ZINC AND BORON NUTRITION IN GROUNDNUT (*Arachis hypogaea* L.) FOR *ONATTUKARA* SANDY PLAIN

by

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(2017-11-085)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"ZINC AND BORON NUTRITION IN GROUNDNUT (*Arachis hypogaea* L.) FOR *ONATTUKARA* SANDY PLAIN "** 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, associate ship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"ZINC AND BORON NUTRITION IN GROUNDNUT (*Arachis hypogaea* L.) FOR *ONATTUKARA* SANDY PLAIN"** is a record of research work done independently by Ms. Reni Francis (2017-11- 085) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

@	At the rate of
^{o}C	Degree Celcius
%	Per cent
₹	Rupees
BCR	Benefit : cost ratio
B	Boron
Ca	Calcium
cc	Cubic centimetre
CD (0.05)	Critical difference at 5 per cent level
CGR	Crop growth rate
cm	Centimetre
cm^2	Square centimetre
DAE	Days after emergence
DAS	Days after sowing
DMP	Dry matter production
dS m^{-1}	Deci Siemens per meter
EC	Electrical conductivity
et al.	Co- workers/ co-authors
Fig.	Figure
FYM	Farmyard manure
g kg^{-1}	Gram per kilogram
g ha^{-1}	Gram per hectare
ha^{-1}	Per hectare
K	Potassium
KAU	Kerala Agriculture University
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
LAD	Leaf area duration
LAI	Leaf area index
mg	Milligram
m	Metre
mg kg^{-1}	Milligram per kilogram
m^{-2}	Per meter square
Mg	Magnesium
N	Nitrogen
NS	Non significant
P	Phosphorus
POP	Package of practices
RDF	Recommended dose of fertilizer
RBD	Randomized block design
RH	Relative humidity

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S	Sulphur
SEm	Standard error of means
t ha^{-1}	Tonnes per hectare
Zn	Zinc
$ZnSO_4$	Zinc sulphate
Zn - EDTA	Zinc – Ethylene Diammine Tetra acetic acid

Introduction

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1. INTRODUCTION

Groundnut is the world's third most important source of vegetable protein and fourth most important source of edible oil. The groundnut seed, known as poor man's nut, supplies high energy, protein and minerals at a comparatively low cost. It is also a rich source of micronutrients including zinc which makes the crop more important in human diet (Singh, 2016). Groundnut seed contain about 50 per cent edible oil, 21.4 to 36.4 per cent high quality protein, 6.0 to 24.9 per cent carbohydrates and also minerals and vitamins. It is also equally rich in Calcium (Ca), iron (Fe) and vitamin B complex like thiamine, riboflavin, niacin and vitamin A.

Groundnut is currently grown in 26.4 million hectares world wide with a total production of 37.1 million tonnes and average productivity of 1400 kg ha^{-1}. India ranks first in acreage with 70 lakh hectares which contributes 85 lakh tonnes of groundnut. Nowadays, groundnut has a share of approximately 25 per cent in the total Indian oilseed production (IOPEPC, 2018). The productivity of groundnut in India is low when compared to the global productivity. This is mainly due to marginal land cultivation, lower adoption of high yielding cultivars, micronutrient deficiencies and incidence of pests and diseases.

Today, intensive cropping systems leads to secondary and micronutrients deficiencies, which is the major constraint for low yield of groundnut. It is quite evident that the full benefit of application of major nutrients cannot be obtained in the absence of available micronutrients in the soil. The micronutrients *viz*., Zn and B plays an important role in improving the yield and quality of groundnut. In India, Zn is now considered the fourth most important yield limiting nutrient after, nitrogen (N), phosphorus (P) and potassium (K), respectively (Arunachalam *et al.*, 2013). Boron is one of the key micronutrients required for groundnut and the need for B is a slightly higher than other legumes (Nasar *et al.,* 2018). Different mode of fertilization *viz.,* soil application, seed coating and foliar application can be suitably adapted to enhance Zn and B uptake by groundnut.

In India, as the groundnut crop is mostly grown on marginal soil, its productivity as well as Zn concentration in seed is low, leading to less per capita availability of groundnut and zinc. High Zn density groundnut may be a solution to ensure adequate level of Zn intake which necessitates increase of Zn concentration of seed through fortification (Cakmak, 2008).

Boron has the ability to increase photosynthetic and enzymatic activity in groundnut. In B deficient acid soils (below 0.4 ppm available B), low pod filling, shrivelled seeds and hollow darkening or off-colour in the centre of the seed are commonly observed as symptoms causing 10 to 50 per cent yield loss (Singh *et al.*, 2007). Boron application increased the shelling percentage and 100 seed weight of peanut indicating the important role of boron in seed quality (Singh, 2009).

Groundnut is an important summer oil seed crop and food grain legume of *Onattukara* region spread over Kollam and Alappuzha districts of Kerala. The soil in this tract is coarse textured with low nutrient and water retention capacity. Problems due to micronutrient deficiencies have been reported recently from many parts of *Onattukara* region. The gap between the actual and achievable yields for groundnut is wide and better nutrient management practices with special emphasis to micronutrients like Zn and B offers a solution to bridge the yield gap. Hence, the present investigation was carried out with the following objectives

- To evaluate the effect of zinc and boron nutrition on growth, yield and quality of groundnut in the summer rice fallows of *Onattukara*
- To work out the economics of cultivation

Review of Literature

2. REVIEW OF LITERATURE

An investigation entitled "Zinc and boron nutrition in groundnut (*Arachis hypogaea* L.) for *Onattukara* sandy plain" was undertaken during 2017-19 to evaluate the effect of Zn and B nutrition on growth, yield and quality of groundnut (*Arachis hypogaea* L.) in the summer rice fallows of *Onattukara* and to work out the economics of cultivation. Studies on Zn and B nutrition in groundnut were reviewed and presented in this chapter.

Groundnut (*Arachis hypogaea* L.) is an important legume used as oilseed and as a food crop in India. Micronutrients play an important role in the physio morphological characteristics of oilseed crops. Ghosh *et al.* (2002) opined that proper fertilizer management of groundnut with right kind of nutrients at right time adapting right method of application has significant effect on yield and quality. Mathew (2007) reported that micronutrients supplementation helped in correction of hidden hunger and better utilization of major nutrients resulting in better crop growth and yield. Intensive cropping leads to deficiency of secondary and micronutrients, which is the main constraint for low yield of groundnut (Nayak *et al.*, 2009).

Hussain (2018) studied the importance of precision nutrient management on growth and yield of groundnut. Among different practices, precision nutrient management recorded significantly higher pod yield (12.75 q ha^{-1}), plant height (28.8 cm), number of branches (10.3), leaf area (989.6 cm^2), number of pods per plant (20.2) and pod weight (13.29 g) in groundnut over recommended practice and farmer's practice, respectively. The aim of this review was to study the role of micronutrients viz., zinc and boron on growth, yield and quality attributes of groundnut as well as plant nutrient uptake, soil nutrient status and economics.

2.1 EFFECT OF ZINC NUTRITION ON GROWTH, YIELD AND QUALITY OF GROUNDNUT

Zinc is an essential micronutrient and plays an important role as a structural constituent or regulatory cofactor of a wide range of different enzymes and proteins in biochemical pathways including carbohydrate metabolism, photosynthesis, conversion of sugars to starch, protein metabolism, auxin metabolism, pollen formation, integrity of biological membranes and resistance to certain plant diseases (Alloway, 2008).

Zinc is an essential nutrient for human health and about two billion people globally and particularly in India are at the risk of Zn deficiency, which calls for a food based solution to combat Zn malnutrition (WHO, 2002). Several estimates projected that more than 30 per cent of agricultural soils globally were low in available Zn leading to deficiency in crops cultivated on these soils (Alloway, 2008). Indian soils are generally low in Zn, the total and available Zn ranges 7 to 2960 mg kg^{-1} and 0.1 to 24.6 mg kg^{-1} respectively (Singh, 2009).

In India, Zn is one of the multi-nutrient deficiencies that are causing poor crop yields. Zn malnutrition has become a major health concern among the resource poor people (Singh 2011). In India, Zn is considered as the fourth important yield-limiting nutrient after major nutrients (Arunachalam *et al.,* 2013). Suresh *et al.* (2013) observed that the future Zn management strategy should be able to meet 25 per cent of the crop requirements through renewable organic sources, 5 to 10 per cent through mobilization by crops and the rest through the application of Zn containing fertilizers.

Periodic assessment of soil test data also suggests that Zn deficiency in soils of India is likely to increase from 49 per cent to 63 per cent by the year 2025 as most of the marginal soils brought under cultivation were showing Zn deficiency (Singh, 2006). Major soil physical and chemical factors affects the availability of Zn to roots are high $CaCO_3$, high pH, high clay soil, low organic matter, low soil moisture, high Fe and Al oxides (Cakmak, 2008).

Saha *et al.* (2014) reported that highest yield was obtained in groundnut by the application of 10 kg Zn ha^{-1} which caused a yield increase to the magnitude of 28.3 per cent. Arunachalm *et al.* (2013) revealed that 40 per cent yield loss in groundnut due to Zn deficiency and average response to Zn fertilization ranges from 210 to 470 kg ha^{-1} in groundnut.

Chaudhari (2018) reported that yield and quality of *kharif* groundnut (*Arachis hypogaea*) as influenced by different sources of nutrients. The results revealed that the higher plant height (45.15cm), more number of branches (9.25), effective pegs (12.90) and filled pods (20.50) per plant with less number of unfilled pods per plant (7.03), maximum 100 kernel weight (48.65 g) and seed yield per plant (14.37 g) with higher pod (3106 kg ha^{-1}) and haulm (4916 kg ha^{-1}) yield of groundnut were achieved with application of 75 per cent recommended dose of fertilizer (RDF) + 5 t farmyard manure (FYM) ha^{-1} + 8 kg $ZnSO_4$ ha^{-1} + 15 kg $FeSO_4$ ha^{-1}. Harvest index was not affected significantly due to different treatments.

2.2 EFFECT OF BORON NUTRITION ON GROWTH, YIELD AND QUALITY OF GROUNDNUT

Boron is a constituent of cell membrane and essential for cell division, N metabolism and protein formation and acts as a regulator of K/Ca ratio in the plant. It helps in N absorption and translocation of sugars and carbohydrates in the plants. It is important in pollination and seed production (Singh *et al.*, 2007). They also stated that the deficiency of B caused yield reduction and boron was highly essential to complete the life cycle in groundnut. As B is a micronutrient and the range in the change from deficient to toxic concentration is extremely narrow and is often exceeded while applying B fertilizers (Gupta, 2006).

According to Singh, (1994) when the soil B content was less than 0.2 ppm its deficiency was reported in groundnut and the critical limits may varied between 0.2 to 0.4 ppm based on the soil and groundnut genotypes.

Maheshkumar and Sen (2004) reported that the pod yield of groundnut was increased significantly by the application of 0.25 to 0.50 kg B ha^{-1}. Singh *et al.* (2016) conducted an experiment to find out the B deficiency and its nutrition in groundnut. They observed that B requirement of groundnut varied with cultivars and the sufficiency level of B in the leaf during flowering and fruiting (40 to 70 DAE) was 25 to 60 ppm. When the leaf B concentration was below 15 ppm, specific deficiency symptoms were noticed.

The growth and yield parameters of groundnut was considerably increased by the application of B at 100, 200 and 300 ppm alone or in combination with rhizobium inoculation (Nasef, 2006). Singh *et al.* (2006) found that for the production of well-filled and quality seeds of groundnut, application of boron @ 1 kg ha^{-1} in the soil either as basal or one month after emergence is necessary.

Chitdeshwari and Poongothai (2003) reported the positive role of B in quality improvement through its involvement in the synthesis of protein and amino acids, thereby increasing the pod yield of groundnut. The highest groundnut pod protein content was recorded at 1.0 ppm and further increase in B levels the protein content get decreased correspondingly (Muthukrishnan, 2007).

In groundnut, application of B @ 1 and 2 kg ha^{-1} significantly increased the B availability in the soil (Singh *et al.*, 2005).

Boron deficiency was responsible for creating male sterility and inducing floral abnormalities (Sharma, 2006). In B deficient acid soils (below 0.4 ppm available B), low pod filling, shriveled seeds and hollow darkening or off-colour in the centre of the seed are commonly observed symptoms causing 10 to 50 per cent yield loss. (Singh *et al.*, 2007).

Naiknaware *et al.* (2015) conducted an experiment to study the effect of varying levels of B and S on growth, yield and quality of groundnut revealed that a significant increase in plant growth parameters *viz.*, number of pegs (43.88) number of nodules at 50 to 55 DAS (102) and yield attributes was obtained by the application of 8 kg B in groundnut crop.

2.3 COMBINED EFFECT OF ZINC AND BORON NUTRITION ON GROWTH, YIELD AND QUALITY OF GROUNDNUT

Combined effect of Zn and B has the ability to improve yield and yield parameters of peanut plant. An average groundnut crop, with 2.0 to 2.5 t ha^{-1} of economic yield requires 160 to 180 kg N, 20 to 25 kg P, 80 to 100 kg K, 60 to 80 kg Ca, 15 to 20 kg S, 30 to 45 kg Mg, 3 to 4 kg Fe, 300 to 400 g Mn, 150 to 200g Zn, 140 to 180 g B, 30 to 40 g Cu and 8 to 10 g Mo (Singh, 1999).

Zinc improved dry matter production (DMP) though the nodulation and N fixation by enhanced root growth and by activation of several enzyme systems and auxins. Whereas, B influenced the nitrogen and carbohydrate metabolism of plants which might have contributed for the better plant growth (Malewar *et al.,* 1982).

Chitdeshwari and Poongothai (2003) reported that the response of groundnut to the soil application of Zn 5 kg ha^{-1} + B 1 kg ha^{-1} + S 40 kg ha^{-1} significantly increased the pod yield to the tune of 24.2 per cent for TMV 7 and 14.8 per cent for JL 24 over control. The soil application of 5, 1, 0.5 kg ha^{-1} Zn, B and molybdenum (Mo) respectively along with NPK increased the groundnut yield to 30 per cent (Nayak *et al.* 2009).

The micronutrient response of groundnut studied under rainfed conditions in India and the study concluded that an application of Zn, B and S along with N and P was economical. The application of these nutrients were critical for higher and sustained productivity of rainfed crops in semi-arid regions of India (Srinivasarao *et al,* 2008). Groundnut performed better in terms of yield and quality under optimum nutrient management coupled with organic and inorganic nutrient management (Veeramani and Subrahmaniyan 2011).

White and Broadley (2015) reported that application of $ZnSO_4$ increase yield and Zn concentrations in legumes because Zn is immobile in the soil and moderately mobile in plants. The application of Zn + B along with organics significantly and positively influenced the growth characters of groundnut at critical stages of crop growth (Elayaraja, 2014).

For DTPA extractable- Zn, 0.6 mg kg^{-1} was taken as the critical nutrient level of deficiency in general (Murthy, 2011). Application of $ZnSO_4$ @ 5 kg ha^{-1} + $FeSO_4$ @ 10 kg ha^{-1} + boron (B) @ 1 kg ha^{-1} with the recommended dose of NPK recorded the highest pod yield, oil content and seed quality (Janakiraman *et al.,* 2005).

Khan *et al.* (2017) reported that seed priming with Zn at 0.5 per cent and 1 per cent increased the number of pods per plant, kernel weight, 100 kernel weight, pod yield, biological yield, harvest index and shelling percentage.

Cikili *et al.* (2015) reported the mutual effects of B and Zn on growth, total chlorophyll, membrane permeability, and nutrient content in groundnut. The treatments were soil applications of five levels of B (0, 4, 8, 16, 32 mg kg^{-1}) and three levels of Zn (0, 10, 20 mg kg^{-1}).They observed that plant growth was progressively depressed with increasing of B. However, Zn addition had an inhibitory effect on B toxicity and decreased growth reduction caused by excess B. In Zn-untreated plants, B and Zn contents were enhanced by increasing of B and both Zn and B addition enhanced Zn content.

