significantly influenced by both the soil and foliar methods of B application (Table 10). Increasing the soil B application levels increased the N uptake by straw, with the higher levels *viz.,* 0.75 and 1.0 kg ha$^{-1}$ producing significantly higher straw nitrogen uptake (71.01 and 72.81 kg ha$^{-1}$) compared to all other soil treatments and the no B control, which were on par. The lowest value was recorded by $T_1$ (54.36 kg ha$^{-1}$) which was statistically on par with $T_2$ (60.07 kg ha$^{-1}$) and the control (58.25 kg ha$^{-1}$). Foliar spray of B @ 250 to 750 ppm resulted in significantly higher straw nitrogen uptake compared to the no B control. The highest uptake (80.57 kg ha$^{-1}$) among these treatments was given by 250 ppm B spray which was on par up to 750 ppm B (73.40 kg ha$^{-1}$). Increasing the B concentration of foliar spray generally decreased the N uptake by straw. The lowest uptake (58.25 kg ha$^{-1}$) was observed for the no boron control which was on par with 1000 ppm B spray (63.69 kg ha$^{-1}$).

Soil and foliar B application though significantly influenced the N uptake by grain, did not give consistent results. Soil application of B @ 0.75 kg ha$^{-1}$ ($T_3$) recorded significantly higher uptake (63.41 kg ha$^{-1}$) as compared to all other soil treatments and the no B control. The lowest value was observed in $T_2$ (47.44 kg ha$^{-1}$) which was on par with the no boron control (49.28 kg ha$^{-1}$) and all other soil treatments except $T_3$. Among the foliar B treatments, 250 ppm (58.58 kg ha$^{-1}$) and 750 ppm (59.49 kg ha$^{-1}$) recorded significantly higher grain nitrogen uptake values compared to the no B control. Foliar B application levels from 250 ppm to 750 ppm gave N uptake values, which were on par. The control plot gave the lowest value (49.28 kg ha$^{-1}$) which was on par with $T_6$ (52.20 kg ha$^{-1}$) and $T_8$ (50.38 kg ha$^{-1}$).

### 4.8.2 Phosphorus

The boron treatments at different levels through both soil and foliar methods had no significant effect on the straw phosphorus content and its uptake (Table 11).

Significant differences in grain phosphorus content were obtained after boron applications through soil and foliar methods. The lowest B application level of 0.25 kg B ha$^{-1}$ recorded significantly higher phosphorus content of 0.158 per cent compared to all other soil treatments and the no B control. The lowest value (0.138 per cent) was obtained for the no B control and $T_4$ which were on par with the all other levels of soil B application except $T_1$. All the foliar treatments registered significantly higher grain phosphorus contents compared to the no B control. The highest among them was given by the lowest spray level of 250 ppm B (0.163 per cent) which was significantly higher than the higher levels of foliar application as well as the no B control.

The different treatments exhibited significant effect on grain phosphorus uptake for both soil and foliar methods of application, with an increase in P uptake values with increased levels of B application either through soil or through foliage. It was also found that the highest uptake values were recorded by the lowest levels of B application either through soil or foliage. The highest uptake among soil treatments was noticed for $T_1$ (8.00 kg ha$^{-1}$) receiving 0.25 kg ha$^{-1}$ B which was on par with $T_3$ (7.67 kg ha$^{-1}$) and $T_4$ (7.61 kg ha$^{-1}$). Foliar spray of 250 ppm B recorded significantly higher P uptake (8.49 kg ha$^{-1}$) than all other foliar treatments and the control. P uptake by the higher foliar B levels $T_6$, $T_7$ and $T_8$ (7.64, 7.66 and 7.64 kg ha$^{-1}$) were on par and significantly greater than control.

Table 10. Effect of boron on the content and uptake of nitrogen in straw and grain

| Treatments | N content (%) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 1.04 | 1.04 | 54.36 | 52.91 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 0.97 | 0.91 | 60.07 | 47.44 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 1.12 | 1.16 | 71.01 | 63.41 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 1.04 | 0.96 | 72.81 | 52.64 |
| $T_5$- Foliar spray of 250 ppm B | 1.18 | 1.13 | 80.57 | 58.58 |
| $T_6$- Foliar spray of 500 ppm B | 1.04 | 1.01 | 70.23 | 52.20 |
| $T_7$- Foliar spray of 750 ppm B | 1.09 | 1.16 | 73.40 | 59.49 |
| $T_8$- Foliar spray of 1000 ppm B | 0.99 | 0.98 | 63.69 | 50.38 |
| $T_9$- Control – No boron | 1.06 | 1.06 | 58.25 | 49.28 |
| CD (0.05) | NS | 0.144 | 10.846 | 8.059 |

Table 11. Effect of boron on the content and uptake of phosphorus in straw and grain

| Treatments | P content (%) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 0.120 | 0.158 | 6.22 | 8.00 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 0.111 | 0.140 | 6.84 | 7.28 |
| $T_3$- Soil application of 0.75 kg B ha$^{-}$ | 0.122 | 0.141 | 7.77 | 7.67 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 0.107 | 0.138 | 7.48 | 7.61 |
| $T_5$- Foliar spray of 250 ppm B | 0.110 | 0.163 | 7.51 | 8.49 |
| $T_6$- Foliar spray of 500 ppm B | 0.124 | 0.148 | 8.31 | 7.64 |
| $T_7$- Foliar spray of 750 ppm B | 0.110 | 0.150 | 7.37 | 7.66 |
| $T_8$- Foliar spray of 1000 ppm B | 0.114 | 0.149 | 7.29 | 7.64 |
| $T_9$- Control – No boron | 0.119 | 0.138 | 6.55 | 6.41 |
| CD (0.05) | NS | 0.009 | NS | 0.620 |

### 4.8.3 Potassium

Influence of boron application at different levels through soil and foliar methods on the content and uptake of potassium in straw and grain is presented in Table 12.

Soil B application at any of the four levels generally decreased the potassium content of straw compared to control (1.17 per cent). At the lowest application level of 0.25 kg B $ha^{-1}$ a straw K content of 1.01 per cent was attained which was on par with control. Higher levels of B application (0.5, 0.75 and 1.0 kg B $ha^{-1}$) gave significantly reduced potassium content (1.00, 0.97 and 0.95 per cent respectively) compared to control. Among the foliar treatments, the highest straw potassium content was registered by the lower application levels, *viz.*, $T_5$ and $T_6$ (1.31 per cent each,) which was on par with the control (1.17 per cent). Increasing the B concentration of the spray fluid to 750 ppm or 1000 ppm B lowered the straw potassium content and at 1000 ppm B the values were significantly lower than the control.

Observations revealed that the B treatments improved the grain potassium content compared to the no B control with a soil application of 0.25 kg B $ha^{-1}$ giving significantly higher grain potassium content (0.17 per cent) compared to the control (0.13 per cent). Though the uptake values were higher for the higher soil B application levels compared to control, there was no significant difference. Foliar B spray of 250, 500 and 750 ppm recorded significantly higher grain potassium contents (0.18, 0.17, and 0.17 per cent respectively) compared to the control and the highest content among them was given by 250 ppm B spray which was on par up to 750 ppm B spray (0.17 per cent). Increasing the concentration of spray fluid showed a decreasing trend in values. The lowest value of 0.13 per cent was given by the no B control.

Straw potassium uptake was significantly influenced only by foliar treatments. All the soil treatments recorded straw potassium uptake values on par with the no B control. Foliar spray of B @ 250 and 500 ppm registered significantly higher straw potassium uptake values (89.63 and 88.22 kg $ha^{-1}$) compared to the control and the higher levels of application. $T_5$ recorded higher uptake (89.63 kg $ha^{-1}$) values which was found to be on par with $T_6$ (88.22 kg $ha^{-1}$). Increasing the foliar spray concentration to 750 and 1000 ppm B (72.63 and 49.89 kg $ha^{-1}$ respectively) resulted in significantly lower potassium uptake compared to the lower levels and the values were on par with control.

The treatment effect was found to be significant with respect to grain potassium uptake. All the soil and foliar treatments resulted in significantly higher grain potassium uptake values as compared to the no B control. The application of B @ 0.25 kg $ha^{-1}$ resulted in the highest grain uptake (8.68 kg $ha^{-1}$) which was on par with the rest of the soil treatments. Foliar spray of 250 ppm B (9.45 kg $ha^{-1}$) gave the highest grain uptake which was on par up to 750 ppm spray. Significantly lower value compared to all the foliar treatments was obtained for the no B control (5.94 kg $ha^{-1}$). Increasing the level to $T_8$ significantly reduced grain K uptake compared to lower levels though better than control.

### 4.8.4 Calcium

The content and uptake of calcium by straw and grain as influenced by soil and foliar boron treatments is presented in the Table 13.

Observations on straw calcium content showed that both the soil and foliar treatments had significant effect on it. Though increasing the soil B application levels generally increased the straw Ca content, only the highest level gave significantly higher Ca content than control. Soil application of 1.0 kg B $ha^{-1}$ resulted in the highest calcium content (0.321 per cent) which was on par with the soil application of B @ 0.5 to 0.75 kg $ha^{-1}$ and also with the control (0.263 per cent). The lowest calcium content was observed with the application of B @ 0.25 kg ha$^{-1}$ (0.233 per cent) which was found to be on par with $T_2$ (0.292 per cent), $T_3$ (0.263 per cent) and the control. In the case of foliar treatments, the higher foliar levels, *viz.,* $T_8$ (0.379 per cent) and $T_7$ (0.35 per cent) recorded significantly higher calcium contents compared to $T_5$ and the no boron control and they were on par with $T_6$ (0.321 per cent). The lowest content was obtained for both $T_5$ and the control (0.263 per cent each) which were on par with $T_6$ (0.321 per cent).

Grain calcium content was significantly influenced by the soil and foliar B treatments. Soil application of B @ 0.25 to 0.5 kg ha$^{-1}$ recorded significantly higher grain calcium content (0.175 per cent) compared to all other soil treatments and the no B control which recorded the same value of 0.088 per cent. Foliar application of B @ 250 ppm and 500 ppm resulted in significantly higher calcium contents (0.204 and 0.175 per cent respectively) compared to higher foliar levels and the control which were on par. The lowest grain calcium content (0.088 per cent) was given by $T_7$, $T_8$ and the control.

Straw calcium uptake was significantly influenced by both the soil and foliar treatments. Increasing the B application level was found to increase the uptake values for both soil and foliar methods compared to control. The soil treatment which gave significantly higher calcium uptake compared to all other soil treatments and control was $T_4$ with the value of 22.27 kg ha$^{-1}$. This was followed by $T_2$ (17.78 kg ha$^{-1}$) which was on par with $T_3$ (16.69 kg ha$^{-1}$) and the control (14.47 kg ha$^{-1}$). The lowest uptake value among them was 12.05 kg ha$^{-1}$ given by the application of B @ 0.25 kg ha$^{-1}$ which was on par with the no boron control. Higher levels of boron spray from 500 to 1000 ppm resulted in significantly higher straw calcium uptake compared to control and the highest among them was recorded by $T_8$ (24.17 kg ha$^{-1}$) which was on par with $T_7$ (23.56 kg ha$^{-1}$) and $T_6$ (21.32 kg ha$^{-1}$). The lowest value among them was 14.47 kg ha$^{-1}$ given by the no B control which was on par with $T_5$.

Table 12. Effect of boron on the content and uptake of potassium in straw and grain

| Treatments | K content (%) | | Uptake (kg ha$^{1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 1.01 | 0.17 | 52.68 | 8.68 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 1.00 | 0.14 | 60.95 | 7.43 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 0.97 | 0.15 | 61.64 | 8.40 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 0.95 | 0.14 | 66.38 | 7.91 |
| $T_5$- Foliar spray of 250 ppm B | 1.31 | 0.18 | 89.63 | 9.45 |
| $T_6$- Foliar spray of 500 ppm B | 1.31 | 0.17 | 88.22 | 8.80 |
| $T_7$- Foliar spray of 750 ppm B | 1.08 | 0.17 | 72.63 | 8.92 |
| $T_8$- Foliar spray of 1000 ppm B | 0.78 | 0.15 | 49.89 | 7.78 |
| $T_9$- Control – No boron | 1.17 | 0.13 | 64.36 | 5.94 |
| CD (0.05) | 0.163 | 0.026 | 15.124 | 1.468 |

Table 13. Effect of boron on the content and uptake of calcium in straw and grain

| Treatments | Ca content (%) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 0.233 | 0.175 | 12.05 | 8.88 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 0.292 | 0.175 | 17.78 | 9.10 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 0.263 | 0.088 | 16.69 | 4.76 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 0.321 | 0.088 | 22.27 | 4.81 |
| $T_5$- Foliar spray of 250 ppm B | 0.263 | 0.204 | 17.99 | 10.56 |
| $T_6$- Foliar spray of 500 ppm B | 0.321 | 0.175 | 21.32 | 9.06 |
| $T_7$- Foliar spray of 750 ppm B | 0.350 | 0.088 | 23.56 | 4.47 |
| $T_8$- Foliar spray of 1000 ppm B | 0.379 | 0.088 | 24.17 | 4.48 |
| $T_9$- Control – No boron | 0.263 | 0.088 | 14.47 | 4.08 |
| CD (0.05) | 0.063 | 0.029 | 3.790 | 1.371 |

Both the soil and foliar treatments significantly influenced the grain calcium uptake. For soil application, the variation was inconsistent while for foliar application a significant reduction was observed as B concentration increased. Significantly higher grain calcium uptake (9.1 kg ha$^{-1}$) was observed for the treatment receiving 0.5 kg ha$^{-1}$ B in soil compared to the higher levels ($T_3$ and $T_4$) and the no B control. This was followed by $T_1$ with an uptake value of 8.88 kg ha$^{-1}$ which was on par with $T_2$. The lowest uptake was recorded by the controltreatment which was on par with $T_3$ and $T_4$. Among the foliar treatments, both 250 ppm and 500 ppm B spray recorded significantly higher values (10.56 and 9.06 kg ha$^{-1}$ respectively) compared to the other foliar treatments and control. The lowest grain calcium uptake was noticed for the control plot which was on par with $T_7$ and $T_8$.

### 4.8.5 Magnesium

The effect of different levels of boron application through soil and foliar methods on the content and uptake of magnesium in straw and grain, presented in Table 14 revealed that the treatment effects were not significant.

### 4.8.6 Copper

Copper content of straw was significantly influenced by the soil and foliar B treatments (Table 15). B application significantly reduced the straw Cu content with an increase in application level for both methods of application. Significantly higher straw copper content (14.333 mg kg$^{-1}$) was observed with the no boron control compared to all the soil and foliar treatments. Among the soil treatments, the highest copper content was observed for soil application of 0.5 kg B ha$^{-1}$ (10.917 mg kg$^{-1}$) which was on par with rest of the soil treatments and the lowest among them was recorded by soil application of 1.0 kg B ha$^{-1}$ (9.417 mg kg$^{-1}$). In the case of foliar treatments, the highest copper content was noticed for the foliar spray of 250 ppm B (11.667 mg kg$^{-1}$) and lowest for 750 to 1000 ppm B sprays (9.5 mg kg$^{-1}$ each) and these were on par with all the foliar treatments.

