PERFORMANCE EVALUATION OF RICE VARIETIES AND THEIR RESPONSE TO ZINC NUTRITION IN UPLANDS.

by

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(2018-11-076)

THESIS

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COLLEGE OF AGRICULTURE

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2020

DECLARATION

I, hereby declare that this thesis entitled **"PERFORMANCE EVALUATION OF RICE VARIETIES AND THEIR RESPONSE TO ZINC NUTRITION IN UPLANDS."** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani

Date:

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Certified that this thesis entitled **"PERFORMANCE EVALUATION OF RICE VARIETIES AND THEIR RESPONSE TO ZINC NUTRITION IN UPLANDS"** is a record of research work done independently by Miss Ramya Chandra C under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Date: 30-09-2020

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LIST OF ABBREVIATIONS

B: C ratio	:	Benefit cost ratio
CO_2:		Carbon di oxide
CD (0.05)	:	Critical difference at 5 % level
CGR	:	Crop Growth Rate
cm	:	Centimetre
cm^2	:	Square centimeter
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	:	Farm yard manure
g	:	Gram
ha^{-1}	:	Per hectare
IAA	:	Indole Acetic Acid
K	:	Potassium
KAU	:	Kerala Agricultural University
kg	:	Kilogram
kg ha^{-1}	:	Kilogram per hectare
LAI	:	Leaf area index
m	:	Meter
N	:	Nitrogen
NS	:	Not significant
OC	:	Organic carbon
P	:	Phosphorus
pH	:	Potenz hydrogen

POP	:	Package of practices
RBD	:	Randomized Block Design
Zn	:	Zinc

LIST OF SYMBOLS

%	:	Per cent
@	:	at the rate of
ºC	:	Degree Celsius
□	:	Rupee

INTRODUCTION

1 INTRODUCTION

Rice (*Oryza sativa* L.) is the world's second most important cereal crop and it is the staple food of 50 per cent of world population. With the growing population the demand for rice is also escalating. To fulfil this demand the production from the existing rice growing regions should be increased. But the main constraining factor in rice production is the water demand of the crop, as water scarcity is building up in all areas. The water scarcity is threatening the sustainability of rice production. So, deviation from the traditional rice cultivation method is inevitable. One of the methods that can be adopted is the upland rice cultivation.

Upland rice crop is grown in un bunded, un flooded fields, in which field conditions are a bit different. The soil condition prevailing in the root zone will be aerobic throughout the growing season. But there are many constraints associated with this cultivation method like low productivity, susceptibility to pest and diseases, prone to drought and lack of suitable varieties. When the yield stability of the upland varieties was compared, it was found that the individual yield components was more influenced by the environmental factors than the genetic factors (Shrestha *et al.,* 2012). Developing new varieties through breeding program should be done by understanding about genetic variability of yield contributing traits, interrelationship among them and their relation with yield (Singh *et al.,* 2013). Constrains in upland rice cultivation are increased cost of production due to crop weed competition, lower yield of available genotypes, increased labour scarcity, drought condition and lack of high yielding variety (Poudel *et al.,* 2014).While adopting upland rice cultivation selection of variety is a very critical step. The selection of variety should be based on how much the variety is genetically advanced and also adaptation of the variety to the environment is also important, as it was observed that the environment is having a bigger hand in final yield.

Zinc (Zn) is one of the important micronutrients among the 17 essential nutrients. Zinc is inevitable for the normal growth and establishment of crop plants. It is found to be associated with many metallo-enzymes which are even involved in the synthesis of nucleic acids, hormones and their receptors. It is also involved in regulation of several biological and physiological process of the plant. Deficiency of this metal ion is a major problem faced by agriculture which is a regrettable fact. Das and Green (2013) have reported that 50 per cent of the cereal cultivating soils are Zn deficient and it affects the growth and development of crop plants. Deficiency of Zn can lead to total crop failure also.

Zinc is involved in hormone regulations and synthesis of tryptophan and Indole Acetic Acid (IAA) a growth hormone. It is also involved in the repairing of photosystem II during photorespiration and also helps in maintaining the CO_2 in the mesophyll cells (Hansch and Mendel, 2009). Hence, Zn has a role in production of growth hormones in the plant and it is also involved in the photosynthesis of the plant. Application of Zn will be beneficial in many ways like improved production of growth hormones and improved photosynthetic activity. Zinc influences most of the growth and yield attributing characters. Also, Zn improves the uptake of other nutrients by improving the root characteristics (Fageria and Moreira, 2015).

The effect of Zn on crop plant varies with the method of application also. It was found that foliar application improved the Zn content in grains, seed priming helped in early establishment of the crop, both foliar application and soil application was found effective in improving the yield (Nadim *et al.*, 2012). Selection of suitable Zn source and method of application will lead to favorable results.

With this background present study was conducted with the following objectives:

To find out a suitable rice variety for uplands in red loam tracts of Kerala and to standardize the dose and method of zinc application.

REVIEW OF LITERATURE

2 REVIEW OF LITERATURE

The experiment entitled "Performance evaluation of rice varieties and their response to zinc nutrition in uplands" was undertaken to find out a suitable variety and the best method of zinc sulphate application in the red loam tracts of Kerala. The literature pertaining to the subject are reviewed here.

2.1. EFFECT OF VARIETIES ON GROWTH AND PHYSIOLOGICAL CHARACTERS OF RICE

The growth character of rice is influenced by genetic makeup, environmental condition and the interaction. Studies have reported that the varieties with advanced genetic makeup have always outperformed the other varieties in terms of growth characters, yield characters, its adaptability and also recorded better yield. Main (2006) have reported that the total dry matter produced was more in hybrid varieties than the inbred varieties. In a study conducted by Alam *et al.* (2009a) on the growth pattern of three high yielding varieties revealed that the characters *viz*., plant height, total dry matter, crop growth rate (CGR) and relative growth rate (RGR) were differed with due to the difference in genetic makeup.

Higher grain yield recorded in rice hybrids might be due to its vigorous and extensive root system (Yang and Sun, 1989), pronounced translocation of carbohydrate from vegetative plant parts to the spikelets (Song *et al.,* 1990), more efficient sink formation and greater sink size during the reproductive stage (Kabaki,1993), increased crop growth rate during early growth stages (Yamauchi,1994), and larger leaf area index (LAI)(Peng*et al.,* 1998). Likewise, Zayed *et al.* (2007) have also reported the better performance of hybrid varieties compared to the inbred varieties. The study also reported that the hybrid varieties have high seedling vigor, faster growth and high efficiency of photosynthesis and metabolic activities. In a study conducted by Sultana *et al.* (2020),it was found that the number of tillers m^{-2}varied with the varieties.

The physiological parameters like relative water content, stomatal conductance and photosynthetic rate varied with the varieties (Zinzala *et al.,* 2019).

2.2 EFFECT OF VARIETIES ON YIELD PARAMETERS AND YIELD

The yield and the yield attributing characters were also found to affected by the varietal character of rice and environmental conditions. Here also the genetic advancement has an important hand in the final yield of the crop. In a study conducted by Karim *et al.* (2007) observed that number of panicles per hill was found to be highly influenced by environment rather than the genetic factor. Likewise, the characters like filled grains per panicle, number of primary branches per panicle, sterility percentage were also found to be influenced by both environmental conditions and genetic character of the variety. They have also observed that the thousand grain weight was solely influenced by the genetic trait of the variety and was less influenced by the environmental conditions.

However, the harvest index was mainly influenced by the genetic character of the crop (Iftekharuddaula *et al.,* 2001).

Panicle characteristics like panicle length and panicle weight was found to be influenced by genetic character of the variety (Lestari *et al.,* 2015). Hence, genetic character as well as environmental conditions would influence the yield attributing characters which in turn would affect the final yield of the crop.

Yoshida *et al.* (2006) have reported that the newly developed varieties produce greater yield than those of earlier developed varieties. The increased sink capacity was due to larger grain size and larger number of spikelets per panicle Yoshinaga *et al.* (2013) have also revealed that the sink developing capacity and the sink filling capacity was more with high yielding varieties and among them the variety with better genetic advancement performed well in that parameter.

2.3 EFFECT OF VARIETIES ON NUTRIENT UPTAKE

The uptake of nutrients influenced the growth and yield of the crop. The uptake of nutrients and their concentration of nutrients in plant was also influenced by the genetic characters. Sun *et al.* 2014 have reported that in Nuptake and its use efficiency in rice is genetically varied but when it comes to P and K uptake it is less known (Mayamulla *et al.,* 2017). Suriyagoda *et al.* (2019) have reported that nutrient uptake by rice varieties varied with their duration of growth. Among the age class the short duration variety recorded lower nutrient uptake compared to others. The study also revealed that the K accumulation rate was more for high yielding rice varieties. It was also observed that with lower dry matter production the uptake of nutrients was also less.

Islam *et al.*(2008) have also reported that the P uptake was less affected by varieties and the phosphorus concentration in grain was higher at harvest stage. But the N and K concentration were found to be affected by the inherent capacity of the variety.

2.4 EFFECT OF ZINC ON GROWTH AND PHYSIOLOGICAL CHARACTERS OF RICE

Studies conducted by Boonchauy *et al.* (2013) revealed that Zn application have influenced the establishment of rice seedling. It was also observed that high Zn content of seed has improved the seedling growth and development although the effect diminished in later stage.

Rahman *et al.* (2008) observed that Zn application improved the height in Boro rice. The experimental findings of Islam (2015) showed that the plant height of Aman rice was influenced by the application of different level of Zinc. The effect was observed in the treatment, application of Zn @ 3 kg ha^{-1}. Ghoneim (2016) also found that the plant height was improvedwith Zn application and thetallest plant was observed in application of Zn @ 15 Kg ha^{-1}.

In a study conducted by Fageria (1992) reported that Zn influences the root growth of upland rice varieties grown in nutrient solution. The application of Zn has improved leaf area which have improved the photosynthetic activity. Likewise, Fageria *et al.* (2002) reported that Zn applied @ 20mg Znkg^{-1} of soil noted a significant increase in dry weight of roots of upland rice. Improved photosynthetic activity increased the dry matter production (Nadim *et al.*, 2012). It was also found that the element Zn influenced indole acetic acid (IAA) production, as the element is involved in different physiological processes such as hormone regulation.

Zinc is involved in the production of tryptophan the precursor of IAA (Lin *et al.,* 2005). The improved production of IAA has improved the growth characters. In a study conducted by Fageria and Moreira (2015) observed that the application of Zn has improved the root dry weight of upland rice varieties. It was also noticed that the application of Zn has improved the root growth which has improved the nutrient uptake by the crop. The tillers m^{-2}were also found to be affected by application of Zn and the reason behind it partly due to better nutrient uptake and partly due to improved production of growth hormones like IAA as reported by Ghoneim (2016). Studies have revealed that the application of Zn have influenced the chlorophyll content, crop growth rate, stomatal conductance, proline content and soluble protein content.

Aravind and Prasad (2004) have reported that the application of Zn has improved the chlorophyll content, because of its involvement in chlorophyll production through its regulating action on nutrients homeostasis in cytoplasm. Zinc is also involved in the repair process of PS II complex during photoinhibition and they are found to be involved in maintaining the level of CO_2concentration in mesophyll cells (Hansch andMendel, 2009).

The stomatal conductance was also found to be improved with the application of Zn, as Zn influences the activitiesof carbonic anhydrase and ribulose 1-5-bisphosphate carboxylase/oxygenase (Rubisco). Rubisco is necessary forcatalysing the diffusion of CO_2 through cell by surpassing all barriers to reach the chloroplasts (Hatch and Slack, 1970).

2.5 EFFECT OF ZINC ON YIELD COMPONENTS AND YIELD

Parameters like productive tillers per plant, panicles per meter square, 1000 grain weight, number of filled grains and number of grains per panicle are important yield determining factors in rice. In a study conducted by Arif *et al.* (2012) observed that the tillers per plant was enhanced by the supply of Zn @ of 6 kg per acre as compared to the control from 7.49 to 12.16 per plant.

Rehman *et al.*(2011) also found significant effect on tillers per plant with zinc application, the highest number of tillers per hill (11.16) was recorded when Zn was applied @ 20 kg ha^{-1}(9.40). Zinc applied @ 20 kg ha^{-1} recorded the highest panicle length (23.73 cm) and grains per panicle(197.44) and the lowest was recorded in control (Rehman *et al.*,2011). Applying zinc sulphate @ 15 kg ha $^{-1}$improves the tillering capacity of rice crop (Ghoneim, 2016).

The grain yield and straw yield increased up to 38.27 and 31.79 per cent, respectively when Zn was applied @ 6 kg per acre. Gupta and Potalia (1991) found that Zn application improvedthe grain and straw yield of rice.

2.6 EFFECT OF ZINC APPLICATION ON NUTRIENT UPTAKE

Studies conducted by Rana and Kashif (2014) revealed that the application of Zn improved the uptake of N and K.

Takkar *et al.* (1976) reported a negative correlation between grain yield and P/Zn ratio in the soil. The study suggested that checking P induced Zn deficiency is easier by monitoring the P/Zn ratios in the soil rather than going for available phosphorus alone. The total uptake of all nutrients *viz*, N, P and K was found to be significantly affected by the method of application of Zn (Ghoneim, 2016). It was also observed that N uptake was higher with zinc applied through root soaking, P uptake in control (no Zn) and the K in all methods of Zn application than control.

Application of Zn have improved the Zn uptake by the plant. Maximum uptake was recorded with Zn-EDTA (Rana and Kashif, 2014) and among the method of application, foliar application was more effective in terms of Zn content in the crop plants, but the time of application of foliar spray has a crucial role in increasing the Zn content (Ghoneim, 2016).

2.7 EFFECT OF METHOD OF APPLICATION OF ZINC ON THE GROWTH AND YIELD OF RICE

2.7.1 Effect of Seed Priming with Zinc on Rice

In a seed priming study conducted by Prom-u-thai*et al.* (2012) observed that seed priming had significantly improved the germinationrate,root length and coleoptile length. The germination percentage was higher in seeds primed with 2.5 mM Zn and was significantly higher (54–89%) to seeds without priming. Likewise,root and coleoptile growth were also higher in seed priming with 2.5 mM Zn.Foliar application of Zn at assorted growth stages and frequency had a significant effect on Zn concentration of the rice seed but it had no effect on grain yield and yield components. Rameshraddy *et al.* (2017) have observed that seeds treated with ZnO nano particles had shown improved seedling vigour index in rice. The seeds treated with ZnO @ 1000 ppm recorded an increasedroot length, shoot length recorded an increase of 34.88 per centand 45.54 per cent increase in seedling vigor index compared to control.

Slaton *et al.*(2001) have observed that Zn seed treatment improved the DMP and seeds treated with $ZnSO_4$have shown better germination rate.Seed priming is one of the best methods of applyingmicronutrients, because the seeds easily absorbed the nutrients which improved the seedling vigor and growth (Sarwar *et al*., 2017) and cost-effective also.

2.7.2 Effect of Foliar Application of Zinc on Rice

Foliar application of Zn at various growth stages and frequencies had a significant effect on Zn concentration of the rice seed but it had no effect on grain yield and yield components. A study conducted by Boonchuay *et al*. (2013) revealed that scheduling of foliar application of Zn is an inevitable factor in increasingthecontent of Zn in grain. The Zn concentration in paddy rice was maximum with foliar application of Zn at four stages (panicle initiation, booting, 1 and 2 weeks after flowering).The study has also shown that foliar application of Zn after flowering is effective in raising the zinc concentration in seeds. Seeds with high Zn concentration have both agronomic and nutritional benefits (Boonchuay *et al.,* 2013).

Haslett *et al.*(2001) have reported that foliar application of Znbrought easiness in absorptionand transportation of Zn through phloem in wheat. In paddy, xylem transport of Zn is crucial than the re-translocation of Zn from the leaves for its accumulation in rice grain(Palmgren *et al.,* 2008).

Zinc is transported to seeds after the flowering stage, and it is because of improved synthesis of protein during the early stage of seed formation (Ozturk *et al*., 2006).

In case of foliar Zn application, Zn- EDTA applied @ 1 kg ha^{-1} produced significantly higher number of tillers m^{-2}(131) and it was supported by Ghani *et al.* (1990).Shoot dry weight became two-fold by foliar Zn application at 0.5mg Zn $kg^{-1}$of seed but root dry weight did not respond to foliar application. Guo *et al.* (2016) have concluded in his study that foliar application of Zn is the best method to improve the seed Zn content. Phuphong *et al.* (2020) also found that shoot dry weight was improved with foliar application.

2.7.3 Effect of Seed Priming and Foliar Application of Zn on Rice

In a study conducted by Sarwar *et al.* (2017) revealed that among the different methods of Zn fertilization, seed priming + foliar application recorded the tallest plants. Shortest plants were recorded in control treatment.Similarly, productive tillers, panicle length, 1000 grain weight and grain yield were recorded the highest in seed priming + foliar application. Seeds which receivedfoliar application had the highest Zn concentration in rice cultivars.

Ease of absorption of Zn in foliar applicationzinc and their translocation to different parts have led to grain enrichment (Boonchuay *et al.,* 2013). Crops like maize also recorded maximum grain and biological yield in the treatment seed priming (2 %) followed by foliar application (2 %) (Mohsin *et al.,* 2014).

Higher yield due to Zn fertilization can also be due to enhanced synthesis and transport of carbohydrates to the site of grain production (Pedda- Babu*et al.,* 2007). Sarwar *et al*. (2017) reported that the Zn requirement of plant after germination can be supplied through foliar applied Zn at critical growth stages of the crop which would finally improves the yield of the crop.

2.7. 4 Effect of Soil Application of Zinc on Rice

Rana and Kashif (2014) conducted a study with different sources and methods of application of zinc fertilizer on rice yield reveled that the highest paddy yield ha^{-1} was recorded in treatment with soil application of Zn-EDTA @ 10 kg ha $^{-1}$(2.78 t ha^{-1}). Soil applied zinc enhanced the rice grain yield while comparing to foliar spray (Guo *et al*., 2016). It was also observed that the average increase in grain yield due to soil application of Zn ranged from 2.1 to 10.2 per cent compared to control and increase in grain yield due to foliar application was 0.2 to 4.0 per cent. Kulhare *et al*. (2016) reported that soil application of zinc @ 20 kg Zn ha^{-1} as basal along with foliar spray influenced grain yield and Zn uptake positively (Kulhare *et al*., 2017).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The research entitled "Performance evaluation of rice varieties and their response to zinc nutrition in uplands" was conducted during May to August (2019) at Coconut Research Station, Balaramapuram, Kerala, India. The main objectives of the experiment were to find out a suitable rice variety for uplands in red loam tracts of Kerala and to standardise the dose and method of zinc application.

3.1 GENERAL DETAILS

3.1.1 Location

The experiment was conducted at Coconut Research Station (CRS), Balaramapuram, Kerala, India located at 8^o 22' 52'' North latitude and 77^o 1' 47'' East longitude at an altitude of 9m above MSL.

3.1.2 Climate

The weather parameters like mean temperature, relative humidity (RH), rainfall and evaporation were recorded during the cropping period. The data were collected from the Agromet observatory at CRS, Balaramapuram. The weather parameters from 14/05/2019 to 26/08/2019 were recorded and presented in the graph (Fig. 1).

3.1.3 Cropping season

The field experiment was conducted during May to August 2019.

3.1.4 Soil

Prior to the conduct of experiment, a composite soil sample was taken for initial analysis. The soil of the experiment site is red sandy loam, acidic in reaction, medium in organic carbon content, low in available nitrogen content, high in available phosphorus content, medium in available potassium content and deficient in available zinc content. The physicochemical properties are presented in Table 1.

3.1.5 Cropping History of the Field

The crop was raised as an intercrop in coconut planted at a spacing of 7.6 m × 7.6 m.

Table 1. Physicochemical properties of soil before experiment

Sl no.	Fractions	Content in soil, per cent	Method
1	Sand	65.44	Bouyoucous hydrometer method (Bouyoucous, 1962)
2	Silt	19.22	
3	Clay	15.10	

B. Chemical Properties

Sl no.	Parameters	Content	Method
1	Soil reaction	4.5(Very Strongly Acidic)	pH meter (1:2:5 soil water ratio) (Jackson, 1973)
2	EC, (dSm^{-1})	0.1 (Normal)	Conductivity meter (1:2:5 soil water ratio) (Jackson, 1973)
3	Organic carbon, (%)	0.786 (Medium)	Walkley and Black rapid titration method (Walkley and Black, 1934)
4	Available N (kg ha^{-1})	225.3 (Low)	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg ha^{-1})	38.17 (High)	Bray colorimetric method (Jackson, 1973)
6	Available K (kg ha^{-1})	136.28 (Medium)	Ammonium acetate method (Jackson, 1973)
7	Available Zn (mg kg^{-}	0.65 (deficient)	HCl extraction and Atomic

	[1])		Absorption Spectrophotometry (Lindsay and Norwell, 1978)

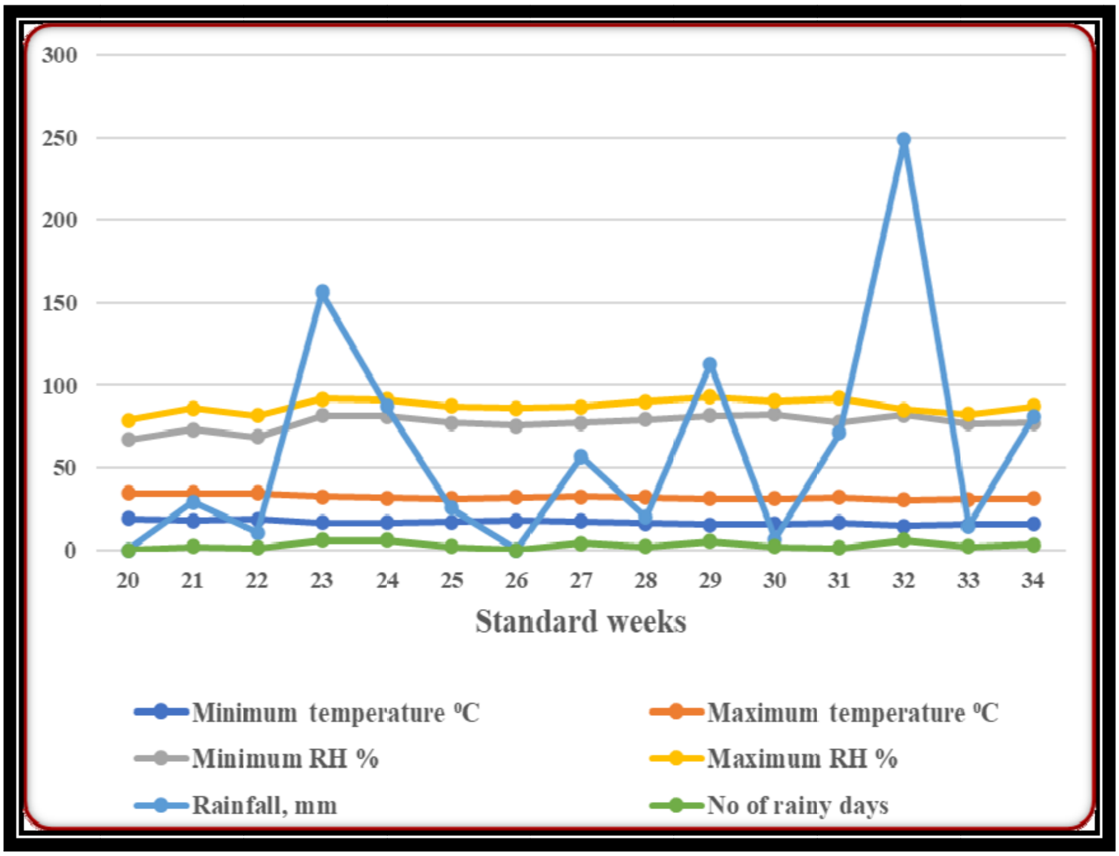


Fig 1. Weather data during the crop season (14/05/2019 to 26/08/2019)

3.2 MATERIALS

3.2.1 Crop Variety

Three rice varieties were selected for the experiment.