2.4 EFFECT OF METHOD OF APPLICATION OF ZINC AND BORON ON YIELD OF GROUNDNUT

According to Singh *et al.* (2006), for the production of well filled and quality seeds of groundnut, application of B @ 1kg ha^{-1} in the soil either as basal or one month after emergence is necessary. Gobarah *et al.* (2006) reported that the highest groundnut seed yield, oil and protein recorded with soil application of P along with foliar spray of zinc. As a result of application of B at 1.0 kg ha^{-1} as soil and 0.1 per cent as a foliar spray in groundnut resulted in higher flowering and pod yield (Singh and Mann, 2008).

Being an easy and cost effective method of micronutrient application, seed treatments offer an attractive option for resource poor farmers (Farooq *et al.,* 2012).

Foliar application of nutrients could improve the nutrient utilization efficiency and lower the risk of environmental pollution by reducing the amounts of fertilizers added to soil (Abou-El-Nour, 2002). Ali and Mowafy (2003) observed that foliar spray of Zn improved the yield attributes, yield and quality of groundnut. Seed Zn concentration of groundnut cultivars showed an average increase of 16 per cent due to foliar application of zinc. (Singh *et al*., 2007).

Singh (2008) reported that two to four sprays of 0.5 per cent $ZnSO_4$ salt solution can efficiently control the Zn deficiency in groundnut. Pendashtek *et al.* (2011) reported that the highest seed yield (2910 kg ha^{-1}) with increase in pod yield, plant height, 100 seed weight, seed length and seed width was recorded with foliar spraying of Zn 1g L^{-1}. Soil applied Zn had residual effects for subsequent crops but foliar sprays have no residual effect and fresh applications must be made to each crop (Hafeez *et al*., 2013).

Gowthami and Ananda (2017) studied the DMP, yield and yield components of Groundnut (*Arachis hypogaea* L.) genotypes as influenced by Zn and Fe through ferti-fortification and they found that among micronutrients application, higher DMP at harvest (43.60 g $plant^{-1}$), pod, kernel and haulm yield (2789, 2051 and 3080 kg ha^{-1}, respectively), number of pods $plant^{-1}$ (34.08), pod weight (32.25 g $plant^{-1}$), 100 kernel weight (31.61 g) and shelling percentage (73.21 %) recorded with soil (25 kg ha^{-1}) and foliar (0.5 %) application of $ZnSO_4$ as compared to control. Gowda *et al.* (2018) found that foliar organic extract of panchagavya (3%) is equally effective as compared to inorganic pulse magic (2%) with respect to improvement in growth yield and quality of groundnut.

2.5 EFFECT OF ZINC AND BORON NUTRITION ON NUTRIENT UPTAKE AND SOIL NUTRIENT STATUS

Chahal and Ahluwalia (1977) studied the Zn uptake at various growth stages of groundnut revealed that at mid- flowering stage maximum amount of Zn was accumulated in shoot portion and maximum translocation of Zn from the shoot portion to fruits occurred between 50 and 75 days growth period. In oilseed crops, the utilization of applied Zn by the crops was found to be less than 0.5 per cent (Prasad, 2006).

Tathe *et al.* (2008) reported that the higher pod yield, protein content and Zn uptake were obtained in groundnut by the application of Zn 40 kg ha^{-1} whereas the highest oil content and S uptake was obtained by the application of 20 kg ha^{-1}. Polara *et al.* (2010) opined that the supremacy of yield parameters was due to combined application of N and Zn in groundnut which increased in plant vigour, accumulation of photo synthates and better translocation from source to sink.

Arunachalam *et al.* (2013) indicated that soil application of Zn at 5 kg ha^{-1} basally increased the pod yield to an average 136.29 kg kg^{-1} in Zn deficient soils in groundnut and concluded that there was a significant increase in the economic yield by the Zn fertilization in the Zn deficient soils.

Saha *et al.* (2014) reported that application of 5 and 10 kg Zn ha^{-1} resulted in 29 and 93 per cent increase respectively in Zn uptake by groundnut over the control. Saha *et al.* (2014) studied the influence of B on the yield and quality of groundnut and found that compared to control, there was a 25 per cent increase in B uptake in nut by 0.25 per cent boric acid spray.

Cikili *et al.* (2015) found that with an increase in B supply, the P and K contents of the shoots get enhanced and with the addition of B and Ca content of the groundnut shoot was also remarkably increased. Nadaf and Chidanandappa (2015) studied the effect of Zn and B application on distribution and contribution of Zn fractions to the total uptake of Zn by groundnut in sandy loam soils of Karnataka and the results showed that the application of $ZnSO_4$ at three different levels (5, 10 and 20 kg ha^{-1}) greatly improved the water soluble Zn (0.36 to 0.52mg kg^{-1}) and sorbed Zn fractions (3.17 to 4.55mg kg^{-1}) in soil at harvest.

Rajitha *et al.* (2018) studied the response of groundnut to secondary and micronutrients was studied and the results revealed that combined foliar application of secondary and micronutrients along with RDF recorded the highest pod yield of 2654 kg $ha^{-1}$and haulm yield of 3603 kg ha^{-1} as compared to RDF (1500 and 2551 kg $ha^{-1}$and of pod and haulm yield, respectively). They also found that the highest uptake of primary nutrients (N, P and K) by haulm and pod at harvest which might be because of the highest DMP with the combined use of all the nutrients.

2.6 ECONOMICS OF GROUNDNUT CULTIVATION AS INFLUENCED BY ZINC AND BORON NUTRITION

Chandravanshi *et al.* (2017) studied long term effect of integrated nutrient management on growth, yield, uptake of nutrients and economics of groundnut. The results revealed that application of recommended dose of NPK + soil test based recommendation of secondary and micro-nutrients (10 kg $ZnSO_4$ ha^{-1}) recorded higher dry pod yield (1953 kg ha^{-1}), kernel yield (1555 kg ha^{-1}), haulm yield (3617 kg ha^{-1}), harvest index (0.57), net returns (Rs. 71717) and benefit cost ratio (BCR) (2.34) as compared to all other organic farming practices.

Rajitha *et al.*(2018) opined that combined foliar application of secondary and micronutrients along with RDF could be evolved as best combination for higher productivity and profitability of groundnut. Ansari *et al.* (2014) studied the efficacy of B sources on groundnut production under North East hill regions and they found that the groundnut productivity, net returns and BCR as well as energy use efficiency and energy productivity were the highest with soil application of solubor followed by borosol over no B application.

Materials and Methods

3. MATERIALS AND METHODS

The field experiment entitled "Zinc and boron nutrition in groundnut (*Arachis hypogaea L.*) for *Onattukara* sandy plain" was conducted during the period from December 2018 to April 2019 in farmer's field at *Onattukara* region of Alappuzha district. The details of the materials used and the methods adopted for the study are briefly described below.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experiment was laid out in the summer rice fallows of *Onattukara* region of Alappuzha district of Kerala state. The field was located at 9^0 09' 34.56" N latitude and 76^0 33' 15.36" E longitude and an altitude of 3.05 m above mean sea level.

3.1.2 Soil

Soil of the experimental site is sandy loam and belongs to the order Entisol. The data regarding the mechanical composition, physical properties and chemical properties of the soil are presented in Table 1 and 2.

3.1.3 Cropping history

Rice was cultivated during the previous season on the experimental site.

3.1.4 Season

The experiment was conducted in summer rice fallow after the harvest of rice crop during December 2018 to April 2019. The data on weather parameters (monthly rainfall, mean maximum temperature, mean minimum temperature, and relative humidity) during the crop period are presented in Appendix I and graphically presented in Fig.1.

Table 1. Mechanical composition and physical characteristics of the soil

Particulars	Value	Method adopted
A. Mechanical composition		
Coarse sand (%)	67.83	Bouyoucos hydrometer method (Bouyoucos, 1962)
Fine sand (%)	17.82	
Silt (%)	5.03	
Clay (%)	9.32	
Textural class	Loamy sand	
B. Soil physical characteristics		
Particulars	**Soil depth (0-30 cm)**	**Method adopted**
Particle density (Mg m^{-3})	2.53	Pycnometer method (Black, 1965)
Bulk density (Mg m^{-3})	1.70	Core method (Gupta and Dakshinamoorthi, 1980)
Porosity (%)	25.38	

Table 2. Chemical characteristics of soil prior to experiment

Particulars	Value	Rating	Method adopted
Soil reaction (pH)	5.08	Moderately acidic	1:2.5 soil solution ratio using potentiometric method with pH meter (Jackson, 1973)
EC (dS m^{-1})	0.09	Normal	Digital electrical conductivity meter
Organic C (%)	0.35	Low	Walkley and Black rapid titration method (Jackson,1973)
Available N (kg ha^{-1})	195.42	Low	Alkaline Permanganate method (Subbiah and Asija,1956)
Available P (kg ha^{-1})	23.17	Medium	Bray's colorimetric method (Jackson, 1973)
Available K (kg ha^{-1})	135	Medium	Ammonium acetate method (Jackson, 1973)
Available Ca (mg kg^{-1})	204	Deficient	EDTA titration method (Tucker and Kurtz,1955)
Available S (mg kg^{-1})	12	Sufficient	Turbidimetric method (Chesnin and Yien, 1950)
Available Zn (mg kg^{-1})	0.32	Deficient	Extraction using 0.5 N HCl and atomic absorption spectroscopy (Sims and Johnson,1991)
Available B (mg kg^{-1})	0.25	Deficient	Hot water extraction and estimation using Azomethane – H spectrophotometer (Gupta, 1967)

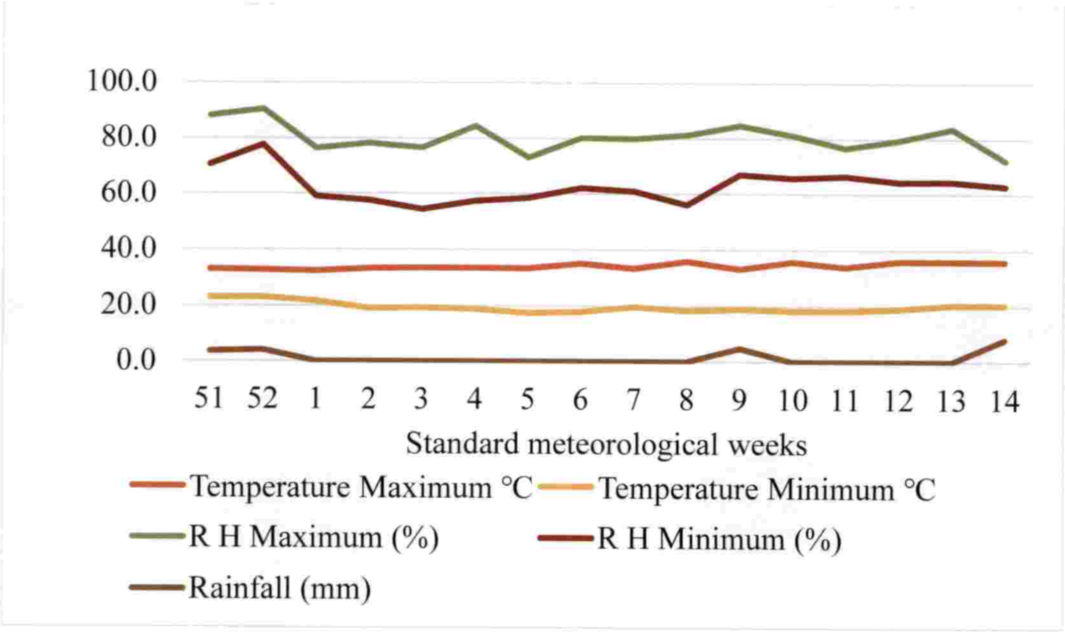

Fig 1. Weather data during the crop period (December 2018 to April 2019)

3.1.5 Weather conditions

The total average rainfall received during the cropping period from December 2018 to April 2019 was 20.4 mm. Mean maximum temperature recorded was 35.85 ^{0}C and minimum temperature recorded during the period was 17.42 ^{0}C. Relative humidity ranged from 54.3 to 90.3 per cent.

3.2 MATERIALS

3.2.1 Seed material

Groundnut variety CO 7 was used for the study. It is a high yielding Spanish bunch groundnut culture ICGV 00351 (a cross derivative of ICGV 87290 X ICGV 87846) developed at International Crops Research Institute for the Semi-Arid Topics and released as CO 7 for cultivation in Tamil Nadu. Seeds were obtained from the Department of Oilseeds, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore.

3.2.2 Manures and fertilizers

Farm yard manure (0.4 % N, 0.3 % P_2O_5 and 0.2 % K_2O) which was locally available was used for the study. Urea (46 % N), Rajphos (20 % P_2O_5) and Muriate of potash (60 % K_2O), Borax (11.5 % B), $ZnSO_4$ (22 % Zn) and lime ($CaCO_3$) was used for the study.

3.3 METHODS

3.3.1 Experimental Design and Layout

The experiment was laid out in randomised block design (RBD) with three replications. The lay out plan of the experiment is given in Fig. 2.

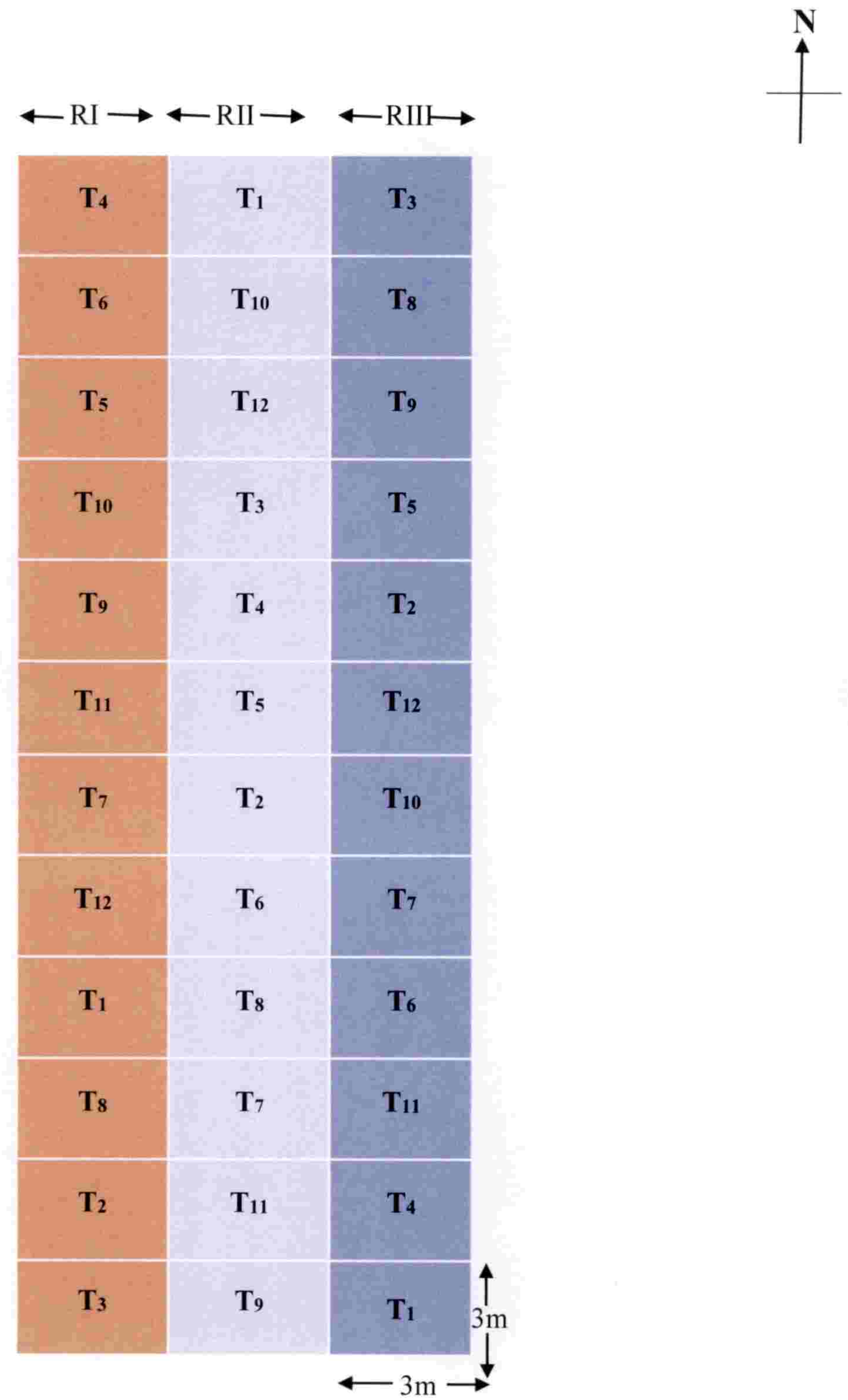

Fig. 2. Lay out of the Experiment

Design	: RBD
Treatment	: 12
Replication	: 3
Plot size	: 3 m x 3 m
Spacing	: 15 cm x 15 cm
Seed rate	: 100 kg kernels ha^{-1}

3.3.2 Treatments

T_1: Soil application of Zn @ 5 kg ha^{-1} as $ZnSO_4$

T_2: Soil application of Zn @ 5 kg ha^{-1} as Zn-EDTA

T_3: Soil application of B @ 1 kg ha^{-1} as borax

T_4: Soil application of Zn @ 2.5 kg ha^{-1} as $ZnSO_4$ + B @ 0.5 kg ha^{-1} as borax

T_5: Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 days after emergence (DAE)

T_6: Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE

T_7: Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE

T_8: Seed treatment with $ZnSO_4$ (250 mg kg^{-1})

T_9: Seed treatment with borax (100 mg kg^{-1})

T_{10}: Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})

T_{11}: Soil test based recommendation

T_{12}: Control

FYM @ 2 t ha^{-1} and N: P_2O_5: K_2O @ 10:75:75 kg ha^{-1} as basal and lime @ 1.5 t ha^{-1} at flowering (KAU, 2016) were applied uniformly to all treatments.