Data on grain copper content indicated that the values were in general higher for the B applied treatments when compared to control. Increasing the level of B application through either method in general, produced a decreasing trend in grain Cu, though the highest level of foliar application registered lower content compared to control. Among the soil treatments, significantly higher grain copper content compared to the control was observed for the soil application of 0.5 kg B ha$^{-1}$ (11.583 mg kg$^{-1}$) which was on par with the application of 0.25 kg B ha$^{-1}$ (10.333 mg kg$^{-1}$). The lowest value obtained was 8.917 mg kg$^{-1}$ (control) which was on par with $T_1$ (10.333 mg kg$^{-1}$), $T_3$ (9.417 mg kg$^{-1}$) and $T_4$ (9.667 mg kg$^{-1}$). Foliar spray of 250 ppm B resulted in significantly higher copper content (10.917 mg kg$^{-1}$) compared to the no boron control and was on par with 500 ppm (10.167 mg kg$^{-1}$) and 750 ppm (9.667 mg kg$^{-1}$) B sprays. The lowest content (8.667 mg kg$^{-1}$) was recorded by the 1000 ppm B spray which was on par with 500 ppm (10.167 mg kg$^{-1}$), 750 ppm (9.667 mg kg$^{-1}$) and the no boron control (8.917 mg kg$^{-1}$). The treatment effects were found to be non-significant with respect to straw copper uptake.

Soil B application in general increased grain Cu uptake while B application as foliar spray gave significant increases in values only up to 500 ppm. In soil treatments, significantly higher values for grain uptake compared to the no B control were noticed in $T_1$, $T_2$ and $T_4$ and the highest among them was given by $T_2$ (0.06 kg ha$^{-1}$) which was on par with all other soil treatments. The lowest uptake was noticed for the control plot (0.042 kg ha$^{-1}$) which was on par with the soil application of 0.75 kg B ha$^{-1}$. In the case of foliar treatments, 250 and 500 ppm B sprays recorded significantly higher grain uptake values compared to control. Increased foliar levels did not further increase the values significantly.

250 ppm B spray registered the highest grain copper uptake (0.057 kg ha$^{-1}$) which was on par with 500 ppm (0.053 kg ha$^{-1}$) and 750 ppm (0.049 kg ha$^{-1}$). The lowest uptake among the treatments was given by the control (0.042 kg ha$^{-1}$) which was on par with $T_7$ (0.049 kg ha$^{-1}$) and $T_8$ (0.044 kg ha$^{-1}$).

Table 14. Effect of boron on the content and uptake of magnesium in straw and grain

| Treatments | Mg content (%) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 0.195 | 0.240 | 10.12 | 12.14 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 0.195 | 0.210 | 11.94 | 10.93 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 0.195 | 0.210 | 12.40 | 11.42 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 0.165 | 0.225 | 11.48 | 12.42 |
| $T_5$- Foliar spray of 250 ppm B | 0.210 | 0.225 | 14.36 | 11.69 |
| $T_6$- Foliar spray of 500 ppm B | 0.165 | 0.195 | 10.74 | 10.13 |
| $T_7$- Foliar spray of 750 ppm B | 0.165 | 0.225 | 11.06 | 11.47 |
| $T_8$- Foliar spray of 1000 ppm B | 0.195 | 0.150 | 12.50 | 7.68 |
| $T_9$- Control – No boron | 0.210 | 0.225 | 11.57 | 10.50 |
| CD (0.05) | NS | NS | NS | NS |

Table 15. Effect of boron on the content and uptake of copper in straw and grain

| Treatments | Cu content (mg kg$^{-1}$) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 10.667 | 10.333 | 0.056 | 0.053 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 10.917 | 11.583 | 0.068 | 0.060 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 9.667 | 9.417 | 0.062 | 0.051 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 9.417 | 9.667 | 0.066 | 0.053 |
| $T_5$- Foliar spray of 250 ppm B | 11.667 | 10.917 | 0.080 | 0.057 |
| $T_6$- Foliar spray of 500 ppm B | 10.083 | 10.167 | 0.068 | 0.053 |
| $T_7$- Foliar spray of 750 ppm B | 9.500 | 9.667 | 0.064 | 0.049 |
| $T_8$- Foliar spray of 1000 ppm B | 9.500 | 8.667 | 0.061 | 0.044 |
| $T_9$- Control – No boron | 14.333 | 8.917 | 0.079 | 0.042 |
| CD (0.05) | 2.172 | 1.582 | NS | 0.009 |

### 4.8.7 Zinc

The treatment effects on the content and uptake of zinc in straw and grain is shown in the Table 16.

The concentration of zinc in straw and grain and the straw zinc uptake were not significantly influenced by the boron treatments.

Effect of treatments on grain zinc uptake was found significant. All the soil treatments registered significantly higher uptake values compared to the no B control and soil application of B @ 1.0 kg ha$^{-1}$ resulted in the highest value among them (0.45 kg ha$^{-1}$) which was on par with rest of the soil treatments. Compared to the no boron control the foliar treatments of 250 ppm and 500 ppm B sprays recorded significantly higher uptake values with the 250 ppm spray (0.40 kg ha$^{-1}$) recording the highest value which was on par with rest of the foliar treatments. The control plot gave the lowest uptake value (0.34 kg ha$^{-1}$) and it was on par with 750 ppm and 1000 ppm B sprays. Increasing the rate of soil B application was found to increase significantly the Zn uptake whereas as the foliar spray concentration increased beyond 500 ppm, a gradual reduction in Zn uptake was noticed though the values were on par with control.

### 4.8.8 Boron

The effect of boron treatments through soil and foliar methods on the content and uptake of boron in straw and grain is presented in Table 17.

Data reveal that both soil and foliar treatments had exerted significant effect on the straw boron content. Increasing B application either through soil or foliage significantly increased B content compared to all other treatments and the control. Soil application of B @ 0.75 kg ha$^{-1}$ (19.25 mg kg$^{-1}$) resulted in the highest straw boron content compared to the other soil levels. The values were decreased as the application of B increased to 1.0 kg ha$^{-1}$. The lowest boron content (11.26 mg kg$^{-1}$)

was given by the lowest level of B application ($T_1$). On comparing the foliar treatments, it was clear that all the levels of boron spray gave significantly higher straw boron content compared to control. The highest among them was given by 250 ppm B spray (15.90 mg $kg^{-1}$) and the lowest straw boron content (7.50 mg $kg^{-1}$) was recorded by 1000 ppm spray.

Both soil and foliar treatments had significant effect on grain boron content. All the soil and foliar treatments registered significantly higher boron contents compared to the no boron control. Among soil treatments, $T_3$ gave the highest grain boron content (14.12 mg $kg^{-1}$) which was on par with $T_4$ (13.33 mg $kg^{-1}$). Soil application of 0.25 kg B $ha^{-1}$ recorded the lowest boron content (10.37 mg $kg^{-1}$) and was superior to the no boron control (6.44 mg $kg^{-1}$). All the foliar treatments gave significantly higher boron contents compared to the control and the highest among them was 10.17 mg $kg^{-1}$ given by the foliar spray of 250 ppm B which was on par with rest of the foliar treatments. 1000 ppm B spray gave the lowest grain boron content (6.46 mg $kg^{-1}$).

The values for straw boron uptake showed that the treatment effect was significant compared to control. Among the soil treatments, all the treatments recorded significantly higher straw boron uptake compared to the control. Soil application of B @ 1.0 kg $ha^{-1}$ gave the highest straw boron uptake (0.127 kg $ha^{-1}$) which was on par with the application of 0.75 kg B $ha^{-1}$ (0.123 kg $ha^{-1}$). For foliar treatments, the lower levels of B spray ($T_5$ to $T_7$) recorded significantly higher values compared to the no boron control. 1000 ppm B spray resulted in the lowest straw boron uptake (0.048 kg $ha^{-1}$) which was on par with the no B control (0.034 kg $ha^{-1}$).

Both soil and foliar treatments had significantly influenced the grain boron uptake. All the soil and foliar treatments registered significantly higher uptake values compared to the no boron control. The soil treatments which recorded the highest grain boron uptake was $T_3$ (0.077 kg $ha^{-1}$) which was on par with $T_4$ (0.073 kg $ha^{-1}$).

Table 16. Effect of boron on the content and uptake of zinc in straw and grain

| Treatments | Zn content (mg kg$^{-1}$) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 88.67 | 81.42 | 0.46 | 0.41 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 90.67 | 82.58 | 0.57 | 0.43 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 82.25 | 80.92 | 0.52 | 0.44 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 82.75 | 81.17 | 0.58 | 0.45 |
| $T_5$- Foliar spray of 250 ppm B | 96.67 | 77.50 | 0.66 | 0.40 |
| $T_6$- Foliar spray of 500 ppm B | 86.58 | 76.67 | 0.58 | 0.40 |
| $T_7$- Foliar spray of 750 ppm B | 79.58 | 74.58 | 0.54 | 0.38 |
| $T_8$- Foliar spray of 1000 ppm B | 80.68 | 76.08 | 0.51 | 0.39 |
| $T_9$- Control – No boron | 86.45 | 73.50 | 0.48 | 0.34 |
| CD (0.05) | NS | NS | NS | 0.056 |

Table 17. Effect of boron on the content and uptake of boron in straw and grain

| Treatments | B content (mg kg$^{-1}$) | | Uptake (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | Straw | Grain | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 11.26 | 10.37 | 0.059 | 0.053 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 16.09 | 13.03 | 0.100 | 0.068 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 19.25 | 14.12 | 0.123 | 0.077 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 18.07 | 13.33 | 0.127 | 0.073 |
| $T_5$- Foliar spray of 250 ppm B | 15.90 | 10.17 | 0.109 | 0.053 |
| $T_6$- Foliar spray of 500 ppm B | 13.43 | 9.97 | 0.090 | 0.052 |
| $T_7$- Foliar spray of 750 ppm B | 11.06 | 9.77 | 0.074 | 0.050 |
| $T_8$- Foliar spray of 1000 ppm B | 7.50 | 9.58 | 0.048 | 0.049 |
| $T_9$- Control – No boron | 6.22 | 6.44 | 0.034 | 0.030 |
| CD (0.05) | 0.957 | 0.957 | 0.0183 | 0.006 |

The lowest uptake among them was 0.03 kg ha$^{-1}$ given by the no B control. All the foliar treatments recorded significantly higher grain uptake compared to the control. The highest among them was 0.053 kg ha$^{-1}$ recorded by 250 ppm B spray which was on par with rest of the foliar treatments.

## 4.9 EFFECT OF BORON ON THE PHENOL CONTENT OF PLANT AT DIFFERENT STAGES

The effect of soil and foliar boron treatments on the phenol content of shoot at tillering and flowering stages, and straw and grain at harvest are presented in the Table 18.

Phenol content of shoot at tillering stage varied significantly with levels and methods of B application. There was an increase in phenol for the soil treatments compared to control while for foliar treatments there was a decrease. Soil application of B @ 0.25 kg ha$^{-1}$ recorded significantly higher phenol content (0.89 mg g$^{-1}$) compared to the no boron control, which was on par with rest of the soil treatments. The lowest content among them (0.84 mg g$^{-1}$) was recorded by soil B application of 1.0 kg ha$^{-1}$. All the foliar B treatments recorded significantly lower phenol contents compared to the higher content recorded for the no B control (0.79 mg g$^{-1}$). The phenol contents of all the foliar treatments were on par with each other and the highest and lowest among them were recorded by 250 ppm (0.57 mg g$^{-1}$) and 1000 ppm (0.54 mg g$^{-1}$) B sprays respectively.

The phenol content of shoot at flowering stage was significantly influenced by the treatments. All the soil and foliar treatments registered significantly lower phenol contents compared to the higher value of the no B control. Soil treatments recorded values which were on par with each other, and the highest among them was 1.03 mg g$^{-1}$ phenol ($T_1$) and the lowest being 1.01 mg g$^{-1}$ ($T_4$). 250 ppm B spray gave the highest shoot phenol content (1.05 mg g$^{-1}$) which was on par with 500 ppm and

750 ppm B sprays whereas 1000 ppm B spray gave the lowest shoot phenol content (0.99 mg $g^{-1}$) which was on par with 500 and 750 ppm sprays.

Data given in Table 18 revealed that the treatments had significantly influenced the phenol content of straw at harvest. All the treatments either soil or foliar registered lower values than the control. The highest recorded value among soil treatments was 0.86 mg $g^{-1}$ ($T_1$) which was on par up to the lowest value of 0.82 mg $g^{-1}$ ($T_4$). The same trend was observed for foliar treatments where the 250 ppm B spray recorded highest phenol content (0.81 mg $g^{-1}$) which was on par up to the highest level of 1000 ppm B spray (0.80 mg $g^{-1}$).

All treatments either soil or foliar registered lower values for grain phenol compared to control and it was found that the reduction in grain phenol content was more than that of straw. The influence of treatments on grain phenol content was significant, with the no B control giving significantly higher value of 0.71 mg $g^{-1}$ compared to both soil and foliar treatments. Among soil B application levels, 0.25 kg B $ha^{-1}$ recorded the highest grain phenol content (0.44 mg $g^{-1}$) which was on par with rest of the soil treatments, and B application @ 1.0 kg $ha^{-1}$ resulted in the lowest phenol content of 0.38 mg $g^{-1}$. Among the foliar treatments, 250 ppm B spray resulted in the highest grain phenol content (0.58 mg $g^{-1}$) which was on par with 500 ppm B spray (0.56 mg $g^{-1}$). The higher levels of B spray recorded significantly lower phenol contents compared to $T_5$, $T_6$ and the control.

## 4.10 EFFECT OF BORON ON SOIL REACTION AND ELECTRICAL CONDUCTIVITY

Table 19 shows the effect of different boron treatments on the soil reaction and electrical conductivity of soil.