1. Anna 4 (PMK 4): a short duration variety (100-105 days) having white, long and slender grains, released from Agriculture Research Station, Paramakudi, Tamil Nadu, Agricultural University.
2. APO 1: a short duration variety (105-110) having white slender grains, released from International Rice Research Institute, Phillipines.
3. Prathyasa (MO 21): a short duration variety (100 – 110 days) having red, long bold grains released from Rice Research Station, Mancompu, Kerala Agricutural University.

3.2.2 Source of Seed:

The seeds required for experiment were procured from:

1. Anna 4 – Agriculture Research Station, Paramakudi, Tamil Nadu, India.
2. APO 1 - Agriculture Research Station, Paramakudi, Tamil Nadu, India.
3. Prathyasa – Rice Research Station, Mancompu, Kerala, India.

3.2.3 Manures and Fertilizers

Dried cow dung (0.45 per cent N, 0.17 per cent P_2O_5 and 0.5 per cent K_2O content) was used. Source of NPK for the experiment were Urea (46 per cent N), Rajphos (20 per cent P_2O_5) and Muriate of potash (60 per cent K_2O) respectively. Solufert (21 per cent Zn; $ZnSO_4$. $7H_2O$) was used as source of Zinc.

3.3 METHODS

3.3.1 Design and layout

Design : Factorial RBD

Treatments : 15

Replications : 3

Season : *Kharif* 2019

Spacing : 20 cm × 10 cm

Gross plot size : 3.6 m × 3.2 m

Net plot size : 3.1 m × 2.7 m

Total number of plots: 45

3.3.2 Treatment details

1. Factor A: Variety (V) – 3

   V_1: Anna 4

   V_2: APO 1

   V_3: Prathyasa

2. Factor B: $ZnSO_4$ Application (S) – 5

   S_1: Seed priming with $ZnSO_4$ @ 2g kg^{-1} seed

   S_2: Foliar application with $ZnSO_4$ @ 0.5 percent at active tillering stage and panicle initiation stage

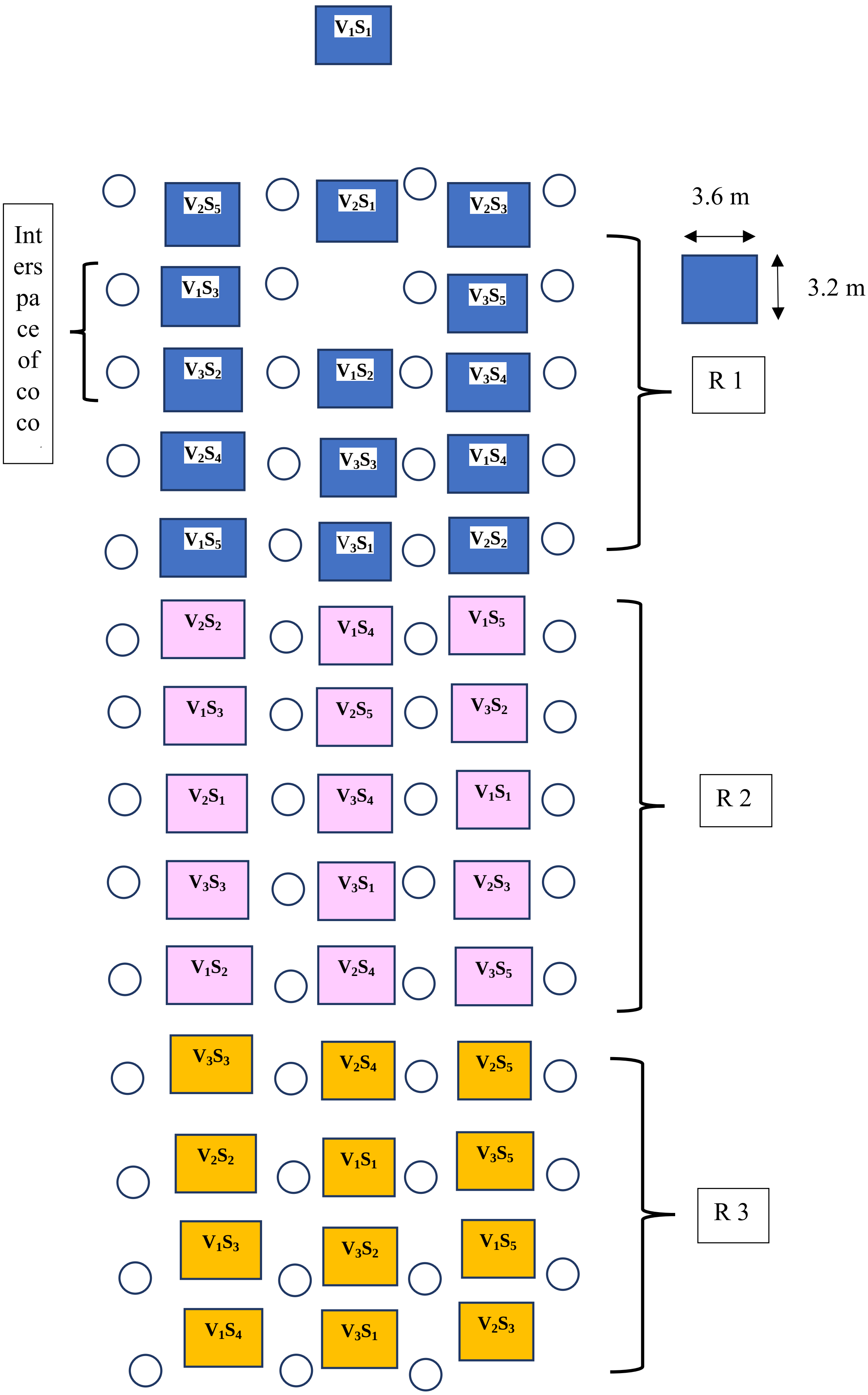
   S_3: $S_1 + S_2$

   S_4: Soil application of $ZnSO_4$ @ 20 kg ha^{-1}

   S_5: Control

Treatment combination:

V_1S_1	V_1S_2	V_1S_3	V_1S_4	V_1S_5
V_2S_1	V_2S_2	V_2S_3	V_2S_4	V_2S_5
V_3S_1	V_3S_2	V_3S_3	V_3S_4	V_3S_5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V2S5
V3S2
V2S1
V3S4
V1S1
R 2
V3S3
V3S1
V2S3
V1S2
V2S4
V3S5
V3S3
V2S4
V2S5
V2S2
V1S1
V3S5
V1S3
V3S2
V1S5
R 3
V1S4
V3S1
V2S3

Fig.2 Layout of experiment

3.3.3 Field preparation and Lay out

The experimental area was ploughed and brought to fine tilth using power tiller. The experimental area was divided into plots of 3.6 m × 3.2 m as per lay out plan.

3.3.4 Application of Lime

Lime was applied @ 600 kg ha $^{-1}$. It was applied in two splits.First dose during first ploughing (350 kg ha^{-1} lime) as basal dressing and the second dose after a month of sowing(250 kg ha^{-1} lime) as top dressing.

3.3.5 Seeds and Sowing

Paddy seeds were dibbled at a spacing of 20 cm × 10 cm on 28/5/2019.For seed priming treatments, seeds were soaked in zinc sulphate solution ($ZnSO_4$ @ 2g kg $^{-1}$) for 16h, washed in clean water and dried to original moisture content (14 per cent). The seed rate adopted was 80 kg ha $^{-1}$.

3.3.6 Application of Manures and Fertilisers

Dried cow dung was applied to all plots @ 5 t ha $^{-1}$ uniformly before sowing. Fertiliser dose adopted was NPK @ 90:30:45 kg per ha standardised by Suman (2018), for the experiment location. Nitrogen was applied in three equal splits as basal application, at tillering and panicle initiating stage.Potassium in two equal splits as basal application and at panicle initiation stage. Phosphorus was applied as basal. Application of $ZnSO_4$was done as per the treatments.

3.3.7 Water Management

The crop was raised as rainfed crop. Irrigation was given when there was absence of rain to raise the moisture level to field capacity.

3.3.8 Weed Management

Almix 20WP(chlorimuron ethyl 10% + metsulfuron methyl 10%@ 4g ha^{-1}was applied 15 DAS for controlling weeds. During 45 DAS and 60 DAS the field was hand weeded.

3.3.9 Plant Protection

Quinalphos was applied against leaf folder @ 1000 mL ha $^{-1}$ and to counter the attack of rice bug malathion was applied @ 1000 mL ha $^{-1}$.

3.3.10 Harvest

The crop was harvested on 22/ 08/2019. The net crop area, leaving the three border rows was harvested and sorted plot wise. They were threshed and winnowed. The grain and straw were sundried, weighedand expressed in kg ha $^{-1}$.

3.4 GROWTH COMPONENTS

3.4.1 Plant Height

Five plants were selected in an indiscriminate mannerfromtreatment net plotat 40, 60 and 80 DAS and the plant height were measured and average was worked out. The total length from base to leaf tip was recorded as plant height at 40 and 60 DAS and at 80 DAS up to panicle tip.

3.4.2 Tillers m^{-2}

Number of tillers was recorded in the net plot area by using quadrate of size 0.5 m × 0.5 m at 40, 60, and 80 DAS in each treatment plots. The number obtained was multiplied with four to obtain the tillers per m^{2}.

3.4.3 Leaf Area Index

Leaf length and breadth of third leaf from top were measured from five randomly selected plants at 40 and 60 DAS. Leaf area index was worked out using the formula suggested by Palanisamy and Gomez (1974).

Leaf area = K (L × B)

K = 0.75 (Yoshida *et al*.,1976)

L = Leaf length in cm

B = Maximum breadth of leaf in cm.

LAI was calculated using the formula:

$$\text{LAI} = \frac{\text{Total leaf area tiller}^{-1} \times \text{number of tillers m}^{-2}}{\text{Area occupied by tillers m}^{-2}}$$

3.4.4 Root Shoot Ratio

For calculating the root shoot ratio of the plant five plants were randomly selected and carefully pulled out outside the net plot area without damaging the root system during fifty per cent flowering stage. The plant samples were dried properly and the root was separated. Dry weight of shoot and root were recorded and the ratio was calculated was using the formula:

$$\text{Root Shoot ratio} = \frac{\text{Dry weight of root}}{\text{Dry weight of shoot}}$$

3.4.5 Dry Matter Production

At harvest stage, five hills were randomly pulled out from the sample row and were air dried. After air drying the samples were oven dried at 65 ± 5 °C to constant weight. The total Dry Matter Production DMP was enumerated and expressed in kg ha^{-1}.

3.5 PHYSIOLOGICAL PARAMETERS

3.5.1 Chlorophyll Content

Total chlorophyll content of the leaves was analysed at fifty per cent flowering by DMSO (dimethyl sulphoxide) method suggested by Yoshida *et al.* (1976). Expressed in (mg g^{-1}).

3.5.2 Crop Growth Rate

For calculating crop growth rate five plants were selected indiscriminately outside the net plot area and uprooted at 40, 60 and 80 DAS and computed the crop growth rate as suggested by Watson (1958).

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{A} \quad g\ m^{-2}\ day^{-2}$$

Where W_2 is weight of the crop at stage n_2 (g), W_1 is the weight of the crop at stage n_1 (g), t_2 is days after sowing at stage n_2, t_1 is days after sowing at stage n_1 and A is ground area.

3.5.3 Soluble Protein

Leaf samples were collected at 50 per cent flowering stage from randomly selected five plants and the analysis was carried out by the method suggested by Bradford (1976). It is based on the absorbance shift observed in acidic solution of dye Coomassie® Brilliant Blue G-250.

3.5.4 Proline Content

Proline content was determined using the method suggested by Bates *et al.* (1973). For this the leaves were collected at fifty per cent flowering for the analysis. The content was determined using the formula.

µmoles per gram tissue =[(µg proline/ml) x ml toluene)/115.5 µg/µmole] / [(g sample)/5]

3.5.5 Relative Water Content

The relative water content of the plant was determined using the formula suggested by Slatyer (1967).

$$\text{Relative Water Content}(\%) = \frac{\text{fresh weight} - \text{dry weight}}{\text{turgid weight} - \text{dry weight}} \times 100$$

3.5.6 Stomatal Conductance

Stomatal conductance was measured in the standing crop at fifty per cent flowering using porometer. The flag leaf is kept between the holder in the porometer and the stomatal conductance is measured by it and the expressed in mmol m^{-2} s^{-2}.

3.6 YIELD COMPONENTS

3.6.1 Days to Fifty Per Cent Flowering

Time taken for 50 per cent of the hills to reach flowering stage was recorded in terms of days.

3.6.2 Number of panicles m^{-2}

At harvest, productive tillers were countedby placing a quadrate of size 0.5 m × 0.5 m in the net plot area and average was calculated and expressed as no. m^{-2}.

3.6.3 Panicle Length

Panicle lengthwas measured from the point of scar to panicle tip by erratically selecting five plants from each treatment plot were collected. The average was arrived and expressed in cm.

3.6.4 Panicle Weight

For calculating panicle weight five panicles were selected erratically from the primary tillers in each treatment plot and the average selected panicles were calculated and expressed in g.

3.6.5 Number of Filled Grains Per Panicle

Grains in the five randomly selected panicles were separated and the filled grains was counted and average was arrived.

3.6.6 Sterility Percentage

Sterility percentage was calculated using the formula:

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

3.6.7 Thousand Grain Weight

From each net plot area 1000 grains were collected at random. The collected grains were dried properly and weighed and expressed in g.

3.6.8 Grain Yield

The grain harvested from the net plot area was dried properly under sun and the moisture was brought down to 14 per cent. After drying, grain weight was recorded and expressed in kg ha^{-1}.

3.6.9 Straw Yield

The straw harvested from each plot and dried under the sun. The weight of dried straw was recorded and expressed in kg ha^{-1}.

3.7 CHEMICAL ANALYSIS

3.7.1 Soil analysis

For initial soil analysis, soil samples were drawn from four random sites at a depth of 15 cm in the experimental site. The samples were shade dried and all the clod particles were ground and composite sample was obtained by quartering. After the harvest of crop composite sample was obtained from each experiment plot for the analysis of N, P, K and Zn.

3.7.1.1 Organic Carbon

The soil samples were sieved using 0.2 mm sieve and analysed for organic carbon using rapid titration method (Walkley and Black, 1934).

3.7.1.2 Available Nitrogen

Soil samples were analysed for available nitrogen using alkaline potassium permanganate method (Subbiah and Asija, 1956).

3.7.1.3 Available Phosphorus

Soil samples were analysed for available phosphorus using spectrophotometer by following the Dickman and Brays molybdenum blue method (Jackson, 1973).

3.7.1.4 Available Potassium

The available potassium content was determined by extraction with neutral normal ammonium acetate and estimated in flame photometer (Jackson, 1973).

3.7.1.5 Available Zinc

Soil samples were analysed for available zinc by extraction with HCl and estimated using atomic absorption spectrum (Lindsay and Norwell, 1978).

3.7.2 Plant Analysis

The plant samples were collected during the harvest stage. The collected samples were subjected for shade drying and then oven drying at a temperature of 65 ± 5 ^{o}C to constant weight. The dried samples were ground to fine powder,subjected to acid digestionand analysed N, P, K and Zn.

3.7.2.1 Total Nitrogen Content

Total nitrogen content was determined by modified microkjeldahl method (Jackson, 1973).

3.7.2.2 Total Phosphorus Content

For estimation of phosphorus sample was subjected to di acid digestion and the content was estimated using vanadomolybdate phosphoric yellow colour method (Jackson, 1973).

3.7.2.3 Total Potassium Content

Samples were subjected for di acid digestion and the potassium content was estimated using flame photometer (Jackson, 1973).

3.7.2.4 Total Zinc content

Total zinc content was determined using atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.8 ECONOMIC ANALYSIS

The economics was calculated based on the cost involved for cultivation and the prevailing market price of rice.

3.8.1 Net Income

Net income was computed using the formula

Net income (□ ha^{-1}) = Gross income – Cost of cultivation

3.8.2 Benefit Cost Ratio

Benefit cost ratio was computed by the formula

$$\text{B:C Ratio} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.9 PEST AND DISEASE INCIDENCE

Regular observations were made to check the pest and disease attack. Leaf folder and rice bug infestation were noticed during the period of study and appropriate control measures were taken to control infestation.

3.10 STATISTICAL ANALYSIS

The experimental data were analysed statically using Analysis of Variance technique for Randomised Block Design and the significance was tested using the F test.

Transformation was done for data which needed the same. Wherever significance was found, critical difference was calculated at five per cent probability level.

RESULTS

4.RESULTS

Field experiment was conducted during *Kharif* 2019 (May – August 2019) at Coconut Research Station, Balaramapuram. The objectives of the study were to find out a suitable rice variety for the upland rice cultivation in the red loam tracts of Kerala and to standardize the dose and method ofzinc application. The results of the study are presented in this chapter.

4.1 CROP GROWTH ATTRIBUTES

4.1.1 Plant height

Data pertaining to the effect of varieties, zinc sulphate application and their interaction on plant height at 40, 60 and 80 DAS are given in Table 2 and 3.

The varieties showed significant difference in plant height at 60 and 80 DAS, but the effect of varieties at 40 DAS was not significant. Among the varieties, APO 1 (V_2) recorded the tallest plants at 60 and 80 DAS and it was significantly superior to others. However, Anna 4 (V_1) recorded the shortest plant at 60 DAS and it was statistically comparable with V_3 (Prathyasa) and at 80 DAS the shortest plant was recorded in V_3 and it was statistically on par with V_1.

Interaction between variety and zinc sulphate application was found non-significant.

4.1.2 Tillers m^{-2}

Data related to the effect of varieties, zinc sulphate application and their interaction on tiller m^{-2} at 40, 60 and 80 DAS are presented in Table 4 and 5.

Tillers m^{-2} was significantly influenced by varieties at all the stages of observation. Results showed that the highest number of tillers $m^{-2}$was documented in Prathyasa (V_3) throughout the stages of observation. APO 1 (V_2) recorded the lowest number of tiller m^{-2} at 40 DAS and Anna 4 (V_1) at 60 and 80 DAS.

Effect of zinc sulphate application on tillers m^{-2} was significant only at 40 and 60 DAS. During 40 DAS S_4 (soil application of $ZnSO_4$ @ 20 kg ha^{-1}) recorded higher number of tillers $m^{-2}$and it was statistically comparable with S_3 (seed priming @ 2g kg^{-1} seed + foliar application @ 0.5 per cent during active tillering and panicle initiation stage). However, at 60 DAS the highest number of tillers m^{-2} wasdocumented in S_3 and it was statistically comparable with S_4. At both the stages the lowest number of tillers m^{-2} was recorded in S_5 (control).

Interaction between varieties and zinc sulphate application was found significant only at 80 DAS. The treatment combination V_3S_3recorded the highest number of tillers m^{-2} and it was statistically comparable with V_2S_4, V_3S_2, V_3S_1, V_2S_1 and V_2S_3.

Table 2. Effect of varieties and zinc sulphate application on plant height at 40, 60 and 80 DAS, cm.

Treatments	Plant height		
	40 DAS	60 DAS	80 DAS
Varieties (V)			
V_1	61.27	77.61	97.05
V_2	63.12	89.38	113.17
V_3	61.86	82.18	94.17
SE m (±)	0.85	1.59	2.07
C.D (0.05)	NS	4.637	6.045
Zinc sulphate application (S)			
S_1	61.12	83.80	99.81

S_2	60.46	83.91	100.67
S_3	63.68	85.37	105.32
S_4	63.17	80.12	100.98
S_5	61.98	82.08	100.53
SE m (±)	1.10	2.05	2.68
C D (0.05)	NS	NS	NS

NS – Not significant

Table 3. Interaction effect of varieties and zinc sulphate application on plant height at 40, 60 and 80 DAS, cm.

Treatments	Plant height		
	40 DAS	60 DAS	80 DAS
V_1S_1	61.80	83.26	99.56
V_1S_2	61.56	80.73	97.33
V_1S_3	62.06	77.33	96.73
V_1S_4	62.76	69.20	97.96
V_1S_5	58.16	77.53	93.66
V_2S_1	62.46	84.40	104.10
V_2S_2	58.50	91.13	113.16
V_2S_3	66.96	94.86	120.26
V_2S_4	63.56	87.73	112.40
V_2S_5	64.13	88.76	115.93
V_3S_1	59.10	83.73	95.76
V_3S_2	61.33	79.86	91.53
V_3S_3	62.03	83.93	98.96
V_3S_4	63.20	83.43	92.60
V_3S_5	63.66	79.96	92.00
SE m (±)	1.90	3.56	4.64

C.D (0.05)	NS	NS	NS

NS – Not significant

Table 4. Effect of varieties and zinc sulphate application on tillers m^{-2}at 40, 60 and 80 DAS, nos.