For soil test based recommendation, N: P_2O_5: K_2O @ 9.7: 45: 70.5 kg ha^{-1} were applied on the basis of soil test based data. Nitrogen was given at 97 per cent of general recommendation and P and K were given at 60 and 94 per cent of general recommendation, respectively. Since the soil was deficient in Zn and B, one foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30 DAE was also provided.

Plate 1. General view of experimental plot

3.3.3 Cultivation practices

3.3.3.1 Field Preparation

The experimental site was ploughed twice followed by two harrowings. Weeds and stubbles were removed and the soil was brought to a fine tilth.

3.3.3.2 Application of Lime, Manures and Fertilizers

Farmyard manure was applied @ 2 t ha^{-1}, uniformly to all the plots. Recommended dose of fertilizers were applied @ 10: 75: 75 kg N: P_2O_5: K_2O ha^{-1} in the form of Urea (46 % N), Rajphos (20 % P_2O_5) and Muriate of potash (60 % K_2O), to all the plots, except T_{11}, as basal dose on one week after planting. Lime @ 1.5 t ha^{-1} was applied to all the plots at the time of flowering. Boron in the form of borax and Zn in the form of $ZnSO_4$ were applied in stipulated doses and time as per the treatment except in the control plots.

3.3.3.3 Seeds and Seeding

Groundnut pods were hand shelled carefully. After shelling, bold kernels of the groundnut variety CO7 were selected and dibbled into the soil at a spacing of 15 cm ×15 cm @ 100 kg ha^{-1}. Sowing was done on 19th December 2018. Seed treatment was done by soaking the seeds in respective solutions for six hours followed by shade drying.

3.3.3.4. Gap filling

Gap filling was done seven days after sowing to maintain the optimum plant population.

3.3.3.5 Irrigation

Nine irrigations were provided. One pre-sowing irrigation and rest at 3, 9, 17, 25, 35, 55, 70 and 90 days after sowing (DAS).

Seedling stage

Flowering stage

Pegging and pod

Harvest stage

Plate 2. Crop at different growth stages

3.3.3.6 Weeding

Weeding operations were carried out manually at different stages of growth starting from 10 to 15 days after germination to pegging stage.

3.3.3.7 Earthing up

Earthing up was done along with lime application and also at 55 DAS to facilitate easy penetration of pegs into the soil after flowering.

3.3.3.8 Plant protection

Minor population of aphids was observed at pegging stage of the crop and was controlled with neem oil - garlic emulsion (2%).

3.3.3.9 Harvesting

The groundnut crop was harvested at its full maturity, ie, 106 DAS on 6^{th} April 2019 by pulling out the plants from border rows and net plot area separately, from each plot when the plants showed symptoms of yellowing and shedding of leaves. The pods were separated and sun dried for a week. Dry weight of pods and haulm were recorded.

3.4 OBSERVATIONS

Five plants were selected at random from each treatment plot and tagged for taking observations on different stages of growth such as 30 DAS, 45 DAS, 60 DAS and at harvest. Main items of observations include growth characters, physiological parameters, yield and yield attributes and quality parameters.

3.4.1 Crop Growth Characters

Growth characters of the crop were recorded at 30 DAS, 45 DAS, 60 DAS and at harvest.

3.4.1.1 Height of the plant

The height of the plant was measured from the base to the tip of the tagged plants and average plant height was worked out and expressed in centimetres.

3.4.1.2 Number of branches per plant

Total number of branches from each tagged plants were counted at different growth stages and the mean value was worked out.

3.4.1.3 Total leaf area per plant

Total leaf area was calculated by measuring the length and width of the leaves.

$$LA = k\,(L \times W)$$

Where, k is the constant (0.821) (Kathirvelan and Kalaiselvan, 2007)

Total leaf area = Average leaf area x average number of leaves

3.4.1.4 Number of nodules per plant

Three plants were dug from uniform depth from each treatment for counting number of nodules. The roots of the plants were washed to remove the soil particles. The number of nodules from each plant was counted and the average number of nodule was recorded.

3.4.2 Physiological Parameters

Observations were taken during the period from 15 to 30 DAS and 30 to 45 DAS.

3.4.2.1 Crop growth rate (CGR) ($g\ m^{-2} d^{-1}$)

CGR was calculated by the formula below

$$CGR = \frac{W2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

where,

W_1 : Initial dry weight W_2 : Final dry weight

t_1: Initial time t_2 : Final time

P: Land area

3.4.2.2 Net assimilation rate (NAR) (g m^{-2} d^{-1})

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e A_2 - \log_e A_1}{A_2 - A_1}$$

where,

W_1: Initial dry weight

W_2: Final dry weight

A_1: Initial area

A_2: Final area

t_1: Initial time

t_2: Final time

3.4.2.3 Leaf area index (LAI)

Using the formula suggested by Watson (1947), LAI was calculated after finding the leaf area.

$$LAI = \frac{\text{Total leaf area plant}^{-1}}{\text{Land area occupied plant}^{-1}}$$

3.4.2.4 Leaf area duration (LAD)

Leaf area duration was calculated by the formula below (Power *et al.*, 1967).

$$LAD = \frac{LAI_1 + LAI_2}{2} \times (t_2 - t_1)$$

where,

LAI_1 = Leaf area index at the first stage

LAI_2 = Leaf area index at the second stage

$t_2 - t_1$ = Time period between the first and second stages

3.4.3 Yield and Yield Attributes

3.4.3.1 Days to 50 per cent flowering

The average number of days taken by 50 per cent of the plants for the emergence of flowers, in each treatment was separately noted and recorded.

3.4.3.2 Number of pods per plant

From each plot, total number of matured pods from the observational plants were counted and the mean value was recorded.

3.4.3.3 Number of seeds per pod

Number of seeds were counted from fifteen randomly selected pods of observational plants and averaged to get number of seeds per pod.

3.4.3.4 100 kernel weight

Hundred kernels were randomly selected from each plot and weighed separately after drying and shelling. This weight in grams was recorded as the 100 kernel weight.

3.4.3.5 Kernel yield

The dry weight of kernels were recorded after proper drying and shelling, from the net plot area of each treatments. The kernel yield per treatment was then converted into kg ha^{-1}.

3.4.3.6 Haulm yield

The plants were uprooted from the net plot area and then sun dried for three days after harvesting of pods. Average dry weight of the haulm thus obtained was expressed in kg ha^{-1}.

3.4.3.7 Harvest index

Harvest index was calculated by the formula given below (Donald and Hanblin, 1976)

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

3.4.3.8 Shelling percentage

Shelling percentage was calculated using the formula furnished below

$$\text{Shelling percentage} = \frac{\text{Dry weight of kernels}}{\text{Dry weight of pods}} \times 100$$

3.4.4 Quality Analysis

3.4.4.1 Protein content of the seed (%)

Protein content of the seed was calculated by multiplying the N content in the kernel with a factor of 6.25 (Angelo and Mann, 1973).

3.4.4.2 Oil content in the seed (%)

Oil content was estimated using Nuclear Magnetic Resonance (NMR) Spectrophotometer (Jambunathan *et al.*, 1985).

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

Oil yield per hectre was worked out using the formula given below

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

3.4.5 Chemical analysis

3.4.5.1 Plant analysis

Plant analysis for N, P, K, Ca, S, Zn and B were done separately for haulm, husk and kernel. The methods adopted for the analysis of nutrient content in plant parts are presented in Table 3. Total nutrient uptake was calculated by adding the nutrient uptake values of haulm, husk and kernel. Nutrient uptake by groundnut at harvest was found out using the formula.

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

3.4.5.2 Soil analysis

Soil samples from each treatment were separately collected after harvest and the soil reaction, electrical conductivity, organic carbon, available N, available P, available K, available Ca, available S, available Zn and B were estimated as per the standard procedures mentioned in Table 2.

3.4.6 Incidence of major pests and diseases

Aphids (*Aphis craccivora*) was observed in the field during pegging stage but it was below the economic threshold level and it was controlled by one spraying of neem-oil garlic emulsion (2%) . No disease was observed in the field.

Table 3. Methods adopted for the analysis of nutrient content of plant parts

Particulars	Method used	Reference
Nitrogen	Modified micro kjeldahl method	Jackson (1973)
Phosphorus	Vanado-molybdo phosphoric yellow colour method using spectrophotometer	Jackson (1973)
Potassium	Flame photometry method	Jackson (1973)
Calcium	Nitric-Perchloric acid (9:4) digestion and versanate titration	Piper (1967)
Sulphur	Nitric-Perchloric acid (9:4) digestion and turbidimetry	Chesnin and Yien (1950)
Zinc	Nitric-Perchloric acid (9:4) digestion and Atomic absorption spectrometry	Jackson (1973)
Boron	Hot water extraction and estimation using Azomethane – H spectrophotometer	Gupta (1967)

3.4.7 Cost benefit analysis

3.4.7.1 Net Income

Net income was calculated by deducting the cost of cultivation from gross income and expressed in ₹ ha $^{-1}$.

Net income (₹ ha $^{-1}$) = Gross income (₹ ha $^{-1}$) – cost of cultivation (₹ ha $^{-1}$)

3.4.7.2. Benefit Cost Ratio

Benefit Cost Ratio was worked out as the ratio of gross income to cost of cultivation.

$$\text{BCR} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.4.8 Statistical Analysis

The data was analysed statistically by using Analysis of Variance technique for RBD (Cochran and Cox, 1965) and the significance was tested using F test. Wherever the F values were found significant, critical difference was calculated at five per cent probability level.

Results

4. RESULTS

The field experiment entitled "Zinc and boron nutrition in groundnut (*Arachis hypogaea L.*) for *Onattukara* sandy plain" was undertaken with the objectives to evaluate the effect of zinc and boron nutrition on growth, yield and quality of groundnut (*Arachis hypogaea* L.) in the summer rice fallows of *Onattukara* and to work out the economics of cultivation. The experiment was conducted during December 2018 – April 2019 in farmer's field, *Onattukara* tract, Kayamkulam. The experimental data was analysed statistically and the results are presented in this chapter.

4.1 Growth Characters

The data generated on growth characters as influenced by zinc and boron nutrition during the study is presented below. The growth characters were recorded at 30, 45 and 60 DAS and at harvest.

4.1.1 Height of Plant

The data is presented in Table 4.

Analyzed data during the study revealed that the treatments significantly influenced the plant height at all growth stages.

At 30 DAS, plant height was significantly higher (33 cm) with soil test based recommendation (T_{11}) and it was on par with soil application treatments. Lower (25.93 cm) plant height was observed for seed treatment with borax (100 mg kg^{-1}) (T_9) and it was on par with other seed treatments and control.

At 45 DAS, foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) recorded more plant height (44.33 cm). Lower (33.46 cm) plant height was observed for seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) and it was on par with other seed treatments and control.

At 60 DAS and at harvest, foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) produced taller plants. At 60 DAS, it was on par with other foliar application treatments, T_1, T_4 and T_{11}. Shorter plants were observed with T_9, it was on par with T_8, T_{10}, T_{12}, T_2 and T_3.

Table 4. Effect of zinc and boron nutrition on plant height of groundnut, (cm)

Treatments	30 DAS	45 DAS	60 DAS	At harvest
T_1 : Soil application of $ZnSO_4$ @5 kg ha^{-1}	31.83	42.01	51.67	62.67
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	31.50	42.03	44.67	56.89
T_3 : Soil application of borax @ 1 kg ha^{-1}	30.90	38.88	44.00	54.55
T_4 : Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} +borax @ 0.5 kg ha^{-1}	32.50	42.20	55.33	63.87
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	27.52	41.24	52.33	58.62
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	27.63	40.00	51.50	56.68
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 percent borax at 30, 45 and 60 DAE	28.00	44.33	56.00	64.66
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	26.27	34.35	43.93	48.12
T_9 : Seed treatment with borax (100 mg kg^{-1})	25.93	37.13	42.33	49.67
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	28.93	33.46	43.17	50.75
T_{11} : Soil test based recommendation	33.00	42.56	52.00	63.33
T_{12} : Control	29.33	35.21	44.80	52.33
SEm (±)	1.49	2.20	1.94	2.45
CD (0.05)	4.420	6.572	5.732	7.247

Table 5. Effect of zinc and boron nutrition on number of branches per plant.

Treatments	30 DAS	45 DAS	60 DAS	At harvest
T_1: Soil application of $ZnSO_4$ @ 5 kg ha^{-1}	4.13	5.10	6.33	6.36
T_2 : Soil application of Zn-EDTA @ 5 kg ha^{-1}	3.30	4.50	5.80	5.86
T_3 : Soil application of borax @ 1 kg ha^{-1}	3.77	4.40	5.27	5.31
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1}+ borax @ 0.5 kg ha^{-1}	4.07	6.47	6.73	6.77
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	3.90	5.10	6.30	6.36
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	3.47	5.30	5.59	5.67
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	3.57	4.70	5.50	5.76
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	3.70	4.90	5.37	5.42
T_9 : Seed treatment with borax (100 mg kg^{-1})	3.97	4.03	5.41	5.46
T_{10}: Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	3.80	4.20	4.60	4.73
T_{11} : Soil test based recommendation	4.30	5.10	5.33	5.49
T_{12}: Control	3.63	3.80	5.40	5.44
SEm (±)	0.21	0.31	0.31	0.21
CD (0.05)	NS	0.908	0.924	0.621

At harvest, all treatments were on par, except seed treatments (T_8, T_9 and T_{10}), control (T_{12}) and T_3 (soil application of borax @ 1 kg ha^{-1}) with respect to plant height.

4.1.2. Number of branches per plant

Data on mean number of branches were given in Table 5.

At 30 DAS, the number of branches per plant was not influenced by the treatments. The perusal of data at 45 DAS showed that the highest number of branches (6.47) were recorded with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and lower number of branches (3.8) were recorded with control treatment (T_{12}) which was on par with T_9, T_{10}, T_3, T_2 and T_7.