The data indicate that the treatments had no significant effect on pH. The highest pH recorded among the soil treatments was 4.91 ($T_1$) and the lowest was 4.77

Table 18. Effect of boron on the phenol content of plant at different stages

| Treatments | Phenol content of shoot (mg $g^{-1}$) | | | |
|---|---|---|---|---|
| | Tillering stage | Flowering stage | Harvest stage | |
| | | | Straw | Grain |
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 0.89 | 1.03 | 0.86 | 0.44 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 0.86 | 1.02 | 0.85 | 0.42 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 0.86 | 1.02 | 0.83 | 0.39 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 0.84 | 1.01 | 0.82 | 0.38 |
| $T_5$- Foliar spray of 250 ppm B | 0.57 | 1.05 | 0.81 | 0.58 |
| $T_6$- Foliar spray of 500 ppm B | 0.56 | 1.02 | 0.81 | 0.56 |
| $T_7$- Foliar spray of 750 ppm B | 0.56 | 1.02 | 0.81 | 0.49 |
| $T_8$- Foliar spray of 1000 ppm B | 0.54 | 0.99 | 0.80 | 0.42 |
| $T_9$- Control – No boron | 0.79 | 1.12 | 0.98 | 0.71 |
| CD (0.05) | 0.088 | 0.054 | 0.077 | 0.061 |

Table 19. Effect of boron on soil reaction and electrical conductivity

| Treatments | pH | EC (dS $m^{-1}$) |
|---|---|---|
| $T_1$- Soil application of 0.25 kg B $ha^{-1}$ | 4.91 | 0.20 |
| $T_2$- Soil application of 0.50 kg B $ha^{-1}$ | 4.88 | 0.16 |
| $T_3$- Soil application of 0.75 kg B $ha^{-1}$ | 4.83 | 0.16 |
| $T_4$- Soil application of 1.00 kg B $ha^{-1}$ | 4.77 | 0.18 |
| $T_5$- Foliar spray of 250 ppm B | 5.07 | 0.17 |
| $T_6$- Foliar spray of 500 ppm B | 4.93 | 0.17 |
| $T_7$- Foliar spray of 750 ppm B | 5.00 | 0.16 |
| $T_8$- Foliar spray of 1000 ppm B | 4.87 | 0.16 |
| $T_9$- Control – No boron | 4.80 | 0.16 |
| CD (0.05) | NS | NS |

($T_4$). The treatments had no significant effect on electrical conductivity of the soil. The values ranged from 0.16 to 0.20 dS $m^{-1}$.

## 4.11 POST HARVEST SOIL NUTRIENT STATUS

Availability of nitrogen, phosphorus, potassium, calcium, magnesium and copper in soil did not vary significantly with different levels and methods of B application.

Soil and foliar boron treatments were found to significantly increase the zinc availability of soil compared to the no boron control. The highest available zinc content among soil treatments was recorded by $T_3$ (8.8 mg $kg^{-1}$) which was on par with $T_2$ (8.62 mg $kg^{-1}$) and $T_4$ (8.26 mg $kg^{-1}$). Among the foliar treatments, the highest zinc availability was registered for the treatment $T_7$ (8.61 mg $kg^{-1}$), which was on par with the rest of the foliar treatments.

The different boron treatments had significant effects on soil boron availability (Table 20). All the soil and foliar treatments recorded significantly higher boron availability compared to the no boron control. Soil treatments up to 0.75 kg B $ha^{-1}$ resulted in increased boron availability and further increase in the level of application to 1000 ppm decreased the soil B availability compared to the lower levels. All foliar treatments were found to be on par with respect to B availability.

## 4.12 EFFECT OF BORON NUTRITION ON SEED GERMINATION AFTER HARVEST

There was no significant effect on seed germination due to different B treatments irrespective of the dose and the mode of application (Table 21).

Table 20. Post harvest soil nutrient status

| Treatments | N | P | K | Ca | Mg | Cu | Zn | B |
|---|---|---|---|---|---|---|---|---|
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 338.69 | 52.06 | 116.33 | 382.00 | 200.00 | 3.38 | 8.19 | 0.529 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 355.41 | 48.59 | 128.05 | 388.00 | 250.00 | 3.58 | 8.62 | 0.529 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 355.41 | 38.49 | 129.77 | 365.00 | 220.00 | 3.54 | 8.80 | 0.535 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 376.29 | 41.33 | 133.39 | 383.00 | 236.00 | 3.68 | 8.26 | 0.522 |
| $T_5$- Foliar spray of 250 ppm B | 330.33 | 50.48 | 126.63 | 380.00 | 200.00 | 3.61 | 8.17 | 0.525 |
| $T_6$- Foliar spray of 500 ppm B | 351.20 | 50.48 | 130.01 | 378.00 | 254.00 | 3.59 | 8.33 | 0.525 |
| $T_7$- Foliar spray of 750 ppm B | 372.14 | 49.75 | 131.92 | 380.00 | 234.00 | 3.95 | 8.61 | 0.527 |
| $T_8$- Foliar spray of 1000 ppm B | 334.51 | 48.34 | 130.41 | 353.00 | 212.00 | 3.89 | 8.30 | 0.510 |
| $T_9$- Control – No boron | 372.14 | 44.46 | 118.19 | 342.00 | 216.00 | 3.48 | 7.49 | 0.489 |
| CD (0.05) | NS | NS | NS | NS | NS | NS | 0.593 | 0.022 |

(N, P and K in kg ha$^{-1}$and others in mg kg$^{-1}$)

Table 21. Effect of boron on seed germination after harvest

| Treatments | Germination percentage |
|---|---|
| $T_1$- Soil application of 0.25 kg B ha$^{-1}$ | 100.00 |
| $T_2$- Soil application of 0.50 kg B ha$^{-1}$ | 100.00 |
| $T_3$- Soil application of 0.75 kg B ha$^{-1}$ | 100.00 |
| $T_4$- Soil application of 1.00 kg B ha$^{-1}$ | 99.33 |
| $T_5$- Foliar spray of 250 ppm B | 100.00 |
| $T_6$- Foliar spray of 500 ppm B | 100.00 |
| $T_7$- Foliar spray of 750 ppm B | 99.33 |
| $T_8$- Foliar spray of 1000 ppm B | 100.00 |
| $T_9$- Control – No boron | 100.00 |
| CD (0.05) | NS |

# *Discussion*

# 5. DISCUSSION

The results of the experiment entitled "Boron nutrition of wet land rice (*Oryza sativa* L.)", conducted at Cropping Systems Research Centre, Karamana during the rabi season of 2016 with the objective of standardizing the dose and method of application of boron to wet land rice, with the medium duration rice variety Uma as test crop are hereunder.

## 5.1 EFFECT OF BORON ON PLANT GROWTH PARAMETERS OF RICE

### 5.1.1 Shoot Length at Harvest

Shoot lengths for soil B treatments from 0.25 to 0.75 kg $ha^{-1}$ were on par with the control (Fig. 3) though numerical increases were obtained for the B applied treatments. As the boron levels increased, crop exhibited reduction in shoot length and significantly lower value was recorded by the treatment receiving B application @ 1.0 kg $ha^{-1}$ in two equal splits at active tillering and flowering stages compared to all other soil treatment levels and the control. Similarly, the crop exhibited reduction in shoot length as the boron concentration in the spray fluid increased beyond 250 ppm. Significantly higher shoot length was recorded only by the foliar B application @ 250 ppm in two equal splits compared to the other foliar treatments and the no B control, which were on par. Increase in shoot length might be due to its role in meristematic activity and thereby increased cell division and cell elongation compared to the control. Similar reports were made by Bohnsack and Albert (1977) and Mouhtaridou *et al.* (2004).

### 5.1.2 Root Length after Harvest

Root length of rice was significantly influenced by boron nutrition (Fig. 4). Among soil treatments, B application @ 0.25 to 0.75 kg $ha^{-1}$ recorded significantly higher root lengths compared to the no B control, which was on par with the

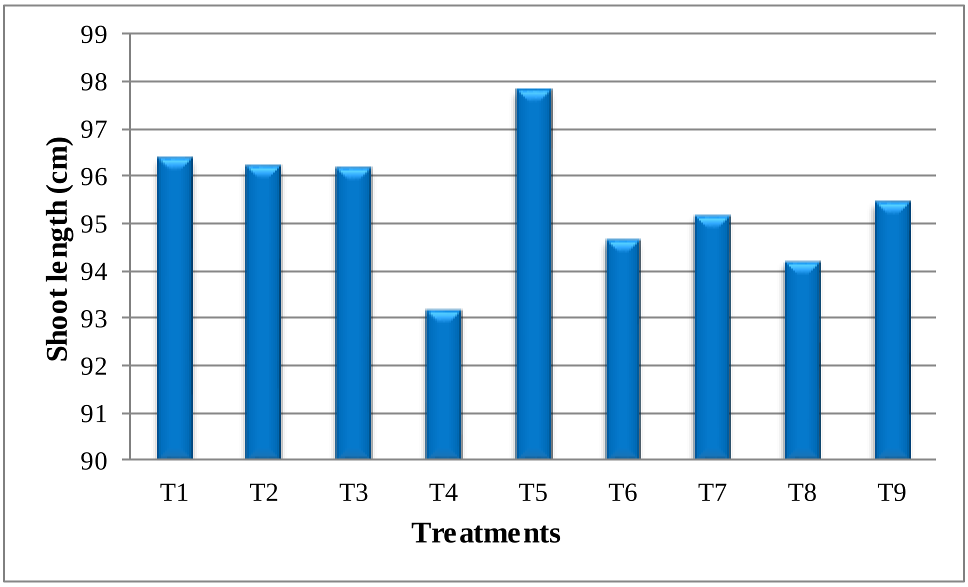


Fig. 3. Effect of B application on shoot length at harvest

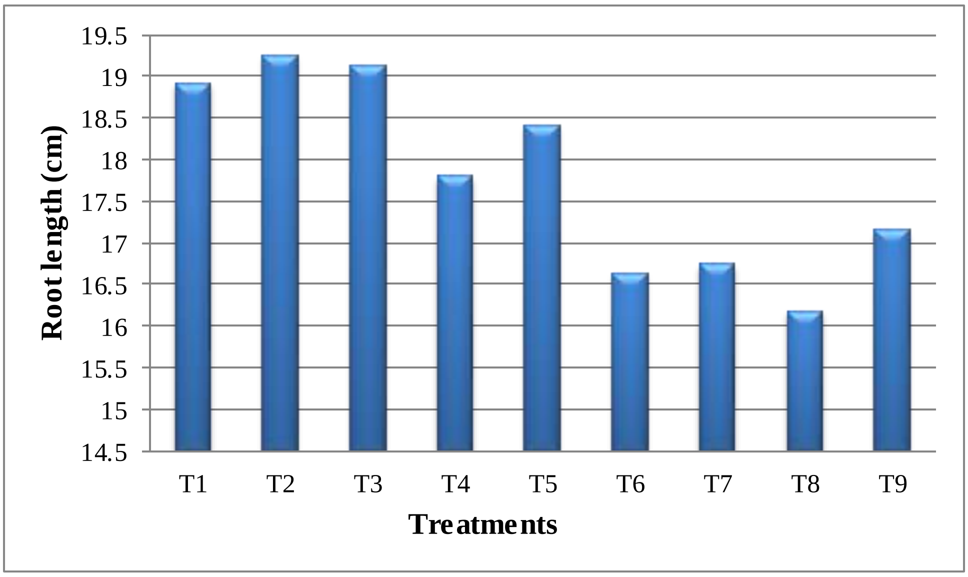


Fig. 4. Effect of B application on root length after harvest

treatment where B was applied @ 1.0 kg ha$^{-1}$ in two equal splits. Thetreatment receiving 250 ppm B spray gave significantly higher root length among the foliar treatments, compared to higher concentrations which were on par with the no B control. Boron is actively involved in cell wall synthesis and meristematic activities and these might be the reasons for increased root length for boron nutrition as compared to the no boron control. Similar results have been obtained by Bohnsack and Albert (1977) and Rahmatullah *et al.* (2006).

### 5.1.3 Number of Total and Productive Tillers per Plant

The different levels and methods of boron application failed to exert any significant influence on the total and productive tillers per plant. However, the soil treatments from 0.25 to 0.75 kg B ha$^{-1}$ exhibited numerically higher number of total and productive tillers as compared to the no boron control. Similar results have been reported by Hussain *et al.* (2006), who obtained non-significant differences in number of total and productive tillers per plant in response to applied boron fertilizer, when it was sprayed on wheat foliage at three growth stages *i.e.*, tillering, booting and milking.

## 5.2 EFFECT OF BORON ON YIELD ATTRIBUTES OF RICE

### 5.2.1 Weight per Panicle

Boron treatments through both soil and foliar methods markedly influenced the weight per panicle (Fig. 5) with the values increasing for soil treatments as the level was increased from 0.25 to 1.0 kg B ha$^{-1}$. Significantly higher panicle weight was given by 0.75 to 1.0 kg B ha$^{-1}$ which were on par. Reducing the levels of soil B application significantly lowered the panicle weights which were on par with the no B control. In foliar treatments, 250 ppm B spray in two equal splits at active tillering and flowering stages recorded significantly higher value than the control but further increment in the B concentration of spray fluid resulted in lower panicle weights, which were on par with control. The applied boron might have been utilized by the plant for reproductive growth, which is the main function of boron in plants. The increase in panicle weight as a result of boron nutrition might be due to the effect of boron in increasing the panicle length and percentage filled grains. Similar results were obtained by Mandal *et al.* (1987), Shafiq and Maqsood (2010) and Nagula (2014).

### 5.2.2 Panicle Length and Number of Grains per Panicle

Panicle length and number of grains per panicle were not statistically influenced by the soil and foliar boron treatments. But there was an increasing trend in values for soil treatments and a decreasing trend for foliar treatments from lower to higher levels of boron application. This might be due to the involvement of B in reproductive growth of rice plant. The maximum number of grains per panicle over control plots might be due to the reduction in pollen sterility of rice and improved grain filling (Rashid *et al.*, 2004; Jana *et al.*, 2005 and Rashid, 2004).

### 5.2.3 Percentage Filled Grains

All the soil treatments increased the percentage filled grains remarkably as compared to the no boron control (Fig. 6). The values showed an increasing trend with increase in boron application levels. Soil application of 1.0 kg B ha$^{-1}$ in two equal splits resulted in significantly higher percentage filled grains (83.67 per cent) compared to the treatments $T_2$ and $T_1$ and it was on par with $T_3$ (1.0 kg B ha$^{-1}$). The foliar treatment of 250 ppm B spray in two splits resulted in significantly higher value (83.20 per cent) compared to higher concentrations *i.e.*, $T_7$ and $T_8$ and the control. The percentage filled grains was improved by boron nutrition which might be due to the active involvement of boron in reproductive growth especially in pollination, seed setting and lowering the spikelet sterility as reported by Mandal *et al.* (1987) and Aslam *et al.* (2002).