Treatments	Tillersm^{-2}		
	40 DAS	60 DAS	80 DAS
Varieties (V)			
V_1	181.33	281.60	330.4
V_2	155.46	290.13	382.7
V_3	185.60	299.46	395.2
SE m (±)	1.60	3.84	4.93
C D (0.05)	12.112	11.187	16.476
Zinc sulphate application (S)			
S_1	167.11	278.22	368.889
S_2	170.22	293.33	371.556
S_3	182.22	316.00	379.556
S_4	188.44	311.11	370.222
S_5	162.66	253.33	356.889
SE m (±)	2.07	4.96	6.37
C D (0.05)	15.63	14.443	NS

NS – Not significant

Table 5. Interaction effect of varieties and zinc sulphate application on Tillers m^{-2}at 40, 60 and 80 DAS, nos.

Treatments	Tillers m^{-2}		
	40 DAS	60 DAS	80 DAS
V_1S_1	186.66	272.00	330.7
V_1S_2	168.00	280.00	357.3
V_1S_3	184.00	304.00	325.3
V_1S_4	200.00	306.66	326.7

V_1S_5	168.00	245.33	312.0
V_2S_1	146.66	280.00	394.7
V_2S_2	166.66	296.00	353.3
V_2S_3	154.66	306.66	393.3
V_2S_4	168.00	304.00	408.0
V_2S_5	141.33	264.00	364.0
V_3S_1	168.00	282.66	400.0
V_3S_2	176.00	304.00	404.0
V_3S_3	208.00	337.33	420.0
V_3S_4	197.33	322.66	376.0
V_3S_5	178.66	250.66	376.0
SE m (±)	3.59	8.59	11.30
C.D (0.05)	NS	NS	36.839

NS – Not significant

4.1.3 Leaf Area Index (LAI)

Data concerned to the influence of varieties, zinc sulphate application and their interaction on LAI during 40 DAS and 60 DAS is furnished in the Table 6 and 7.

The varieties had no effect on LAI during 40 DAS but it was found to be significant at 60 DAS and Prathyasa (V_3) recorded the highest LAI and the lowest LAI was recorded in APO 1 (V_1).

The effect of zinc sulphate application on LAI was found to be significant at both 40 and 60 DAS. The treatment S_3 (seed priming @ 2g kg^{-1} seed + foliar application @ 0.5 per cent during active tillering and panicle initiation stage) recorded higher LAI at 40 DAS and it was statistically comparable with S_4 (soil application @ 20 kg ha^{-1}). However, at 60 DAS, the treatment s_4 recorded the highest LAI and it was statistically comparable with all treatments except S_5 (control).

The interaction effect between varieties and zinc sulphate application was found to be significant only at 40 DAS and it was the highest in $V_1S_{3.}$ and the lowest in V_3S_5.

4.1.4 Root shoot ratio

The data on the root shoot ratio recorded at 50 per cent flowering is presented in Table 8 and 9.

Variety had significant effect on root shoot ratio and it was the highest in APO 1 (V_2) and the lowest was in v_1 Anna 4 (V_1).

Zinc sulphate application had significant effect on root shoot ratio and the treatment S_4(soil application @ 20 kg ha^{-1}) recorded higher root shoot ratio (0.652) and it was significantly better to other method of zinc sulphate application. The control treatment (S_5) recorded the lowest root shoot ratio (0.423).

The interaction effect was significant and the treatment combination V_2S_4recorded significantly higher root shoot ratio and the lowest was recorded in $V_2S_{5.}$

4.1.5 Dry Matter Production (DMP)

Data concerning the effect of varieties, zinc sulphate application and their interaction are presented in Table 8 and 9.

The varieties had significant effect on DMP at harvest. Prathyasa (V_3) recorded the highest DMP and it was statistically comparable with V_2 (APO 1) and Anna 4 (V_1) recorded the lowest DMP.

The application of zinc sulphate also significantly influenced the DMP and the treatment S_4(soil application @ 20 kg ha^{-1} recorded the highest DMP and it was statistically on par with S_3(seed priming @ 2g kg^{-1} seed + foliar application @ 0.5 per cent during active tillering and panicle initiation stage). The treatment S_5 (control) recorded the lowest DMP.

The interaction effect of varieties and zinc sulphate application was also found to be significant and the treatment V_2S_4recorded the highest DMPand it was significantly superior to others. The treatment combination V_2S_5recorded the lowest DMP.

Table 6. Effect of varieties and zinc sulphate application on LAI at 40 and 60 DAS

Treatments	LAI	
	40 DAS	60 DAS
Varieties (V)		
V_1	3.34	5.88
V_2	3.11	6.36
V_3	3.04	7.07
SE m (±)	0.12	0.18
C.D (0.05)	NS	0.530
Zinc sulphate application (S)		
S_1	2.48	6.58
S_2	3.30	6.79
S_3	3.81	6.59
S_4	3.61	6.81
S_5	2.61	5.41
SE m (±)	0.15	0.23
C D (0.05)	0.460	0.684

NS – Not significant

Table 7. Interaction effect of varieties and zinc sulphate application on LAI

Treatments	LAI	
	40 DAS	60 DAS
V_1S_1	2.26	6.41
V_1S_2	3.62	6.44
V_1S_3	4.75	5.84
V_1S_4	3.56	5.71
V_1S_5	2.50	4.99
V_2S_1	2.77	6.87

V_2S_2	3.23	6.85
V_2S_3	3.14	6.57
V_2S_4	3.33	6.79
V_2S_5	3.10	4.74
V_3S_1	2.40	6.47
V_3S_2	3.07	7.36
V_3S_3	3.56	7.08
V_3S_4	3.93	7.92
V_3S_5	2.23	6.52
SE m (±)	0.27	0.40
C.D (0.05)	0.796	NS

NS – Not significant

Table 8. Effect of varieties and zinc sulphate application on root shoot ratio at 50 % flowering and dry matter production at harvest.

Treatments	Root shoot ratio	Dry matter production (kg ha^{-1})
Varieties (V)		
V_1	0.539	7,863.70
V_2	0.632	9,041.28
V_3	0.540	9,479.59
SE m (±)	0.019	137.51
C D (0.05)	0.054	400.433
Zinc sulphate application (S)		
S_1	0.458	8,745.67
S_2	0.594	8,607.40
S_3	0.652	9,985.12
S_4	0.727	10,237.33
S_5	0.423	6,398.76

SE m (±)	0.024	177.53
C D (0.05)	0.070	516.957

Table 9. Interaction effect of varieties and zinc sulphate application on root shoot ratio at 50 % flowering and dry matter production at harvest.

Treatments	Root shoot ratio	Dry matter production (kg ha^{-1})
V_1S_1	0.375	8,255.55
V_1S_2	0.517	8,222.22
V_1S_3	0.706	8,555.56
V_1S_4	0.713	8,559.26
V_1S_5	0.385	5,725.92
V_2S_1	0.417	8,988.88
V_2S_2	0.514	8,085.18
V_2S_3	0.859	10,688.89
V_2S_4	1.009	11,732.37
V_2S_5	0.362	5,711.11
V_3S_1	0.582	8,992.59
V_3S_2	0.752	9,514.81
V_3S_3	0.389	10,710.92
V_3S_4	0.457	10,420.37
V_3S_5	0.521	7,759.24
SE m (±)	0.042	307.50
C.D (0.05)	0.121	895.396

4.2 PHYSIOLOGICAL PARAMETERS

4.2.1 Crop Growth Rate (CGR)

Varieties and zinc sulphate application is significantly influencing the Crop growth rate at 40-60 DAS and 60-80 DAS. Interaction effect had a significant effect on CGR at 40-60 DAS only and the results are furnished in Table 10 and 11.

Among the varieties, APO 1 (V_2) recorded the highest CGR at both the stages of observation however, at 40-60 DAS, it was statistically comparable with Prathyasa (V_3).

Among the zinc sulphate application, S_4 (soil application @ 20 kg ha^{-1}) recorded the highest CGR throughout the stages of observation and it was statistically superior to all other treatments and the lowest CGR was recorded in S_5.

Results on interaction effect of varieties and zinc sulphate application on CGR at 40-60 DAS revealed that CGR was better in the treatment combination $V_2S_4$and it was statistically comparable with V_3S_4, V_1S_4, V_2S_3 and V_1S_3. The interaction effect was not significant during 60-80 DAS.

Table 10. Effect of varieties and zinc sulphate application on CGR

Treatments	CGR (g m^{-2} day^{-1})	
	40-60 DAS	60-80 DAS
Varieties (V)		
V_1	16.29	22.02
V_2	20.62	27.37
V_3	19.87	25.47
SE m (±)	0.69	0.49
C D (0.05)	2.019	1.454
Zinc sulphate application (S)		
S_1	16.15	21.84
S_2	17.29	23.85
S_3	22.39	28.15
S_4	25.13	31.44
S_5	13.68	19.48
SE m (±)	0.89	0.64
C D (0.05)	2.606	1.877

Table 11. Interaction effect of varieties and zinc sulphate application on CGR

Treatments	CGR (g m^{-2} day^{-1})	
	40-60 DAS	60-80 DAS
V_1S_1	9.48	18.66
V_1S_2	11.50	21.67
V_1S_3	21.46	25.02
V_1S_4	24.33	28.62
V_1S_5	14.70	16.13
V_2S_1	20.85	24.89
V_2S_2	19.74	24.23
V_2S_3	22.93	30.75
V_2S_4	26.65	33.59
V_2S_5	12.96	23.39
V_3S_1	18.12	21.97
V_3S_2	20.64	25.64
V_3S_3	22.78	28.68
V_3S_4	24.41	32.13
V_3S_5	13.38	18.92
SE m (±)	1.55	1.11
C.D (0.05)	4.514	NS

NS – Not significant

4.2.2 Chlorophyll Content

Results on the effect of varieties, zinc sulphate application and their interaction effect on chlorophyll content at 50 per cent flowering stage are presented in Table 12 and 13.

The effect of varieties on chlorophyll content was found to be non-significant. However, the effect of zinc sulphate application was found to be significant and treatment S_4 (soil application @ 20 kg ha^{-1}) recorded the highest chlorophyll content (2.027 mg g^{-1}) among the treatments and d the lowest was recorded in S_1 (seed priming @ 2g kg^{-1} seed).

The effect of interaction of varieties and zinc sulphate application was found to be non-significant.

4.2.3 Relative Water Content

Data on the effect of varieties, zinc sulphate application and their interaction on relative water content at 50 per cent flowering stage is presented in Table 12 and 13.

Varieties and zinc sulphate application had significant effect on relative water content at 50 per cent flowering stage. Among the varieties, variety APO 1 (V_2) recorded the highest relative water content and it was statistically superior to other varieties. Prathyasa recorded the lowest relative water content.

Among the zinc sulphate application, S_3(seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 per cent at active tillering and panicle initiation) recorded the highest relative water content and it was significantly superior to other methods of zinc sulphate application. The lowest relative water content was recorded in S_5 (Control).

The interaction effect of varieties and zinc sulphate application on relative water content during 50 per cent flowering was non-significant.

4.2.4 Soluble Protein

Data obtained on the effect of varieties, zinc sulphate application and their interaction on soluble protein content at 50 per cent flowering are furnished in Table 12 and 13.

The effect of varieties was found to be significant and the treatment Prathyasa (V_3) recorded the highest soluble protein and it was statistically comparable with APO1 (V_2). The variety Anna 4 (V_1) recorded the lowest soluble protein among the varieties.

The effect of zinc sulphate application was also found to be significant and the treatment S_3(seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation) recorded the highest soluble protein and it was statistically comparable with S_2 (foliar application @ 0.05 % at active tillering and panicle initiation stage) and S_4 (soil application @ 20 kg ha^{-1}). The lowest soluble protein was recorded in S_5 (control).

The interaction effect was also found to be significant and the treatment combination V_3S_4recorded the highest soluble protein, which was statistically comparable with V_2S_2andV_2S_3.

Table 12. Effect of varieties and zinc sulphate application on Chlorophyll content, Relative water content and soluble protein content at 50 per cent flowering.

Treatments	Chlorophyll content (mg g^{-1})	Relative Water Content (%)	Soluble protein (mg mL^{-1})
Varieties (V)			
V_1	2.018	35.73 (34.10)	0.289
V_2	2.017	39.90 (41.11)	0.312
V_3	2.017	34.77(32.52)	0.346
SE m (±)	0.001	1.35	0.012
C D (0.05)	NS	3.958	0.035
Zinc sulphate application (S)			
S_1	2.013	38.21 (38.25)	0.257
S_2	2.017	36.86(35.98)	0.357
S_3	2.014	39.93(41.19)	0.365
S_4	2.027	37.20 (36.55)	0.353
S_5	2.016	31.77(27.72)	0.246
SE m (±)	0.001	1.75	0.016
C D (0.05)	0.004	5.109	0.045

The values in the parenthesis are the original and they are subjected to arc sine transformation

NS – Not significant

Table 13. Interaction effect of varieties and zinc sulphate application on chlorophyll content, Relative water content and soluble protein content.

Treatments	Chlorophyll content (mg g^{-1})	Relative water content (%)	Soluble protein (mg mL^{-1})
V_1S_1	2.013	40.18 (41.62)	0.230
V_1S_2	2.019	34.39 (31.90)	0.295
V_1S_3	2.013	38.79(39.24)	0.333
V_1S_4	2.026	36.09(34.69)	0.286
V_1S_5	2.020	29.19(23.78)	0.302
V_2S_1	2.013	36.79(35.86)	0.225
V_2S_2	2.014	38.19(38.22)	0.449
V_2S_3	2.015	46.35 (52.35)	0.412
V_2S_4	2.027	43.97 (48.20)	0.324
V_2S_5	2.016	34.18(31.56)	0.154
V_3S_1	2.012	37.67(37.34)	0.317
V_3S_2	2.018	38.01(37.92)	0.329
V_3S_3	2.014	34.66 (32.34)	0.351
V_3S_4	2.029	31.55 (27.37)	0.450
V_3S_5	2.012	31.95 (27.72)	0.282
SE m (±)	0.002	3.03	0.027
C.D (0.05)	NS	NS	0.078

The values in the parenthesis are the original and they are subjected to arc sine transformation.

NS – Not significant

4.2.5 Proline Content

Effect of varieties, zinc sulphate application and their interaction on proline content at 50 per cent flowering are extended in Table 14 and 15.

The effect of varieties was found to be significant. Among the varieties, APO 1 (V_2) recorded the highest proline content and it was significantly superior compared to other two varieties. Anna 4 (V_1) recorded the lowest proline content.

The effect of zinc sulphate application was significant on proline content and the treatment S_3(seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation) recorded the highest proline content and it was significantly superior to others. The treatment S_5 (control) recorded the lowest proline content.

The interaction effect of varieties and zinc sulphate application was also significant and the treatment combination V_2S_3recorded the highest proline content and the lowest was recorded in V_1S_1.

4.2.6 Stomatal conductance

Data obtained son the effect of varieties, zinc sulphate application and their interaction on stomatal conductance at 50 per cent flowering are furnished in Table 14 and 15.

The effect of varieties on stomatal conductance was significant and it was higher in Prathyasa (V_3) and the lowest was in Anna 4 (V_1).

The application of zinc sulphate was also had a significant effect on stomatal conductance at 50 per cent flowering. The treatment S_2 (foliar application @ 0.05 % at active tillering and panicle initiation stage) recorded the highest stomatal conductance and it was statistically comparable with S_3(seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation) and S_4 (soil application @ 20 kg ha^{-1}). The treatment S_1 (seed priming @ 2g kg^{-1} seed) recorded the lowest stomatal conductance and it was statistically comparable with S_5 (control).

The interaction effect of varieties and zinc sulphate application on stomatal conductance was significant and the treatment combination V_3S_2recorded the highest stomatal conductance and it was statistically comparable with V_3S_3 and V_3S_4.

Table 14. Effect of varieties and zinc sulphate application on proline content and stomatal conductance at 50 per cent flowering

Treatments	Proline (µ mole per g)	Stomatal conductance (mmol m^{-2} s^{-2})

Varieties (V)		
V_1	0.029	13.13
V_2	0.046	16.74
V_3	0.036	19.45
SE m (±)	0.001	0.464
C D (0.05)	0.003	1.352
Zinc sulphate application (S)		
S_1	0.029	14.60
S_2	0.033	17.97
S_3	0.050	17.24
S_4	0.045	16.40
S_5	0.028	15.99
SE m (±)	0.001	0.600
C D (0.05)	0.004	1.746

Table 15. Interaction effect of varieties and zinc sulphate application on proline content and stomatal conductance

Treatments	Proline (µ mole per g)	Stomatal conductance (mmol m^{-2} s^{-2})
V_1S_1	0.022	12.50
V_1S_2	0.032	13.53
V_1S_3	0.031	12.50
V_1S_4	0.036	12.06
V_1S_5	0.023	15.05
V_2S_1	0.039	16.70
V_2S_2	0.032	17.80
V_2S_3	0.082	17.73
V_2S_4	0.045	15.73
V_2S_5	0.032	15.76
V_3S_1	0.025	14.60

V_3S_2	0.035	22.60
V_3S_3	0.038	21.50
V_3S_4	0.055	21.40
V_3S_5	0.027	17.16
SE m (±)	0.003	1.03
C.D (0.05)	0.007	3.024

4.3 YIELD PARAMETERS

4.3.1 Days to 50 per cent flowering

Effect of varieties, zinc sulphate application and their interaction on days to 50 per cent flowering are extended in the Table 16 and 17.

Varieties, Zinc sulphate application and their interaction did not have any significant effect on days to 50 per cent flowering.

4.3.2 Number of panicles m^{-2}

Data related to effect of varieties, zinc sulphate application and their interaction effect on number of panicles m^{-2} is extended in Table 16 and 17.

The influence of varieties on panicles m^{-2} was found to be significant was found to be significant and Prathyasa (V_3) recorded the highest number of panicles m^{-2}(358.13) and it was statistically comparable with APO 1 (V_2). The lowest number of panicles m^{-2} was recorded in Anna 4 (V_1).

Zinc sulphate application had significant effect on number of panicles m^{-2} (386.66). The treatment S_3 (seed priming @ 2g kg^{-1} of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) recorded the highest number of panicles m^{-2} and it was significantly superior to other method of application and the control treatment (S_5) recorded the number of panicles per m^2.

Number of panicles m^{-2} was also significantly influenced by interaction between varieties and zinc sulphate application. Number of panicles $m^{-2}$was recorded the highest in V_3S_3 and it was statistically comparable with V_3S_4, V_2S_4, V_3S_1, V_2S_3 andV_3S_2.The treatment combination V_1S_1 documented lowest number of panicle m^{-2}.

4.3.3 Panicle length

Effect of varieties, zinc sulphate application and their interaction on panicle length are presented in Table 16 and 17.

The effect of varieties on panicle length was significant and Anna 4 (V_1) recorded the panicle with the highest panicle length and it was statistically superior to other varieties and Prathyasa (V_3) recorded panicles with shorter length compared to APO 1 and Anna 4.

Interaction effect was non-significant.

Table 16. Effect of varieties and zinc sulphate application on days to 50 per cent flowering, number of panicles m^{-2} and panicle length.

Treatments	50 per cent flowering (days)	Number of panicles m^{-2}	Panicle length (cm)
Varieties (V)			
V_1	69.53	291.73	26.72
V_2	71.46	346.66	24.88
V_3	68.40	358.13	23.94
SE m (±)	0.904	5.785	0.602
C.D (0.05)	NS	14.369	1.753
Zinc sulphate application (S)			
S_1	69.11	324.44	23.85
S_2	70.00	327.77	25.00
S_3	69.33	386.66	24.98
S_4	68.22	338.88	25.17
S_5	72.33	303.55	26.91
SE m (±)	1.16	7.461	0.777
C.D (0.05)	NS	18.550	NS

NS – Not significant

Table 17. Interaction effect of varieties and zinc sulphate application on days to 50 per cent flowering, number of panicles m^{-2} and panicle length.

Treatments	50 per cent flowering (days)	Number of panicles m^{-2}	Panicle length (cm)
V_1S_1	68.00	262.00	24.43
V_1S_2	70.00	307.33	25.93
V_1S_3	69.33	328.66	27.26
V_1S_4	68.00	280.00	26.36
V_1S_5	72.33	280.66	29.63
V_2S_1	71.33	344.66	22.96
V_2S_2	71.00	320.00	23.76
V_2S_3	69.66	366.22	25.10
V_2S_4	69.33	368.00	25.76
V_2S_5	76.00	314.00	26.83
V_3S_1	68.00	366.66	24.16
V_3S_2	69.00	356.00	25.30
V_3S_3	69.00	383.33	22.60
V_3S_4	67.33	368.66	23.40
V_3S_5	68.66	316.00	24.26
SE m (±)	2.02	12.924	1.346
C.D (0.05)	NS	32.129	NS

NS – Not significant

4.3.4 Panicle weight

Data obtained on the effect of varieties, zinc sulphate application and their interaction on panicle weight are extended in Table 18 and 19.

Effect of varieties on panicle length was significant. Panicle weight was higher in APO 1 (V_2) and it was statistically comparable with Anna 4 (V_1).

Panicle weight showed significant difference with the application of zinc sulphate. Panicle weight was the highest in S_2(foliar application @ 0.5 per cent at active tillering and panicle initiation stage) and it was statistically comparable with S_3

(seed priming @ 2g kg^{-1} of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) and S_4 (soil application @ 20 kg ha^{-1}). Panicle weight was recorded the lowest in S_1 (seed priming @ 2g $kg^{-1}$of seed).

The interaction effect of varieties and zinc sulphate application on panicle weight was significant and it was the highest in V_1S_3 and it was statistically comparable with V_2S_2, V_2S_4, V_1S_2, V_2S_5, V_2S_3, $V_3S_2$and V_1S_5.

4.3.5 Filled grains per panicle

Data pertaining to effect of varieties, zinc sulphate application and their interaction on filled grains per panicle are presented in Table 18 and 19.

Effect of varieties on filled grains per panicle was significant and it was the highest in Parthyasa (V_3) and it was statistically comparable with APO 1 (V_2). Anna 4 (V_1) recorded the lowest filled grains per panicle and it was statistically comparable with APO1.

Effect of zinc sulphate application on filled grains per panicle was significant. Treatment, S_3(seed priming @ 2g $kg^{-1}$of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) recorded the highest number of filled grains per panicle and it was statistically comparable with S_4. The control treatment (S_5) recorded the lowest number of filled grains per panicle.

Interaction effect was significant and the highest number of filled grains per panicle recorded in V_3S_3 and it was statistically comparable with V_1S_4, V_2S_3, V_3S_2andV_3S_1. The lowest number of filled grains per panicle in V_1S_5.

4.3.6 Sterility percentage

Data related to the effect of varieties, zinc sulphate application and their interaction is presented in the Table 18 and 19.

The effect of varieties on sterility percentage was significant. Anna 4 (V_1) recorded the lowest sterility percentage and it was statistically comparable with APO 1 (V_2). Sterility percentage was the highest in Prathyasa (V_3).