At 60 DAS, soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{1} (T_4) recorded more number of branches (6.73) which was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1) and foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). At harvest also soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) was found to be superior to all other treatments except soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5).

4.1.3. Total leaf area per plant

Total leaf area per plant is presented in Table 6. Leaf area was significantly influenced by the treatments.

At 30 DAS, soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) recorded more leaf area (361.64 cm^2) and it was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of borax @ 1 kg ha^{-1} (T_3).

At 45 DAS, higher leaf area (668.00 cm^2) was recorded with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and it was on par with all treatments except seed treatments (T_8, T_{10}, T_9).

At 60 DAS, all treatments were on par and produced more leaf area except seed treatments and control. At harvest, foliar application of 0.5 per cent $ZnSO_4$ at

Table 6. Effect of zinc and boron nutrition on leaf area per plant, (cm^2)

Treatments	30 DAS	45 DAS	60 DAS	At harvest
T_1: Soil application of $ZnSO_4$ @ 5 kg ha^{-1}	359.85	613.08	1078.50	806.27
T_2 : Soil application of Zn-EDTA @ 5 kg ha^{-1}	313.12	540.74	1025.73	636.94
T_3: Soil application of borax @ 1 kg ha^{-1}	328.87	624.51	971.23	618.22
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1}+ borax @ 0.5 kg ha^{-1}	361.64	668.00	1138.07	847.02
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	291.03	646.11	1010.75	903.18
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	282.12	608.29	1167.35	857.32
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	292.53	652.00	1062.73	798.20
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	296.36	586.66	753.37	564.42
T_9 : Seed treatment with borax (100 mg kg^{-1})	300.62	506.22	755.29	413.69
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	291.11	582.82	835.59	626.78
T_{11} : Soil test based recommendation	303.68	605.11	1212.72	797.32
T_{12}: Control	279.63	642.58	851.64	721.21
SEm (±)	13.89	24.80	82.77	51.95
CD (0.05)	41.007	73.229	244.34	153.363

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30, 45 and 60 DAE (T_5) recorded more leaf area (903.18 cm^2), and was comparable with foliar application of 0.5 per cent borax at 30, 45 and 60 DAE (T_6), soil application of $ZnSO_4$ @ 2.5 kg ha^{-1}+ borax @ 0.5 kg ha^{-1} (T_4), soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1), foliar application of 0.25 per cent $ZnSO_4$ + 0.25 borax per cent at 30, 45 and 60 DAE (T_7) and soil test based recommendation (T_{11}).

4. 1. 4. Number of nodules per plant

The mean number of nodules per plant are presented in Table 7.

Soil application with Zn-EDTA@ 5 kg ha^{-1} (T_2) recorded higher number of nodules (30.9) at 30 DAS. It was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4).

At 45 DAS, more number of nodules were observed with soil application treatments of zinc (T_2 , T_4 and T_1), seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}), foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and seed treatment with borax (100 mg kg^{-1}) (T_9).

The nodule number at 60 DAS and at harvest were significantly influenced by the treatments. Soil application with Zn-EDTA @ 5 kg ha^{-1} (T_2) produced more number of nodules at 60 DAS (67) and it was on par with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4), foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (61.67), soil test based recommendation (T_{11}) and foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7).

At harvest, soil test based recommendation (T_{11}) produced more number of nodules (57.67) and it was on par with, T_4, T_2, T_7 and T_1.

4.2 PHYSIOLOGICAL PARAMETERS

4.2.1 Crop Growth Rate (CGR)

Crop Growth Rate during 15 to 30 DAS and 30 to 45 DAS were presented in Table 8.

Table 7. Effect of zinc and boron nutrition on number of nodules per plant

Treatments	30 DAS	45 DAS	60 DAS	At harvest
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	27.00	42.45	61.67	53.00
T_2: Soil application of Zn-EDTA@5 kg ha^{-1}	30.90	47.63	67.00	55.83
T_3 : Soil application of borax @ 1 kg ha^{-1}	20.00	37.43	52.00	47.00
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	30.50	45.25	65.00	56.50
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	24.00	43.70	61.67	54.00
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	18.50	38.13	50.00	43.00
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	21.50	37.38	60.00	55.33
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	24.00	35.13	46.00	42.67
T_9 : Seed treatment with borax (100 mg kg^{-1})	25.00	42.63	52.33	48.67
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	22.50	43.86	48.33	45.00
T_{11} : Soil test based recommendation	25.50	37.38	61.00	57.67
T_{12}: Control	18.50	38.00	48.67	47.17
SEm (±)	1.34	1.19	2.44	2.58
CD (0.05)	3.950	3.530	7.221	7.627

Analysis of data revealed that CGR values varied with treatments and CGR increased from 15 to 30 DAS to 30 to 45 DAS. During 15 to 30 DAS, soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) recorded higher CGR (1.56 g m^2d^{-1}) and it was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1). During 30 to 45 DAS, T_1 and T_4 were on par and superior over other treatments.

4.2.2. Net Assimilation Rate (NAR)

The values of NAR showed a decreasing trend as crop advanced in age (Table 9).

The results revealed that the effect of Zn and B nutrition on NAR was not significant at 15 to 30 DAS. At 30 to 45 DAS, foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) recorded higher NAR (1.787 g $m^{-2}d^{-1}$) and it was on par with all the treatments except soil application with Zn-EDTA @ 5 kg ha^{-1} (T_2), seed treatment with $ZnSO_4$ (250 mg kg^{-1}) (T_8), seed treatment with borax (100 mg kg^{-1}) (T_9), seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) and control (T_{12}).

4.2.3. Leaf Area Index (LAI)

The mean LAI are given in Table 10.

The LAI at different stages of growth was significantly influenced by Zn and B nutrition. At 30 DAS, soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4), recorded the higher LAI (1.61) which was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of borax @ 1 kg ha^{-1}(T_3). At 45 DAS, higher LAI was recorded with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (2.97) and it was on par with all other treatments except seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) and control (T_{12}) at 45 DAS.

4.2.4. Leaf Area Duration (LAD)

Data on LAD at various crop growth stages are presented in Table 11.

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Table 8. Effect of zinc and boron nutrition on crop growth rate, (g $m^{-2}d^{-1}$)

Treatments	15 to 30 DAS	30 to 45 DAS
T_1: Soil application of $ZnSO_4$ @ 5 kg ha^{-1}	1.35	3.42
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	1.09	2.69
T_3 : Soil application of borax @ 1 kg ha^{-1}	1.15	2.93
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	1.56	3.85
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 & 60 DAE	1.18	3.23
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	1.12	3.19
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	1.20	3.33
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	1.09	2.84
T_9 : Seed treatment with borax (100 mg kg^{-1})	0.96	2.45
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	1.04	2.59
T_{11} : Soil test based recommendation	1.11	3.33
T_{12}: Control	0.95	2.51
SEm (±)	0.09	0.15
CD (0.05)	0.263	0.444

Table.9 Effect of zinc and boron nutrition on net assimilation rate, (g $m^{-2}d^{-1}$)

Treatments	15 to 30 DAS	30 to 45 DAS
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	4.980	1.621
T_2: Soil application of Zn-EDTA@5 kg ha^{-1}	4.510	1.344
T_3: Soil application of borax @ 1 kg ha^{-1}	4.520	1.547
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	5.760	1.739
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	5.180	1.634
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	5.040	1.709
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	5.240	1.787
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	4.700	1.418
T_9 : Seed treatment with borax (100 mg kg^{-1})	4.090	1.226
T_{10}: Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	4.560	1.386
T_{11} : Soil test based recommendation	4.690	1.714
T_{12} : Control	4.320	1.480
SEm (±)	0.392	0.094
CD (0.05)	NS	0.2780

Table 10. Effect of zinc and boron nutrition on leaf area index

Treatments	30 DAS	45 DAS
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	1.60	2.72
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	1.39	2.40
T_3 : Soil application of borax @ 1 kg ha^{-1}	1.46	2.77
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	1.61	2.97
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	1.29	2.87
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	1.25	2.70
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	1.30	2.60
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	1.31	2.89
T_9 : Seed treatment with borax (100 mg kg^{-1})	1.33	2.85
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	1.29	2.59
T_{11} : Soil test based recommendation	1.34	2.69
T_{12}: Control	1.24	2.24
SEm (±)	0.06	0.11
CD (0.05)	0.183	0.325

Leaf area duration during 15 to 30 DAS and 30 to 45 DAS differed significantly due to treatments. Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{1} (T_4), recorded higher LAD at both stages of observation. During 15 to 30 DAS, soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4) recorded more LAD (24.11 days) and was on par with soil application of $ZnSO_4$ @ 5 kg ha^{1} (T_1) and soil application of borax @ 1 kg ha^{-1} (T_3) (21.92 days).

During 30 to 45 DAS, also soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4), recorded higher leaf area duration (34.32 days). It was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1).The lowest LAD was recorded with control (T_{12}) (26.20 days) and it was inferior to all other treatments.

4.3. YIELD AND YIELD ATTRIBUTES

4.3.1. Days to 50 per cent flowering

The data pertaining to days to 50 per cent flowering are presented in Table 12.

Days to 50 per cent flowering varied from 38 to 41 days in groundnut. The treatment effects were not significant with respect to the number of days taken for 50 per cent flowering.

4.3.2. Number of pods per plant

The data were summarized in Table 12.

The results revealed that foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) produced more number of pods per plant (33.50) and it was comparable with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4), foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) and soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1).

4.3.3. Number of seeds per pod

The data pertaining to average number of seeds per pod is presented in Table 13.

Table 11. Effect of zinc and boron nutrition on leaf area duration, (days)

Treatments	15 to 30 DAS	30 to 45 DAS
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	23.99	32.43
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	20.87	28.99
T_3 : Soil application of borax @ 1 kg ha^{-1}	21.92	31.25
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	24.11	34.32
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	19.40	31.24
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	18.81	29.68
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	19.50	29.31
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	19.76	31.61
T_9 : Seed treatment with borax (100 mg kg^{-1})	20.04	31.44
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	19.41	29.13
T_{11} : Soil test based recommendation	20.25	30.29
T_{12}: Control	18.64	26.20
SEm (±)	0.93	0.77
CD (0.05)	2.734	2.260

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Table 12. Effect of zinc and boron nutrition on days to 50 per cent flowering and number of pods per plant

Treatments	Days to 50 per cent flowering	No of pods per plant
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	38.67	29.00
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	40.33	23.33
T_3 : Soil application of borax @ 1 kg ha^{-1}	40.33	24.50
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	38.67	32.17
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	39.50	33.50
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	40.33	21.83
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	40.33	31.89
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	40.33	23.25
T_9 : Seed treatment with borax (100 mg kg^{-1})	41.00	19.66
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	40.33	20.67
T_{11} : Soil test based recommendation	39.67	26.60
T_{12}: Control	40.33	23.00
SEm (±)	1.46	2.71
CD (0.05)	NS	7.992

Number of seeds per pod varied from 1.9 to 2.2 and it did not significantly differed due to treatment effects.

4.3.4. 100 Kernel weight

Effect of Zn and B nutrition on 100 kernel weight of groundnut were presented in Table 13.

Hundred kernel weight was significantly influenced by zinc and boron nutrition. It varied from 37.7g to 45.5g with different treatments. Higher 100 kernel weight (45.5 g) was recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). It was on par with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil test based recommendation (T_{11}).

4.3.5. Kernel yield

The mean kernel yield is presented in Table 14.

The results revealed that kernel yield was significantly influenced by treatments. Higher kernel yield (1523 kg ha^{-1}) was recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). It was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). The lowest kernel yield (989 kg ha^{-1}) was obtained from the control treatment (T_{12}).

4.3.6. Haulm yield

Summarized data (Table 14) revealed that the haulm yield was influenced by Zn and B nutrition. Higher haulm yield (3978 kg ha^{-1}) was recorded with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). It was comparable with all treatments except seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) and seed treatment with borax (100 mg kg^{1}) (T_9).

Table 13. Effect of zinc and boron nutrition on number of seeds per pod and 100 kernel weight

Treatments	Number of seeds per pod	100 kernel weight(g)
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	1.9	44.2
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	2.2	39.7
T_3 : Soil application of borax @ 1 kg ha^{-1}	1.9	39.2
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	2.1	44.5
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	2.1	45.5
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	2.2	37.8
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	2.1	39.5
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	2.1	37.7
T_9 : Seed treatment with borax (100 mg kg^{-1})	1.9	39
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	2.1	39.8
T_{11} : Soil test based recommendation	2.0	41.5
T_{12}: Control	1.9	38.3
SEm (±)	0.2	1.75
CD (0.05)	NS	5.176

Table 14. Effect of zinc and boron nutrition on kernel yield and haulm yield, ($kg\ ha^{-1}$)

Treatments	Kernel yield	Haulm yield
T_1: Soil application of $ZnSO_4$ @ 5 $kg\ ha^{-1}$	1438	3939
T_2 : Soil application of Zn-EDTA @ 5 $kg\ ha^{-1}$	1170	3900
T_3 : Soil application of borax @ 1 $kg\ ha^{-1}$	1090	3725
T_4: Soil application of $ZnSO_4$ @ 2.5 $kg\ ha^{-1}$ + borax @ 0.5 $kg\ ha^{-1}$	1372	3978
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	1523	3922
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	1200	3876
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	1230	3903
T_8 : Seed treatment with $ZnSO_4$ (250 $mg\ kg^{-1}$)	1064	3585
T_9 : Seed treatment with borax (100 $mg\ kg^{-1}$)	1009	3074
T_{10} : Seed treatment with $ZnSO_4$(250 $mg\ kg^{-1}$) + borax (100 $mg\ kg^{-1}$)	1108	3395
T_{11} : Soil test based recommendation	1231	3796
T_{12}: Control	989	3648
SEm (±)	71	156
CD (0.05)	210	459

4.3.7. Harvest index

The mean data are presented in Table15.

Harvest index did not differ significantly due to zinc and boron nutrition in groundnut However, it varied from 0.29 in control treatment (T_{12}) to 0.35 in foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5).

4.3.8. Shelling percentage

Data pertaining to shelling percentage is presented in Table 15.

Shelling percentage was significantly higher (70.75%) with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and it was on par with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) (70.17%), soil test based recommendation (T_{11}), soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7).

4.4. QUALITY PARAMETERS

4.4.1. Protein content

The mean data are presented in Table 16.

Results revealed that the mean protein content differed significantly with respect to the various treatments.

Higher protein content (23.2%) was recorded with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). It was on par with all treatments except soil application with Zn-EDTA@5 kg ha^{-1}(T_2) and seed treatment with borax (100 mg kg^{-1}) (T_9).

4.4.2. Oil content

The mean values of oil content in the seed are presented in Table 16.

Table 15. Effect of zinc and boron nutrition on harvest index and shelling percentage

Treatments	Harvest index	Shelling percentage
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	0.34	70.75
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	0.31	67.92
T_3 : Soil application of borax @ 1 kg ha^{-1}	0.30	67.13
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	0.33	69.45
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	0.35	70.17
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	0.32	66.75
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	0.32	68.28
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	0.30	67.70
T_9 : Seed treatment with borax (100 mg kg^{-1})	0.33	66.53
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	0.33	67.27
T_{11} : Soil test based recommendation	0.32	69.81
T_{12}: Control	0.29	67.32
SEm (±)	0.02	0.91
CD (0.05)	NS	2.688

Table 16. Effect of zinc and boron nutrition on protein content, oil content and oil yield

Treatments	Protein content of seed (%)	Oil content (%)	Oil yield (kg ha^{-1})
T_1: Soil application of $ZnSO_4$ @ 5 kg ha^{-1}	22.2	49.13	706.4
T_2 : Soil application of Zn-EDTA @ 5 kg ha^{-1}	20.7	48.13	562.9
T_3 : Soil application of borax @ 1 kg ha^{-1}	22.7	47.57	518.7
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	23.2	49.00	672.2
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	23.0	49.38	752.2
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	22.3	47.55	570.8
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	22.2	48.55	597.2
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	22.8	47.25	502.6
T_9 : Seed treatment with borax (100 mg kg^{-1})	20.3	46.63	470.6
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	22.7	47.55	526.7
T_{11} : Soil test based recommendation	22.6	48.69	599.3
T_{12}: Control	20.3	46.50	460.0
SEm(±)	0.6	0.12	34.4
CD (0.05)	1.91	0.342	101.41

Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) recorded higher oil content (49.38%). It was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4).