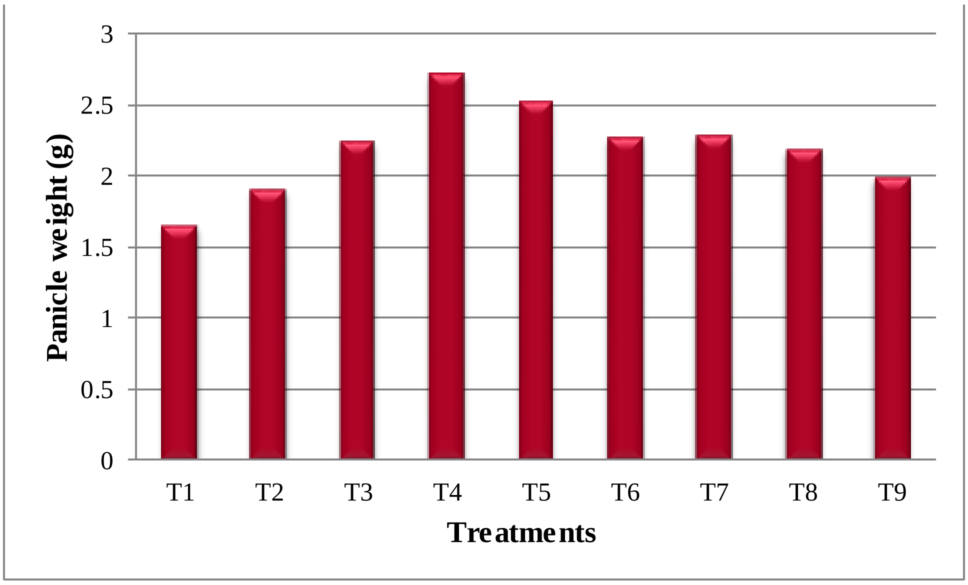


Fig. 5. Effect of B application on panicle weight

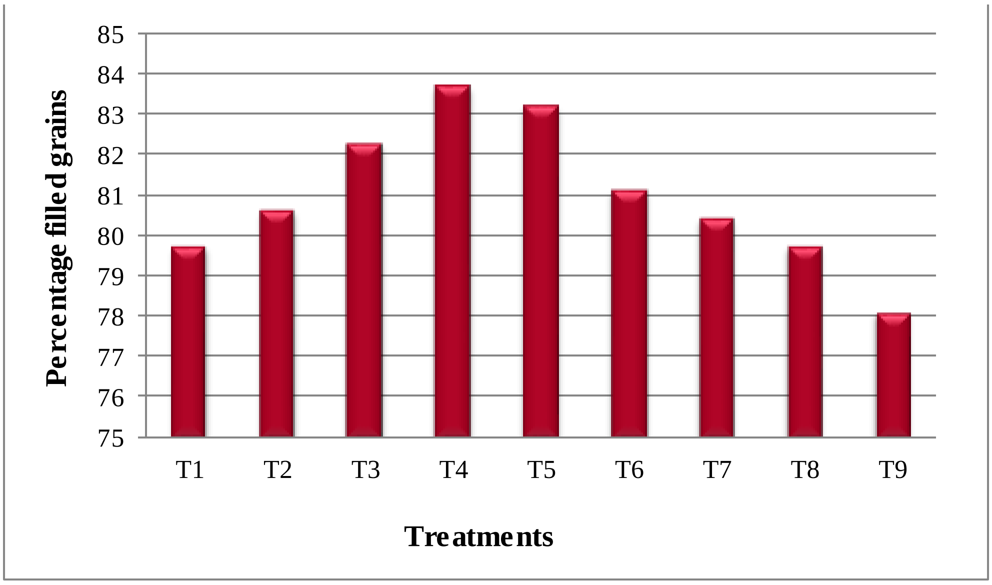


Fig. 6. Effect of B application on percentage filled grains

### 5.2.4 Spikelet Sterility

The effect of boron treatments irrespective of the method of application was found to be significant in reducing spikelet sterility (Fig. 7). Supplying boron through soil reduced the percentage of sterile spikelets and the highest soil B treatment @ 1.0 kg ha$^{-1}$ recorded the lowest value (16.33 per cent), which was significantly lower than the lower levels of B application, which were on par with the control (21.93 per cent). The higher levels, $T_3$ and $T_4$ were on par and it was found that increasing the soil B levels showed a steady decrease in spikelet sterility. Among the foliar treatments, 250 ppm B spray in two equal splits gave significantly lower spikelet sterility (16.80 per cent) whereas increasing the foliar B concentrations beyond this level *viz.*, $T_7$ and $T_8$ produced sterile spikelets on par with the no boron control. A reduction in spikelet sterility due to B application might be due to the role of boron in improving pollination and seed setting. The positive response of boron application in reducing spikelet sterility was also reported by Aslam *et al.* (2002) and Rao *et al.* (2013). Generally, soil treatments recorded lower spikelet sterility compared to foliar treatments, which indicated the effectiveness of soil application of boron over foliar spray.

### 5.2.5 Thousand Grain Weight

All the four levels of soil application (0.25 to 1.0 kg B ha$^{-1}$) were on par and registered significantly higher values for thousand grain weight compared to the no boron control (Fig. 8). Foliar application of boron did not result in a significant increase in the thousand grain weight compared to the no B control. It might be due to the role of boron in grain setting and translocation of photosynthates. Studies on the effect of boron on rice confirm that boron nutrition increases the thousand grain weight (Shah *et al.*, 2011; Santhosh, 2013 and Nagula, 2014).

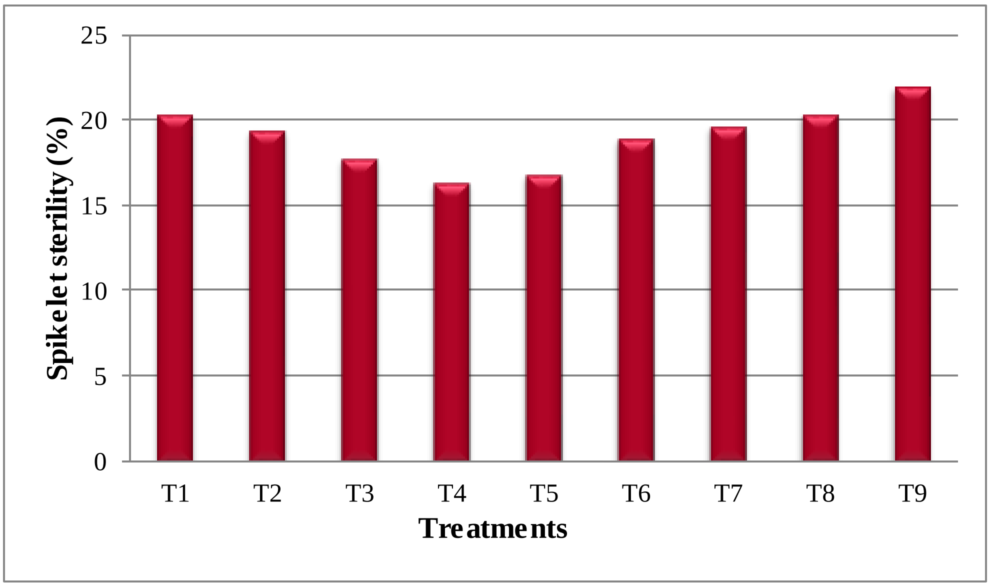


Fig. 7. Effect of B application on spikelet sterility

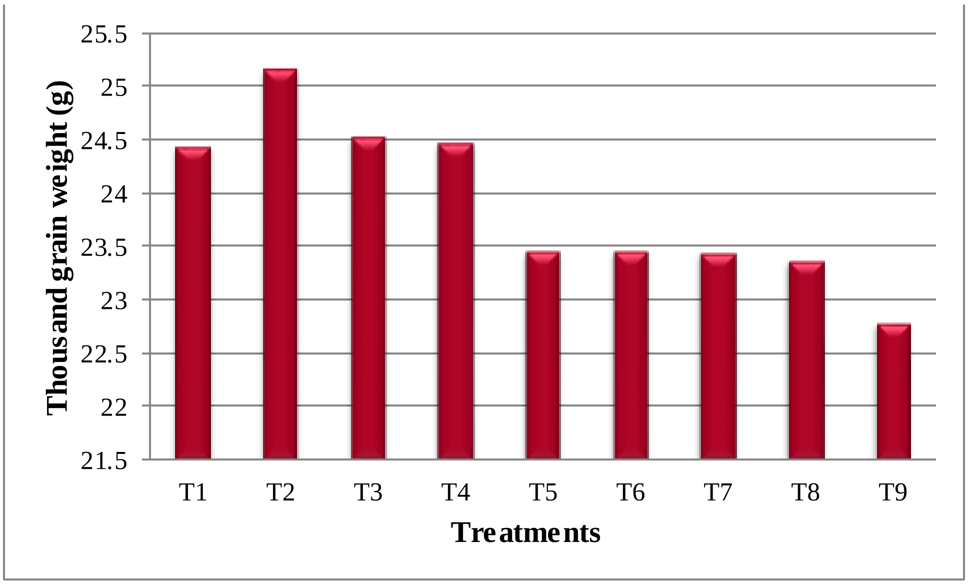


Fig. 8. Effect of B application on thousand grain weight

## 5.3 EFFECT OF BORON ON GRAIN AND STRAW YIELDS

### 5.3.1 Grain Yield

Boron application through either soil or foliage significantly increased the grain yield as compared to the no B control (Fig. 9). A steady increase in grain yield was observed as the level of soil boron application increased from 0.25 to 1.0 kg $ha^{-1}$. Application of 1.0 kg B $ha^{-1}$ resulted in the highest grain yield (5502.85 kg $ha^{-1}$) which was on par with $T_3$ (0.75 kg B $ha^{-1}$). Similar result was also obtained by Rashid *et al.* (2004) who reported that rice responds positively to an optimum B dose of 0.75 kg $ha^{-1}$. Boron is involved in carbohydrate metabolism and translocation of photosynthates in the form of borate-sugar complexes. Improved grain yield due to boron application might be due to better starch utilization that results in higher seed setting and translocation of assimilates to developing grains, which increases the grain size and number of grains per panicle (Hussain *et al.*, 2012). A decrease in spikelet sterility, increase in number of grains per panicle and thousand grain weight might also have contributed to increased grain yield.

The highest grain yield among foliar treatments was registered by the treatment receiving 250 ppm B spray. However, beyond 250 ppm, higher concentrations of B in spray fluid had a tendency to decrease the yield though they were on par with each other. Soil application of boron @ 1.0 kg $ha^{-1}$ in two equal splits at active tillering and flowering stages resulted in significantly higher grain yield compared to all the foliar treatments. Similar result was obtained by Dunn *et al.* (2005) who claimed that soil application of boron resulted in remarkably higher yields rather than foliar application. B deficiency is known to cause depreciation in grain set and severe reduction in yield.

### 5.3.2 Straw Yield

Straw yield is also an important component of rice economics, which decides the net returns and B:C ratio. Though application of boron through soil or foliar methods significantly influenced straw yield, the effect of foliar spray was more than that of soil treatments (Fig. 10). Among the soil application levels, significantly higher straw yield (7014.52 kg $ha^{-1}$) was registered by $T_4$ receiving 1 kg B $ha^{-1}$ in two equal splits compared to $T_9$ where B was missed. The treatment $T_4$ was on par with $T_3$ and $T_2$ and the lowest level of soil application did not produce any significant effect on straw yield. Among the foliar treatments, 250 to 750 ppm B spray in two equal splits, registered straw yields significantly higher than the treatments receiving only N, P and K without any B application. Even though the yields were found to be increasing for incremental levels of soil B application, results revealed that an increase in B supply through foliage causes subsequent decline in straw yields. The decrease in yield is mainly due to the toxic effects of increasing B concentration of foliar spray. The effect of foliar B application was more marked in straw yield compared to soil B application. Foliar B application also influenced straw yield more than grain yield. Influence of boron in nucleic acid, protein and indole acetic acid metabolisms might have caused an increase in vegetative growth and thereby improved the straw yield. Previous studies have also indicated that addition of boron in the growing media increases the number of leaves and tillers of rice, which might be responsible for increased straw yields. Rashid and Yasin (2004), Khan *et al.* (2006) and Nagula (2014) also reported similar positive responses of straw yield to boron application.

### 5.4 EFFECT OF BORON ON INCIDENCE OF PESTS AND DISEASES

The different levels and methods of application of boron could not exert any significant influence on the incidence of leaf folder. Except $T_2$ (0.5 kg B $ha^{-1}$), all other treatments including the no boron control recorded the same score.

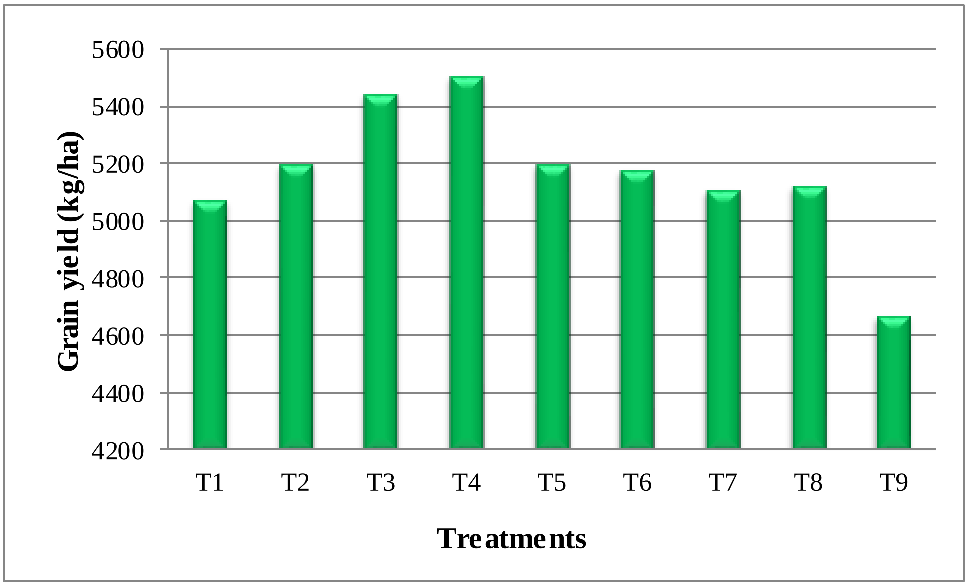


Fig. 9. Effect of B application on grain yield

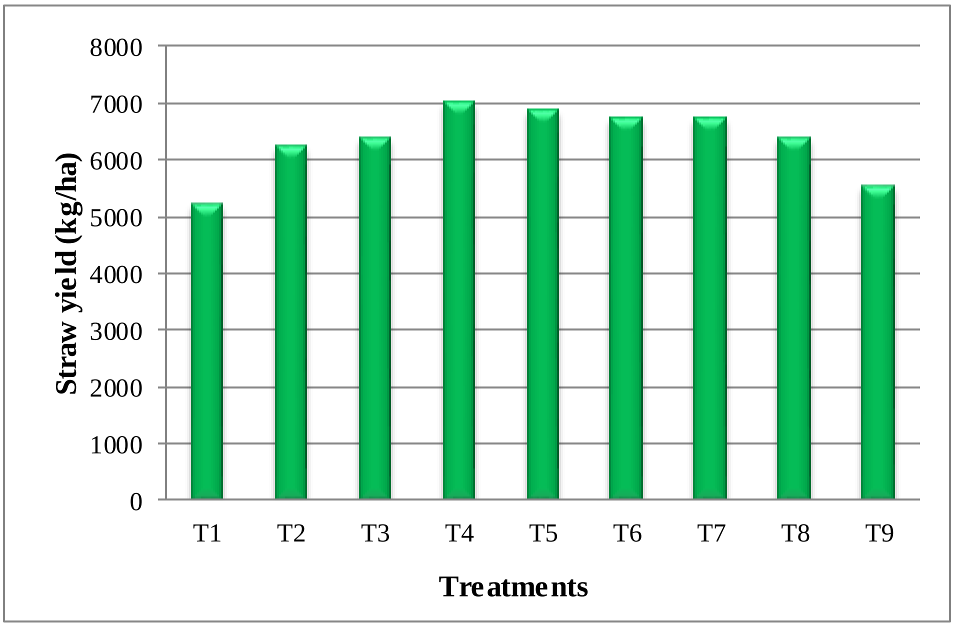


Fig. 10. Effect of B application on straw yield

The different boron treatments exhibited significant effect on the incidence of brown leaf spot. The no boron control recorded the highest percentage of disease incidence (12.22 per cent) compared to all the other treatments. Among the soil treatments, the PDI decreased as the levels of boron application increased with the application of 0.75 to 1.0 kg B ha$^{-1}$ recording the lowest PDI as compared to the control. Similarly, the highest levels of boron spray (1000 ppm) resulted in the lowest disease incidence (9.63 per cent) which was on par with the rest of the foliar treatments and significantly lower than control. Boron nutrition reduced the disease severity due to its direct role in cell wall structure and integrity. It is reported that boron actively supports the strength and shape of the plant cell and thus contribute to disease resistance (Brown *et al.,* 2002).