Sterility percentage was influenced by zinc sulphate application. The treatment S_3 (seed priming @ 2g kg^{-1} of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) recorded the lowest sterility percentage and it was found significantly superior to other treatments. S_1 (seed priming @ 2g $kg^{-1}$of seed) recorded the highest sterility percentage and it was statistically comparable with control (S_5).

The interaction effect was significant and the treatment combination V_1S_3recorded the lowest sterility percentage and it was statistically comparable with V_1S_2.

Table 18. Effect of varieties and zinc sulphate application on panicle weight, filled grains per panicle and sterility percentage.

Treatments	Panicle weight (g)	Filled grains per panicle (No.)	Sterility percentage
Varieties (V)			
V_1	12.57	140.1	10.05 (18.49)
V_2	13.46	146.2	10.81 (19.20)
V_3	11.15	156.6	13.62 (21.66)
SE m (±)	0.454	3.594	0.409
C.D (0.05)	1.321	10.465	1.191
Zinc sulphate application (S)			
S_1	10.97	144.4	15.01 (22.80)
S_2	13.77	136.0	9.8 (18.25)
S_3	13.44	163.4	7.8 (16.32)
S_4	12.47	160.5	10.83 (19.22)
S_5	11.32	134.0	14.42 (22.32)
SE m (±)	0.586	4.640	0.528
C.D (0.05)	1.705	13.511	1.538

The values in the parenthesis are the original and they are subjected to arc sine transformation

Table 19. Interaction effect of varieties and zinc sulphate application on panicle weight, filled grains per panicle and sterility percentage.

Treatments	Panicle weight (g)	Filled grains per panicle (No.)	Sterility percentage	
V_1S_1	8.70	144.0	16.82	(24.22)
V_1S_2	13.85	105.3	6.02	(14.21)
V_1S_3	15.46	151.3	4.95	(12.86)
V_1S_4	12.24	168.7	10.7	(19.12)
V_1S_5	12.60	131.3	14.0	(22.01)
V_2S_1	11.80	134.3	13.04	(21.17)
V_2S_2	14.80	146.3	9.8	(18.26)
V_2S_3	13.24	163.6	8.88	(17.34)
V_2S_4	14.15	152.0	9.82	(18.27)
V_2S_5	13.30	135.0	12.78	(20.95)
V_3S_1	12.40	155.0	15.26	(23.00)
V_3S_2	12.65	156.3	14.37	(22.28)
V_3S_3	11.63	175.3	10.33	(18.75)
V_3S_4	11.03	161.0	12.40	(20.62)
V_3S_5	8.05	135.6	16.54	(24.00)
SE m (±)	1.014	8.036	0.915	
C.D (0.05)	2.953	23.401	2.664	

The values in the parenthesis are the original and they are subjected to arc sine transformation

4.3.7 Thousand grain weight

Data obtained on the effect of varieties, zinc sulphate application and their interaction effect on thousand grain weight are extended in Table 20 and 21.

Effect of varieties on thousand grain weight was found significant and it was the highest in Anna 4 (V_1) and was statistically comparable with APO 1 (V_2) and Prathyasa (V_3).

The effect of zinc sulphate application was also found significant. The treatment S_3 (seed priming @ 2g $kg^{-1}$of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) recorded the highest test grain weight (30.g) and it was statistically comparable with S_1(seed priming @ 2g $kg^{-1}$of seed), S_5 (control) and S_2(foliar application @ 0.5 per cent at active tillering and panicle initiation stage).

The interaction effect also influenced the parameter and it was the highest in V_1S_3 and it was statistically comparable with V_3S_1, V_1S_2, V_2S_5, V_2S_1, V_1S_4 and V_1S_1.

4.3.8 Grain yield

Data obtained on effect of varieties, zinc sulphate application and their interaction are presented in Table 20 and 21.

Effect of varieties on grain yield was significant and the highest grain yield of 3524.0 kg ha^{-1} was documented in Prathyasa (V_3) and it was statistically superior to others and Anna 4 (V_4) recorded the lowest grain yield (2554.1 kg ha^{-1}) among the varieties.

Effect of zinc sulphate application on grain yield was significant and was the highest with S_3 (seed priming @ 2g $kg^{-1}$of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) and it can be statistically compared with S_4 (soil application of zinc sulphate @ 20 kg ha^{-1}) and the lowest grain was recorded in control (S_5).

The interaction effect was also significant and the treatment combinationV_3S_3recorded the highest grain yield of 4384.99 kg ha^{-1} and was statistically comparable with V_2S_3, V_2S_4 and V_3S_4.

4.3.9 Straw yield

Data related to the effect of varieties, zinc sulphate application and their interaction are furnished in Table 20 and 21.

The effect of varieties on straw yield was found to be significant. The variety V_2 (APO 1) recorded the highest straw yield and it was statistically comparable with Prathyasa (V_3). The straw yield was the lowest in Anna 4 (V_1).

The effect of zinc sulphate application on straw yield was also significant and it was superior in S_4 (soil application @ 20 kg ha $^{-1}$) and it was statistically comparable with S_3 (Seed priming @ 2g kg^{-1}of seed + foliar application @ 0.5 per cent at active tillering and panicle initiation stage) and S_1 (seed priming @ 2g kg^{-1} of seed). The lowest straw yield was recorded in control (S_5).

Straw yield was significantly influenced by the interaction effect of varieties and zinc sulphate application. Straw yield was higher in $V_2S_4$and it was statistically superior to other treatment combinations. The lowest straw yield was recorded by the treatment combination V_1S_5.

Table 20. Effect of varieties and zinc sulphate application on thousand grain weight, grain yield and straw yield.

Treatments	Thousand grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Varieties (V)			
V_1	29.6	2554.07	5,309.63
V_2	28.9	2,948.82	6,092.46
V_3	28.1	3,524.03	5,955.55
SE m (±)	0.675	47.967	132.146
C.D (0.05)	1.09	139.671	384.788
Zinc sulphate application (S)			
S_1	29.1	2700.00	6,045.67
S_2	28.6	3053.08	5,554.32
S_3	30.0	3,877.71	6,107.40
S_4	27.7	3,760.99	6,476.33
S_5	29.0	1653.08	4,745.67
SE m (±)	0.871	61.925	170.600
C.D (0.05)	1.41	180.315	496.759

Table 21. Interaction effect of varieties and zinc sulphate application on thousand grain weight, grain yield and straw yield.

Treatments	Thousand grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
V_1S_1	29.39	2,444.4	5811.11
V_1S_2	30.33	2,900.0	5,322.22
V_1S_3	31.76	2,977.7	5,577.78
V_1S_4	29.39	2,922.2	5,637.04
V_1S_5	26. 91	1,525.9	4200.00
V_2S_1	29.73	2377.7	6611.11
V_2S_2	28.17	2,640.7	5444.60
V_2S_3	29.26	4270.3	6,418.52
V_2S_4	27.98	4199.6	7,532.70
V_2S_5	29.77	1,255.5	4,455.55
V_3S_1	30.62	3,277.78	5714.81
V_3S_2	27.21	3,618.5	5,896.29
V_3S_3	29.11	4,384.99	6,325.92
V_3S_4	25.85	4,161.11	6,259.26
V_3S_5	27.86	2,177.76	5,581.48
SE m (±)	1.50	107.257	295.488
C.D (0.05)	2.44	312.315	860.412

4.4 CHEMICAL ANALYSIS

4.4.1 Organic carbon content of soil after the experiment

Data obtained on the effect of varieties, zinc sulphate application and their interaction areextended in Table 22 and 23.

The effect of varieties and zinc sulphate application on organic carbon status of post experiment soil was found to be not-significant.

The interaction effect of varieties and zinc sulphate application was found to be significant. It was the highest in the treatment combination $V_2S_4$and $V_2S_5$and was statistically on par with all treatment combinations except V_2S_2, V_3S_2, V_3S_1, V_1S_3 and V_1S_4.

4.4.2 Available Soil N Status of Post Experiment Soil

Results on the effect of varieties, zinc sulphate application and their interaction on available nitrogen are depicted in Table 22 and 23.

The effect of varieties on available soil nitrogen was found to be non-significant.

However, the effect of zinc sulphate application on available soil N was significant. The treatment S_5 (Control) recorded the highest available soil N was statistically comparable with S_1 (seed priming @ 2g $kg^{-1}$of seed). The control treatment (S_4) recorded the lowest available soil N.

The interaction effect was found significant. The treatment combination V_2S_2recorded higher available soil nitrogen and it was statistically comparable with all treatments except V_2S_4 and V_1S_4.

4.4.3 Available Soil P Status of Post Experiment Soil

Data related to the effect of varieties, zinc sulphate application and their interaction on available phosphorus in the soil is presented in Table 22 and 23.

The effect varieties on available phosphorus was found to be non-significant.

However, the effect of zinc sulphate application on available P status of post experiment soil was found to be significant and it was the highest in S_4 (soil application @ 20 kg ha^{-1}) and the lowest in S_2 (foliar application @ 0.05 % at active tillering and panicle initiation stage).

The interaction effect of varieties and zinc sulphate application was found to be significant and it was the highest in the treatment combination $V_1S_4$and it was significantly comparable with V_2S_4andV_3S_4.

Table 22. Effect of varieties and zinc sulphate application on organic carbon status, available nitrogen, available phosphorus after the experiment.

Treatments	Organic carbon (%)	Available nitrogen(kg ha^{-1})	Available phosphorus(kg ha^{-1})
Varieties (V)			
V_1	0.718	244.82	16.77
V_2	0.730	267.47	18.11
V_3	0.715	289.24	16.94
SE m (±)	0.005	17.994	0.450
C.D (0.05)	NS	NS	NS
Zinc sulphate application (S)			
S_1	0.718	285.09	16.03
S_2	0.711	236.13	14.28
S_3	0.728	266.91	18.26
S_4	0.724	173.52	22.49
S_5	0.725	374.23	15.30
SE m (±)	0.006	23.230	0.580
C.D (0.05)	NS	67.643	1.690

NS – Not significant

Table 23. Interaction effect of varieties and zinc sulphate application on organic carbon status, available nitrogen, available phosphorus after the experiment.

Treatments	Organic carbon (%)	Available nitrogen(kg ha^{-1})	Available phosphorus(kg ha^{-1})
V_1S_1	0.726	226.49	14.04
V_1S_2	0.735	213.60	15.68
V_1S_3	0.702	289.21	16.12

V_1S_4	0.705	142.86	24.31
V_1S_5	0.721	351.93	13.70
V_2S_1	0.726	251.58	20.16
V_2S_2	0.699	205.58	14.18
V_2S_3	0.741	301.76	17.52
V_2S_4	0.742	176.31	21.72
V_2S_5	0.742	402.10	16.99
V_3S_1	0.702	377.20	13.89
V_3S_2	0.699	289.21	12.99
V_3S_3	0.740	209.77	21.15
V_3S_4	0.724	201.40	21.45
V_3S_5	0.712	368.65	15.23
SE m (±)	0.011	40.236	1.005
C.D (0.05)	0.033	NS	2.927

NS – Not Significant

4.4.4 Available Soil K Status of Post Experiment Soil

Results on the effect of varieties, zinc sulphate application and their interaction on available soil potassium status of post experiment is presented in Table 24 and 25.

The effect of varieties on available K status of post experiment soil was non-significant.

The effect of zinc sulphate application on available K status of post experiment soil was found to be significant and it was the highest in S_5 (control) and it was statistically superior to other treatments. Available soil potassium was recorded the lowest in the treatment S_3(seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation stage).

The interaction effect of varieties and zinc sulphate application was found to be significant and the treatment combination V_1S_5 recorded the highest available soil K and was statistically comparable with V_2S_1. The treatment combination V_2S_3 recorded the lowest available soil K.

4.4.5 Available Soil Zn Status of Post Experiment Soil

Data pertaining to the effect of varieties, zinc sulphate application and their interaction on available zinc content of post experiment soil are presented in Table 24 and 25.

The effect of varieties on available zinc status was found significant. Variety Anna 4 (V_1) recorded the highest available soil Zn status and the lowest was recorded in Prathyasa (V_3).

The effect of zinc sulphate application was found to be significant on available zinc content in the soil after the experiment. The available zinc content was the highest in S_4 (soil application @ 20 kg ha^{-1}) and the lowest in S_1 (seed priming @ 2g $kg^{-1}$of seed).

The interaction effect was also significant and the treatment combination V_1S_4recorded the highest available soil zinc content and it was significantly superior over other treatments. The treatment combination V_3S_1 (0.180 mg g^{-1}) recorded the lowest available zinc content.

Table 24. Effect of varieties and zinc sulphate application on available potassium and available zinc content after the experiment.

Treatments	Available potassium (kg ha^{-1})	Available zinc (mg kg^{-1})
Varieties (V)		
V_1	139.54	0.483
V_2	134.74	0.407
V_3	132.51	0.401
SE m (±)	2.424	0.011
C.D (0.05)	NS	0.032
Zinc sulphate application (S)		
S_1	166.88	0.226
S_2	135.90	0.338
S_3	87.04	0.424
S_4	112.08	0.892

S_5	176.09	0.272
SE m (±)	3.130	0.014
C.D (0.05)	9.113	0.042

NS – Not significant

Table 25. Interaction effect of varieties and zinc sulphate application on available potassium and available zinc content after the experiment.

Treatments	Available potassium (kg ha^{-1})	Available zinc (mg kg^{-1})
V_1S_1	167.18	0.283
V_1S_2	125.36	0.383
V_1S_3	98.36	0.500
V_1S_4	122.35	0.970
V_1S_5	184.47	0.280
V_2S_1	174.70	0.213
V_2S_2	149.51	0.280
V_2S_3	73.69	0.373
V_2S_4	110.04	0.903
V_2S_5	165.76	0.263
V_3S_1	158.75	0.180
V_3S_2	132.82	0.350
V_3S_3	89.07	0.400
V_3S_4	103.87	0.803
V_3S_5	178.06	0.273
SE m (±)	5.421	0.025
C.D (0.05)	15.784	0.072

4.4.6 Nitrogen Uptake by Crop.

Effect of varieties, zinc sulphate application and their interaction on N uptake by crop are furnished in Table 26 and 27.

The effect of varieties on N uptake by crop was found to be non-significant.

The effect of zinc sulphate application on nitrogen uptake was found to be significant and the treatment S_4 (soil application @ 20 kg ha^{-1}) recorded the highest N uptake by crop and the lowest in S_5 (control).

The interaction effect was significant and the treatment combination V_2S_4recorded the highest nitrogen uptake and it was statistically comparable with V_3S_4 and V_2S_3. The lowest N uptake by crop was recorded in in V_2S_1.

4.4.7 Phosphorus Uptake by Crop

Results on the effect of varieties, zinc sulphate application and their interaction on P uptake by crop are presented in Table 26 and 27.

The effect of varieties and zinc sulphate application were found to be significant on phosphorus uptake.

Among the varieties, Prathyasa (V_3) recorded the highest uptake and it was statistically on par with Anna 4 (V_1) and the lowest P uptake was recorded in APO 1 (V_2).

Among the zinc sulphate application method, S_3 (seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation stage) recorded the highest P uptake by crop and it was comparable with S_2 (foliar application @ 0.05 % at active tillering and panicle initiation stage). The lowest P uptake by crop was recorded in S_5 (control).

The interaction effect of varieties and zinc sulphate application was found to be significant and the treatment combination V_3S_3recorded the highest phosphorus uptake and it was statistically comparable with V_2S_3, V_2S_4 and V_3S_4.

Table 26. Effect of varieties and zinc sulphate application on total nitrogen uptake and phosphorus uptake at harvest, kg ha^{-1}.

Treatments	N uptake	P uptake
Varieties (V)		
V_1	96.54	80.90
V_2	105.64	65.49

V_3	106.60	82.90
SE m (±)	3.651	1.672
C.D (0.05)	NS	4.853
Zinc sulphate application (S)		
S_1	80.56	64.62
S_2	91.86	89.39
S_3	125.78	91.84
S_4	143.75	83.44
S_5	72.69	55.88
SE m (±)	4.714	2.164
C.D (0.05)	13.725	6.265

NS – Not significant

Table 27. Interaction effect of varieties and zinc sulphate application on total nitrogen uptake and phosphorus uptake at harvest, kg ha^{-1}.

Treatments	N uptake	Puptake
V_1S_1	82.56	67.22
V_1S_2	101.41	87.58
V_1S_3	100.57	88.37
V_1S_4	122.53	89.00
V_1S_5	75.65	72.36
V_2S_1	74.42	56.05
V_2S_2	82.25	80.93
V_2S_3	149.09	91.47
V_2S_4	159.15	71.50
V_2S_5	63.32	27.98
V_3S_1	84.72	70.60
V_3S_2	91.93	90.67
V_3S_3	127.69	95.67
V_3S_4	149.59	90.27
V_3S_5	79.11	67.30

SE m (±)	8.164	3.747
C.D (0.05)	23.773	10.852

4.4.8 Potassium Uptake by Crop

Results related to the effect of varieties, zinc sulphate application and their interaction on uptake of K uptake by crop are presented in Table 28 and 29.

Results revealed that varieties had significant effect on K uptake by crop. The variety APO 1 (V_2) recorded the highest K uptake by crop and it was statistically superior to other two varieties. Variety V_1 (Anna 4) recorded the lowest uptake of potassium.

Among the method of zinc sulphate application, S_3 (seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation stage)recorded the highest K uptake by crop and was statistically comparable with S_4 (soil application @ 20 kg ha^{-1}). The K uptake by crop was recorded the lowest in S_5 (control).

The interaction effect was also significant and the highest K uptake by crop was recorded in the treatment combination V_2S_3 and it was statistically comparable with V_2S_4 and the lowest K uptake by crop was recorded in the treatment combination V_3S_5.

4.4.9 Zinc Uptake by Crop

Results on the effect of varieties, zinc sulphate application and their interaction on Zn uptake bycropareextended in Table 28 and 29.

The effect of varieties on Zn uptake by crop was found to be significant. Prathyasa (V_3) recorded the highest Zn uptake by crop and it was significantly superior to others and the lowest Zn uptake by crop was recorded in Anna 4 (V_1).

The effect of zinc sulphate application was also found to be significant and the treatment S_4 (soil application @ 20 kg ha^{-1}) recorded the highest Zn uptake and it was significantly superior to all other treatments. The lowest Zn uptake by crop was recorded in S_5 (control).

The interaction effect of varieties and zinc sulphate application was found to be significant and it was the highest in the treatment combination V_3S_4 and it was significantly superior to others.

Table 28. Effect of varieties and zinc sulphate application on total potassium uptake and total zinc uptake at harvest stage.

Treatments	Potassium uptake (kg ha^{-1})	Zinc uptake (kg ha^{-1})
Varieties (V)		
V_1	140.93	0.191
V_2	171.53	0.236
V_3	150.00	0.329
SE m (±)	4.056	0.007
C.D (0.05)	11.809	0.021
Zinc sulphate application (S)		
S_1	124.77	0.122
S_2	142.55	0.223
S_3	199.55	0.377
S_4	188.11	0.450
S_5	115.77	0.088
SE m (±)	5.236	0.009
C.D (0.05)	15.246	0.028

Table 29. Interaction effect of varieties and zinc sulphate application on total potassium uptake and total zinc uptake at harvest stage.

Treatments	Potassium uptake (kg ha^{-1})	Zinc uptake (kg ha^{-1})
V_1S_1	123.00	0.081
V_1S_2	138.00	0.175
V_1S_3	165.33	0.308

V_1S_4	157.33	0.315
V_1S_5	121.00	0.075
V_2S_1	133.33	0.139
V_2S_2	152.66	0.148
V_2S_3	238.00	0.336
V_2S_4	216.66	0.493
V_2S_5	117.00	0.065
V_3S_1	118.00	0.145
V_3S_2	137.00	0.346
V_3S_3	195.33	0.486
V_3S_4	190.33	0.541
V_3S_5	109.33	0.125
SE m (±)	9.069	0.016
C.D (0.05)	26.406	0.048

4.5 ECONOMIC ANALYSIS

4.5.1 Net Income

Results on the effect of varieties, zinc sulphate application and their interaction on net return are presented in Table 30 and 31.

Among the varieties, Prathyasa (V_3) recorded the highest net return and the lowest net return was recorded in Anna 4 (V_1).

Among the different methods of zinc sulphate application S_3 (seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation stage) recorded the highest net return and it was closely followed by S_4 (soil application @ 20 kg ha^{-1}) and the lowest net return was recorded in S_5 (control).

Among the treatment combination V_3S_3recorded the highest net return and it was closely followed by V_2S_4 and the lowest net return was recorded inV_2S_5.

4.5.2 B C Ratio

Data pertaining to the effect of varieties, zinc sulphate application and their interaction on B C ratio are presented in Table 30 and 31.

The effect of varieties and zinc sulphate application on B:C ration were found to be significant and results followed the same trend of net return.

Among the varieties, Prathyasa (V_3) recorded the highest B C ratio and the lowest was recorded by Anna 4 (V_1).

Among the method of zinc sulphate application, S_3 (Seed priming @ 2g kg^{-1} seed + foliar application @ 0.05 % at active tillering and panicle initiation stage) recorded the highest B: C ratio which was closely followed by S_4 (soil application of zinc sulphate @ 20 kg ha^{-1}) and the lowest B: C ratio was recorded in S_5 (control).

The interaction effect was also found to be significant and the treatment combination V_3S_4recorded the highest B C ratio, and the lowest was in V_1S_5.

4.6 PEST AND DISEASE INCIDENCE

4.6.1 Pest and disease incidence

Incidence of leaf folder attack was observed during the active tillering stage and rice bug during the flowering stage. It was observed throughout the experiment field irrespective of the treatments. For controlling the leaf folder attack quinalphos was sprayed @ 1000 ml of 25 EC per ha and for the control of rice bud malathion @ 1000 ml of 50 EC per ha was applied.

Table 30. Effect of varieties and zinc sulphate application on net income and B C Ratio.