4.4.3. Oil yield

The results on oil yield are given in Table 16.

Oil yield differed significantly with respect to treatments. An oil yield of 752.2 kg ha^{-1} was recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and it was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{1} (T_4).

4.5. PLANT ANALYSIS AND NUTRIENT UPTAKE

The data on nutrient uptake by the crop at harvest were presented in Table 17, 18 and 19.

4.5.1. N, P and K uptake

Total N uptake was significantly influenced by the treatments. Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) recorded higher N uptake (125.67 kg ha^{-1}) followed by soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). Total plant uptake of P and K was not influenced by the treatments and the P uptake varied from 21.28 kg ha^{-1} (T_9) to 26.46 kg ha^{-1} (T_5). Similarly plant uptake of K varied between 50.76 kg ha^{-1} (T_8) and 66.29 kg ha^{-1}(T_4).

4.5.2. Ca and S uptake

Analysed data on the uptake of Ca by plants revealed that it did not significantly differed by the treatments. But the uptake of S was influenced by the treatments and S uptake (14.5 kg ha^{-1}) was higher for the treatment, foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). It was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4). The lowest uptake (7.23 kg ha^{-1}) was recorded with Control (T_{12}).

Table 17. Effect of zinc and boron nutrition on the uptake of N, P and K at harvest, (kg ha^{-1})

Treatments	N uptake	P uptake	K uptake
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	123.00	26.19	58.91
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	97.33	24.68	58.85
T_3 : Soil application of borax @ 1 kg ha^{-1}	98.16	22.21	59.55
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	120.25	24.50	66.29
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30,45 and 60 DAE	125.67	26.46	65.00
T_6 : Foliar application of 0.5 per cent borax at 30,45 and 60 DAE	97.57	25.09	62.15
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30,45 and 60 DAE	100.92	25.81	63.97
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	98.61	22.89	50.76
T_9 : Seed treatment with borax (100 mg kg^{-1})	96.65	21.28	52.05
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	97.83	22.56	63.54
T_{11} : Soil test based recommendation	105.77	22.46	59.05
T_{12}: Control	95.26	21.50	51.03
SEm (±)	4.32	1.83	6.31
CD (0.05)	12.741	NS	NS

Table 18. Effect of zinc and boron nutrition on the uptake of Ca and S at harvest, (kg ha^{-1})

Treatments	Ca uptake	S uptake
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	46.43	13.15
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	36.63	9.08
T_3 : Soil application of borax @ 1 kg ha^{-1}	44.67	8.63
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	53.26	11.65
T_5 : Foliar application of 0.5 percent $ZnSO_4$ at 30,45 and 60 DAE	48.55	14.5
T_6 : Foliar application of 0.5 percent borax at 30,45 and 60 DAE	41.67	9.69
T_7 : Foliar application of 0.25 percent $ZnSO_4$ + borax 0.25 per cent at 30,45 and 60 DAE	45.25	10.96
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	47.01	8.00
T_9 : Seed treatment with borax (100 mg kg^{-1})	41.58	8.78
T_{10} :Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	46.76	9.18
T_{11} : Soil test based recommendation	43.20	10.00
T_{12}: Control	38.33	7.23
SEm (±)	4.32	1.09
CD (0.05)	NS	3.204

4.5.3. Zn and B uptake

The results showed that effect of Zn and B nutrition on the uptake of zinc varied with treatments and Zn uptake (36.94 g ha^{-1}) was higher with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (33.85 g ha^{-1}). Boron uptake was also significantly influenced by the treatments. Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE (T_6) recorded higher uptake (61.71 g ha^{-1}) of B when compared to other treatments. Control treatment (T_{12}) recorded the lowest (22.2 g ha^{-1}) uptake of B.

4.6. SOIL ANALYSIS AFTER THE EXPERIMENT

Soil samples after the experiment were analysed for pH, EC, organic carbon, available nutrient status. The data are presented in Table 20, 21, 22 and 23.

4.6.1. Soil pH, EC and Organic Carbon

The results of soil pH, EC and organic carbon after the experiment (Table 20.) revealed that they were not influenced by the treatments. In general soil pH, EC and organic carbon showed an increase after the experiment. The soil pH ranged from 5.38 (T_2) to 5.91 (T_8). Electrical conductivity varied from 0.27 dS m^{-1} (T_7, T_8, T_9) to 0.36 dS m^{-1} (T_3). The soil organic carbon status also varied from 0.38 % (T_6) to 0.45% (T_5).

4.6.2. Available N, P and K

Effect of Zn and B nutrition on soil nutrient status revealed that there was a build-up of N in the soil in all treatments when compared to the initial soil status (Table 21.). Available N (246.33 kg ha^{-1}) after the experiment was higher with seed treatment with borax (100 mg kg^{-1}) (T_9). It was comparable with control (T_{12}), foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE

Table 19. Effect of zinc and boron nutrition on crop uptake of Zn and B at harvest, ($g\ ha^{-1}$)

Treatments	Zn uptake	B uptake
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	33.85	29.81
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	25.87	28.38
T_3 : Soil application of borax @ 1 kg ha^{-1}	21.92	40.99
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	33.42	44.23
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30,45 and 60 DAE	36.94	33.74
T_6 : Foliar application of 0.5 per cent borax at 30,45 and 60 DAE	24.03	61.71
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30,45 and 60 DAE	31.03	43.63
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	27.71	26.59
T_9 : Seed treatment with borax (100 mg kg^{-1})	20.32	32.73
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	26.93	32.02
T_{11} : Soil test based recommendation	29.14	35.03
T_{12}: Control	20.03	22.20
SEm (±)	1.00	3.60
CD (0.05)	3.200	10.600

Table 20. Effect of zinc and boron nutrition on pH, EC and organic carbon status after the experiment

Treatments	pH	EC ($dS\ m^{-1}$)	OC (%)
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	5.74	0.31	0.42
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	5.38	0.31	0.39
T_3 : Soil application of borax @ 1 kg ha^{-1}	5.82	0.36	0.44
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	5.80	0.33	0.39
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	5.85	0.28	0.45
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	5.83	0.30	0.38
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	5.60	0.27	0.43
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	5.91	0.27	0.42
T_9 : Seed treatment with borax (100 mg kg^{-1})	5.78	0.27	0.39
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	5.87	0.30	0.40
T_{11} : Soil test based recommendation	5.86	0.35	0.41
T_{12}: Control	5.64	0.30	0.40
SEm (±)	0.17	0.04	0.02
CD (0.05)	NS	NS	NS

Table 21. Effect of zinc and boron nutrition on available N, P and K status after the experiment, (kg ha^{-1})

Treatments	Available N	Available P	Available K
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	214.65	27.41	154.40
T_2 : Soil application of Zn-EDTA @ 5 kg ha^{-1}	225.66	31.06	157.27
T_3 : Soil application of borax @ 1 kg ha^{-1}	221.40	32.33	161.33
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1}+ borax @ 0.5 kg ha^{-1}	204.90	31.33	146.00
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	214.57	28.15	142.27
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	220.00	35.50	175.33
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	238.67	30.22	148.33
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	203.84	31.67	153.76
T_9 : Seed treatment with borax (100 mg kg^{-1})	246.33	31.94	165.33
T_{10} : Seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1})	229.75	35.33	181.00
T_{11} : Soil test based recommendation	213.74	29.55	165.33
T_{12}: Control	241.00	31.66	172.34
SEm (±)	9.19	2.22	6.45
CD (0.05)	27.120	NS	19.045

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(T_7), seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}), soil application with Zn-EDTA @ 5 kg ha^{-1}(T_2), soil application of borax @ 1 kg ha^{-1} (T_3) and foliar application of 0.5 per cent borax at 30, 45 and 60 DAE (T_6).

Available P status (Table 21) also improved after the experiment and it did not significantly differ with treatments. P content in the soil varied from 27.41 kg ha^{-1} (T_1) to 35.5 kg ha^{-1}(T_6). K status was influenced by the treatments and improved after the experiment. Higher available K was recorded with seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) (181.00 kg ha^{-1}) and it was on par with T_6, T_{12}, T_{11}, T_9 and T_3.

4.6.3. Available Ca, and S

Data pertaining to the Ca and S content in the soil after the experiment (Table 22) revealed that both Ca and S content in the soil was not significantly influenced by the treatments. Available Ca status was increased to the near sufficiency level after the experiment. The Ca status ranged from 270. 58 mg kg^{-1} (T_{12}) to 294.00 mg kg^{-1} (T_2). Available S content also varied from14.12 mg kg^{-1}(T_{12}) to 17.17 mg kg^{-1}(T_{11}) among treatments.

4.6.4. Available Zn and B

Effect of zinc and boron nutrition on soil nutrient status after the experiment (Table 23) revealed that the available zinc and boron was influenced by the treatments. Soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1), recorded higher available zinc (0.37 mg kg^{-1}) which was on par with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4)(0.33 mg kg^{-1}) and were superior to other treatments. Soil application of borax @ 1 kg ha^{-1}(T_3) recorded the highest available boron (0.66 mg kg^{-1}) after the experiment.

4.7. COST BENEFIT ANALYSIS

Data pertaining to cost benefit analysis were presented in Table 24.

The highest net income (₹ 72720 ha^{-1}) was obtained from foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) with a BCR of 2.28. It was

Table 22. Effect of zinc and boron nutrition on available Ca and S status after the experiment, (g ha^{-1})

Treatments	Available Ca	Available S
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	271.67	14.33
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	294.00	15.00
T_3 : Soil application of borax @ 1 kg ha^{-1}	278.33	14.78
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	276.67	15.75
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	289.33	14.18
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	277.67	15.58
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30,45 and 60 DAE	276.67	16.45
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	285.67	14.42
T_9 : Seed treatment with borax (100 mg kg^{-1})	271.68	16.33
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	285.00	15.25
T_{11} : Soil test based recommendation	282.33	17.17
T_{12}: Control	270.58	14.12
SEm (±)	15.35	1.12
CD (0.05)	NS	NS

Table 23. Effect of zinc and boron nutrition on available Zn and B status after the experiment, (g ha^{-1})

Treatments	Available Zn	Available B
T_1: Soil application of $ZnSO_4$ @5 kg ha^{-1}	0.37	0.26
T_2 : Soil application of Zn-EDTA@5 kg ha^{-1}	0.29	0.26
T_3 : Soil application of borax @ 1 kg ha^{-1}	0.25	0.66
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	0.33	0.44
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	0.29	0.30
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	0.28	0.38
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 percent borax at 30,45 and 60 DAE	0.29	0.48
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	0.29	0.30
T_9 : Seed treatment with borax (100 mg kg^{-1})	0.29	0.25
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	0.24	0.30
T_{11} : Soil test based recommendation	0.28	0.21
T_{12}: Control	0.26	0.26
SEm (±)	0.02	0.04
CD (0.05)	0.056	0.107

Table 24. Effect of zinc and boron nutrition on net income & benefit cost ratio.

Treatments	Net income (₹ ha^{-1})	BCR
T_1: Soil application of $ZnSO_4$ @ 5 kg ha^{-1}	67131	2.22
T_2 : Soil application of Zn-EDTA @ 5 kg ha^{-1}	42201	1.74
T_3 : Soil application of borax @ 1 kg ha^{-1}	37367	1.68
T_4: Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}	60354	2.07
T_5 : Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE	72720	2.28
T_6 : Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE	42085	1.70
T_7 : Foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE	46225	1.79
T_8 : Seed treatment with $ZnSO_4$ (250 mg kg^{-1})	35624	1.65
T_9 : Seed treatment with borax (100 mg kg^{-1})	30918	1.56
T_{10} : Seed treatment with $ZnSO_4$(250 mg kg^{-1}) + borax (100 mg kg^{-1})	39316	1.72
T_{11} : Soil test based recommendation	48870	1.88
T_{12}: Control	29266	1.53

followed by soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) with a net income of ₹ 67131 ha^{-1} and ₹ 60354 ha^{-1}, respectively. T_1 and T_4 recorded a BCR of 2.22 and 2.07, respectively. The lowest net income (₹ 29266 ha^{-1}) was realized from the control (T_{12}) with a BCR of 1.53.

Discussion

5. DISCUSSION

The field experiment entitled "Zinc and boron nutrition in groundnut (*Arachis hypogaea* L.) for *Onattukara* sandy plain" was undertaken during 2017-19 to evaluate the effect of zinc and boron nutrition on growth, yield and quality of groundnut (*Arachis hypogaea* L.) in the summer rice fallows of *Onattukara* and to work out the economics of cultivation. The data collected on various growth, yield characters, quality attributes, yield, nutrient uptake, soil nutrient status and economics were analysed statistically and the results are discussed in this chapter.

5.1. EFFECT OF ZINC AND BORON NUTRITION ON GROWTH ATTRIBUTES OF GROUND NUT

Though growth is a genotypic character, it is largely influenced by edaphic factors like plant nutrition and environmental factors. Analysis of the crop growth characters at different growth stages (30, 45 and 60 DAS and at harvest) revealed that the growth attributes of groundnut were influenced by Zn and B nutrition. During the different growth stages, the plant height (Fig.3) was influenced by the treatments. Taller plants were observed with soil and foliar application treatments due to the effect of Zn and B nutrition.

Sreelatha *et al.*, (2018) reported that branching in groundnut is related to pod yield and there was a positive correlation between yield and branching. Further, it is desirable to initiate early branching which increases the flower formation and pod formation. In this experiment, at 60 DAS and at harvest (Fig.4), foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) or $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) produced more number of branches leading to more yield at harvest.