## 5.5 EFFECT OF BORON ON ECONOMICS OF CULTIVATION

Economic analysis reveals the feasibility of B application in wet land rice culture. Though the different treatments had no significant effect on the cost of cultivation, they significantly influenced the gross and net returns and B:C ratio of the experiment.

Different levels of B application either through soil or as foliar spray significantly increased the gross returns (Fig. 11). Soil B application at levels 0.5 to 1.0 kg ha$^{-1}$ in equal splits at active tillering and flowering stages gave gross returns significantly greater than control. Application of B @ 1.0 kg ha$^{-1}$ resulted in the highest gross returns (₹ 156135) which was on par with the application of 0.75 kg B ha$^{-1}$ (₹ 151564). With respect to foliar treatments, all foliar levels gave gross returns significantly greater than control and $T_5$ recorded the highest gross returns (₹ 148563) which was on par with rest of the foliar application levels.

Soil B application from 0.5 to 1.0 kg ha$^{-1}$ gave net returns significantly higher than the no B control and 1.0 kg B ha$^{-1}$ gave the highest net returns (₹ 53427) which

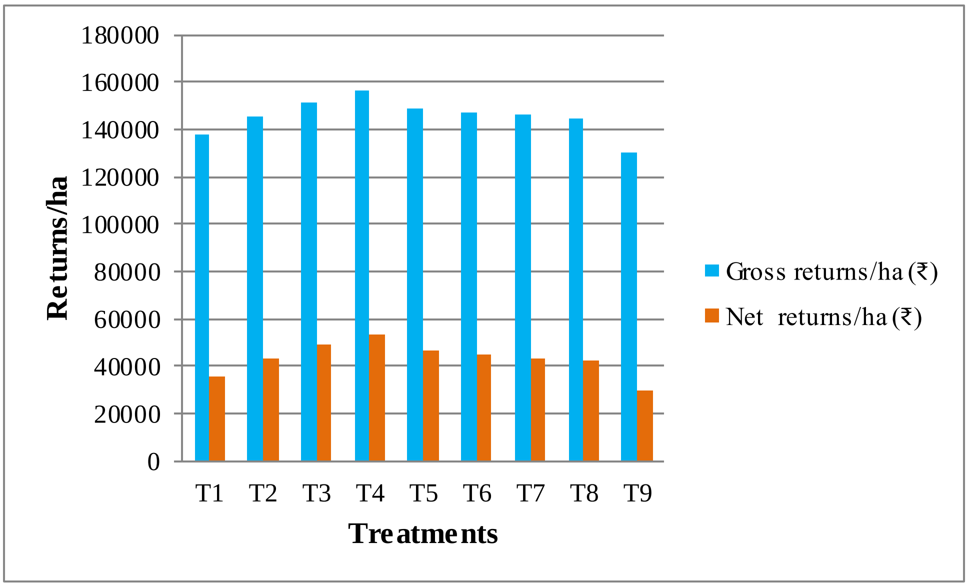


Fig. 11. Effect of B application on gross and net returns per ha

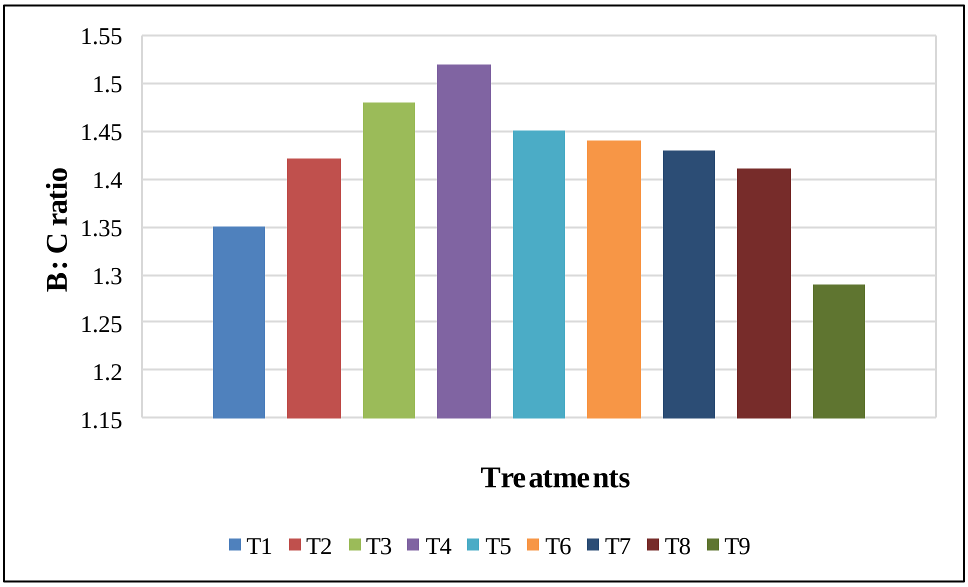


Fig. 12. Effect of B application on B:C ratio

was on par with 0.75 kg B ha$^{-1}$ (₹ 48970). Though foliar spray of 250 ppm B in two splits resulted in the highest net returns (₹ 46253) all the foliar levels were on par.

The B:C ratio of the various treatments was found to differ considerably, with all the treatments except $T_1$ giving values significantly higher than control (Fig. 12). Increasing the level of soil B application was found to increase the B:C ratio. The highest computed B:C ratio among soil treatments was 1.52, recorded by treatment $T_4$ which was on par with $T_3$ (1.48). Among the foliar treatments, 250 ppm B spray in two splits resulted in the highest B:C ratio (1.45) which was found to be on par with rest of the foliar treatments.

The increase in gross and net returns and B:C ratio for B applied treatments could be attributed to the higher grain and straw yields obtained due to boron application. The control plot recorded significantly lower values because of the lower grain and straw yields given by the no B control.

## 5.6 EFFECT OF BORON ON THE CONTENT OF BORON IN INDEX LEAF AT CRITICAL STAGES

The boron treatments exhibited significant effect on the boron content of index leaf at critical stages *viz.*, active tillering, panicle initiation and flowering stages (Fig. 13). All the soil and foliar treatments recorded significantly higher boron contents compared to the no boron control at all three stages. Among soil treatments, the boron content of index leaf increased as the level of application increased from 0.25 to 1.0 kg B ha$^{-1}$ at active tillering and panicle initiation stages and for flowering stage, an increase in boron level beyond 0.75 kg ha$^{-1}$ resulted in a decrease in the content. Similar result was also reported by Santhosh (2013). The boron treatments were applied in two equal splits at active tillering and flowering stages and this is might be the reason for increase in boron content of index leaf. Increasing the level of B application through soil application gave corresponding increases in B content up to 1.0 kg ha$^{-1}$. Increased nutrient translocation along xylem and transpiration favoured by the wet land paddy field might have resulted in boron accumulation in leaves. Oertli and Richardson (1970) and Shelp *et al.* (1987) also have emphasized the role of xylem stream and transpiration in boron accumulation in leaves. A decrease in boron content of index leaf for soil application of B @ 1.0 kg ha$^{-1}$ at flowering stage was observed and this might be because B absorption by the plant roots occurs at a steady rate and the nutrient needs to be translocated to the entire plant body. Hence, a dilution effect occurs as this treatment recorded the maximum straw and grain yields.

For foliar treatments, 250 ppm B spray recorded the highest B content and the higher concentrations in spray fluid resulted in a decrease in the boron content of index leaf at all the three critical stages. When B is applied as foliar spray, higher levels of B beyond 250 ppm resulted in a general decrease in boron contents, which might be due to the damaging effect on the cell wall, resulting in impaired absorption by the plant cells.

## 5.7 EFFECT OF BORON ON THE CONTENT AND UPTAKE OF NUTRIENTS IN STRAW AND GRAIN

### 5.7.1 Nitrogen

Nitrogen content of straw though not markedly influenced by boron treatments had significant effect on its uptake (Fig. 14). Increasing the soil B application levels increased straw nitrogen uptake with the higher levels *viz.*, 0.75 and 1.0 kg ha$^{1}$ producing significantly higher uptake values (71.01 to 72.81 kg ha$^{1}$) compared to all other soil treatments and the no B control. Foliar spray of B @ 250 to 750 ppm resulted in significantly higher straw nitrogen uptake compared to the no B control but a further increase in the foliar B level generally decreased the nitrogen uptake by straw though higher than the control. Soil and foliar treatments though significantly influenced the content and uptake of nitrogen in grain, it could not give

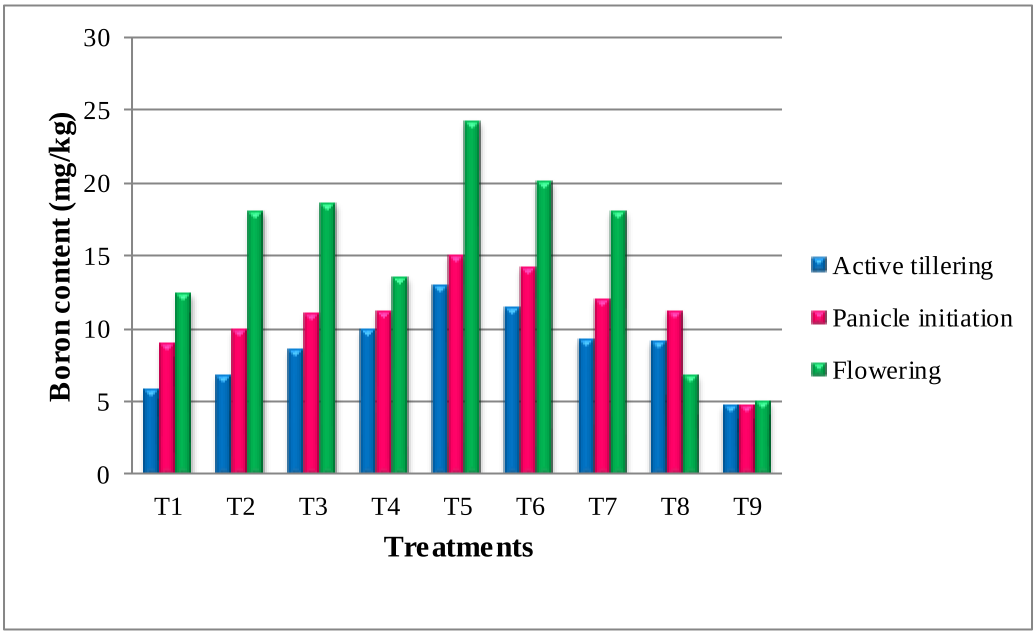


Fig. 13. Effect of B application on B content of index leaf at critical stages

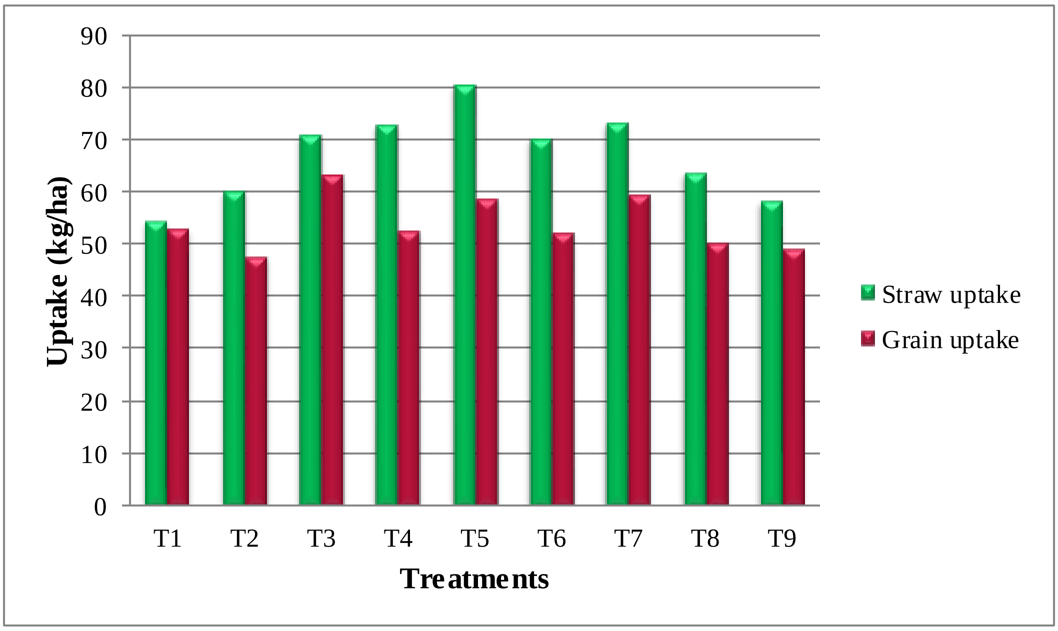


Fig. 14. Effect of B application on N uptake by straw and grain

any consistent result. The maximum grain nitrogen uptakes were given by the corresponding treatments which recorded the maximum grain nitrogen contents. So the best treatments were $T_3$ and $T_7$ with respect to the content and uptake of nitrogen by straw and grain. Boron application improved the vegetative and reproductive growth of the plant, which might be the reason for increased nitrogen uptake, since nitrogen is actively involved in plant growth and metabolism. The increased levels of B application through both soil and foliar methods might have significant effect on increasing the content and uptake of nitrogen by straw and grain. Similar results were also reported by Aref (2012).