Treatments	Net income	B C Ratio
Varieties (V)		
V_1	13,750	1.20
V_2	25,233	1.38
V_3	38,921	1.58
Zinc sulphate application (S)		
S_1	19,103	1.31

S_2	26,430	1.39
S_3	47,897	1.71
S_4	47,041	1.70
S_5	-10,630	0.83

Table 31. Interaction effect of varieties and zinc sulphate application on net returns and B C Ratio

Treatments	Net income	B C Ratio
V_1S_1	13,234	1.19
V_1S_2	21,906	1.32
V_1S_3	23,809	1.35
V_1S_4	23,554	1.35
V_1S_5	-13,753	0.78
V_2S_1	10,297	1.21
V_2S_2	15,791	1.23
V_2S_3	58,646	1.87
V_2S_4	61,177	1.91
V_2S_5	-19,746	0.69
V_3S_1	33,778	1.51
V_3S_2	41,591	1.62
V_3S_3	61,234	1.91
V_3S_4	56,393	1.84
V_3S_5	1,608	1.02

DISCUSSION

5. DISCUSSION

The results of the field experiment “performance evaluation of rice varieties and their response to zinc nutrition in uplands” carried out at Coconut Research Station, Balaramapuram are discussed in this chapter.

5.1 EFFECT OF VARIETIES ON GROWTH PARAMETERS OF THE CROP

The varieties have shown significant differences in growth characters like plant height, tillers per m^{-2}, leaf area index, root shoot ratio and dry matter production. The effect on plant height was significant at 60 and 80 DAS. The variety APO 1 (V_2) recorded the highest plant height compared to other two varieties. This is supported by De Datta *et al.* (1988); Alam *et al.* (2009a) and Dessie *et al.* (2018) who observed that the plant height was varied among the varieties mainly due to its genetic characters. The tillers per m^{-2} was recorded the highest in Prathyasa in all the stages of growth when compared to other two varieties. It might be due to better stand establishment with good vigour which led to the better expression of tillers. The leaf area index was also found to be vary with varieties. At 60 DAS, Prathyasa recorded higher LAI, higher tiller number might have contributed to increased leaf area index. El-Khoby (2004) and Khalifa *et al.*(2014) reported that better development of leaf lamina and better coverage of the ground might be the reason for improved LAI in rice varieties. Root shoot ratio was also found significantly influenced by the varieties, variety, APO 1 (V_2) recorded higher root shoot ratio than other varieties. This indicated that the root growth of APO 1 was better compared to others. Fageria and Moreira (2015) reported that the root growth and their characteristics are genetically controlled.

The dry matter production was higher in variety V_3 (Prathyasa), followed by variety V_2 (APO 1). The dry matter recorded by variety V_3 was 9479.59 kg ha^{-1}(Table 8) (Fig 3). This might be due to the fact that V_3performed well in terms of growth characters and also the yield parameters when compared to other two varieties. Alam *et al.* (2009a) and Namai *et al.*(2009) observed that the difference in dry matter production is due to the difference in growth pattern from seedling stage to harvest stage and its rate of growth.

Fig 3. Effect of varies and zinc sulphate application on Dry Matter Production (kg ha^{-1}).

5.2 EFFECT OF VARIETIES ON PHYSIOLOGICAL PARAMETERS

The effect of varieties was significant in all physiological parameters except chlorophyll content. Crop Growth Rate (CGR) was higher in variety V_2 (APO 1) followed by V_3(Prathyasa). The better crop growth rate observed in APO 1 might be due better growth pattern of the variety. Relative water content was also found to be significant and it was the highest in variety V_2 (APO 1), better root development enabled the crop to absorb more amount of water from the soil and resulted in higher relative water content. However, the soluble protein content was found to be higher in variety V_3 (Prathyasa) and it might be due to the better metabolic efficiency of the variety and also might be due better utilization of micronutrients as they regulate the process of protein formation as reported by Cakmak,(2000). The proline content was also found to be significantly affected by the varieties and the variety V_2 (APO 1) recorded higher proline content. Since the APO 1 variety released by IRRI for aerobic condition the proline content of the variety was higher, because the antioxidant enzymes were produced in a better rate (Kumar *et al.,* 2017). The stomatal conductance which have influence on photosynthetic rate, the variety V_3(Prathyasa) showed higher stomatal conductance compared to the other varieties. The variation in the stomatal conductance might be due to higher number of stomata. Dore *et al.* (2018) and Zinzala *et al.* (2019) reported that varieties showed differences in the number of stomata.

5.3 EFFECT OF VARITIES ON NUTRIENT AVAILABILITY AFTER THE EXPERIMENT.

The nutrient status of soil was not much affected by the varieties except zinc status. The available zinc status was lower than the initial status. Among the varieties, the available zinc status was higher in variety V_1 (ANNA 4). It might be due to lower uptake by the variety (Xie *et al.,* 2008).

5.4 EFFECT OF VARIETIES ON NUTRIENT UPTAKE

Except N, P, K and Zn uptake by crop was significantly influenced by varieties. The phosphorus uptake was higher in variety V_3 (Prathyasa) (Fig 5) might be better absorption and translocation of phosphorus which led to higher P content in plant and also due to higher dry matter production. However, the uptake of potassium uptake was higher with the variety V_2 (APO 1) (Fig 6) and it might be due to higher K content of the crop and higher straw yield (Table 28). Dubey and Sharma (1996) and Gill *et al.* (2009)have reported that the concentration of K is higher in straw compared to the grain. The zinc uptake was also found to be significantly affected by the varieties. It was the highest in variety V_3 (Fig 7) followed by variety V_2 (APO 1). The better accumulation of zinc can be attributed to higher dry matter production, higher Zn content and better adaptability to the field environment (Xie *et al.,* 2008). The genetic makeup also has a big hand in zinc uptake, zinc efficiency of the crop and tolerance to zinc deficiency in soil. So, the genetic character of the crop also might have improved the zinc uptake (Graham and Rendel, 1993).

5.5 EFFECT OF VARIETIES ON YILED PARAMETERS AND YIELD

The varieties have shown significant difference in yield parameters and the yield also. The number of panicle $m^{-2}$was found to be higher in the variety V_3 (Prathyasa). The variety have shown higher tillers per m^{-2}in all stages of growth, which might be the reason for higher productive tillers. Better metabolic activity of the crop in the early stages of growth also contributed to higher tiller and productive tiller production (Kohli *et al.,* 1997; Khalifa *et al.,* 2014). The panicle length was found to be significantly affected by varieties and among the varieties, variety V_1 (Anna 4) and it might be a genetic character of this variety. The effect of varieties on panicle weight was also found to be significant, it was the highest in variety V_2 (APO 1) it can be due to better accumulation of photosynthates in sink (grains), which increased the weight of the grains and thus the panicle weight. Filled grains per panicle was also found to be affected by the varieties significantly and it was higher in the variety V_3 (Prathyasa). Higher stomatal conductance improved the photosynthetic rate which might have improved the production of photosynthates, translocation, better development of sink and accumulation of photosynthates in sink. This might be the possible reason behind the improved filled grains per panicle. Similar observations were also made by Mobasser *et al.* (2007). Sterility percentage was also found to be significantly affected by varieties. Among the varieties, variety V_1 (Anna 4) recorded the lowest, this can be attributed to the genetic makeup of the variety (Obaidullah, 2007) and its adaptability to stress conditions (Alam *et al.,* 2009b). The same variety have shown higher thousand

Fig 4. Effect of varieties and zinc sulphate application on Total Nitrogen uptake (kg ha^{-1})

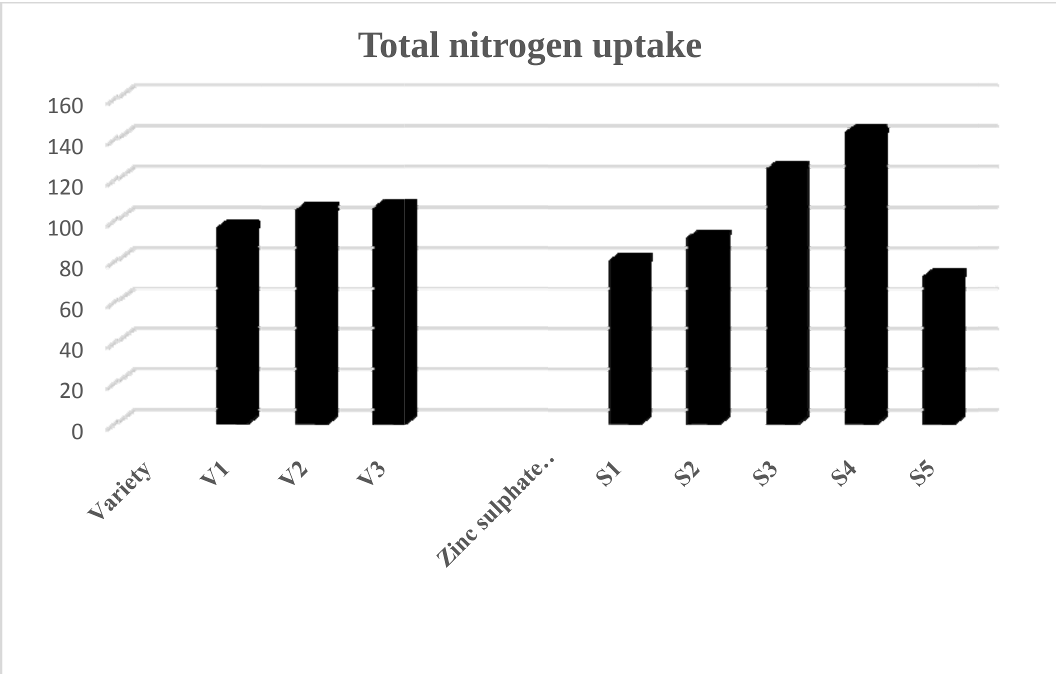


Fig 5. Effect of varieties and zinc sulphate application on Total Phosphorus uptake (kg ha^{-1}).

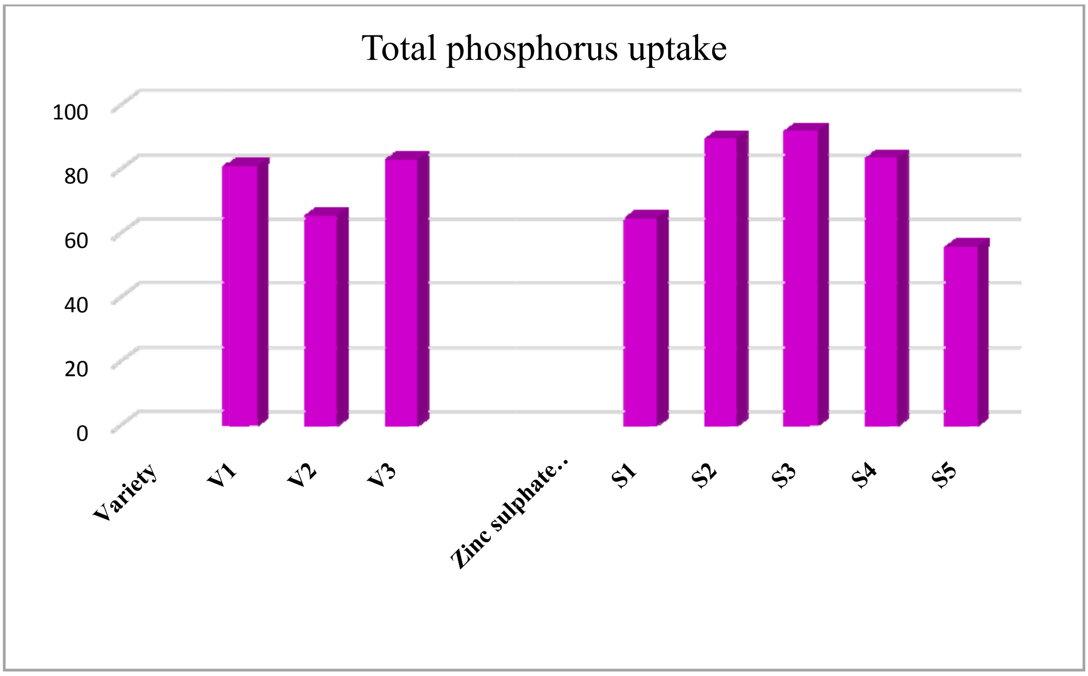


Fig 6. Effect of varieties and zinc sulphate application on Total Potassium uptake (kg ha^{-1}).

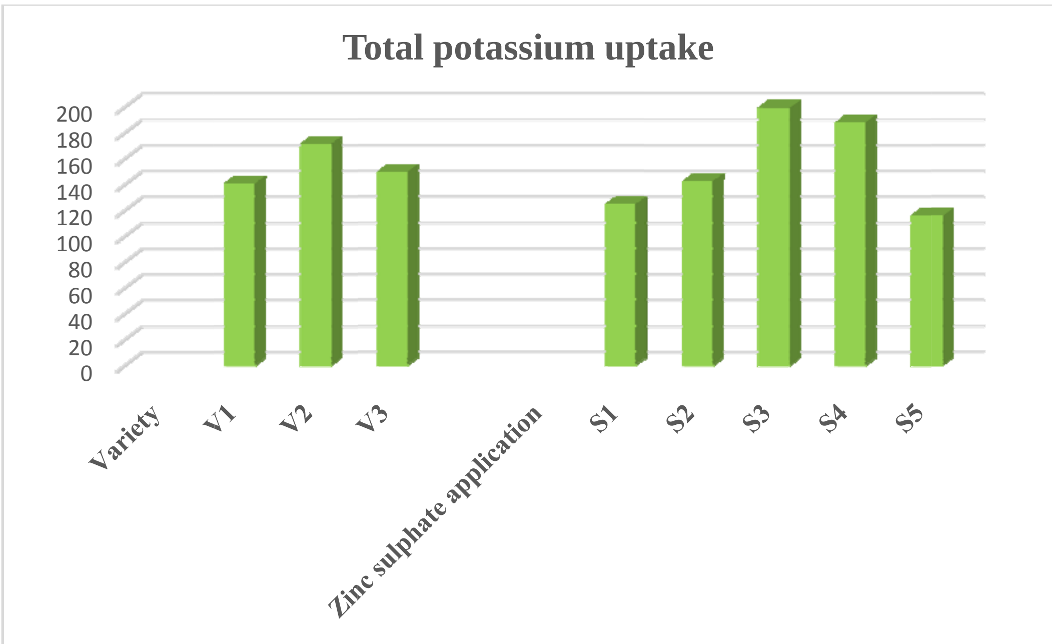
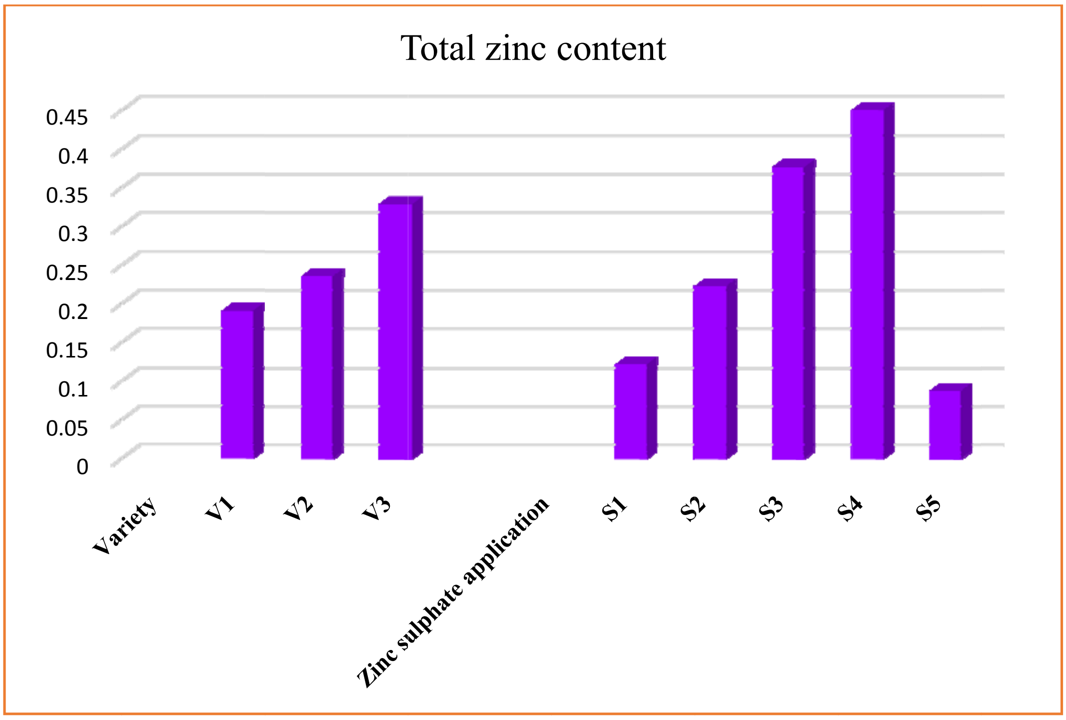


Fig 7. Effect of varieties and zinc sulphate application on Total Zinc uptake (kg ha^{-1}).



grain weight compared to other varieties. The grain yield and straw yield was also found to be significantly affected by the varieties. Grain yield was the highest in V_3 (Prathyasa). This was due to the production of among higher number of panicle $m^{-2}$and filled grains per panicle (Table 16,18) (Fig 8,9). Sultana *et al.* (2020) have observed enhancement in the production of yield attributes contributed to higher grain yield (Fig 10). This was also supported by Karim *et al.* (2007); Hasamuzzaman *et al.* (2009) and Khalifa *et al.* (2014). But higher straw yield was recorded in variety V_2 (APO 1) (Fig 11) it might be due to better vegetative growth as evident from the data on plant height. Alam *et al.* (2009b) have reported that higher straw yield might be due to better accumulation of biomass by the variety.

5.6 EFFECT OF VARIETIES ON ECONOMICS

The net returns as well as the B C ratio were higher in the variety V_3 (Prathyasa) due to higher grain yield registered in the variety. The net return was □ 38,921.56 and the B C ratio was 1.58 (Table 30) (Fig 12, 13). The lowest net returns and B:C ratio was recorded in variety V_1(ANNA 4) (□ 13,750.33 and B C ratio 1.20, respectively). This was due to poor performance and the lowest yield recorded by the variety. Even though the variety recorded higher thousand grain weight, lower sterility percentage and panicle length, the yield determining factors like number of panicle m^{-2}, filled grains per panicle were less compared to others.

Fig 8. Effect of varieties and zinc sulphate application on Number of panicles per m^{-2}

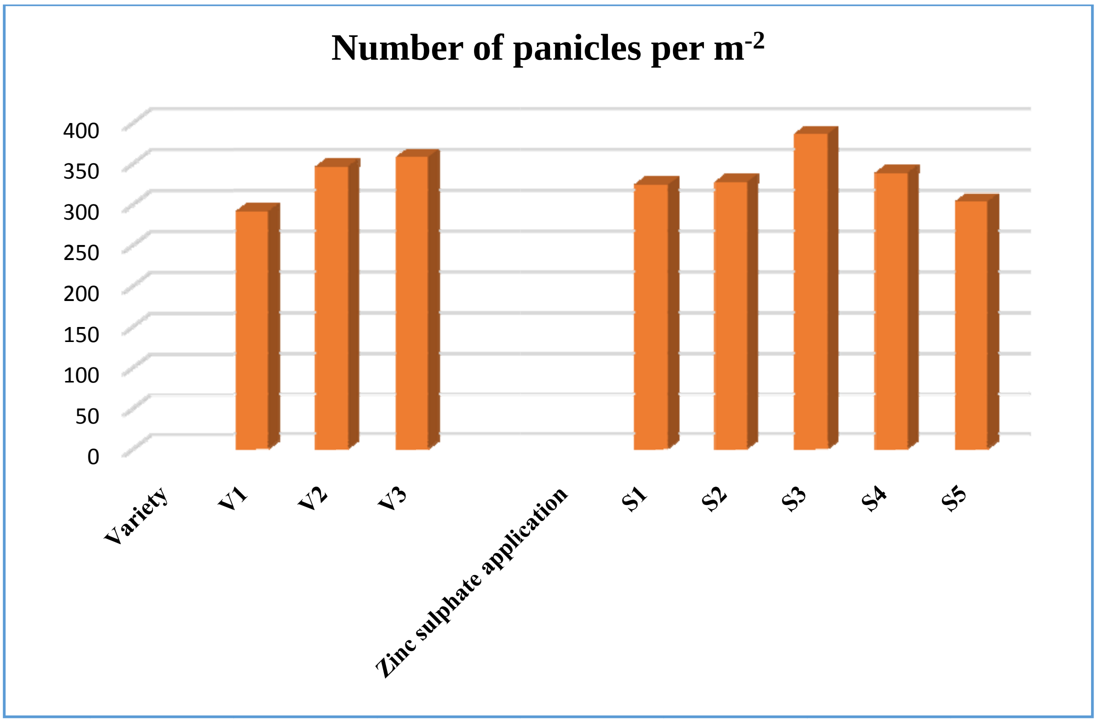


Fig 9. Effect of varieties and zinc sulphate application on Filled grains per panicle (No.)