The role of leaf parameters viz., functional leaf area, LAI and LAD are crucial in determining the yield potential. In the present study, the groundnut leaves showed

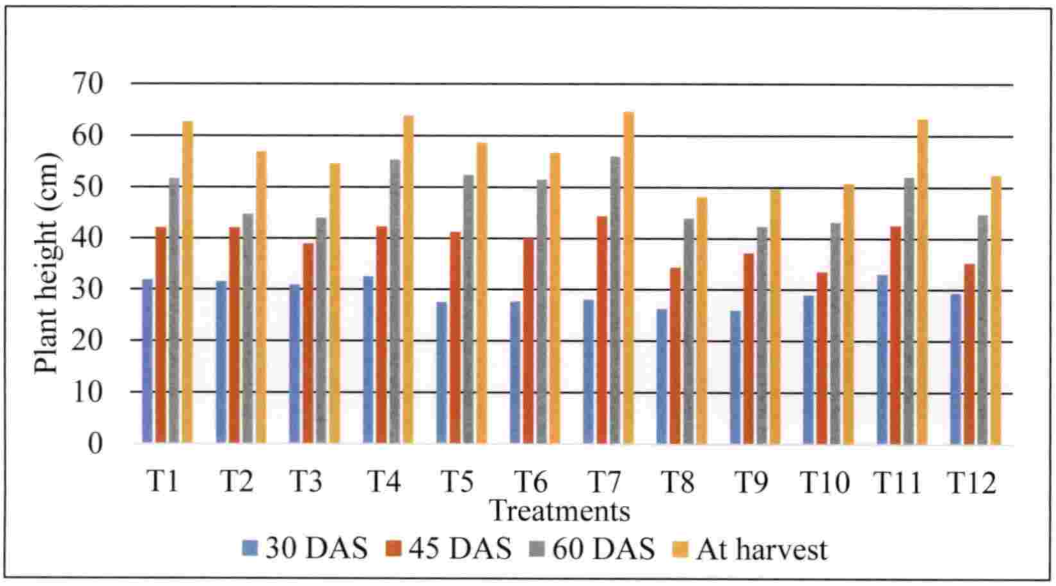

Fig. 3. Effect of zinc and boron nutrition on plant height

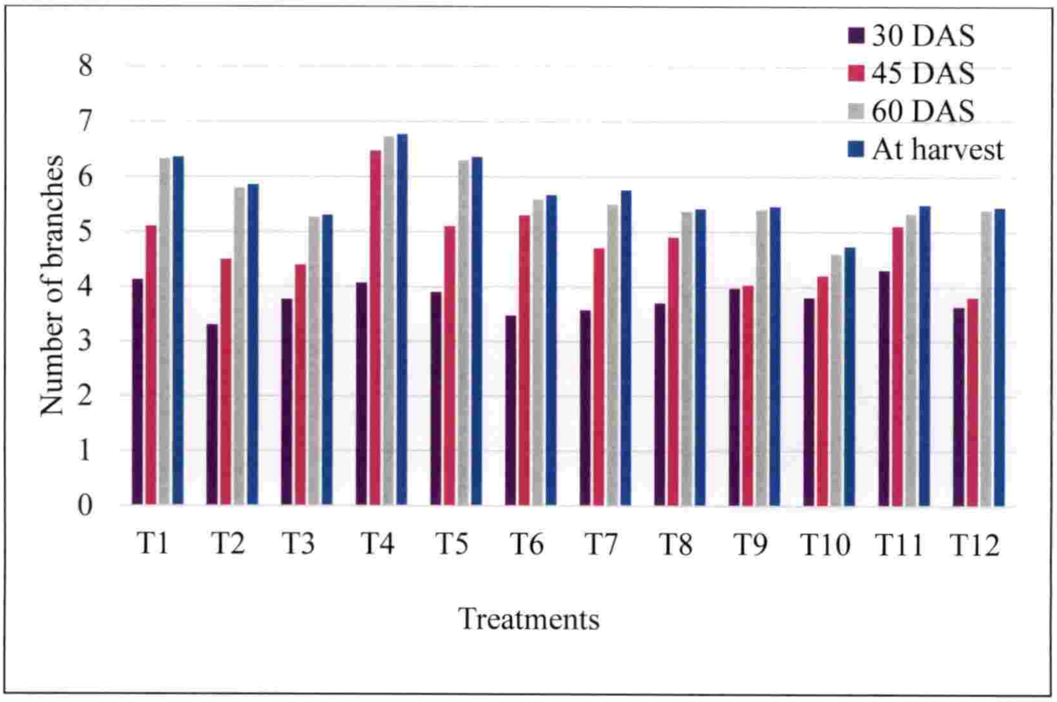

Fig. 4. Effect of zinc and boron nutrition on number of branches

rapid increase in leaf area from 30 to 60 DAS, but it varied with the treatments (Fig.5). At 60 DAS, soil and foliar application treatments produced higher leaf area. At harvest, foliar application of Zn and B at 30, 45 and 60 DAE (T_7) provided better functional leaf area. The canopy development at crop maturity was not always related to kernel yield. However, canopy development at peak flowering had a strong positive association with kernel yield (Prasad, 1993).

Soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4) and soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) recorded higher leaf area from initial stages to final stage. The foliar applications and soil test based recommendations also recorded more leaf area from pegging stage onwards. But the seed treatments could not cope up with growth and field cover to produce optimum leaf area due to the initial slow growth of seed treatments. The non significant effect of seed treatment might be due to the lower concentration of nutrients applied. Similar findings were also reported by Singh and Singh (2000) and Chitdeshwari and Poongothai (2003).

Early high vigour during initial stages of growth upto the pod filling stage, high LAD from the pod filling stage to maturity and efficient translocation of photosynthates were the major physiological parameters responsible for high yields. The increase in CGR, NAR, LAI and LAD indicated higher photosynthetic efficiency of the crop that resulted in higher yield under Zn and B nutrition. The increase in yield with Zn and B could be due to activation of various enzymes, enhanced synthesis of carbohydrates and proteins and increased N assimilation in plant.

Das and Ali (1993) studied the combined application of Zn, B and Mo to groundnut and observed that Zn and B increased the vegetative growth, Mo increased the nodule number and Zn increased the flower number, pod number, pod weight and kernel weight.

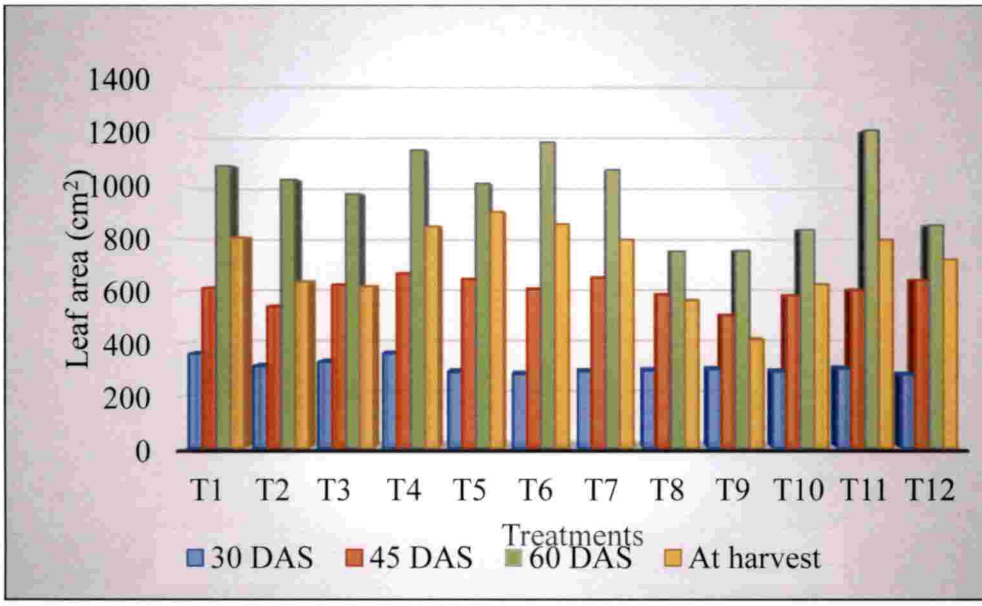

Fig. 5. Effect of zinc and boron nutrition on leaf area

5.2 EFFECT OF ZINC AND BORON NUTRITION ON YIELD ATTRIBUTES

Economic yield is expressed as a function of factors that contribute to yield, which are known as yield attributes. The main yield attributing parameters in groundnut are *viz.,* number of pods per plant, 100 kernel weight and shelling percentage which were significantly higher in foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4). The difference in the yield attributes might be due to differential translocation of photosynthates from vegetative to reproductive parts.

The results indicated that number of days taken for 50 per cent flowering was found to have any significant influence on yield. The results revealed that foliar application of 0.5 percent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) produced more number of pods per plant (33.50) and it was comparable with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4) (32.17), foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) (31.89) and soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1) (29). Improvement in soil fertility and productivity due to application of micronutrients might have supported more number of pods and increased the number of pods and pod weight. These results were in conformity with the findings of Singh (2007) and Marious *et al.* (2011) who observed that the higher yield and yield parameters in groundnut due to soil and foliar application of micronutrients.

The improvement in yield attributes leading to higher yield by Zn might be due to the enhanced synthesis of carbohydrates and proteins and their transport to the sink through effective physiological activities in plants, as evident from improved physiological parameters.

The increasing trend in test weight in T_1, T_4 and T_5 (Fig.6) due to soil or foliar application of $ZnSO_4$ during the experiment showed that, application of Zn led to increase in the availability of Zn to plants in the Zn deficient soil. Zn is an important substrate involved in photo system-II of photosynthesis and plays vital role in energy

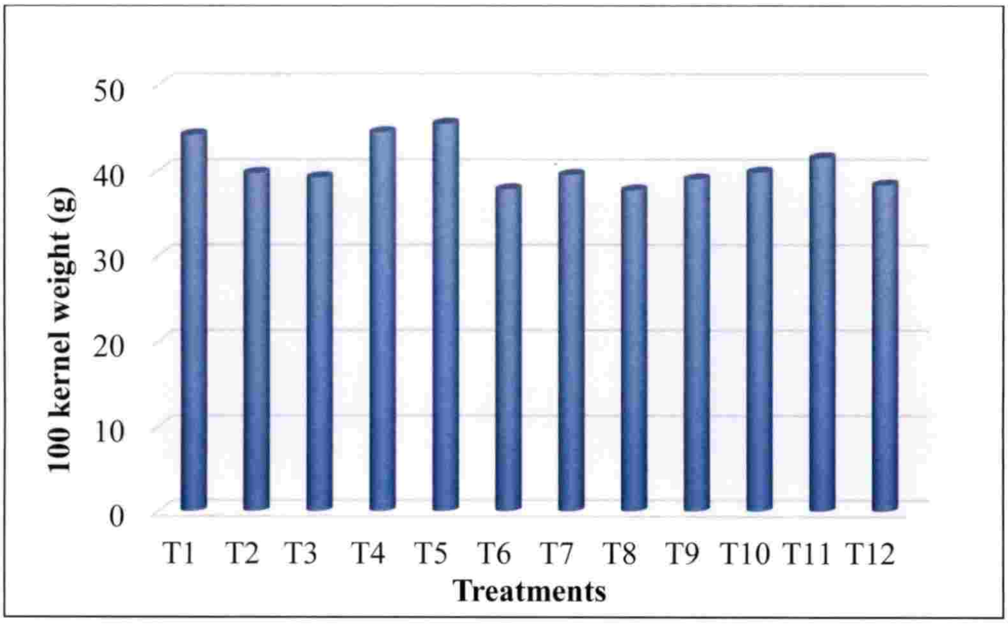

Fig. 6. Effect of zinc and boron nutrition on 100 kernel weight

metabolism process in plants. Thus, the increased availability and efficient absorption of Zn resulted in vibrant metabolism in plant which is an important reason for increase in test weight of the kernels (Prashantha *et al.*, 2019).

5.3 EFFECT OF ZINC AND BORON NUTRITION ON YIELD

Significantly higher kernel yield (1523, 1438 and 1372 kg ha^{-1}, respectively) of groundnut (Fig.7) were recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). Haulm yield (3978 kg ha^{-1}) was higher with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and was comparable with all treatments except T_9 and T_{10} (Fig. 7). Harvest index was not influenced by the treatments. The HI varied from 0.29 to 0.35. The variations in yield due to treatments could be attributed to the variations in the yield attributes.

The higher pod yield might be due to higher protein as well as oil content of the kernels by the addition of Zn and boron. Krishnasamy *et al.* (1994) reported that combined application of $ZnSO_4$ and S along with borax was found to be better in enhancing the yield of groundnut when compared to the individual application of B and S. The positive role of B in quality improvement through its involvement in the synthesis of protein and amino acids further increased the pod yield of groundnut in T_4. Arunachalm *et al.* (2013) reported that 40 per cent yield loss was reported in groundnut due to Zn deficiency and average response to Zn fertilization ranges from 210 to 470 kg ha^{-1}.

The higher seed yield may be attributed to higher total dry matter production due to better N as well as Zn uptake and their translocation to the reproductive parts and improvement in yield attributing characters like number of pods per plant, pod weight, 100 kernel weight and shelling percentage. The positive response of micronutrients with recommended NPK can be attributed to the availability of sufficient amount of plant nutrients throughout the growth period, resulting in more

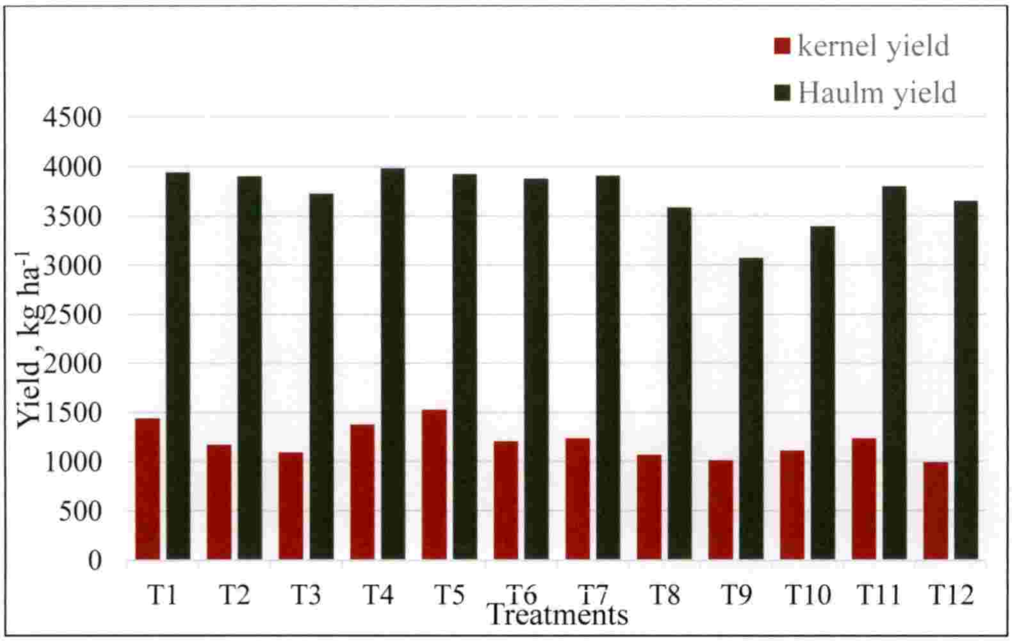

Fig. 7 Effect of zinc and boron nutrition on kernel yield and haulm yield

uptake and yield advantage. In this experiment, the requirement of boron might have been met from the FYM in treatments T_1 and T_5. Plant ability to adopt at high or low concentrations of B may depend on the germplasm, physiological mechanisms and genetic diversity of species (Bolanos *et al.*, 2004).

5.4 EFFECT OF METHOD OF APPLICATION OF ZINC AND BORON ON YIELD

In this experiment, the method of application of micronutrients influenced the kernel yield. The yield response varied from 2 to 54 per cent among treatments over control (Fig.8). The soil application of micronutrient resulted in 10 to 45 per cent yield increase over control. The foliar application of micronutrients at 30, 45 and 60 days after emergence increased the yield from 21 to 54 per cent over control. The soil test recommendation produced 24 per cent more kernel yield than control. However, seed treatment with micronutrients resulted in 2 to 12 per cent increase in kernel yield. This might be due to the less efficiency of seed treatments on growth and yield parameters in groundnut. In general, the seed treatments took three to four days more for field emergence and reduced germination causing lower plant stand and yield.