### 5.7.2 Phosphorus

Boron treatments at different levels through both soil and foliar methods had no significant effect on the straw phosphorus content and its uptake (Fig. 15). Phosphorus content and uptake of grain were significantly influenced by boron nutrition and all the treatments resulted in higher contents and uptakes as compared to the no boron control. Grain phosphorus contents were conspicuously higher than the corresponding straw contents, which might be due to the partitioning of phosphorus from straw to grain. Soil application of 0.25 kg B $ha^{-1}$ and foliar spray of all the levels of B resulted in significantly higher grain phosphorus contents. All the soil and foliar treatments recorded significantly higher content and uptake by grain and the highest grain uptake values were given by the corresponding treatments that recorded the highest grain contents. Significantly lower grain phosphorus content and uptake recorded for the no boron control revealed that boron treatments exhibited a marked effect on phosphorus nutrition. The increase in grain phosphorus content and uptake by boron application might be due to the role of B in plasmalemma permeability, which might have increased the absorption of phosphorus by the plant and its partitioning to grain. Similar results were obtained by Patel and Golakiya (1986). Higher levels of boron application through either methods have a tendency to slightly reduce the grain phosphorus content and uptake as reported by Aref (2012).

### 5.7.3 Potassium

Graded levels of boron application exerted significant influence on the content and uptake of potassium by straw and grain (Fig. 16). Soil application of B @ 0.25 kg $ha^{-1}$ and foliar spray of 250 and 500 ppm B in equal splits at active tillering and flowering stages recorded the highest straw and grain potassium contents. Higher levels of B irrespective of the method of application had a decreasing effect on the content of potassium in straw and grain. All the soil treatments recorded straw potassium uptake values on par with the no B control but lower levels of foliar B spray @ 250 and 500 ppm registered significantly higher straw potassium uptakes compared to control and the higher levels of application. All the soil and foliar treatments resulted in significantly higher grain potassium uptake compared to the no B control. Boron has a crucial role in translocation of potassium in plant body, which might be the possible reason for increased potassium uptake by the plant with the application of boron. Similar reports were also made by Aref (2012) and Koohkan and Maftoun (2015).

### 5.7.4 Calcium

There was a significant influence on the content and uptake of calcium by straw and grain due to soil or foliar boron application (Fig. 17). Though the straw calcium content increased as the level of soil B application increased from 0.25 to 1.0 kg $ha^{-1}$, the values were not significant compared to the no B control. Foliar spray of B increased the calcium content of straw as the concentration of spray fluid increased from 250 to 1000 ppm. The higher levels (750 and 1000 ppm) recorded significantly higher calcium contents than the control. Increasing the soil boron application level was found to increase the straw calcium uptake values and the highest level (1.0 kg B $ha^{-1}$) gave significantly higher calcium uptake compared to all other soil treatments and control. Increasing the foliar application level also increased the straw calcium uptake with the higher levels of boron spray *viz.*, 500 to 1000 ppm being on par and

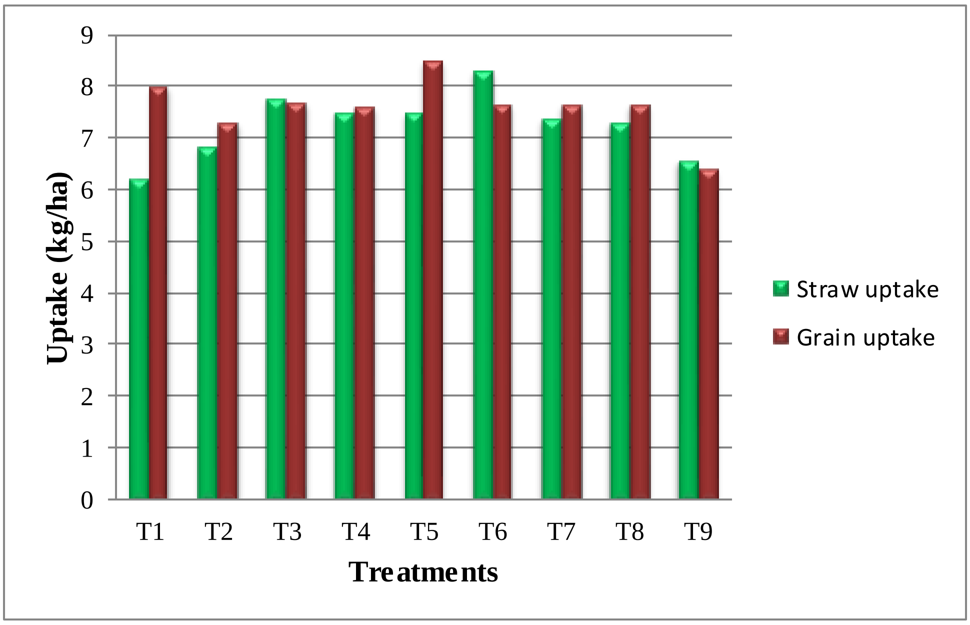


Fig. 15. Effect of B application on P uptake by straw and grain

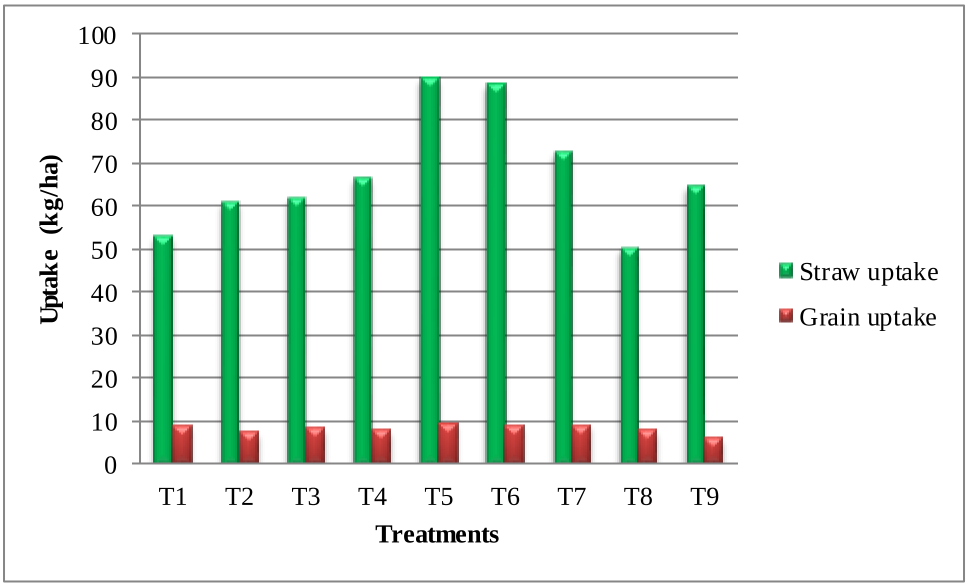


Fig. 16. Effect of B application on K uptake by straw and grain

registering significantly higher uptake values compared to control. The soil of the experimental site washigh in available calcium and in addition to this, lime was applied in order to bring down the soil acidity. Thus, the calcium content of soil was increased which might be the reason for increased calcium content and uptake by straw. Also the increased root length noticed as a result of boron application might have increased the calcium uptake by straw. There exists a synergistic relationship between boron and calcium, and boron also has a positive effect on the translocation and accumulation of calcium as reported by Neumann and Davidov (1993) and Bonilla *et al.* (1995).

Grain calcium content was found to decrease as the level of both soil and foliar B application increased and the lower levels registered higher grain contents. Soil B application, though significant, gave inconsistent variation for grain calcium uptake while for foliar application a significant reduction was observed as B concentration increased. Among the foliar treatments, lower levels *viz.*, 250 ppm and 500 ppm B spray recorded significantly higher values (10.56 and 9.06 kg ha$^{-1}$ respectively) compared to higher foliar treatments and the control. The lowest grain calcium uptake was noticed for the control plot, which was on par with $T_7$ and $T_8$. Calcium is relatively immobile in plant system and hence it is not translocated to grains from the straw leading to lower calcium contents and uptake by grain.

### 5.7.5 Magnesium

The different boron treatments had no significant effect on the content and uptake of magnesium in straw and grain.

### 5.7.6 Copper

The content of copper in straw and grain and grain copper uptake were significantly affected by the soil and foliar boron treatments (Fig. 18). All the levels of soil and foliar application of boron significantly reduced the straw copper content

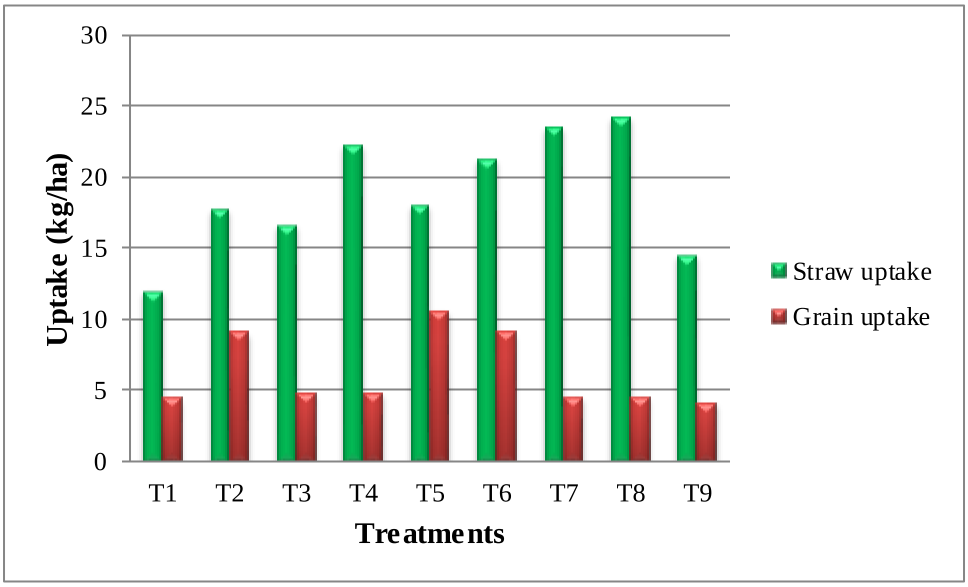


Fig. 17. Effect of B application on Ca uptake by straw and grain

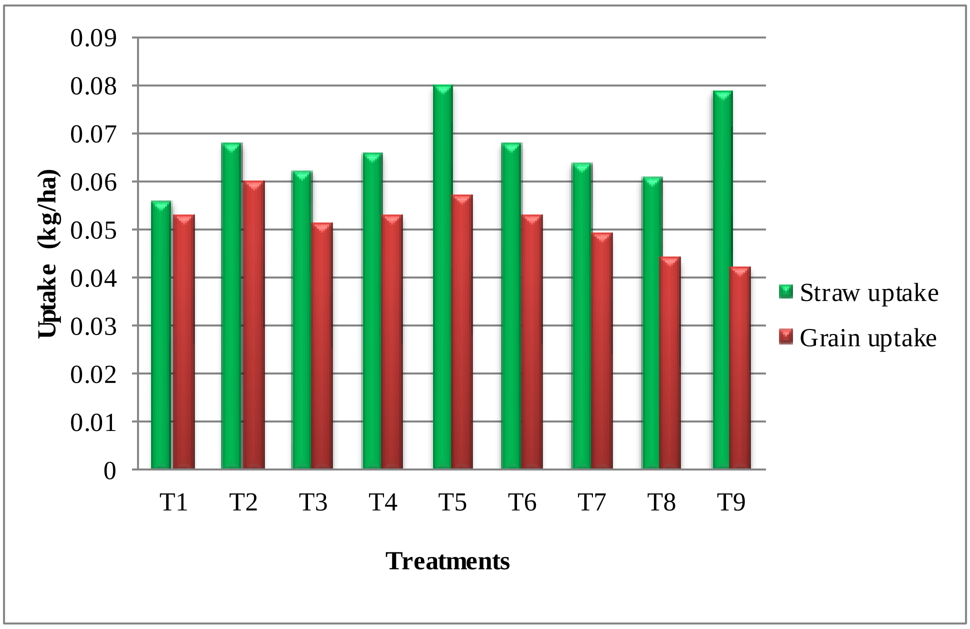


Fig. 18. Effect of B application on Cu uptake by straw and grain

and all the treatments were on par. But the treatment effects were found to be non-significant with respect to the straw copper uptake. Soilapplication of boron gave inconsistent results for grain copper content and a significantly higher content was given by application of 0.5 kg B ha$^{-1}$ in equal splits at active tillering and flowering stages as compared to the control. Foliar boron application generally decreased the grain copper content and 250 ppm B spray resulted in significantly higher copper content of grain. All the soil B application levels significantly increased grain copper uptake while boron application as foliar spray gave significant increase in values only up to 500 ppm. Copper is a component of plastocyanin in photosynthetic electron transport system and boron application increases the rate of photosynthesis. Hence, copper might be absorbed in sufficient quantity to meet the photosynthetic requirements. It is also involved in several enzymatic activities of plants and the increased plant growth due to boron application might have increased the copper uptake. The lower contents of copper in straw might be due to its partitioning into grains.

### 5.7.7 Zinc

The different levels of boron application through either method could not exhibit any significant effect on the zinc content of straw and grain and the straw zinc uptake (Fig. 19). But all the soil treatments registered significantly higher grain zinc uptake values compared to the no B control. Soil application of B @ 1.0 kg ha$^{-1}$ in equal splits at active tillering and flowering stages resulted in the highest value, which was on par with rest of the soil treatments. The foliar treatments of 250 ppm and 500 ppm B sprays recorded significantly higher grain zinc uptake values compared to control. Zinc actively participates in metabolism of auxin and protein and serves as an activator of certain enzymes required for plant growth. The increased plant growth due to boron application might have increased the zinc uptake to balance the requirements of plants. There are previous reports for increase in grain zinc uptake with increased boron application rates by Sinha *et al.* (2000) and Bhutto *et al.* (2013).

### 5.7.8 Boron

All the soil and foliar treatments significantly influenced the content and uptake of boron in straw and grain (Fig. 20). Soil boron treatments registered increased values for straw boron content and increase in boron application through soil gave a corresponding increase in boron content of straw up to 0.75 kg B ha$^{-1}$. The effect of soil B application in significantly increasing the straw boron content was more marked at higher levels *viz.*, 0.5 to 1.0 kg ha$^{-1}$ compared to T$_1$ and the no boron control. On comparing the foliar treatments, it was clear that all levels of boron spray (250 and 1000 ppm) gave significantly higher straw boron content compared to the control even though there was a corresponding decrease with increase in B concentration in the spray fluid. The soil and foliar treatments at all levels registered significantly higher grain boron contents compared to the no boron control. Similar to straw B content, increasing the boron level gave corresponding increases in grain boron content for soil treatments only up to 0.75 kg B ha$^{-1}$. The foliar treatments had a decreasing effect on the grain B content as the level of spray increased from 250 to 1000 ppm.