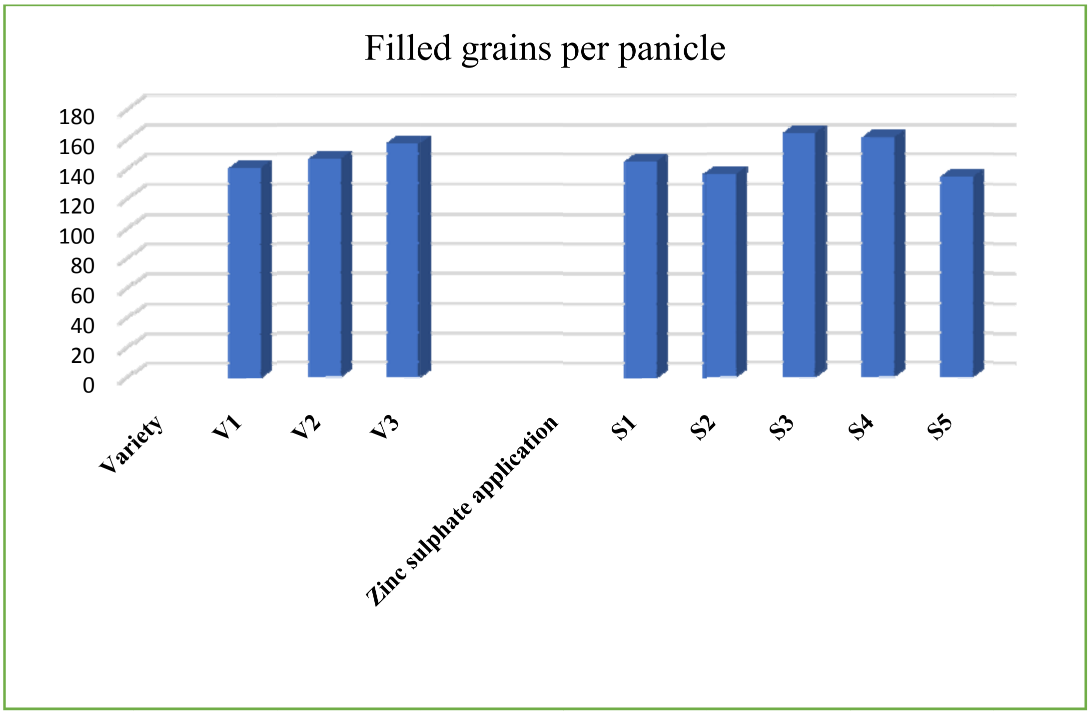


Fig 10. Effect of varieties and zinc sulphate application on grain yield (kg ha^{-1})

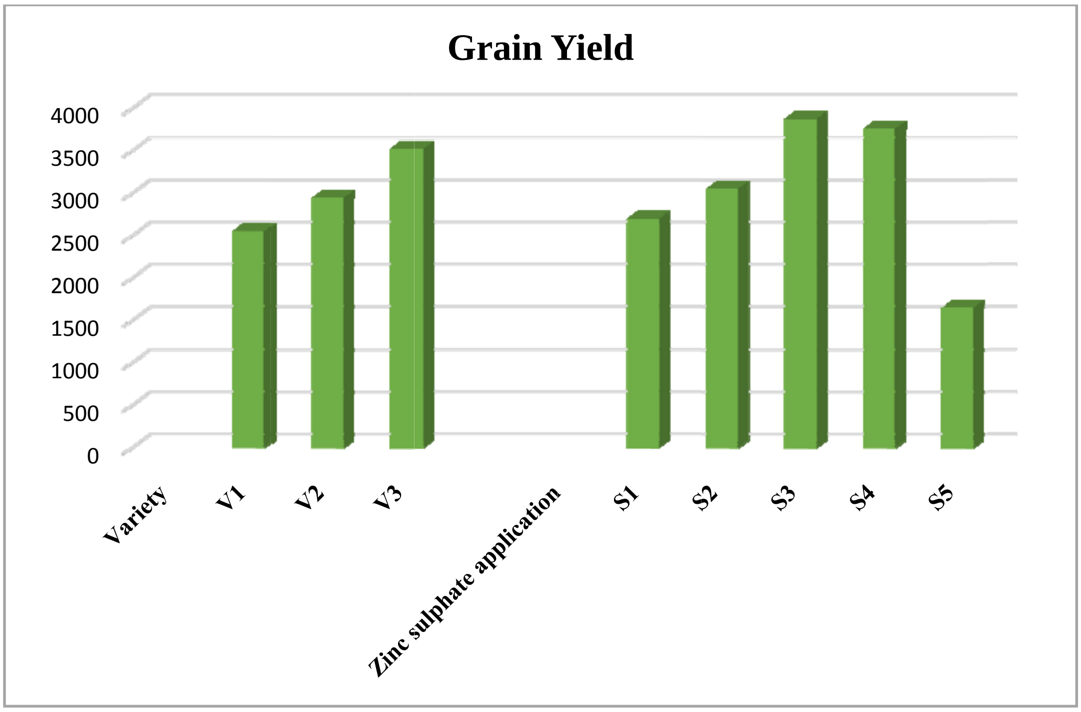


Fig 11. Effect of varieties and zinc sulphate application on straw yield (kg ha^{-1})

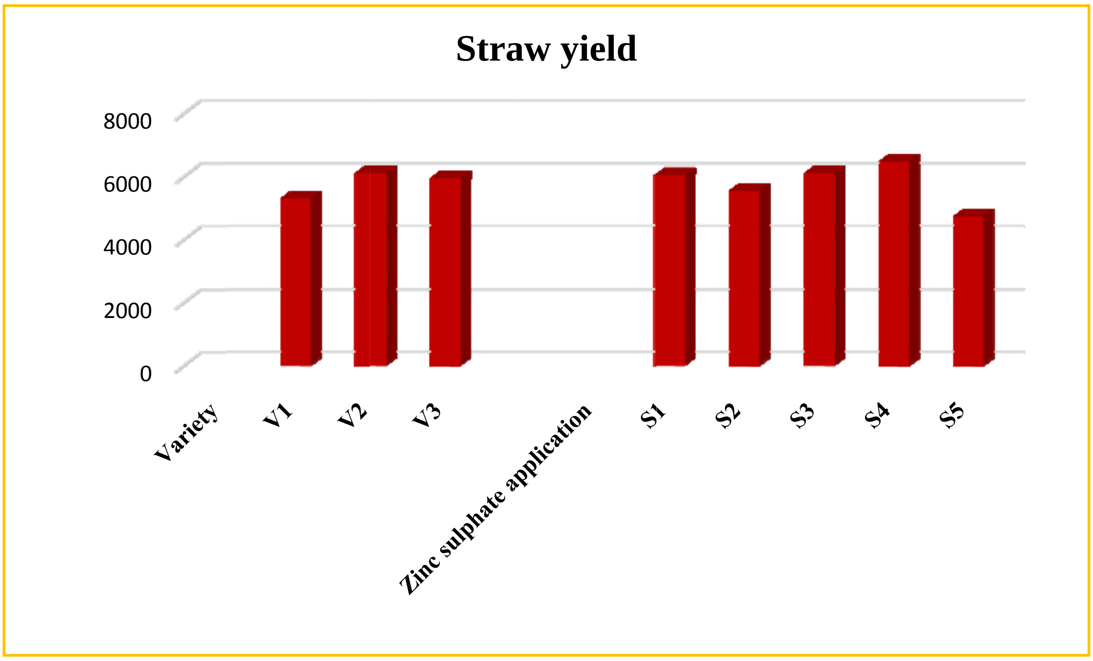


Fig 12.Effect of varieties and zinc sulphate application on net returns (□ ha^{-1}).

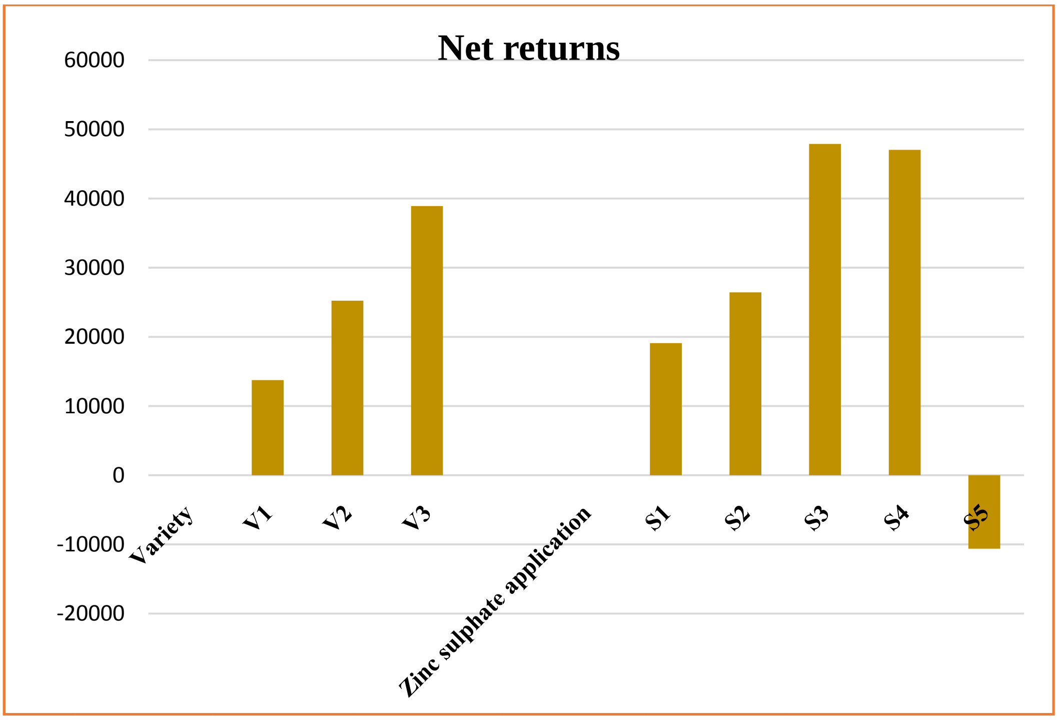
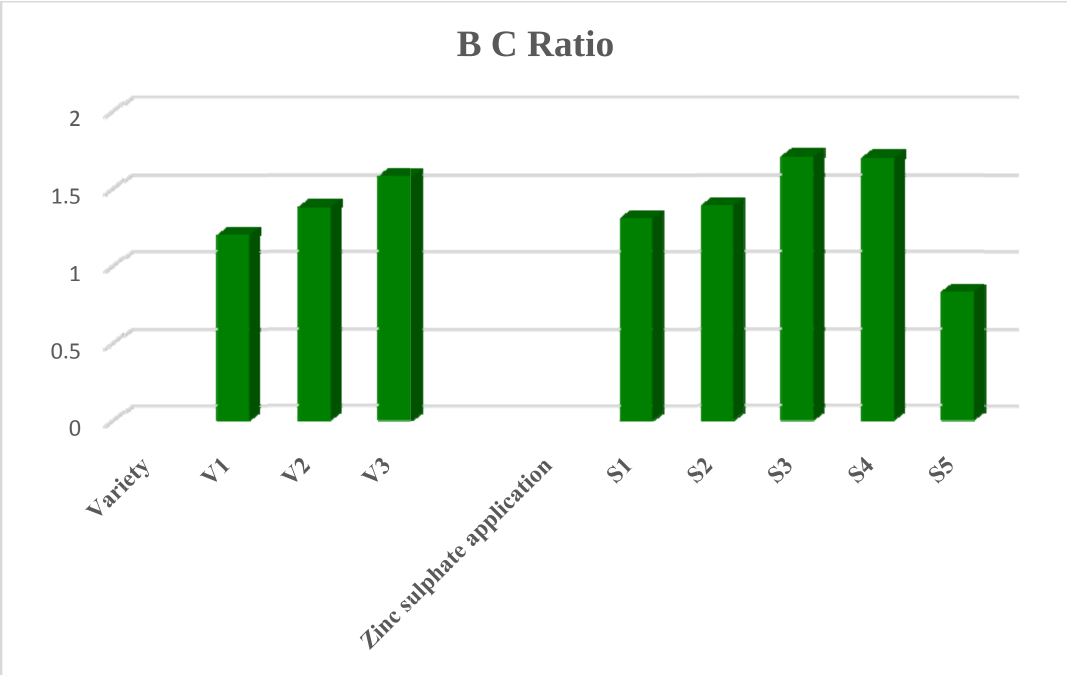


Fig 13. Effect of varieties and zinc sulphate application on B C Ratio.



5.7 EFFECT OF ZINC SULPHATE APPLICATION ON GROWTH PARAMETERS OF THE CROP.

Application of zinc sulphate have improved the growth characters. The parameters like tillers per m^{-2}, LAI, root: shoot ratio and the dry matter production were positively influenced by the application of zinc sulphate. Higher number of tillers per m^{-2} observed in S_3 at 60 DAS might be due to better absorption of zinc through leaves as the foliar application was given during active tillering stage. Similar observations were also made by Tejasarwana, (1991) and Rana and Kashif, (2014).Zinc sulphate application increasedthe enzymatic activity and stimulate the production of Indole Acetic Acid (IAA) which would have resulted in the production of a greater number of tillers m^{-2}. The interaction effect was found to be significant only during 80 DAS and it was highest in the treatment combination V_3S_3.The interaction effect was showing significantly only after, when the crop received the required zinc for its growth.

Leaf area index is an indicator of the photosynthetically active area and the study conducted revealed that the application of zinc had a favorable impact on leaf area index. During early stages of growth (40 DAS) the combination of seed priming and foliar spraying of zinc sulphate had significant effect and it might be due to better establishment of the crop due to seed priming. However, during 60 DAS the crop which received zinc sulphate through soil application have recorded higher leaf area index and it was statistically comparable to other methods of zinc sulphate application implying the fact that the irrespective of the method of application, zinc sulphate application favored the crop growth. These findings are in line with the observation of Nadim *et al.* (2012), Singh and Singh, (2018) and Nataraja *et al.* (2006), who reported that the Zn availability increased the leaf area through improved metabolic activity and auxin production. The interaction effect was only significant during 40 DAS. During 40 DAS the treatment combination V_1S_3recorded higher leaf area index, the differential response of varieties to zinc sulphate application might be the reason behind this.

Root shoot ratio was significantly improved due to zinc sulphate application and this can be attributed to the better growth characteristic of the crop. Better growth and spread of root are a reason for the better root shoot ratio. Increased root dry weight was observed with the application of Zn in upland rice (Fageria, 2002; Fageria and Moreira, 2015). Fageria and Moreira, (2015) also reported that adequate amount of Zn might have improved the root growth which in turn improved the uptake of water and nutrients. These findings pointing the positive effect of Zn in influencing the vegetative growth of the crop. The interaction effect was also found to be significant and it was the highest in V_2S_4.

Zinc sulphate application had significant impact on Dry matter production. Among the methods, the soil application of zinc sulphate recorded the highest dry matter production followed by combined application of seed priming and foliar application, and the lowest was observed in control. The increased dry matter production might be due to the overall enhancement of the growth characters observed in these treatments (Table 8) (Fig 3). The interaction effect of varieties and zinc sulphate application was found to be significant; it was the highest in V_2S_4. It might be due to enhanced accumulation of biomass with soil application of zinc sulphate.

5.8 EFFECT OF ZINC SULPHATE APPLICATION ON PHYSIOLOGICAL PARAMETERS

The crop growth rate was also influenced by zinc sulphate application in all stages of growth and it was observed that the soil application of zinc sulphate had higher influence compared to other methods. Same observation was also made by Nadim *et al.* (2012). The improved leaf area index and crop growth rate can be attributed to the better growth of the crop and also because of the influence of zinc in cell division and cell elongation processes. Influence of zinc in the production of auxin can be a contributing factor to this (Hansch and Mendel 2009). The interaction effect on CGR was significant only at 40 DAS and it was the highest in V_2S_4.

The chlorophyll content was significantly influenced by zinc sulphate application, among the different method's, soil application of zinc sulphate recorded the highest chlorophyll content, which was followed by combination of seed priming and foliar application. Higher chlorophyll content observed in zinc sulphate applied plots might be due to the involvement of zinc in chlorophyll formation through its regulating action on nutrients homeostasis in cytoplasm(Aravind and Prasad, 2004). Likewise, the relative Water Content (RWC) was also found to be significantly affected by zinc application and the RWC was the highest in application of zinc sulphate sulphate through seed priming and foliar spray and the lowest in control (no zinc). This indicates that zinc sulphate application has significant effect on RWC, and the improved RWC might be due improved root growth and root spread which helps in better absorption of water from soil. These results are in line with Fageria and Moreira(2015) and Wasaya *et al.* (2017), they have observed that the root length and root dry weight are improved with application of zinc which have enabled the crop to maintain a good water status in the plant.

The soluble protein content was significantly affected by the application of zinc sulphate application. Among methods of application, foliar application of zinc sulphate recorded higher soluble protein and the lowest was in control. Zinc is an important component of protein in plants, so the application of zinc naturally influences the RNA content which in turn affects the protein content and the total free amino acid content (Brown *et al.,* 1993; Ashraf *et al.,* 2014). The interaction effect of varieties and zinc sulphate application was significant and the effect was the highest in V_3S_4. The proline content was also found to be significantly influenced by the application of zinc and this might be due to the role of zinc in increased production of antioxidant in plants (Bradáčová *et al.,* 2016). Among the methods of application, treatment S_3 (Seed priming @ 2g per Kg of seed + Foliar application during active tillering and panicle initiation @ 0.5 per cent) followed by soil application. Similar observation was made by Babaeian *et al.* (2011);Singh *et al.* (2015) andArough *et al.* (2016). The interaction effect was significant and the treatment combination V_2S_3 recorded the highest. The stomatal conductance was also found to be improved with the application of zinc sulphate and it might be due to its influence of zinc in the activity of carbonic anhydrase and ribulose 1-5- bisphosphate carboxylase/oxygenase (Rubisco). Rubisco is involved in catalysisof diffusion of CO_2 to the chloroplasts (Hatch and Slack, 1970). The interaction effect was significant and the treatment combination V_3S_2 recorded higher stomatal conductance.

5.9 EFFECT OF ZINC SULPHATE APPLICATION ON AVAILABLE NUTRIENTS IN SOIL AFTER THE EXPERIMENT.

The available soil nutrient status was found to be significantly affected by zinc sulphate application. Available nitrogen was the highest in $S_5$where there was no zinc application. The high availability of nitrogen might be due to lower uptake. The availability of zinc was lower in S_4(Soil application of zinc sulphate @ 20 kg per ha) the improved uptake of the nitrogen might be the reason, because positive interaction exists between nitrogen and zinc (Loneragan and Webb, 1993). The available phosphorus content was also found to be affected by the zinc sulphate application. The available phosphorus content was higher in S_4, it might be due to lower uptake as zinc and phosphorus have an antagonistic relationship (Loneragan and Webb, 1993). The uptake of phosphorus was not found to be affected in other treatments.Likewise, the relationship between potassium and zinc is also antagonistic, but not as prominent as in the case of phosphorus and zinc (Sadana and Takkar, 1983). The available potassium was the highest in $S_5$where zinc was not applied. The lower uptake might be due to low dry matter production as presented in table 8. The application of zinc has improved the zinc status in the soil, the availability was high in S_4(soil application @ 20 kg per ha) similar result was observed by Singh *et al.*(2012), where they observed that with application of zinc the zinc status became sufficient from being deficient. They have also reported that the level of N, P and K was improved with application of zinc.

5.10EFFECT OF ZINC SULPHATE APPLICATION ON NUTRIENT UPTAKE BY CROP.

The effect of zinc sulphate application on the uptake of nutrients was found to be significant. The uptake of nitrogen, phosphorus, potassium and zinc was positively influenced by application of zinc sulphate compared to control (S_5). The uptake of nitrogen was higher with soil application of zinc. Zinc application increased the growth of crop due to its effects on photosynthetic rate, which in turn improved the nutrient uptake. Similar results were observed by Rahman *et al.* (2008); Rana and Kashif (2014). The improved uptake in soil application can also be attributed to enhanced nutrient recycling and mineralization of organic matter due to enhanced activity of microorganisms (Lal *et al.,* 2002; Ghoneim, 2016). The interaction effect was also significant. The treatment combination V_2S_4recorded the highest uptake. However, the uptake of phosphorus was higher in application of zinc sulphate through seed priming and foliar spray. The improved uptake through foliar application compared to soil application can be attributed to the antagonistic relation between phosphorus and zinc (Loneragan and webb, 1993). The result is in line with Srivastava *et al.* (2013) who observed that increased concentration of zinc in the soil affects the phosphorus uptake. The interaction effect was also found to be significant and it was the highest in treatment combination V_3S_3. The uptake of potassium was also significantly influenced by zinc sulphate application. Uptake was higher with application of zinc sulphate through seed priming and foliar spray. The better uptake of potassium in treatment S_3 might be due to better establishment of crop and better expression of growth attributes which might have improved the absorption of potassium which resulted in higher content of potassium in grain and straw. This is in line with Sieling *et al.* (2006), Yassen *et al.* (2011),Tharakan and Gite (2018). The interaction effect was also found to be significant and the treatment combination V_2S_3recorded the highest uptake. The uptake of zinc was higher with soil application of zinc sulphate. This was because of higher availability of zinc in soil application. Hossain *et al.* (1989) and Rahman *et al.* (2008) reported that with the increased availability of zinc in soil the uptake was also found to be improved. The interaction effect was also found to be significant and it was highest with V_3S_4.

5.11EFFECT OF ZINC SULPHATE APPLICATION ON YIELD PARAMETERS

The yield parameters like panicles per m^{-2}, filled grains per panicle, sterility percentage, panicle weight and thousand grain weight were found to be positively influenced by the application of zinc sulphate. The number of panicles per $m^{-2}$was found to be the highest in application of zinc sulphate through seed priming and foliar spray followed by soil application. The increased number of panicles observed in these treatments might be due to better growth, establishment and increased production of tillers. Similar observations were made by Dobermann and Fairhurst (2000), Rana and Kashif (2014) and Sarwar *et al.* (2017) have reported that zinc sulphate application improved the productive tillers. The interaction effect was also found to be significant and the highest number of productive tillers in V_3S_3.

Panicle weight was also improved with application of zinc sulphate application. Among the method of application, the highest panicle weight was noted in foliar application of zinc sulphate followed by application of zinc sulphate through seed priming and foliar spray. The higher panicle weight observed in the treatment might be due to better absorption of zinc by the leaves and better accumulation of photosynthates in sink and better development of sink. Increase in panicle weight due to application of zinc sulphate was also reported by Phattarakul *et al.*(2012); Zou *et al.*(2012) and Gupta *et al.* (2016). The interaction effect was also found to be significant and the highest in V_1S_3. It might be due to higher thousand weight and lower sterility percentage recorded in the variety Anna 4. Filled grains per panicle was improved with application of zinc sulphate application and it was the lowest in control. The highest number of filled grains per panicle was observed in application of zinc sulphate through seed priming and foliar spray of zinc sulphate. This could be due to better translocation of assimilates from source to sink. The result obtained were accordance with the findings of Ghoneim, (2016) and Gupta *et al.* (2016). Higher values of yield attributes recorded in zinc sulphate applied treatmentscould be due to the requisitefurnishing of zinc which have improved the uptake and availability of other essential nutrients.With improved nutrient uptake the plant metabolic process wasimprovedand finally the crop growth was improved(Naik and Das 2008). The interaction effect of varieties and zinc sulphate application was also found to be significant and it was the highest in $V_3S_3$and it might be due to the combined effect of varieties and zinc sulphate application.

Application of zinc sulphate had significantly reduced the sterility percentage and it was the lowest in application of zinc sulphate through seed priming and foliar spray followed by foliar application alone and soil application. Lopes *et al.*(1985) have reported the rice crop grown on zinc deficient soil have shown higher sterility percentage and the same can be reduced with application of zinc through any fertiliser source, which implies the availability of zinc have an important role in this parameter. The interaction effect was also found to be effective and the treatment combination V_1S_3 recorded lesser sterility percentage. The thousand grain weight of the crop was also found to be influenced by the application of zinc sulphate and it was the highest with the application of zinc sulphate through seed priming and foliar spraying, followed by foliar spraying and soil application. The improvement in photosynthesis might have resulted in the better accumulation of photosynthates in the grain and might have led to increase in thousand grain weight. Better partitioning of photosynthates with the application of zinc sulphate application was also reported by Yin *et al.* (2016) and Sarwar *et al.* (2017). The interaction effect was also found to be effective and it was highest in V_1S_3.