5.5 EFFECT OF ZINC AND BORON NUTRITION ON QUALITY ATTRIBUTES

Groundnut is mainly grown for oil extraction. Although oil content in groundnut kernels is a genetic factor, it is also influenced by environment and management practices including crop nutrition. Sulphur in groundnut, constitutes methionine, cysteine and cystine amino acids and increases oil synthesis. It improves nodulation and pod yield besides reducing the incidence of diseases and is as important as P for oilseed crop (Singh, 2016). Application of S containing fertilizers like $ZnSO_4$ increased the available S which enhanced the oil content in foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5), soil application of

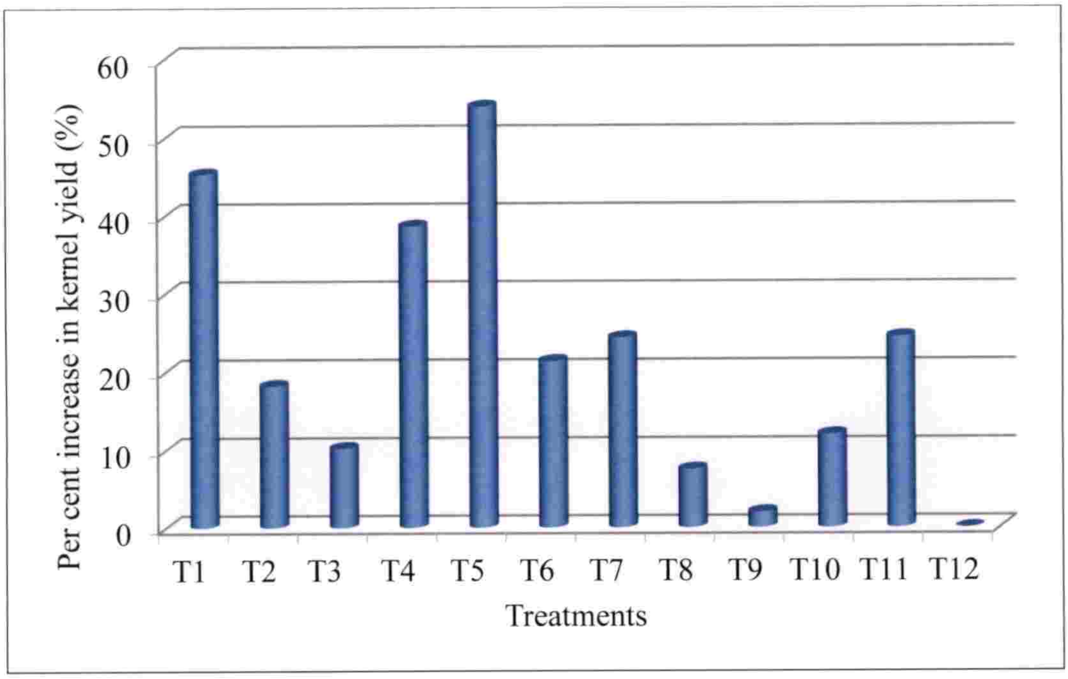

Fig.8. Effect of zinc and boron nutrition on per cent increase in kernel yield

$ZnSO_4$ @ 5 kg ha^{-1}(T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). Similarly the oil yield was also higher in the above treatments.

Oil yield (Fig. 9) differed significantly with respect to the treatments. Among treatments, higher oil yield of 752.2 kg ha^{-1} was recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and it was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (706.4 kg ha^{-1}) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{1} (T_4) (672.2 kg ha^{-1}). Higher oil yield might also be due to higher kernel yield in the above treatments.

Results of the effect of Zn and B nutrition on protein content revealed that the mean protein content differed significantly with respect to the various treatments. The reason for higher protein may be due to more availability of nutrients particularly N which is an integral part of protein. The reason for higher protein content may also be due to the application of micronutrients Zn and B contributed to higher NPK uptake, there by favouring higher protein content in the kernels except soil application of Zn EDTA, seed treatment with borax and control. Higher protein content may also due to large reserve of nutrients in the kernel leads to larger size. Higher uptake of N and micronutrients may enhanced the synthesis of carbohydrate, methionine, protein and their transport to the site of seed formation (Rizwan *et al.*, 2011).

5.6 EFFECT OF ZINC AND BORON NUTRITION ON NUTRIENT UPTAKE AND SOIL NUTRIENT STATUS

Uptake efficiency is influenced by several factors which varies with agro-climatic regions like soil factors, method of application, mineral mobility and its accumulation site.

A perusal of data showed that different treatments exerted their significant influence on nutrients uptake (Fig.10 & 11) by pod and haulm. Higher yield accounted for the balanced application of nutrients which were conducive to higher dry matter production and nutrient uptake. Thus, the application of Zn and B to a soil

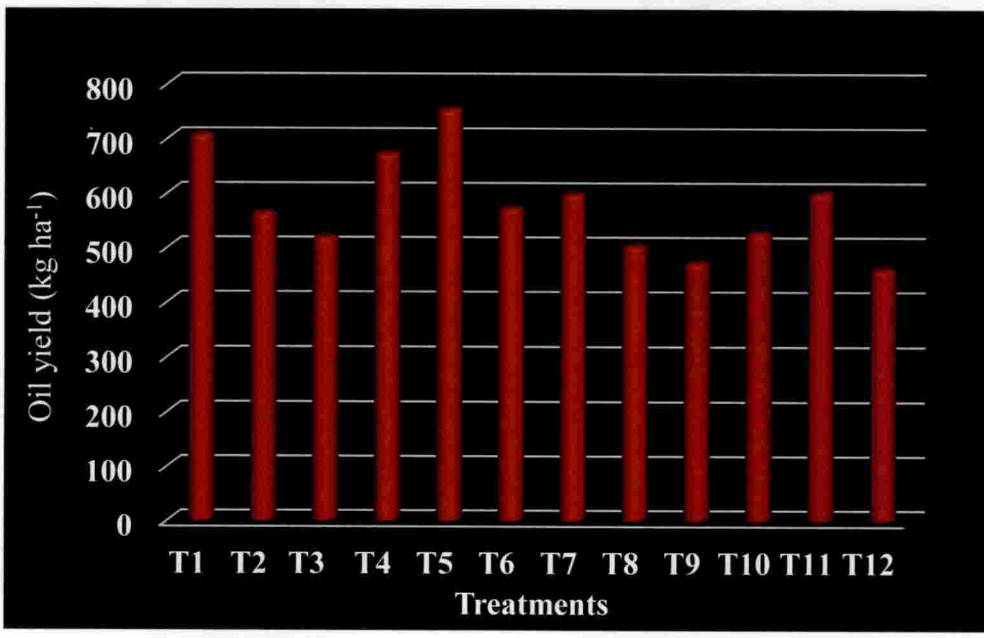

Fig. 9. Effect of zinc and boron nutrition on oil yield

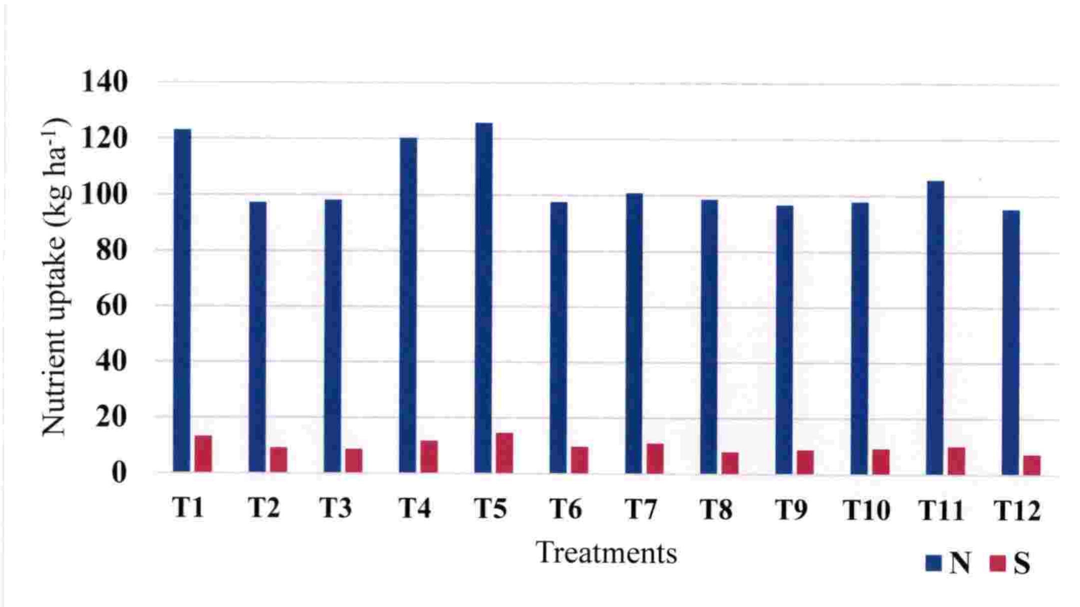

Fig. 10. Effect of zinc and boron nutrition on N and S uptake

deficient in Zn and B improved overall growth and development of plants and ultimately led to higher kernel yield.

The soil and foliar applications resulted in the increased availability and uptake of the respective nutrients during the active growth stages of the crop. According to Singh (2016), the groundnut crop removes 4 to 12, 42 to 88 and 6 to 53 per cent of total nutrient during vegetative (0 to 25 days), reproductive (25 to 75 DAE) and pod development (75 to 105 DAE) stages, respectively. The present study revealed that N, S, Zn and B uptake by the crop was significantly influenced by treatments. Thus increase in uptake was either due to the higher concentration of these nutrients in pod and haulm or higher yield and biomass production. The results of present investigation are in close agreement with the findings of Zalate and Padmani (2010), Tatpurkar *et al.,* (2014) and Vallabh and Brigendra (2015).

Like other legumes groundnut has the ability to fix atmospheric N through symbiotic N fixation. Available N status was increased after the experiment due to N fixation by the crop. Available N (246.33kg ha^{-1}) after the experiment was higher with seed treatment with borax (100 mg kg^{-1}) (T_9). It was comparable with T_{12}, T_7, T_{10}, T_2, T_3 and T_6. This might be due to lower plant uptake and lower dry matter production. Available P status was not influenced by the Zn and B addition but the content was slightly higher than the initial status. This may be due to the nutrient addition through FYM and fertilizer application to the crop. Available K status in soil was influenced by the treatments due to the differential uptake of soil K. Higher available K was recorded with seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) (181.00kg ha^{-1}) and it was on par with T_6, T_{12}, T_{11}, T_9 and T_3. Available soil K was lower in soil and foliar application treatments of B (T_3 and T_6) and combined seed treatment of Zn and B (T_{10}). This might be due to the impaired uptake of soil K by plants. The study also revealed that the uptake of N, P, S and Zn by groundnut were higher with S containing fertilizers ($ZnSO_4$) than without S containing fertilizers in all the treatments. Patel and Zinzala (2018) studied the effect of S and B on nutrient content and uptake by summer groundnut and the study

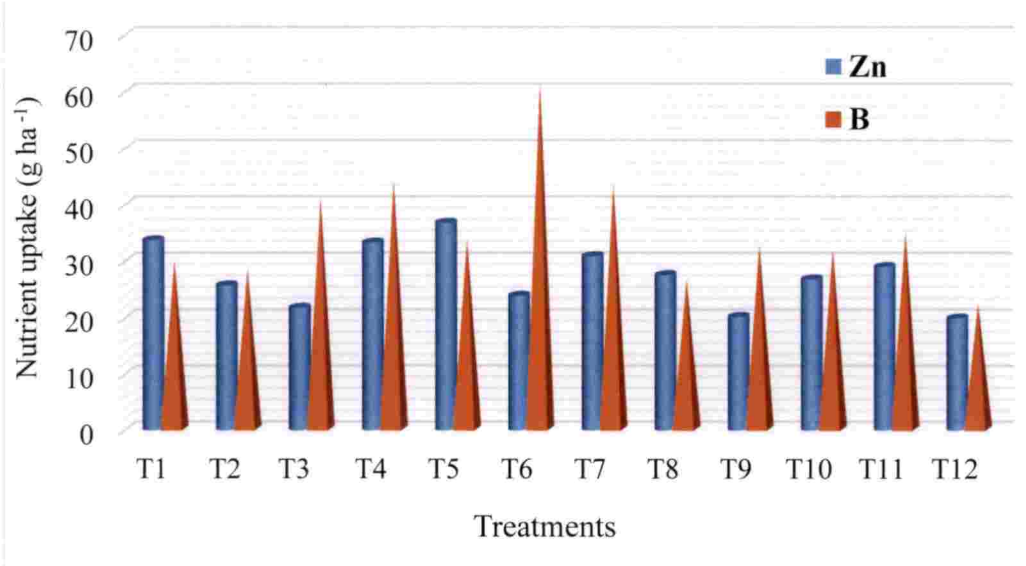

Fig. 11. Effect of zinc and boron nutrition on Zn and B uptake

revealed that S content in pod, haulm and its uptake by pod, haulm and total S uptake by groundnut were increased significantly upto 1 kg B ha^{-1}.

The increased Zn and B availability might be attributed to the direct addition of these nutrients by fertilizers. Further the complexation of micronutrients with applied organics might have mobilized and increased the availability of Zn and B in soil. Application of Zn and B in the soil as well as foliar spray increased the availability of these elements and hence increase in the Zn and B concentrations of plants were obtained in the respective treatments. Arunachalam *et al.* (2013) opined that soil application of Zn is a cost effective way to enrich the groundnut kernel with zinc.

Soil status of secondary nutrients (Ca and S) were not influenced by the treatments. The Ca level is brought to near neutral level due to uniform application of lime. Generally the soil application treatments showed the superiority over other methods of applications.

Soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1), recorded higher available Zn (0.37mg kg^{-1}) which was on par with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (0.33 mg kg^{-1}) and were superior to other treatments. Acid forming fertilizers like $ZnSO_4$ may increase the uptake of both native and supplemental Zn. Soil application of borax @ 1 kg ha^{-1} (T_3) recorded the highest available B (0.66mg kg^{-1}) after the experiment. This is due to the superiority of soil application over other methods. But the sufficiency level of Zn and B can be reached only after regular soil test based repeated additions on cropping system based approach.

5.7 COST BENEFIT ANALYSIS OF ZINC AND BORON NUTRITION

Economic analysis also showed the same trend as that of kernel yield of groundnut (Fig.12). The cost of cultivation of groundnut varied with the treatments. Correct choice of the method of application helped to reduce the cost of cultivation. The economic analysis of data revealed that cost of cultivation was higher for foliar

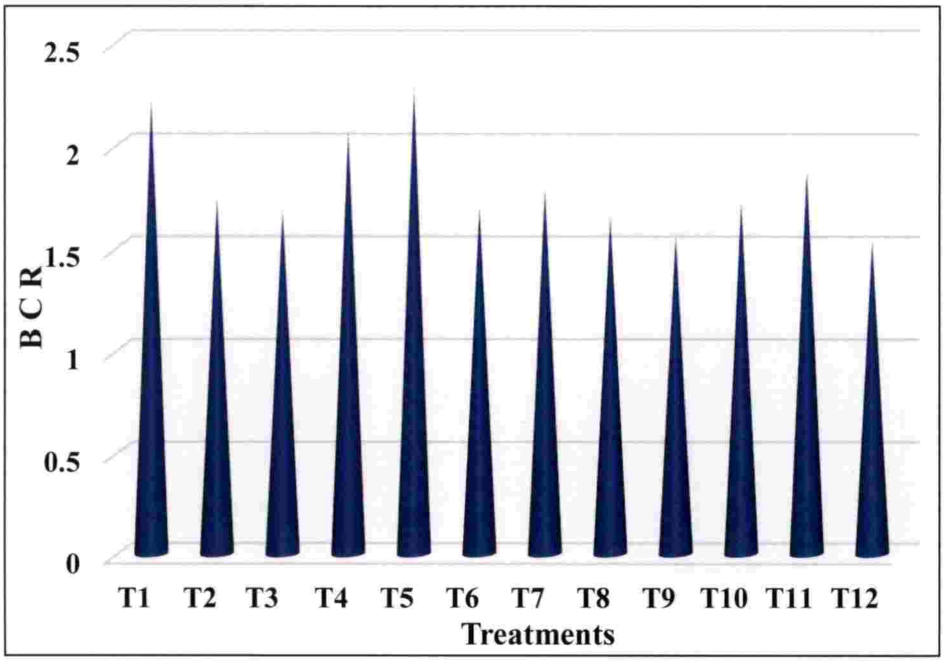

Fig. 12. Effect of zinc and boron nutrition on benefit cost ratio

application treatments because of the high labour charge incurred during the crop period when compared to soil application treatments, seed treatments and control.

The highest net income (₹ 72720 ha^{-1}) was obtained from foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) with a BCR of 2.28. It was followed by soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) with a net income of ₹ 67131 ha^{-1} and ₹ 60354 ha^{-1}, respectively which recorded BCR of 2.22 and 2.07, respectively. The lowest net income (₹ 29266 ha^{-1}) was realized from the control (T_{12}) with a BCR of 1.53.