All the soil treatments recorded significantly higher straw boron uptake compared to the control. The highest uptake was given by soil application of 1.0 kg B ha$^{-1,}$ which was on par with the application of 0.75 kg B ha$^{-1}$. Among the foliar treatments, all the levels of boron spray except the highest level (1000 pppm B) recorded significantly higher straw uptake values compared to the no boron control. The highest value was recorded by the lowest concentration *viz.*, 250 ppm B spray. Results clearly show that all the soil and foliar treatments registered significantly higher grain boron uptake values compared to the no boron control. The results further revealed that there was a corresponding increase in content and uptake of

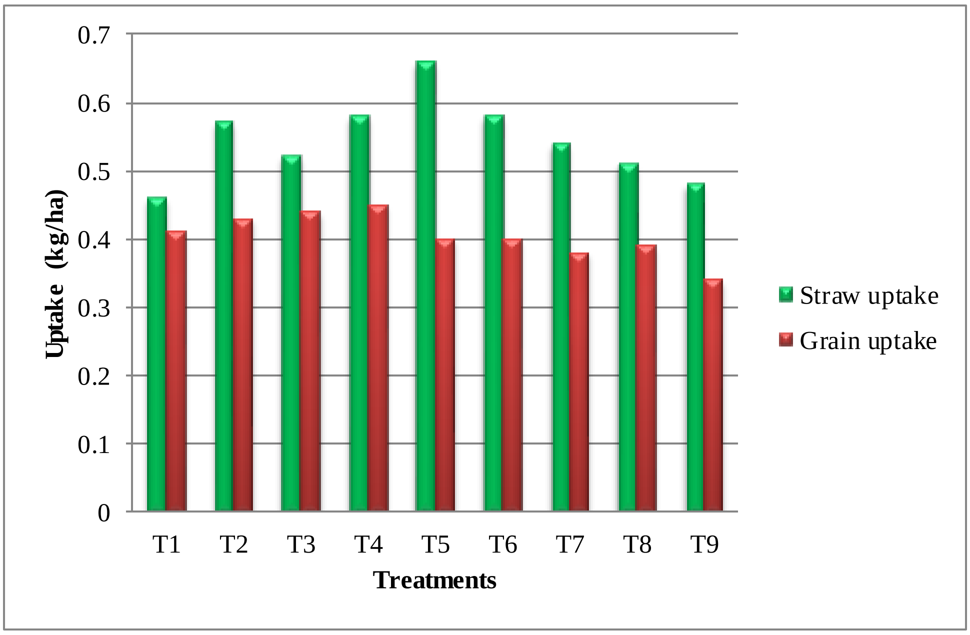


Fig. 19. Effect of B application on Zn uptake by straw and grain

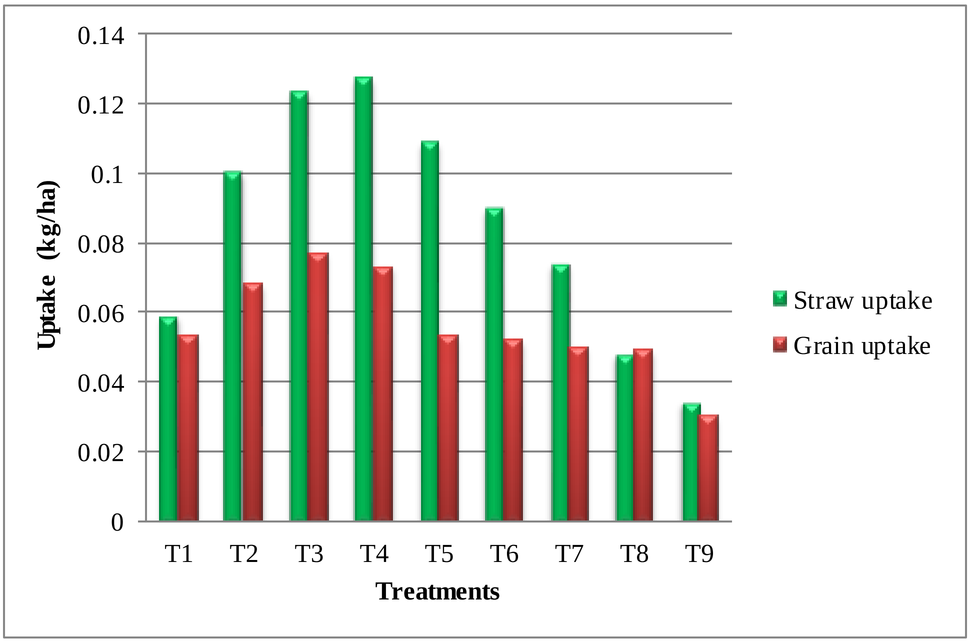


Fig. 20. Effect of B application on B uptake by straw and grain

boron in straw and grain with increasing rates of soil boron application (Johnson *et al.,* 2005). This indicates that if the nutrients are in plenty, the plant continues to partition them to the grains. Similar results were reported by Cheng and Rerkasem (1993) and Debnath and Ghosh (2012). A decrease in boron content of straw and grain was observed when B was applied @ 1.0 kg $ha^{-1}$. This might be because B absorption by the plant roots occurs at a steady rate and the nutrient needs to be translocated to the entire plant body. Hence, a dilution effect occurs as this treatment recorded the maximum straw and grain yields. When B is applied as foliar spray, higher levels of B beyond 250 ppm resulted in a general decrease in straw and grain boron contents, which might be due to the damaging effect which results in impaired absorption by the plant cells beyond a certain concentration level.

## 5.8 EFFECT OF BORON ON THE PHENOL CONTENT OF PLANT AT DIFFERENT STAGES

Phenol content of shoot at tillering and flowering stages (Fig. 21) and that of straw and grain at harvest (Fig. 22) were significantly influenced by the soil and foliar boron treatments. At tillering stage, though there was an increase in phenol content for the soil treatments compared to the no B control, they were on par with the control except for $T_{1,}$ while for the foliar treatments there was a decrease. As crop growth progressed, it was found that all boron applied treatments showed a significant decrease in phenol content compared to the no B control. Similarly, the phenol contents of straw and grain were also significantly lower than the control. Phenol is found to accumulate in boron deficient tissues because of its increased synthesis and inhibited utilization, since proper cell wall synthesis does not occur in the absence of boron. Similar results have also been made by Marschner (1995) and Cakmak and Romheld (1997).

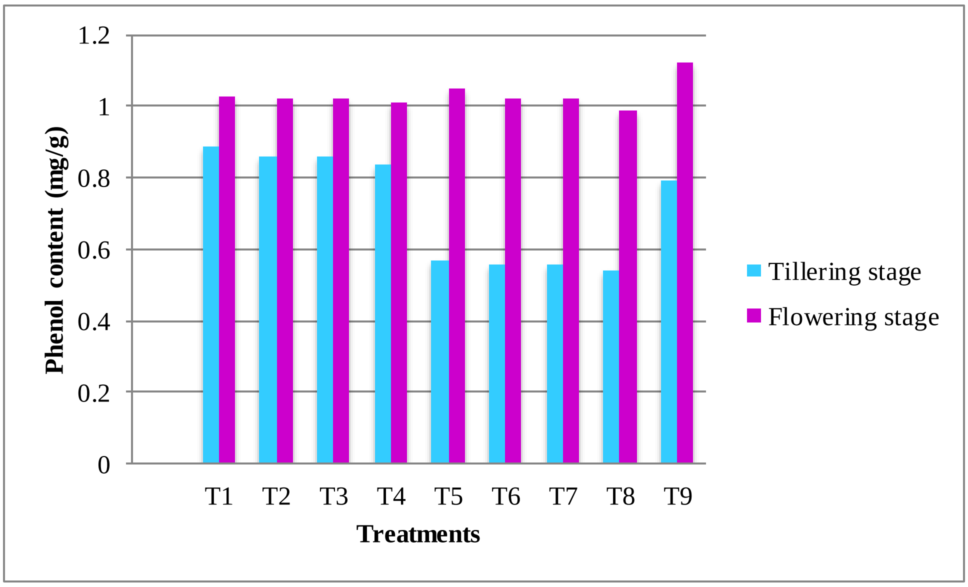


Fig. 21. Effect of B application on phenol content of shoot at tillering and flowering stages

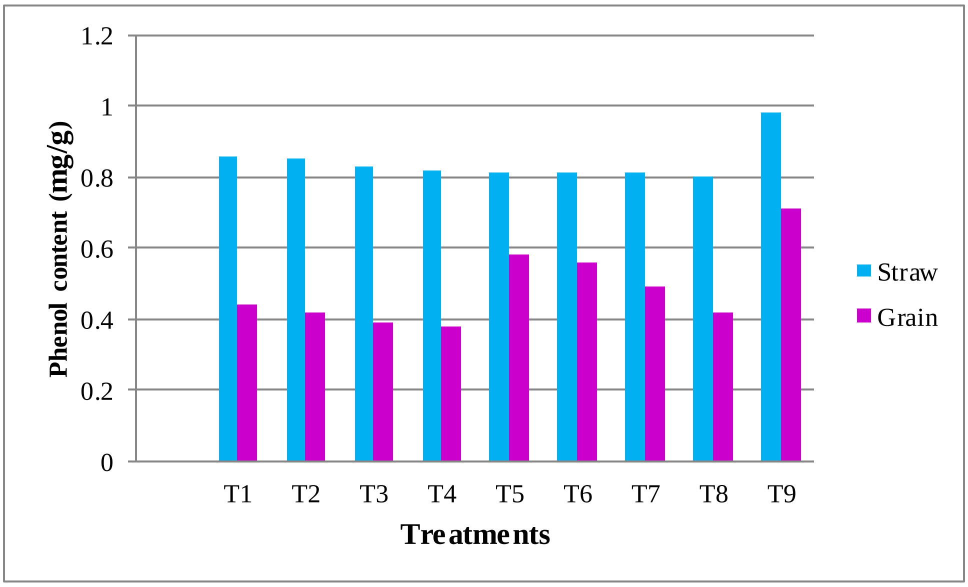


Fig. 22. Effect of B application on phenol content of straw and grain at harvest

## 5.9 POST HARVEST SOIL CHEMICAL PROPERTIES AND NUTRIENT STATUS

The different B treatments through soil and foliar methods had no significant effect on pH or EC of the soil.

Soil nutrient status after harvest showed no significant differences among the treatments in the availability of nitrogen, phosphorus, potassium, calcium, magnesium and copper.

All the soil and foliar boron treatments were found to increase the soil zinc availability significantly compared to the no boron control. The initial soil was sufficient in available zinc and high in magnesium contents. Magnesium has similar ionic radii as that of zinc and it might have interacted with relatively insoluble zinc compounds in the soil to release the zinc in an available form. This might be the possible reason for increased zinc availability in soil.

All the soil and foliar treatments recorded significantly higher boron availability compared to the no boron control. The application of boron in soil resulted in increased availability of boron in treated plots. Since boron requirement of plants could be met through the foliar spray of B, it might have reduced the rate of B absorption through the plant roots. Therefore, the available boron status of the soil of the foliar treated plots remains more or less unchanged or increased.

## 5.10 EFFECT OF BORON ON SEED GERMINATION

There was no significant effect on seed germination by the treatments irrespective of the dose and the mode of application.

# *Summary*

# 6. SUMMARY

The salient findings obtained from the study on "Boron nutrition of wet land rice (*Oryza sativa* L.)" are summarised in this chapter.

A field experiment was conducted in a randomized block design with three replications and nine treatments using the medium duration rice variety Uma at Cropping Systems Research centre, Karamana, Thiruvananthapuram, to assess the dose and method of application of the micronutrient boron to wet land rice in the acid soils of Kerala.

Soil and foliar application of B at two stages *viz.*, active tillering and flowering were evaluated using borax as the source of B. Four levels of soil application and four levels of foliar spray were tried along with a no boron control. Both the soil and foliar treatments were applied in two equal splits at active tillering and flowering stages. All the treatments were given lime, FYM and fertilizers as per the Package of Practices recommendations of Kerala Agricultural University, in addition to B.

The conclusions drawn from the results obtained from the study, are summarized below.

Initial analysis of the soil of the experimental site revealed that the soil was strongly acidic with normal electrical conductivity. The soil was either medium or high in the available status of primary and secondary nutrients with sufficient quantities of copper and zinc but boron was found to be deficient.

On analysing the effect of boron application on plant growth parameters of rice, it was found that soil B application from 0.25 to 0.75 kg ha$^{-1}$ recorded shoot lengths on par with the control and foliar spray of B @ 250 ppm gave significantly higher shoot length compared to the no B control. Significantly higher root lengths compared to control were given by the soil B application of 0.25 to 0.75 kg ha$^{-1}$ and foliar spray of 250 ppm B. The number of total and productive tillers were not significantly influenced by the treatments.

Significantly higher panicle weights were obtained from the treatments receiving 1.0 kg B ha$^{-1}$ in soil and 250 ppm B as foliar spray in two equal splits. Higher levels of soil B application ($T_3$ and $T_4$) and lower levels of foliar spray ($T_5$ and $T_6$) resulted in significantly higher percentage of filled grains. It was observed that soil B application @ 0.75 to 1.0 kg ha$^{-1}$and foliar spray of 250 to 500 ppm B resulted in significant reduction in spikelet sterility compared to the control. All the levels of soil application registered significantly higher values for thousand grain weight but foliar application did not affect the values. The panicle length and number of grains per panicle were not significantly affected by the different boron treatments.

Both grain and straw yields were significantly influenced by B application. All the B treatments irrespective of the method of application produced significantly higher grain yield as compared to the control where no B was applied, which revealed the beneficial effect of boron on grain yield. The treatments $T_4$, $T_5$, $T_6$ and $T_7$ recorded significantly higher straw yields compared to control but foliar B application was better in increasing straw yields compared to soil application. On comparing the method of application, better grain yields were given by the soil B application and improved straw yields were obtained when B was sprayed on the foliage.

The different treatments had significant effect in reducing the brown leaf spot disease incidence. The no boron control recorded the highest percentage of disease incidence compared to the B treated plots. Soil B application from 0.5 to 1.0 kg ha$^{-1}$ and a foliar spray of 1000 ppm B in equal splits registered significantly lower PDI as compared to the control. It was observed that as the level of B application increased, the PDI decreased gradually. But the treatments could not exert any effect on reducing the attack of leaf folder.

Economic analysis revealed that all the soil and foliar treatments except $T_1$ significantly increased the gross and net returns and the B:C ratio compared to the treatment receiving no B application. The highest B:C ratio was recorded by the treatment $T_4$, which was on par with $T_3$ and $T_5$ indicating the efficiency of soil application.

All the treatments exerted significant effect on the boron content of index leaf at critical stages *viz.*, active tillering, panicle initiation and flowering stages. It was observed that increasing the level of boron application through soil gave corresponding increases in the boron content of index leaf at active tillering and panicle initiation stages, while at flowering stage, further increase in B application beyond 0.75 kg ha$^{-1}$ decreased the B content. Among the foliar treatments, the maximum B content of index leaf at all the three stages was recorded by 250 ppm B spray while the higher levels exhibited a decreasing trend.