Grain and straw yields were positively influenced by zinc sulphate application (Fig 10, 11). The highest grain yield was recorded with the application of zinc sulphate through seed priming and foliar spraying followed by application of soil application. Throughout the growth stages crops which received seed priming along with foliar spray at the stage of active tillering and panicle initiation have performed the best in growth parameters and in yield parameters. Yield parameters like number of panicles m^{-2}, filled grains per panicle and thousand grain weight were higher with application of zinc sulphate through seed priming and foliar spray which have finally contributed to better grain yield. Similar observation was made by Sarwar *et al.* (2017). The improved grain yield might be due to better photosynthetic rate, better uptake of nutrient by the plant, better development of the sink structures and accumulation of photosynthates in the sink. Zinc act as an essential component of many enzymes and controls several biochemical processes in the plants which are essential for growth Dobermann and Fairhurst (2000).These might have improved the yield parameters which in turn improved the yield (Chhabra and Kumar, 2018; Zinzala *et al.,* 2019). The interaction effect was also found to be effective and the treatment combination V_3S_3 recorded the higher grain yield. This was due tohigher number of panicles m^{-2} and filled grains per panicle. The straw yield was higher with soil application followed by the combination of seed priming and foliar spray. This can be attributed to the better expression of growth attributes. The amount of available zinc was high with soil application, it might have improved the root characteristics, which might have improved the nutrient uptake and led to increased straw yield as reported by Karak *et al.* (2005), Gupta and Potalia (1991) Rahman *et al.* (2011). The interaction effect was also found to be effective on straw yield. Among the treatment combinations, V_2S_4recorded higher straw yield This due to higher crop growth rate and dry matter production registered in the treatment.

5.12 EFFECT OF ZINC SULPHATE APPLICATION ON ECONOMICS

The net return and B C ratio were higher in S_3 which was seed priming @ 2g kg^{-1} and foliar spraying of zinc sulphate @ 0.5 % at active tillering and panicle initiation stage when compared to soil application of zinc sulphate @ 20 kg per ha (S_4). The net return and B C ratio recorded in all zinc sulphate application method was higher than the control (no zinc sulphate application). The highest net return (□ 47,897.11) and B:C ratio (1.71) was recorded in S_3. This was due to higher grain yield registered in the treatment. Soil application of zinc sulphate recorded the net returns of

 47,041.95 and the B C ratio was 1.70. B C ratio (Fig 12, 13). Though yield was less in soil application of zinc sulphate, the cost involved is less.

The interaction effect was also found to be significant for net returns and B C ratio. The highest net returns and B C ratio was recorded in the treatment combination V_3S_3. This might be due to higher yield registered in the treatment due to the production of higher number of panicles m^{-2} and filled grains per panicle.

CONCLUSION:

After considering the performance of varieties and the effect of zinc sulphate application, it was variety Prathyasa (V_3) which have recorded higher yield, higher net income and B C ratio. Among the zinc sulphate application method, seed priming @ 2 g kg^{-1} seed + Foliar application @ 0.5 per cent during active tillering and panicle initiation stage (S_3) have shown better performance, this treatment recorded the highest yield, higher net income and B C ratio.

Considering the yield, economics and B:C ratio, variety prathyasa (V_3) performed well with application of NPK @ 90:30:45 kg ha^{-1},seed priming with zinc sulphate 2 g kg^{-1} seed + foliar application of zinc sulphate 0.5 per cent at active tillering and panicle initiation stage (S_3) for uplands in red loam tracts of Kerala.

PLATES

PLATES

Plate 1: General view of experiment

After land preparation and layout

During tillering stage.

During maturity stage

Plate 2: Performance of Variety V_1

During 30 DAS

During flowering stage

Plate 3: Performance of Variety V_2

During tillering stage

During flowering stage

Plate 4: Performance of $v_3s_3$at different stages

At 40 Days after sowing

At 60 Days after sowing

During maturity stage

6. SUMMARY

SUMMARY

6. SUMMARY

Experiment entitled “Performance evaluation of rice varieties and their response to zinc nutrition in uplands” was carried out at Coconut Research Station, Balaramapuram during May 2019 to August 2019 to find out a suitable variety and the best method of zinc sulphate application for the red loam tracts of Kerala.

The soil was low in available nitrogen, high in available phosphorus, medium in available potassium and deficient in available zinc content. The experiment was carried out in factorial randomised block design (RBD), with three replications. Two factors were there, variety (V) with three levels and method of zinc sulphate application (S) at five levels.

3. Factor A: Variety (V) – 3
   V_1: Anna 4
   V_2: APO 1
   V_3: Prathyasa
4. Factor B: $ZnSO_4$ Application (S) – 5
   S_1: Seed priming with $ZnSO_4$ @ 2g kg^{-1} seed
   S_2: Foliar application with $ZnSO_4$ @ 0.5 percent at active tillering stage and panicle initiation stage
   S_3: $S_1 + S_2$
   S_4: Soil application of $ZnSO_4$ @ 20 kg ha^{-1}
   S_5: Control

Treatment combination:

V_1S_1	V_1S_2	V_1S_3	V_1S_4	V_1S_5
V_2S_1	V_2S_2	V_2S_3	V_2S_4	V_2S_5
V_3S_1	V_3S_2	V_3S_3	V_3S_4	V_3S_5

Important results obtained and conclusions drawn from the experiment is presented here:

- Among the growth characters, only plant height remained unaffected by zinc sulphate application.
- The growth parameters like tillers m^{-2}, Leaf Area Index (LAI) and dry matter production was higher in variety V_3 (Prathyasa) and the variety V_2(APO 1) recorded higher plant height and root shoot ratio.
- Likewise, application of zinc sulphate through seed priming @ 2g kg^{-1} seed + Foliar application @ 0.5 percent at active tillering stage and panicle initiation stage have recorded higher tillers m^{-2} and Leaf Area Index (LAI). However, the root shoot ratio and Dry Matter Production (DMP) was higher with soil application @ 20 kg ha^{-1}.
- The interaction between the two factors were also found to be significant in all growth parameters except plant height. So, we can conclude that among the varieties the growth pattern differs and their response to zinc sulphate application also varies.
- The Crop Growth Rate (CGR), Relative Water Content (RWC) and proline content was higher in variety V_2 (APO 1) but soluble protein content and stomatal conductance was higher in Prathyasa (V_3). However, chlorophyll content was not significantly affected by varieties.
- Application of zinc sulphate had significant effect on physiological parameters and the effect varied between the methods. Soil application of zinc sulphate @ 20 kg ha^{-1} have improved the Crop Growth Rate (CGR) and the chlorophyll content compared to other methods of application.
- Among zinc sulphate application method S_3(seed priming @ 2g kg^{-1} seed + Foliar application @ 0.5 percent at active tillering stage and panicle initiation stage) recorded higher Relative Water Content (RWC), Soluble protein and proline content. However, the stomatal conductance was higher with S_2 (Foliar application with $ZnSO_4$ @ 0.5 percent at active tillering stage and panicle initiation stage).
- All the varieties recorded significant difference in all yield parameters except days to 50 per cent flowering.

- The yield determining characters like number of panicles per m^{-2} and filled grains per panicle were higher for variety V_3(Prathyasa) and the highest yield was recorded by the same variety.
- Other parameters like panicle length and thousand grain weight was higher for variety V_1 (ANNA 4) and the same variety recorded the lowest sterility percentage.
- Variety V_2(APO 1) recorded the highest panicle weight and straw yield
- All the three varieties differed in their performance because of the difference in their genetic makeup and their adaptability to the environment.
- The application of zinc sulphate has positively influenced the yield attributing characters and the yield.
- Among the method of application S_3(seed priming @ 2g kg^{-1} seed + Foliar application @ 0.5 percent at active tillering stage and panicle initiation stage) recorded the highest number of panicles m^{-2}, filled grains per panicle, the lowest sterility percentage.
- The same treatment recorded the highest thousand grain weight and yield.
- Panicle length was not influenced by application of zinc sulphate.
- Panicle weight was the highest with foliar application with $ZnSO_4$ @ 0.5 percent at active tillering stage and panicle initiation stage.
- The highest straw yield was recorded with the soil application of $ZnSO_4$ @ 20 kg ha^{-1}.
- The available nutrient status of the soil after the experiment was significantly influenced by the application of zinc sulphate.
- The uptake of nutrients by the crop varied with varieties. Variety V_3(Prathyasa) recorded higher uptake of phosphorus and zinc. Meanwhile variety V_2 (APO 1) recorded higher uptake of potassium. Uptake of nitrogen was not significantly affected by the varieties.
- Application of zinc have improved the uptake of all nutrients; the method of application had a big hand in uptake of phosphorus.
- The phosphorus uptake was less with soil application of zinc sulphate, it might be due to antagonistic relationship of zinc and phosphorus. The lowest uptake was in control. The highest uptake was recorded in S_3 (seed priming with

$ZnSO_4$@ 2g kg^{-1} seed + Foliar application with $ZnSO_4$@ 0.5 percent at active tillering stage and panicle initiation stage).

- Uptake of nitrogen and zinc uptake was higher with soil application of $ZnSO_4$@ 20 kg ha^{-1}. Uptake of potassium was higher with seed priming with $ZnSO_4$@ 2g kg^{-1} seed + Foliar application with $ZnSO_4$@ 0.5 percent at active tillering stage and panicle initiation stage.
- The net returns and B C ratio were higher in variety Prathyasa (V_3) and it was higher in S_3(seed priming with $ZnSO_4$@ 2g kg^{-1} seed + Foliar application with $ZnSO_4$@ 0.5 percent at active tillering stage and panicle initiation stage).
- Considering the yield, economics and B:C ratio, variety prathyasa (V_3) performed well with application of NPK @ 90:30:45 kg ha^{-1},seed priming with zinc sulphate 2 g kg^{-1} seed + foliar application of zinc sulphate 0.5 per cent at active tillering and panicle initiation stage (S_3) for uplands in red loam tracts of Kerala.

REFERENCE

7 REFERENCE

Akanda, M. A. L., Alam, M. S. and Uddin, M. M. 1997. Genetic variability, correlation and path analysis in maize (Zea mays L.) inbreds. *Bangladesh J. Pl. Breed. Genet.* 10(2): 57-61.

Alam, M.M., Hasanuzzaman, M. and Nahar, K. 2009a. Growth Pattern of Three High Yielding Rice Varieties under Different Phosphorus Levels.*Adv. Biol. Res.* 3: 110-116.

Alam, M.M., Ali, M.H., Ruhulamin, A.K.M. and Hasanuzzaman, M. 2009b. Yield attributes, yield and harvest index of three irrigated rice varieties under different levels phosphorus.*Adv. Biol. Res.* 3: 132-139.

Aravind P. and Prasad M.N.V. 2004. Zinc protects chloroplasts and associated photochemical functions in cadmium exposed Ceratophyllum demersum L. a freshwater macrophyte. *Plant Sci.*166: 1321–1327.

Arif, M., Shehzad, M. A., Bashir, F., Tasneem, M., Yasin, G. and Iqbal, M. 2012. Boron, zinc and microtone effects on growth, chlorophyll contents and yield attributes in rice (Oryza sativa L.) cultivar. *Afr. J. Biotechnol.* 11(48): 10851-10858.

Arough, Y.K.,Sharifi, R.S., Sedghi, M., Barmak, M. 2016. Effect of Zinc and Bio Fertilizers on Antioxidant Enzymes Activity, Chlorophyll Content, Soluble Sugars and Proline in Triticale Under Salinity Condition.*Not. Bot. Horti. Agrobo.* 44(1):116-124.

Ashraf, M. Y., Iqbal, N. Ashraf, M. and Akhter, J. 2014. Modulation of physiological and biochemical metabolites in salt stressed rice by foliar application of zinc.*J. Plant Nutr.* 37(3): 447-457.

Atlin, G.N., Lafitte, H.R., Tao, D., Laza, M., Amante, M. and Courtois, B. 2006. Developing rice cultivars for high-fertility upland systems in the Asian tropics. *Field Crops Res.* 97: 43–52.

Bailey, S., Thompson, E., Nixon, P.J., Horton, P., Mullineaux, C.W., Robinson, C. and Mann, N.H. 2002. A critical role for the Var2 FtsH homologue of Arabidopsis thaliana in the photosystem II repair cycle in vivo. *J. Biol. Chem.* 277:2006–2011.

Babaeian, M., Tavassoli, A., Ghanbari, A., Esmaeilian, Y., Fahimifard, M. 2011. Effects of foliar micronutrient application on osmotic adjustments, grain yield and yield components in sunflower (Alstar cultivar) under water stress at three stages. *Afr. J. Agric. Res.* 6:1204–1208.

Bates, L.S., Waldren, R.P. and Teare, I.D. 1973. Rapid determination of free proline for water stress studies. *Plant Soil*.39: 205-207.

Biswas, P. S., Prasad, B. and Dewan, S. B. A. 2000. Variability, character association and path analysis in rice (Oryza sativa L.). *Bangladesh J. Pl. Breed. Genet.* 13(1): 19-25.

Boonchuay, P., Cakmak, I., Rerkasem, B. and Prom-U-Thai, C. 2013. Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice.*Soil Sci. Plant Nutr.* 59(2): 180-188.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils. *Agron. J.* 54(5): 464.

Bradáčová, K., Weber, N.F., Morad-Talab, N., Asim, M., Imran, M., Weinmann, M., Neumann, G. 2016. Micronutrients (Zn/Mn), seaweed extracts, and plant growth-promoting bacteria as cold-stress protectants in maize. *Chem. Biol. Technol. Agri.* 3:19p.

Bradford, M.M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.* 72(1): 248-254.

Brown P.H., Cakmak, I., and Zhang, Q. 1993. Form and function of Zinc in Plants, In: A.D. Robson (ed.), *Zinc in soil and plants*. Kluwer academic publishers, Dordrecht, Netherlands. pp. 93-106.

Cakmak, I. 2000. Role of Zn in protecting plant cells from reactive oxygen species. *New Phytol.* 146:185–205.

Cheema, N. M., Ullah, N. and Khan, N.K. 2006. Effect of Zn on the panicle structure and yield of coarse rice-IR – 6. *Pakist. J. Agric. Res.*19(4): 33-37.

Chhabra, V. and Kumar, R. 2018. Role of zinc application on rice growth and yield.*Plant Arch.* 18 (2): 1382-1384.

Choudhury, P. K. D. and Das, P. K. 1997. Genetic variability, correlation and path analysis in deep water rice. *J. Agril. Sci. Soc.* 10(1): 155-157.

Chutipaijit, S., Cha-um, S. and Sompornpailin, K. 2009. Differential accumulations of proline and flavonoids in indica rice varieties against salinity *Pak. J. Bot.* 41(5): 2497-2506.

Das, S. and Green, A. 2013. Importance of zinc in crops and human health. *J. SAT. Agric. Res.* 11:1–7.

Dasgupta, P., Das, B. S. and Sen, S. K. 2015. Soil water potential and recoverable water stress in drought tolerant and susceptible rice varieties. *Agric. Water Manag.* 152: 110–118.

De Datta, S. K., Malabuyoc, J. A., Bernasor, P.C., Abilay, W.P., Obcemea, W. N., Migo, T.R. and Llagas, M.A. 1988. Upland Rice: Varietal performance, yield constraints, weed control and other technology. *Philipp. Crop Sci.* 13(1): 51-60.

Dessie, A., Zewdu, Z., Worede, F. and Bitew, M. 2018. Yield stability and agronomic performance of rain fed upland rice genotypes by using GGE Bi-plot and AMMI in north west Ethiopia. *Int. J. Res. Stud. Agric. Sci.*4(6): 1-7.

Dixit, S., Singh, A., and Kumar, A. 2014. Rice breeding for high grain yield under drought: A strategic solution to a complex problem. *Int. J. Agron.*pp 1–15.

Dobermann, A. and Fairhurst, T. 2000.Rice: Nutrient disorders and nutrient management. International Rice Research Institute, Manila, Philippines.

Dore, V., Koti, R. V. and Hanamaratti, N. G. 2018. Impact of zinc application on morphological and biophysical parameters of rice genotypes in pot experiment. *Adv. Res.* 16 (2): 1-7.

Dubey, Y.P. and Sharma, S.K. 1996. Effect of irrigation and fertilizers on growth, yield and nutrient uptake by wheat (Triticum aestivum). *Indian J Agron.* 41:48–51

El-Khoby, W.M. 2004. Study the effect of some cultural practices on rice crop. Ph. D. (Ag) thesis, Faculty of Agriculture, Kafr El-sheikh, Tanta University.140p.

Fageria, N.K. 1992.*Maximizing Crop Yields*. Marcel Dekker, New York. 274pp.

Fageria, N. K. 2002. Micronutrients' influence on root growth of upland rice, common bean, corn, wheat, and soybean.*J. Plant Nutr*. 25(3): 613–622.

Fageria,N.K. and Moreira, A. 2015. Zinc-Use Efficiency in Upland Rice Genotypes, Communications in Soil Science and Plant Analysis, 46(1): 94-108.

Ghani, A., M. Shah and D.R. Khan. 1990. Response of rice to elevated rates of Zn in mountainous areas of Swat. *Sarhad J. Agric.* 6: 411-415.

Ghoneim, A.M. 2016. Effect of different methods of Zn application on rice growth, yield and nutrients dynamics in plant and soil.*J. Agric. Ecol. Res. Int.*6(2): 1-9.

Gill, R.I.S., Singh, B., Kaur, N., Luna, R.K. 2007. Evaluation of crops in poplar plantation with three spacing in two row directions. *Indian For.* 133:45–57.

Gill, R. I. S., Singh, B., and Kaur, N. 2009. Productivity and nutrient uptake of newly released wheat varieties at different sowing times under poplar plantation in north-western India. *Agrofor. Syst.*76(3): 579–590.

Gomaa, M. A.,Radwan, F.I., Kandil, E.E. and Gharib, A.F. 2015. Effect of Nitrogenous Sources and Zinc application Method on Productivity and Quality of Rice (Oryza sativa L.) *Middle E. J. Appl. Sci.*5(4): 913-919.

Graham, R. D. and Rengel, Z. 1993. Genotypic Variation in Zinc Uptake and Utilization by Plants. In: Robson, A.D. (ed.) *Zinc in Soils and Plants*.Kluwer Academic Publishers, Berlin, Germany.107–118.

Guo, J. X., Feng, X. M., Hu, X. Y., Tian, G. L., Ling, N., Wang, J. H., Shen, Q. R. and Guo, S. W. 2016. Effects of soil zinc availability, nitrogen fertilizer rate and zinc fertilizer application method on zinc biofortificationof rice.*J. Agric. Sci.* 154: 584-597.

Gupta, L. K. and Potalia, U. P. 1991. Response of Zn contraction on grain and straw yield of rice. *Indian J. Soc. Soil Sci.* 39(1): 32-44.

Gupta, N., Ram, H., and Kumar, B. 2016. Mechanism of Zinc absorption in plants: uptake, transport, translocation and accumulation. *Rev. Environ. Sci. Biotechnol.*15(1): 89-109.

Hansch, R.and Mendel, R.R. 2009. Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Curr. Opin. Plant Biol.* 12:259–266.

Hasamuzzaman, M., Fujita, M., Islam, M.N., Ahamed, K.U. and Nahar, K. 2009. Performance of four irrigated rice varieties under different levels of salinity stress.*Int. J. Integrative Biol.*6(2): 85p.

Hatch, M.D.and Slack, C.R. 1970. Photosynthetic CO_2 fixation pathways. *Annu. Rev. Plant Physiol.* 21:141–162.

Hossain, A., and Islam, M.R. and Mian, N.A.1989. Response of rice to sulphur and zinc fertilization. *Bd. J. Agril. Sci.* 16(2): 131-134.

Iftekharuddaula, K. M., Badshah,M. A., Hassan, M. S., Bashar M. K. and Akter. K. 2001. Genetic variability, character association and path analysis of yield components in irrigated rice (Orya sativa L.). *Bangladesh J. Pl. Breed. Genet.* 14(2): 43-49.

Imtiaz, M., Rashid, A., Khan, P., Memon, M. Y. and Aslam, M.2010. The role of micronutrients in crop production and human health. *Pak. J. Bot.* 42: 2565 - 2578.

Islam, R. 2015. Effect of boron and zinc on the growth and yield of t. aman rice (BRRI dhan34). M.Sc. (Ag) thesis. Sher-E-Bangla agricultural university,Dhaka.

Islam, M.A., Islam, M.R. and Sarker, A.B.S. 2008. Effect of phosphorus on nutrient uptake of japonica and indica rice. *J. Agric. Rural Dev.* 6(1): 7–12.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Ltd., New Delhi, India.929p.

Kabaki, N. 1993. Growth and yield of japonica-indicia hybrid rice. *Jpn. Agric. Res. Q.* 27:88-94.

Karak, T., Singh, U.K., Das, S., Das, D.K. and Kuzyakov, Y. 2005. Comparative efficacy of $ZnSO_4$ and Zn-EDTA application for fertilization of rice (Oryza sativa L.).*Arch. Agron. Soil Sci.* 51(3): 253-264.

Karim, D., Sarkar, U., Siddique, M.N.A., Khaleque miah, M. A. and Hasnat, M. Z. 2007. Variability and genetic parameter analysis in aromatic rice.*Int. J. Sustain. Crop Prod.* 2(5):15-18.

Khalifa, A.A.A., El-khoby, W. and Okasha, E.M. 2014. Effect of sowing dates and seed rates on some rice cultivars. *Afr. j. Agric. Res.* 9(2): 196-201.

Kohli, R.K., Singh, H.P. and Batish, D.R. 1997. Phytotoxic potential of Populus deltoides Bartr. Ex. Marsh. I. Comparative contribution of different parts. *Indian J. For.* 20:300–304.

Kulhare, P.S., Tagore, G.S. and Sharma, G.D. 2017.Effect of foliar spray and sources of zinc on yield, zinc content and uptake by rice grown in avertisol of central India. *Int. J. Chem. Stud.* 5(2): 35-38.

Kumar, A., Nayak, A. K., Pani, D. R. and Das, B. S. 2017. Physiological and morphological responses of four different rice cultivars to soil water potential based deficit irrigation management strategies. *Field Crops Res.* 205: 78–94.

Lal, B., Majumdar, B., Venkatesh, M.S. 2002. Individual and interactive effects of phosphorus and zinc in lowland rice. *Indian J. Hill Farming.* 13:44–46.

Lestari, A. P., Suwarno, Trikoesoemaningtyas, Sopandie, D. and Aswidinnoor, H. 2015. Panicle length and weight performance of F3 population from local and introduction hybridization of rice varieties. *Hayati J. Biosci.* 22(2): 87–92.