The results revealed that soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1), soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) recorded higher net returns and benefit - cost ratio. This may be due to the higher yield realized from these treatments.

Summary

6. SUMMARY

An investigation entitled "Zinc and boron nutrition in groundnut (*Arachis hypogaea* L.) for *Onattukara* sandy plain" was undertaken during 2017-19 to evaluate the effect of Zn and B nutrition on growth, yield and quality of groundnut (*Arachis hypogaea* L.) in the summer rice fallows of *Onattukara* and to work out the economics of cultivation. The experiment was conducted during December 2018 to April 2019 in farmer's field at *Onattukara* region of Alappuzha district.

The experiment was laid out in RBD with 12 treatments replicated thrice. The treatments were T_1 - soil application of Zn @ 5 kg ha^{-1} as $ZnSO_4$; T_2 - soil application of Zn @ 5 kg ha^{-1} as Zn-EDTA ; T_3 - soil application of B @ 1 kg ha^{-1} as borax ; T_4 - soil application of Zn @ 2.5 kg ha^{-1} as $ZnSO_4$ + B @ 0.5 kg ha^{-1} as borax ; T_5 - foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 days after emergence (DAE) ; T_6 - foliar application of 0.5 per cent borax at 30, 45 and 60 DAE ; T_7 - foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE ; T_8 - seed treatment with $ZnSO_4$ (250 mg kg^{-1}) ; T_9 - seed treatment with borax (100 mg kg^{-1}) ; T_{10} - seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) ; T_{11} - soil test based recommendation and T_{12} - control. FYM @ 2 t ha^{-1}, N: P_2O_5: K_2O @ 10:75:75 kg ha^{-1} (as basal) and lime 1.5 t ha^{-1} (at flowering) were applied uniformly to all treatments. For soil test based recommendation, N: P_2O_5: K_2O @ 9.7: 45: 70.5 kg ha^{-1} were applied on the basis of soil test based data. Since the soil was deficient in Zn and B, one foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30 DAE was also provided. The bunch type groundnut variety, CO 7 was sown at a spacing of 15 cm x 15 cm.

The results of the experiment are summarized below.

The growth attributes of groundnut were recorded at 30, 45 and 60 DAE and at harvest. Among the treatments, foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) recorded significantly higher growth parameters *viz*., plant height, number of branches per plant, leaf area and number of nodules per plant. At 60 DAS, soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kgha^{-1} (T_4) recorded more number of branches (6.73) which was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (6.33) and foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) (6.30) . At 60 DAS, all treatments were on par and produced more leaf area except seed treatments and control. At all stages of growth, soil application treatments recorded more number of nodules per plant. The physiological parameters such as CGR, NAR, LAI, and LAD recorded during 15 to 30 and 30 to 45 DAS, also varied with Zn and B nutrition. Higher CGR values were obtained with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and was on par with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). During 30 to 45 DAS, NAR was found to be significant and recorded higher values in all treatments except seed treatment. LAI and LAD were higher with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and was comparable with $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) during 15 to 30 DAS and 30 to 45 DAS.

The results revealed that yield parameters *viz*., number of pods per plant, 100 kernel weight and shelling percentage varied significantly with the treatments.

Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) produced more number of pods per plant (33.50) and it was comparable with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (32.17), foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) (31.89) and soil application of ZnSO4 @ 5 kg ha^{-1} (T_1) (29). Higher 100 kernel weight (45.5 g) was recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). It was on par with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1}(T_4) (44.5 g), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (44.2 g) and soil test based recommendation (T_{11}) (41.5 g), respectively. Shelling percentage was significantly higher (70.75%) with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and it was on par with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) (70.17%), soil test based recommendation (T_{11}) (69.81%), soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (69.45%) and foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE (T_7) (68.28%). However the treatment effects were not significant with respect to the number of days taken for 50 per cent flowering and number of seeds per pod.

Kernel yield was superior (1523 kg ha^{-1}) with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). Haulm yield (3978 kg ha^{-1}) was higher with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and was comparable with all treatments except T_9 and T_{10}. Harvest index did not differ significantly due to Zn and B nutrition in groundnut.

Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) recorded higher oil content (49.38%). It was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) with an oil content of 49.13 % and 49.00%, respectively. Oil yield differed significantly with respect to the treatments. An oil yield of 752.2 kg ha^{-1} was recorded with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and it was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (706.4 kg ha^{-1}) and soil application of ZnSO4 @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (672.2 kg ha^{-1}). Protein content of seed (23.2%) was higher with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and was on par with all treatments except T_2, T_9 and T_{12}.

No serious pest and disease were observed during the experiment.

Total N uptake was significantly influenced by the treatments. Foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) recorded higher N uptake (125.67 kg ha^{-1}) followed by soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (123.0 kg ha^{-1}) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (120.25 kg ha^{-1}). Total plant uptake of P and K was not influenced by the treatments. But the uptake of S was influenced by the treatments and S uptake

(14.5 kg ha^{-1}) was higher for the treatment, foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and it was on par with T_1 and T_4.

The results showed that effect of Zn and B nutrition on the uptake of Zn varied with treatments. Zn uptake (36.94 g ha^{-1}) was higher with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) (33.85 g ha^{-1}). B uptake was also significantly influenced by the treatments. Foliar application of 0.5 per cent borax at 30, 45 and 60 DAE (T_6) recorded higher uptake (61.71 g ha^{-1}) of B when compared to other treatments.

Soil pH, EC organic carbon and available P, Ca and S status after the experiment were not significantly influenced by the treatments. Available N (246.33 kg ha^{-1}) after the experiment was higher with seed treatment with borax (100 mg kg^{-1}) (T_9) and it was on par with T_7, T_{12}, T_{10}, T_2, T_6 and T_3. Higher available K was recorded with seed treatment with $ZnSO_4$ (250 mg kg^{-1}) + borax (100 mg kg^{-1}) (T_{10}) (181.00 kg ha^{-1}) and it was on par with T_6, T_{12}, T_{11}, T_9 and T_3. Soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1), recorded higher available Zn (0.37 mg kg^{-1}) which was on par with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) (0.33 mg kg^{-1}) and were superior to other treatments. Soil application of borax @ 1 kg ha^{-1} (T_3) recorded the highest available B (0.66 mg kg^{-1}) after the experiment.

The highest net income (₹ 72720 ha^{-1}) was obtained from foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) with a BCR of 2.28. It was followed by soil application of $ZnSO_4$ @ 5 kg ha^{-1}(T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) with a net income of ₹ 67131 ha^{-1} and ₹ 60354 ha^{-1} respectively which recorded BCR of 2.22 and 2.07. The lowest net income (₹ 29266 ha^{-1}) was realized from the control (T_{12}) with a BCR of 1.53.

From the present study, it can be concluded that soil application of $ZnSO_4$ @ 5 kg ha^{-1} or soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} or foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 days after emergence along with the recommended dose of FYM @ 2 t ha^{-1}, N: P_2O_5: K_2O @ 10:75:75

kg ha^{-1} (as basal) and lime 1.5 t ha^{-1} (at flowering) can be recommended for better growth, yield, quality and profitability of groundnut in the *Onattukara* sandy plain.

Future Line of Work

- To study effect of Zn and B nutrition in groundnut on succeeding crop of rice
- To study the nutrient interactions with different sources of fertilizers

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Appendices

APPENDIX- I

Standard week	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum	
51	32.9	22.9	88.0	70.4	3.6
52	32.6	22.9	90.3	77.5	4
1	32.3	21.6	76.1	58.9	0
2	33.1	19.0	78.0	57.6	0
3	33.4	19.3	76.4	54.3	0
4	33.4	18.7	84.3	57.3	0
5	33.3	17.4	73.0	58.4	0
6	35.0	17.9	80.0	62.0	0
7	33.3	19.5	79.7	60.8	0
8	35.9	18.3	81.1	56.0	0
9	33.1	18.9	84.6	67.0	4.8
10	35.7	18.3	81.0	65.7	0
11	33.9	18.3	76.6	66.4	0
12	36.0	19.0	79.3	64.3	0
13	36.0	20.4	83.4	64.4	0
14	35.9	20.4	72.0	62.9	8

Weather data during the crop period (December 2018 to April 2019)

ZINC AND BORON NUTRITION IN GROUNDNUT (*Arachis hypogaea* L.) FOR *ONATTUKARA* SANDY PLAIN

by

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ABSTRACT

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ABSTRACT

A field experiment on "Zinc and boron nutrition in groundnut (*Arachis hypogaea* L.) for *Onattukara* sandy plain" was undertaken during 2017-19 to evaluate the effect of zinc and boron nutrition on growth, yield and quality of groundnut (*Arachis hypogaea* L.) in the summer rice fallows of *Onattukara* and to work out the economics of cultivation. The experiment was conducted during December 2018 to April 2019 in farmer's field at *Onattukara* region of Alappuzha district.

The experiment was laid out in randomized block design with 12 treatments replicated thrice. The treatments were T_1 - soil application of Zn @ 5 kg ha^{-1} as $ZnSO_4$; T_2 - soil application of Zn @ 5 kg ha^{-1} as Zn-EDTA ; T_3 - soil application of B @ 1 kg ha^{-1} as borax ; T_4 - soil application of Zn @ 2.5 kg ha^{-1} as $ZnSO_4$ + B @ 0.5 kg ha^{-1} as borax ; T_5 - foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 days after emergence (DAE), T_6 - foliar application of 0.5 per cent borax at 30, 45 and 60 DAE; T_7 - foliar application of 0.25 per cent $ZnSO_4$ + 0.25 per cent borax at 30, 45 and 60 DAE; T_8 - seed treatment with $ZnSO_4$ (250 mg kg^{-1}); T_9 - seed treatment with borax (100 mg kg^{-1}); T_{10} - seed treatment with $ZnSO_4$ (250 mg kg^{1}) + borax (100 mg kg^{-1}); T_{11} - soil test based recommendation and T_{12} - control. FYM @ 2 t ha^{-1}, N: P_2O_5: K_2O @ 10:75:75 kg ha^{-1} (as basal) and lime 1.5 t ha^{-1} (at flowering) were applied uniformly to all treatments. The bunch type groundnut variety, CO 7 was sown at a spacing of 15 cm x 15 cm.

The growth attributes of groundnut were recorded at 30, 45, 60 DAE and at harvest. Among the treatments, foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5), soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) recorded significantly higher growth parameters *viz*., plant height, number of branches, leaf area and number of nodules per plant. At all stages of growth, soil application treatments recorded more number of nodules. The physiological parameters such as CGR, NAR, LAI, and LAD recorded during 15 to 30 and 30

to 45 DAS, also varied with Zn and B nutrition. Higher CGR values were obtained with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and was on par with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5). During 30 to 45 DAS, NAR was found to be significant and recorded higher values in all treatments except seed treatment. Leaf area index, LAI and LAD were higher with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and was comparable with $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) during 15 to 30 DAS and 30 to 45 DAS.

The results revealed that yield parameters *viz*., number of pods per plant, 100 kernel weight and shelling percentage varied significantly with the treatments. Number of pods per plant was higher with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was on par with T_{11}, T_4, T_7 and T_1. Shelling percentage (70.75 %) was higher with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and was on par with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5).

Kernel yield was significantly higher (1523 kg ha^{-1}) with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was on par with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4). Haulm yield (3978 kg ha^{-1}) was higher with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and was comparable with all treatments except T_9 and T_{10}.

Protein content of seed (23.2 %) was higher with soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and was on par with all treatments except T_2, T_9 and T_{12}. Oil content (49.38 %) and oil yield (752.2 kg ha^{-1}) were higher with foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) and was comparable with soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1) and soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4).

Higher uptake of N, S and Zn were observed with T_1, T_4 and T_5. The results on soil nutrient status after the experiment indicated that there was a build up of available N, K, B and Zn status after the experiment and the soil nutrient status of zinc and boron were higher with soil application treatments.

The results revealed that soil application of $ZnSO_4$ @ 5 kg ha^{-1} (T_1), soil application of $ZnSO_4$ @ 2.5 kg ha^{-1} + borax @ 0.5 kg ha^{-1} (T_4) and foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 DAE (T_5) recorded higher net income and benefit - cost ratio.

From the present study, it can be concluded that soil application of Zn @ 5 kg ha^{-1} as $ZnSO_4$ or soil application of Zn @ 2.5 kg ha^{-1} as $ZnSO_4$ + B @ 0.5 kg ha^{-1} as borax or foliar application of 0.5 per cent $ZnSO_4$ at 30, 45 and 60 days after emergence along with the recommended dose of FYM @ 2 t ha^{-1}, N: P_2O_5: K_2O @ 10:75:75 kg ha^{-1} (as basal) and lime 1.5 t ha^{-1} (at flowering) can be recommended for better growth, yield, quality and profitability of groundnut in the *Onattukara* sandy plain.

സംഗ്രഹം

ഓണാട്ടുകര മണൽ പ്രദേശത്തെ നിലക്കടലയിലെ സിങ്ക്, ബോറോൺ എന്നീ സൂക്ഷ്മ മൂലകങ്ങളുടെ പോഷണം എന്ന പരീക്ഷണ വിഷയത്തെ ആസ്പദമാക്കി ഒരു ഗവേഷണ പഠനം 2017 - 19 കാലഘട്ടത്തിൽ വെള്ളായണി കാർഷിക കോളേജിലും ഓണാട്ടുകര വേനൽക്കാല തരിശുനിലത്തിലുമായി നടത്തുകയുണ്ടായി. ഓണാട്ടുകര വേനൽക്കാല തരിശുനിലത്തെ നിലക്കടലയുടെ വളർച്ചയിലും വിളവിലും ഗുണത്തിലും സിങ്ക്, ബോറോൺ എന്നീ സൂക്ഷ്മ മൂലകങ്ങളുടെ സ്വാധീനം മനസ്സിലാക്കുക, വരവ് ചെലവ് കണക്കാക്കുക എന്നിവയായിരുന്നു ഗവേഷണത്തിന്റെ പ്രധാന ലക്ഷ്യങ്ങൾ.

റാൻഡമൈസ്സ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന രീതിയാണ് വിള പരീക്ഷണത്തിനായി അവലംബിച്ചത്. സിങ്കും ബോറോണും മണ്ണിലും, ഇലകൾ നനച്ചു നൽകിയും വിത്ത് പരിചരണമായും വിവിധ സംയോജനരീതിയിൽ നൽകിയാണ് പരീക്ഷണം നടത്തിയത് .

ഈ പരീക്ഷണത്തിൽ നിന്നും ഓണാട്ടുകരയിലെ മണൽ പ്രദേശത്തെ വേനൽക്കാല നിലക്കടല കൃഷിക്ക് ശുപാർശ ചെയ്യപ്പെട്ട വളങ്ങൾ (അടിവളമായിചാണകം @ 2 t/ha , N : P : K @ 10 :75 :75 kg/ha + പൂവിടുന്ന സമയത്തു കുമ്മായം @ 1.5 t/ha) നൽകുന്നത് കൂടാതെ സൂക്ഷ്മ മൂലകങ്ങളായ സിങ്ക്, മണ്ണിൽ കൂടി 5 കിലോഗ്രാം സിങ്ക് സൽഫേറ്റുമായി ചേർക്കുകയോ സംയോജിതമായി 2.5 കിലോഗ്രാം സിങ്ക് സൽഫേറ്റും 0.5 കിലോഗ്രാം ബൊറാക്സും നൽകുകയോ ഇല്ലെങ്കിൽ ഇലകൾ വഴി അര ശതമാനം സിങ്ക് സൽഫേറ്റ് സ്പ്രേ ആയി വിത്ത് മുളച്ചു 30 , 45 , 60 ദിവസങ്ങൾക്കുള്ളിൽ നൽകുകയോ ചെയ്യുന്നത് കപ്പലണ്ടിയുടെ വളർച്ചയും മികച്ച വിളവിനും ഗുണമേന്മക്കും ലാഭകരമായ കൃഷിക്കും സഹായിക്കുന്നതാണ്.