Though the different treatments significantly influenced the nutrient contents of straw and grain, the values were not consistent. The content of N, P, Mg and Zn in straw and that of Mg and Zn in grains were found non- significant.

The different boron treatments exerted significant influence on the uptake of nutrients by straw and grain. Straw N uptake was significantly higher for $T_3$, $T_4$, $T_5$, $T_6$ and $T_7$ while $T_3$, $T_5$ and $T_7$ recorded significantly higher grain uptake. Though the P uptake by straw was not significantly affected by the treatments, all the soil and foliar treatments gave significantly higher grain P uptake. Even though the soil treatments had no significant effect on straw K uptake, the lower levels of foliar treatments ($T_5$ and $T_6$) registered significantly higher K uptake whereas all the B treatments increased the grain K uptake significantly. For Ca, the higher B levels $T_4$, $T_6$, $T_7$ and $T_8$ recorded significantly higher straw uptake while the lower levels *viz.*, $T_1$, $T_2$, $T_5$ and $T_6$ recorded significantly higher grain uptake. Neither the soil treatments nor the foliar treatments had significant effect on the Mg uptake by straw and grain. In the case of Cu, the treatments had no significant effect on straw uptake while significantly higher grain uptake was observed for $T_1$, $T_2$, $T_4$, $T_5$ and $T_6$. The treatments had no significant influence on straw Zn uptake whereas all the soil treatments and the foliar treatments $T_5$ and $T_6$ gave significantly higher grain uptake. All the treatments except $T_1$ and $T_2$

registered significantly higher straw B uptake while grain B uptake was significantly higher for all the B applied plots.

Foliar application of B recorded significantly lower phenol content of shoot at active tillering stage compared to control with the exception of $T_1$. All the soil and foliar treatments recorded significantly lower phenol content of shoot at flowering stage and that of straw and grain at harvest compared to control. It was observed that as crop growth progressed, the phenol content decreased with increase in levels of B application with the no boron control registering significantly higher phenol content compared to all the treatments.

The boron treatments had no significant effect on soil reaction, electrical conductivity, and available nutrient status of N, P, K, Ca, Mg and Cu. But both Zn and B content showed positive response with respect to their availability due to B application. The soil availability of both Zn and B showed significant increases as compared to the no B control.

Neither the soil treatments nor the foliar treatments had any significant influence on seed germination after harvest. Except $T_4$ and $T_7$, all the other treatments recorded 100 percent germination of seeds.

From the experiment, it was found that soil application of B @ 1.0 kg ha$^{-1}$ ($T_4$) in equal splits at active tillering and flowering stages recorded the highest grain yield and the factors contributing to increased yield were observed to be increased panicle weight and percentage filled grains. It also recorded significantly lower spikelet sterility and PDI. Treatment $T_3$ (0.75 kg B ha$^{-1}$) was found to be on par with $T_4$. Among the foliar treatments, though the 250 ppm B spray in two equal splits gave higher yields, higher levels of spray had an inhibitory effect on plant growth parameters, yield attributes and nutrient uptake. So soil application of B @ 0.75 kg ha$^{-1}$ in two equal splits at active tillering and flowering stages can be recommended to meet the boron requirement of wet land rice in the acid soils of Kerala.

## FUTURE LINE OF WORK

Since B spray @ 250 ppm in two equal splits produced the highest yield among foliar treatments and higher foliar application levels had a diminishing effect on yield, the effect of B spray at levels below 250 ppm is to be validated.

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# BORON NUTRITION

# OF WET LAND RICE (*Oryza sativa* L.)

*by*

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**(2014-11-153)**

**Abstract of the thesis**

**Submitted in partial fulfilment of the**

**requirement for the degree of**

**MASTER OF SCIENCE IN AGRICULTURE**

**Faculty of Agriculture**

**Kerala Agricultural University**

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**

**COLLEGE OF AGRICULTURE**

**VELLAYANI, THIRUVANANTHAPURAM-695 522**

**KERALA, INDIA**

**2016**

## ABSTRACT

The investigation entitled "Boron nutrition of wet land rice (*Oryza sativa* L.)" was conducted at Cropping Systems Research Centre, Karamana, during 2015-2016 with medium duration rice variety Uma, to assess the optimum dose and methods of application of boron to be recommended for wet land rice in the acid soils of Kerala.

The experiment was laid out in a randomized block design with three replications and nine treatments. The treatments consisted of four levels of soil application of boron (B) *viz.*, $T_1$- 0.25 kg B ha$^{-1}$, $T_2$- 0.50 kg B ha$^{-1}$, $T_3$- 0.75 kg B ha$^{-1}$ and $T_4$- 1.0 kg B ha$^{-1}$ and four levels of foliar spray *viz.*, $T_5$- 250 ppm B, $T_6$- 500 ppm B, $T_7$- 750 ppm B and $T_8$- 1000 ppm B in addition to a no boron control ($T_9$). The B treatments were applied in two equal splits at active tillering and flowering stages. All treatments were provided with manures and fertilizers as per the KAU POP.

The initial analysis of the soil of the experimental site revealed that the soil was strongly acid in reaction with normal EC and sandy clay in texture. The soil was low in CEC, high in organic carbon, medium in the available status of N and K, high in P, Ca, Mg and S, sufficient in Cu and Zn and deficient in B (0.5 ppm). Results revealed that among the soil treatments, $T_4$ recorded minimum spikelet sterility (16.33 %) and maximum percentage of filled grains (83.67 %). It also recorded higher values for panicle weight (2.71 g) and thousand grain weight (24.48 g) which resulted in producing the highest grain (5502.85 kg ha$^{-1}$) and straw (7014.52 kg ha$^{-1}$) yields. The maximum B content of index leaf at active tillering and panicle initiation stages were recorded by $T_4$ and that at flowering stage was recorded by $T_3$. Uptake of N, K, Ca and B by straw and that of K, Cu, Zn and B by grain were found to be higher in $T_4$. Lower values for percentage disease incidence and phenol contents were also observed in $T_4$. All soil treatments significantly increased the availability of Zn and B. The treatment $T_3$ receiving 0.75 kg ha$^{-1}$ B as soil application was found to be statistically on par with $T_4$.

Among the graded levels of foliar treatments ranging from 250 to 1000 ppm, it was found that 250 ppm B ($T_5$) was superior to higher levels with respect to biometric observations, yield and yield attributes, B content of index leaf, nutrient uptake and phenol content.

The number of total and productive tillers, panicle length, number spikelets per panicle, scoring of leaf folder attack, cost of cultivation, seed germination, uptake of P, Mg, Cu and Zn by straw and that of Mg by grain, soil pH and EC and availability of N, P, K, Ca, Mg and Cu were found non-significant by the treatments.

Soil treatments gave significantly higher grain yields compared to foliar treatments. Economic analysis revealed the superiority of B treatments over control. The highest gross and net returns and B:C ratio was recorded for the soil treatment $T_4$ (1.52) which was on par with $T_3$ (1.48).

Since the yield and B:C ratios for $T_4$ and $T_3$ were on par, in the case of micronutrient recommendations, it is mandatory to recommend the lower dose *i.e.*, 0.75 kg B ha$^{-1}$ as soil application in two splits at active tillering and flowering stages to meet the B requirement of wet land rice in the acid soils of Kerala.

# സംഗ്രഹം

നെല്ലിന്റെ ബോറോൺ പോഷണം എന്ന പേരിൽ ഒരു പരീക്ഷണം 2015 സെപ്തംബർ മുതൽ 2016 ജനുവരി വരെയുള്ള കാലയളവിൽ കരമന ക്രോപ്പിംഗ് സിസ്റ്റംസ് റിസർച്ച് സെന്ററിലെ നെൽപ്പാടത്ത് നടത്തുകയുണ്ടായി. നെല്ലിന്റെ വിളവ് വർദ്ധിപ്പിക്കുന്നതിന് ആവശ്യമായ ബോറോൺ എന്ന മൂലകത്തിന്റെ കൃത്യമായ തോതും പ്രയോഗരീതിയും കണ്ടെത്തുക എന്നതായിരുന്നു ലക്ഷ്യം.

പ്രസ്തുത പരീക്ഷണത്തിന് റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പരീക്ഷണ രീതിയാണ് അവലംബിച്ചത്. ഉമ എന്ന നെല്ലിനമാണ് പഠനവിധേയമാക്കിയത്. നാലു വ്യത്യസ്ത അളവുകൾ വീതം രണ്ടുതവണകളായി (ചിനപ്പുകൾ വരുന്ന സമയത്തും പൂക്കുന്ന സമയത്തും) മണ്ണുവഴിയും പത്രപോഷണം വഴിയും ബോറോൺ പ്രയോഗം നടത്തി. ഇതിനു പുറമേ ശുപാർശ ചെയ്ത അളവിൽ മറ്റു മൂലകങ്ങളും (പാക്യജനകം : ഭാവകം : ക്ഷാരം– 90:45:45 കിലോഗ്രാം ഒരു ഹെക്ടറിന്) നൽകി. താരതമ്യ പഠനത്തിനായി ഒരു ബോറോൺ രഹിത കൺട്രോൾ പ്ലോട്ടും പഠന വിധേയമാക്കി.

ഒരു കിലോഗ്രാം ബോറോൺ മണ്ണുവഴി പ്രയോഗിക്കപ്പെട്ട ചെടികളിലാണ് ഏറ്റവും കുറഞ്ഞ സ്പൈക്‌ലെറ്റ് സ്റ്റെറിലിറ്റിയും കൂടാതെ ഏറ്റവും കൂടുതൽ കതിർതൂക്കം, ആയിരം നെന്മണികളുടെ തൂക്കം, കതിരിലെ നിറഞ്ഞ നെന്മണികളുടെ ശതമാനം, വിളവ് എന്നിവ കാണപ്പെട്ടത്. സൂചന ഇലകളിലെ ബോറോണിന്റെ അളവും ചെടികൾ ആഗിരണം ചെയ്ത അവശ്യമൂലകങ്ങളുടെ അളവും ഏറ്റവും കൂടുതലായി കാണപ്പെട്ടതും ഇതേ ചെടികളിലാണ്. രോഗങ്ങളും ഫീനോളിന്റെ അളവും ഇവയിൽ വളരെ കുറവായിരുന്നു. മണ്ണിലെ സിങ്ക്, ബോറോൺ എന്നീ മൂലകങ്ങളുടെ ലഭ്യതയും ഗണ്യമായി വർദ്ധിക്കുകയുണ്ടായി. ഇതിനോട് സാമ്യമുള്ള ഫലം തന്നെയാണ് 0.75 കിലോഗ്രാം ബോറോൺ മണ്ണുവഴി പ്രയോഗിച്ച ചെടികളിലും കാണപ്പെട്ടത്. ഇലകളിൽ കൂടി ദ്രവരൂപത്തിൽ ബോറോൺ തളിച്ച പ്ലോട്ടുകളിൽ ഏറ്റവും മികച്ചതായി കണ്ടെത്തിയത് 250 പി.പി.എം. ബോറോൺ രണ്ടുതവണയായി (ചിനപ്പുകൾ വരുന്ന സമയത്തും പൂക്കുന്ന സമയത്തും) തളിച്ചതാണ്.

പത്രപോഷണത്തെ അപേക്ഷിച്ച് ഏറ്റവും ഉയർന്ന വിളവ് ലഭ്യമായത് മണ്ണുവഴിയുള്ള ബോറോൺ വളപ്രയോഗത്തിലാണ്. ബോറോൺ രഹിത കൺട്രോൾ പ്ലോട്ടിലെ ചെടികളെക്കാൾ മികച്ച ഫലമാണ് ബോറോൺ പ്രയോഗിച്ച പ്ലോട്ടിലെ ചെടികൾ നൽകിയത്. ഏറ്റവും ഉയർന്ന അറ്റാദായവും വരവ് ചെലവ് അനുപാതവും കാണപ്പെട്ടത് 0.75 – 1.0 കിലോഗ്രാം ബോറോൺ മണ്ണിലൂടെ പ്രയോഗിച്ച പ്ലോട്ടുകളിലാണ്. അതിനാൽ 0.75 കിലോഗ്രാം ബോറോൺ രണ്ടു തവണയായി മണ്ണിലൂടെ നൽകുന്നതാണ് നെല്ലിന് ഉയർന്ന വിളവ് ലഭിക്കാൻ ഉത്തമം.

# *Appendix*

# Appendix I

## Weather data for the cropping period

## (September 2015 to January 2016)- Weekly averages of temperature and relative humidity and weekly sum of rainfall

| Standard week | Date | Temperature (°C) | | Relative humidity (%) | Rain fall (mm) |
|---|---|---|---|---|---|
| | | Maximum | Minimum | | |
| 35 | 27 Aug-2 Sept | 32.1 | 25.6 | 92.7 | 0 |
| 36 | 3-9 Sept | 28.5 | 23.1 | 98.4 | 38.4 |
| 37 | 10-16 Sept | 29.9 | 24.0 | 98.5 | 15.7 |
| 38 | 17-23 Sept | 30.9 | 24.9 | 96.1 | 0 |
| 39 | 24-30 Sept | 30.5 | 24.1 | 96.9 | 0.3 |
| 40 | 1-7 Oct | 31.5 | 24.0 | 98.7 | 2.8 |
| 41 | 8-14 Oct | 30.6 | 24.4 | 98.9 | 0 |
| 42 | 15-21 Oct | 32.9 | 24.6 | 99.2 | 23.1 |
| 43 | 22-28 Oct | 30.6 | 23.8 | 98.2 | 21.1 |
| 44 | 29 Oct-4 Nov | 30.6 | 24.0 | 99.9 | 9.4 |
| 45 | 5-11 Nov | 30.8 | 24.7 | 100.0 | 3.0 |
| 46 | 12-18 Nov | 31.1 | 24.1 | 99.5 | 3.0 |
| 47 | 19-25 Nov | 31.6 | 24.4 | 97.9 | 0 |
| 48 | 26 Nov-2 Dec | 28.4 | 23.5 | 97.9 | 14.2 |
| 49 | 3-9 Dec | 30.9 | 23.9 | 98.7 | 0 |
| 50 | 10-16 Dec | 30.8 | 24.1 | 99.4 | 24.1 |
| 51 | 17-23 Dec | 29.9 | 22.0 | 99.6 | 0 |
| 52 | 24-31 Dec | 30.8 | 21.3 | 93.6 | 0 |
| 1 | 1-7 Jan | 31.3 | 21.6 | 97.9 | 0 |
| 2 | 08-14 Jan | 31.2 | 22.9 | 94.9 | 0 |
| 3 | 15-21 Jan | 30.7 | 22.6 | 94.3 | 0 |
| 4 | 22-28 Jan | 30.9 | 23.9 | 94.4 | 0 |