Lindsay, W. L. and Norwell, W. A. 1978. Development of a DTPA soils test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* 42: 421-8.

Loneragan, J.F. and Webb, M.J. 1993. Interactions Between Zinc and Other Nutrients Affecting the Growth of Plants.In: Robson. A.D. (ed.), *Zinc in soils and plants.* Kluwer Academic Publishers, Netherlands, pp.119-134.

Lopes, M.S., Santos, O.S.D., Carol, J. T. and Cloche, B. 1985. The effect of trace elements on the yield of irrigated rice. Pilots Brazil: p: 226-234.

Main, M.A. 2006. Influence of planting technique Phosphorus Nutrition in Rice. Information from on growth and yield of aman rice. M.Sc. (Ag)thesis, Sher-e-Bangla Agricultural University, Dhaka, 112p.

Mayamulla, S., Weerarathne, L. V. Y., Marambe, B., Sirisena, D. N. and Suriyagoda, L. D. B. 2017. Variation in seed nutrient content, seedling growth and yield of rice varieties grown in a paddy field without application of fertilisers for forty years. *Crop Pasture Sci.* 68 (4):337–48.

Mobasser, H. R., Delarestaghi, M.M., Khorgami, A., Tari, D.B. and Pourkalhor, H. 2007. Effect of planting density on agronomical characteristics of rice (Oryza sativa L.) varieties in north of Iran. *Pakist. J. Biol. Sci.*10: 3205-3209.

Mohsin, A. U., Ahmad, A. U. H., Farooq, M. and Ullah, S. 2014. Influence of zinc application through seed treatment and foliar spray on growth, productivity and grain quality of hybrid maize. *J. Anim. Plant Sci.*24(5): 1494-1503.

sMunirah, N., Khairi, M., Nozulaidi, M. and Jahan, M. 2015. The Effects of Zinc Application on Physiology and Production of Corn Plants. *Aust. J. Basic Appl. Sci.* 9(2): 362-367.

Nadim, M. A., Awan,I. U., Baloch, M. S., Khan,E. A., Naveed, K. and Khan, M. A. 2012. Response of wheat (Triticum aestivum l.) to different micronutrients and their application methods.*J. Anim. Plant Sci.* 22(1):113-119.

Naik, S. K. and Das, D. K. 2008. Relative performance of chelated zinc and zinc sulphate for lowland rice (Oryza sativa L.). *Nutr. Cycling Agroecosystems.* 81: 219–227.

Namai, S., Toriyama, K., and Fukuta, Y. 2009. Genetic variations in dry matter production and physiological nitrogen use efficiency in rice (Oryza sativa L.) varieties. *Breed. Sci.* 59(3): 269–276.

Nataraja, T. H., Halepyati, A. S., Pujari, B. T. and B. K. Desai. 2006. Influence of phosphorus levels and micronutrients on the physiological parameters of wheat. *Karnataka J. Agri. Sci.* 19(3): 685-687.

Obaidullah, M. 2007. Influence of clonal tillers age on growth and yield of inbred and hybrid rice. M.Sc. (Ag) thesis. Sher-e-Bangla agricultural university. Dhaka.120p.

Ozturk, L., Yazici, M., Yucel, C., Torun, A., Cekic, C., Bagci, A., Ozkan, H., Braun, H., Sayers, Z. and Cakmak, I. 2006. Concentration and localization of zinc during seed development and germination in wheat. *Physiol. Plant.* 128: 144–152.

Palanisamy, K. H. and Gomez, K.A. 1974. Length-width method for estimating leaf area for rice. *Agron. J.* 66: 430-33.

Palmgren, M.G., Clemens, S., Williams, L., Kramer, U., Borg, S., Schjorring, K. and Sanders, D. 2008. Zinc biofortification of cereals: problems and solutions. *Trends Plant Sci*. 13: 464–473.

Parihar, S.S. and Tiwari, R.B. 2003. Effect of irrigation and nitrogen level on yield, nutrient uptake and water use of late-sown wheat (Triticum aestivum). *Indian J. Agron.* 48:103–107.

Pedda-Babu, P., Shanti,M., Prasad, B.R. and Minhas, P.S. 2007. Effect of zinc on rice in rice –black gram cropping system in saline soils. *Andhra Agric. J.* 54 (1-2): 47-50.

Peng, S., Yang, J., Garcia, F.V., Laza, R.C., Visperas, R.M., Sanico, A.L., Chavez, A.Q. and Virmani, S.S. 1998. Physiology-based crop management for yield maximization of hybrid rice. In: Virmani, S.S., Siddiq, E.A. and Muralidharan, k.(eds),*Advances in Hybrid Rice Technology*. Proceedings of the 3rd International Symposium on Hybrid Rice, Hyderabad, India, pp 157- 176.

Phattarakul, N., Rerkasem, B., Li, L.J., Wu, L.H., Zou, C.Q., Ram, H., Sohu, V.S., Kang, B.S., Surek, H., Yazici, A., Zhang, F.S., Cakmak, I. 2012. Biofortification of rice grain with zinc through zinc fertilization in different countries. *Plant Soil*. 361: 131–141.

Phuphong, P., Cakmak, I., Yazici, A., Rerkasem, B.and Prom-u-Thai, C. 2020. Shoot and root growth of rice seedlings as affected by soil and foliar zinc applications, *J. Plant Nutr.*

Poudel, A.P., Thapa, B., Subedi, S., Subedi, M., Poudel, H.P. and Ranabhat, R.B. 2014. Upland rice varietal trial for the Tars of western hills of Nepal. In: Proceedings of 11th National outreach workshop, Lumle, Kaski:1-5.

Prom-u-thai, C., Rerkasem, B., Yazici, A. and Cakmak, I. 2012. Zinc priming promotes seed germination and seedling vigor of rice. *J. Plant Nutr. Soil Sci.* 2012. 175: 482-488.

Rahman, K.M.M., Chowdhury, A.K., Sharmeen, F., Sarkar, A., Hye, M. A. and Biswas, G.C. 2011. Effect of zinc and phosphorus on yield of Oryza sativa (cv. BR-11). *Bangladesh Res. Pub. J.* 5(4): 351-358.

Rahman, M. T., Jahiruddin, M., Humauan, M. R., Alam, M. J. and Khan, A. A. 2008. Effect of sulphur and zinc on growth, yield and nutrient uptake of boro rice (cv. BRRI Dhan 29). *J.Soil.Nature.* 2(3): 10-15.

Rameshraddy, Pavithra, G. J., Reddy, B. H. R., Salimath, M., Geetha, K. N. and Shankar, A. G. 2017. *Ind J Plant Physiol.*22(3): 287-294.

Rana, W.K. and Kashif, S.R. 2014. Effect of different Zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw.*J. Environ. Agric. Sci.*1:9p.

Sadana, U.S. and Takkar, P.N. 1983. Effect of calcium and magnesium on ^{65}zinc absorption and translocation in rice seedlings. *J. Plant Nutr.*6(8): 705-715.

Samreen, T., Shah, H.U., Ullah, S., Javid, M. 2013. Zinc effect on growth rate, chlorophyll, protein and mineral contents of hydroponically grown mung beans plant (Vigna radiata). *Arabian J. Chem.*10(2): 1802-1807.

Sarwar, N., Ali, H. andRehman, A. 2017. Zinc fertilization improves the aerobic rice productivity. Proceedings of the 18th Australian Society of Agronomy Conference, 24 – 28 September 2017, Ballarat, Australia.

Sieling, K., Brase, T. and Svib, V. 2006. Residual effects of different N fertilizer treatments on growth N uptake and yield of oil seed rape, wheat and barley. *Europ. J. Agron.* 25: 40-48.

Shereen, A., Ansari,R.U., Yamin, S., Raza,S., Mumtaz, S., Khan, M.A. and Mujtaba, S.M. 2007. Physiological responses of rice (Oryza sativa L.) to saline stress. *Pak. J. Bot.* 39: 2527-2534.

Shrestha, S., Asch, F., Dusserre, J., Ramanantsoanirina, A. and Brueck, H. 2012. Climate effects on yield components as affected by genotypic responses to variable environmental conditions in upland rice systems at different altitudes. Field crops Research. 134: 216-228.

Singh, Y. V. 2012. Crop and water productivity as influenced by rice cultivation methods under organic and inorganic sources of nutrient supply. *Paddy Water Environ.* 11: 531–542.

Singh, A.K., Manibhushan, Meena, M.K. and Upadhyaya, A. 2012. Effect of sulphur and zinc on rice performance and nutrient dynamics in plants and soil of Indo Gangetic Plains. *J. Agric. Sci.* 4(11): 162-170.

Singh, Singh, A. K., Sharma, P. and Singh, P. K. 2013. Studies on Genetic Characteristic of Upland Rice (Oryza sativaL.). *Int. J. Agric. Environ. Biotechnol.* 6(4): 515p.

Singh, A.K. and Singh, V.2018. Effect of Foliar Application of Iron, Zinc and Age of Seedlings on Growth and Yield of Rice (Oryza sativa L.). *Int. J. Curr. Microbiol. Appl. Sci.*7(8):1062-1068.

Singh, D., Ram,P.C., Singh, A., Singh,Y. P., Sharma, P. C., and Srivastava,S. 2015. Alleviating adverse effect of soil salinity on biomass production and physiological changes in wheat (Triticum aestivum L.) through application of zinc fertilizer.*Res. Environ. Life Sci.* 8(2): 251-254.

Slaton, N. A., Wilson, C. E., Ntamatungiro, S., Norman, R.J. and Boothe, D.L. 2001. Evaluation of Zinc Seed Treatments for Rice. *Agron. J.* 93: 152-157.

Slatyer, R.O. 1967. Plant Water Relationships. Academic press, London. 160p.

Song, X., Agata, W. andKawamitsu, Y. 1990. Studies on dry matter and grain production of F1 hybrid rice in China. II. Characteristics of grain production. *Jpn. J. Crop Sci.* 59:29-33.

Srivastava, P.C., D. Ghosh and V.P. Singh. 1999. Evaluation of different zinc sources for lowland rice production. Biol. Fert. Soils. 30: 168-172.

Srivastava, P.C., Bhatt, M., Pachauri, S.P. and Tyagi, A.K. Effect of zinc application methods on apparent utilization efficiency of zinc and phosphorus fertilizers under basmati rice–wheat rotation. 2013. *Arch. Agron. Soil Sci.* 60(1): 33-48.

Subbiah, B.V. and G.L. Asijia. 1956. A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci.* 25: 259–260.

Sultana, A., Zahan, M.S., Islam, S.A., Akter, N., Mahbub, M.M. andIssak, M. 2020. Response of transplanting date on growth and yield components of selected advanced genotypes of short duration T. Aman rice.*Eco-friendly Agril. J.* 13(03):23-29.

Suman, B.M. 2018. Nutrient scheduling for upland rice intercropped in coconut. M.Sc(Ag.) thesis, Kerala Agriculture University, Thrissur, India. p. 171.

Sun, H., Qian, Q., Wu,K., Luo,J., Wang,S., Zhang,C., Ma, Y., Liu,Q., Huang, X., Yuan, Q.2014. Heterotrimeric G proteins regulate nitrogen-use efficiency in rice. *Nat. Genet.* 46 (6):652–656.

Suriyagoda, L., Sirisena, D., Kekulandara, D., Bandaranayake, P., Samarasinghe, G. and Wissuwa, M. 2019. Biomass and nutrient accumulation rates of rice cultivars differing in their growth duration when grown in fertile and low-fertile soils. *J. Plant Nutr.* 1–19.

Takkar, P.N., Mann, M.S., Bansal,R.L., Randhawa,N.S., and Singh,H. 1976. Yield and uptake response of corn to zinc as influenced by phosphorus fertilisation.*Agron.j*. 68: 942-946.

Tejasarwana, R. 1991. The effect of Zn, N and P fertilizers on the yield of low land rice. Media-PanelitionSukamandi (Indonesia), 10: 17-20.

Tharakan, M. and Gite, P.A. 2018. Effect of zinc application on yield, growth characters and nutrient uptake by paddy (Oryza sativa. L).*J. Pharmacognosy Phytochemistry*.7(5): 1726-1729.

Walkley, A. and Black, I. A. 1934. An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37(1): 29 – 38.

Wasaya, A., Shabir, M. S., Hussain, M., Ansar, M., Aziz, A., Hassan, W. and Ahmad, I. 2017. Foliar application of Zinc and Boron improved the productivity and net returns of maize grown under rainfed conditions of Pothwar plateau *J. Soil Sci. Plant Nutr.* 17 (1): 33-45.

Watson, D. J. 1958. The dependence of net assimilation rate on leaf-area index. *Ann. Bot.* 22(1): 37-54.

Wissa, M.T. 2017. Response of Egyptian Hybrid Rice One Cultivar to Zinc Sulphate, Potassium Sulphate and Magnesium Silicate as Foliar Application.*J. Plant Prod.*8(11): 1085 – 1092.

Xie, G., Yu, J., Wang, H., and Bouman, B. 2008. Progress and yield bottleneck of aerobic rice in the north china plain: A case study of varieties Handao 297 and Handao 502. *Agric. Sci. China*. 7(6): 641–646.

Yamauchi, M. 1994. Physiological bases of higher yield potential in F1 hybrids. In: Virmani, S.S.(ed.)*Hybrid rice technology: new developments and future prospects*. International Rice Research Institute, Manila, Philippines.pp71-80.

Yang, X. and Sun, X. 1989. Characteristics of F1 hybrid rice roots. In: *Hybrid rice*. International Rice Research Institute, Manila, Philippines.pp. 159-164.

Yassen, A.A., Hellal, F.A. and Abo-Basha, D.M. 2011. Influence of Organic Materials and Foliar Application of Zinc on Yield and Nutrient Uptake by Wheat Plants.*J. Appl. Sci. Res.* 7(12): 2056-2062.

Yin, H., Gao, X., Stomph, T., Li, L., Zhang, F.and Zou, C. 2016. Zinc Concentration in Rice (Oryza Sativa L.) Grains and allocation in plants as affected by different zinc fertilization strategies.*Commun. Soil Sci. Plant Anal.* 47(6): 761-768.

Yoshida, S., Forno, D.A., Cock, Y.H. and Gomez, K.A. 1976. Laboratory Manual for Physiological Studies of Rice. Los Banos, Philippines. 61p.

Yoshida, H., Horie, T. and Shiraiwa, T. 2006. A model explaining genotypic and environmental variation of rice spikelet number per unit area measured by cross-locational experiments in Asia. *Field Crops Res.* 97: 337–343.

Yoshinaga, S., Takai, T., Arai-Sanoh, Y., Ishimaru, T. and Kondo, M. 2013. Varietal differences in sink production and grain-filling ability in recently developed high-yielding rice (Oryza sativa L.) varieties in Japan. *Field Crops Res.* 150: 74–82.

Zayed, B.A., Elkhoby, W.M., Shehata, S.M.and Ammar, M. H. 2007. Role of potassium application on the productivity of some inbred and hybrid rice varieties under newly reclaimed saline soils. African Crop Science Conference Proceedings, Rice Research and training center, Sakha, Kafr El- Sheikh. 8: pp. 53-60.

Zinzala, V. N., Narwade, A.V., Karmakar, N. and Patel, P.B. 2019. Influence of Zinc Applications on Photosynthesis, Transpiration and Stomatal Conductance in Kharif Rice (Oryza sativa L.) Genotypes.*Int. J. Curr. Microbiol. App. Sci.* 8(10): 150-168.

Zou, C.Q., Zhang, Y.Q., Rashid, A., Ram, H., Savasli, E., Arisoy, R.Z., Ortiz-Monasterio, I., Simunj, S., Wang, Z.H., Sohu, V. and Hassan, M. 2012. Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant Soil.* 361: 119–130.

ABSTRACT

8 ABSTRACT

A field trial entitled "Performance evaluation of rice varieties and their response to zinc nutrition in uplands" was conducted during Kharif 2019 (May – August 2019) at Coconut Research Station, Balaramapuram. The objective of the study was to find out a suitable rice variety for uplands in red loam tracts of Kerala and to standardize the dose and method of zinc application. The experiment was conducted in Factorial Randomized Block Design with varieties as first factor and zinc sulphate application as second factor in three replications. Three varieties were used for the experiment were Anna 4 (V_1), APO 1 (V_2), and Prathyasa (V_3) and the zinc sulphate application comprised of seed priming with $ZnSO_4$ @ 2g kg $^{-1}$ seed (S_1), foliar application with $ZnSO_4$ @ 0.5 per cent at active tillering stage and panicle initiation stage (S_2), combination of S_1 and S_2 (S_3), soil application of $ZnSO_4$ @ 20 Kg ha^{-1} (S_4), and control (without $ZnSO_4$ application) (S_5). Crop was manured with FYM @ 5 t ha^{-1}and N:P:K @ 90:30:45 kg ha^{-1} (Suman, 2018). Varieties had significant effect on plant height, tillers per m^2, root shoot ratio and dry matter production (DMP). Among the varieties V_2 (APO 1) shown significantly higher plant height and root shoot ratio. Variety V_3 (Prathyasa) shown significantly higher tiller m^{-2} and DMP. Zinc sulphate application had significant effect on growth attributes viz., tillers m^{-2}, Leaf area index (LAI), root shoot ratio and DMP. Combination of seed priming and foliar application (S_3) recorded significantly higher tillers per m^{-2}, Leaf area index, root shoot ratio and DMP. Interaction of varieties and zinc sulphate application was significant in tillers m^{-2}, LAI, root shoot ratio and DMP. The treatment V_2S_4 recorded the highest DMP (11732.37 kg ha^{-1}). Varieties, zinc sulphate application and their interaction shown significant effect on crop growth rate (CGR), relative water content, soluble protein, proline content and stomatal conductance but only zinc sulphate application had significant effect on chlorophyll content. Varieties, zinc sulphate application and their interaction had significant effect on nutrient uptake. Among the varieties phosphorus and Zn uptake was higher in V_3 (prathyasa) and potassium uptake was higher in V_2 (APO 1). Among the method of zinc sulphate application higher uptake was noted in soil application (S_4). Varieties had significant effect on available potassium and zinc. Zinc sulphate application had significant effect on available nutrients after the experiment. Varieties had significant effect on yield

attributes viz., panicle length, panicle weight, panicles m^{-2}, filled grains per panicle, sterility percentage and thousand grain weight. However, zinc sulphate application had significant effect only on panicle weight, filled grains per panicle, sterility percentage and thousand grain weight. Among the varieties, the highest number of panicles m^{-2} and the highest number of filled grains per panicle were recorded in the V_3 (Prathyasa). The highest panicle weight was recorded in V_2 (APO 1) and the highest panicle length, the highest thousand seed weight and the lowest sterility percentage were recorded in V_1 (Anna 4). Among the method of zinc sulphate application, foliar application (S_2) recorded the highest panicle weight, combination of seed priming and foliar application (S_3) recorded higher number of panicles m^{-2}, filled grains per panicle, the lowest sterility percentage and grains with higher thousand grain weight. Grain yield was also significantly influenced by varieties and zinc sulphate application. Among the varieties, V_3 (Prathyasa) recorded significantly higher grain yield among the varieties (3,524.03 kg ha^{-1}). Compared to control, all method of zinc application recorded higher grain yield. Combined application of seed priming and foliar application (S_3) recorded the highest grain yield (3,877.71 kg ha^{-1}) among the different methods of zinc sulphate application. The interaction between varieties and zinc sulphate application also had significant effect. Among the varieties, APO 1 (V_2) recorded the highest straw yield and it was significantly superior to other treatments. Soil application of $ZnSO_4$ @ 20 kg ha^{-1} recorded the highest straw yield. Among the varieties, prathyasa (V_3) recorded the highest net returns (38,921 □ ha-1) and B C ratio (1.58). Among zinc sulphate application, S_3 (seed priming with zinc sulphate 2 g kg^{-1} seed + foliar application of zinc sulphate 0.5 per cent at active tillering and panicle initiation stage) recorded highest net returns (47,897 □ ha^{-1}) and B C ratio (1.71). Considering the yield, economics and B:C ratio, variety prathyasa (V_3) performed well with application of NPK @ 90:30:45 kg ha^{-1},seed priming with zinc sulphate 2 g kg^{-1} seed + foliar application of zinc sulphate 0.5 per cent at active tillering and panicle initiation stage (S_3) for uplands in red loam tracts of Kerala.

കേരളത്തിലെ ചുവന്ന പശിമരാശി മണ്ണുള്ള കരപ്രദേശങ്ങൾക്ക് അനുയോജ്യമായ നെല്ലിനം കണ്ടെത്തുക. സിങ്ക് പ്രയോഗത്തിന്റെ അളവും രീതിയും കണ്ടെത്തുക എന്നതായിരുന്നു പഠനത്തിന്റെ ലക്ഷ്യം.

ഫാക്ടോറിയൽ റാന്റമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന സ്റ്റാറ്റിസ്റ്റിക്കൽ പഠനരീതി യാണ് അവലംബിച്ചത്. ഇതിൽ രണ്ട് ഘടകങ്ങളാണ് പഠനത്തിന് വിധേയമാക്കിയത്.

ഘടകം A (V) : നെല്ലിനം

V_1 : അണ്ണാ 4

V_2 : APO 1

V_3 : പ്രത്യാശ (MO - 21)

ഘടകം B (S) : സിങ്ക് സൾഫേറ്റ് പ്രയോഗം

S_1 : വിത്ത് ഉപചാരം, $ZnSO_4$@2g/kg വിത്ത്

S_2 : പത്രപോഷണം ചിനപ്പ് പൊട്ടുന്ന സമയവും
കതിര് കിളർക്കുന്ന സമയവും
$ZnSO_4$@ 0.05 %

S_3 : $S_1 + S_2$

S_4 : $ZnSO_4$@20kg/ha മണ്ണിലേക്ക് ചേർക്കുക.

S_5 : സിങ്ക് പോഷണം നൽകുന്നില്ല

എല്ലാ നെല്ലിനങ്ങളുടെയും പ്രകടനം സിങ്ക് സൾഫേറ്റിന്റെ പ്രയോഗത്താൽ ബാധിക്കുന്ന തായും ഓരോ ഇനങ്ങളും വ്യത്യസ്ഥമായി പ്രതികരിക്കുന്നതായും പഠനത്തിൽ കണ്ടെത്തി.

സിങ്ക് സൾഫേറ്റ് പ്രയോഗ രീതിയായ S_3– യുടെയും പ്രത്യാശ എന്ന നെല്ലിനത്തിന്റെയും സംയോജനം എറ്റവും ഉയർന്ന വിളവും വരവ് ചെലവ് അനുപാതവും അറ്റാദായവും രേഖപ്പെടുത്തി.