MAGNESIUM SULPHATE FERTILIZATION FOR YIELD ENHANCEMENT IN DIRECT SEEDED RICE

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled "**Magnesium sulphate fertilization for yield enhancement in direct seeded rice**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Magnesium sulphate fertilization for yield enhancement in direct seeded rice"** is a record of research work done independently by Ms. Daly George (2016-11-012) 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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LIST OF ABBREVIATIONS AND SYMBOLS USED

@	At the rate of
a.i.	Active ingredient
B: C ratio	Benefit cost ratio
CD	Critical difference
Cm	Centimetre
DAS	Days after sowing
DAT	Days after transplanting
DMP	Dry matter production
et al.	And other co workers
Fig.	Figure
FMP	Fused magnesium phosphate
FYM	Farmyard manure
g	Gram
GML	Ground magnesium limestone
ha	Hectare
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
LAI	Leaf area index
MSL	Mean sea level
%	Per cent
ha^{-1}	Per hectare
K	Potassium
K_2O	Potash

m^2	Square metre
m^{-2}	Per square metre
Mm	Millimetre
N	Nitrogen
No.	Number
P	Phosphorus
P_2O_5	Phosphate
PI	Panicle initiation
₹	Rupees
RBD	Randomized block design
SE	Standard error
viz.	Namely

INTRODUCTION

1. INTRODUCTION

Rice (*Oryza sativa* L.) plays a key role in food security in India; it is the staple food crop for more than half of the global population. A continuous gain in rice grain yield is essential to meet the targeted rice requirement of 135-145 MT by 2020 (Subbaiah and Balasubramanian, 2000), which could be achieved by efficient and cost effective nutrient management practices. The application of large amounts of nitrogen, phosphorus and potassium (N-P-K) fertilizers increased the crop production during green revolution, but imbalanced use of these primary nutrients for prolonged periods created shortage of secondary nutrients such as magnesium (Mg) and it decreased the productivity and quality of crops.

Magnesium is one of the essential secondary nutrients for plants; it is the most abundant divalent cation in cytosol of plant cells (Li *et al.*, 2001). Magnesium has critical role in living system as it performs a number of key functions in plants such as photo phosphorylation (ATP formation in chloroplasts), photosynthetic carbon dioxide (CO_2) fixation, protein synthesis, chlorophyll structure and formation, phloem loading, partitioning and utilization of photo assimilates, generation of reactive oxygen species, and photo oxidation in leaf tissues. If Mg is inadequate in plants, these processes are adversely affected, leading to impairment in growth, yield and quality. The prime role of Mg in plants is carbohydrate partitioning between source and sink organs, thereby increasing dry matter yield of economically important parts of the crop. The agronomists and scientists have been given minor importance to the significance of Mg in crop growth, yield and quality in the last decades even though it is essential for crop production. Therefore, Mg is often considered a "forgotten essential element" (Cakmak and Yazici, 2010).

Moreover dietary deficiency of magnesium as well as abnormalities in Mg metabolism has been linked with many serious diseases in human beings like alzheimer's disease, depression, brain injury, cystic fibrosis, arrhythmia, osteoporosis, coronary artery disease and even parkinsons disease (de Baaij et al., 2015). Since plant products are the predominant source of Mg for human beings, maintenance of internal equilibrium of Mg in plant tissues (Mg homeostasis) is important for attaining high plant productivity and human health.

The supply of Mg from soil minerals is mostly small compared with the amounts required for obtaining higher crop yield and quality. The Mg present in the soil is highly amenable for leaching loss because of its weak bonding with soil colloids. In addition high or low soil pH, drought and competition from basic cations such as K^{+}, Al^{3+}, NH^{4+}, Ca^{2+} and H^{+} also reduce Mg availability to plants even though it is having high concentration in soil solution. Therefore, application of Mg fertilizers together with N, P and K is desirable and crucial for achieving potential yield and quality, besides application of Mg fertilizers in cereals especially in rice also has advantage in human nutrition. A variety of Mg sources are available now, while magnesium sulphate ($MgSO_4$) is totally soluble and easily available in the market, thus most suitable as a fertilizer.

According to Package of Practices Recommendations crops of Kerala Agricultural University (KAU, 2016), application of 20 kg MgO ha^{-1} either as $MgSO_4$ or as magnesite or as dolomite is recommended in rice for Mg deficient soils. To supply 20 kg MgO ha^{-1}, the requirement of $MgSO_4$/magnesite/dolomite is 125 kg ha^{-1}/50 kg ha^{1}/ 200 kg ha^{-1} respectively. The research findings of a study conducted in Rice Research Station (RRS), Moncompu, Kerala revealed that addition of 20 Kg $MgSO_4$ ha^{-1} is effective for increasing rice yield (Raj *et al.*, 2013). Similarly, the work conducted in West Bengal also revealed the significance of lower dose of $MgSO_4$ in increasing rice yield (Biswas *et al.*, 2013).

Hence to assess whether the lower dose of Mg is sufficient for increasing yield and for economising rice production, the present investigation was undertaken with the following objective:

- To find out the optimum dose, time and method of application of $MgSO_4$ for growth and yield enhancement in direct seeded rice.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Rice (*Oryza sativa* L.) is the staple food of Kerala which plays a key role in food security. Application of magnesium together with N, P, K fertilizers is desirable for obtaining higher crop yield and soil fertility maintenance. This chapter attempts to review the available literature on the effect of magnesium in rice and wherever references are not sufficient, review on other cereal crops are also included.

2.1 EFFECT OF MAGNESIUM ON CROP GROWTH PARAMETERS

2.1.1 Plant height

Singh and Singh (2005) reported that combined application of Mg and Zn increased the plant height of rice in alkali soils. Application of magnesium sulphate @ 10 kg ha^{-1} along with zinc @ 25 kg ha^{-1} increased plant height by 3 cm whereas zinc with no magnesium application tends to decrease plant height.

In a field experiment conducted by Panhwar *et al.* (2014) with rice on acid sulfate soils, it was found that application of bio-fertilizer in combination with GML (Ground Magnesium Limestone) or biofertilizer alone produced higher plant height at 60 days of growth. Rice in kole lands recorded the highest plant height at 30 DAS by combined application of magnesium, boron and silica (Rani, 2014).

The efficiency of foliar and soil applied nutrients in irrigated rice was studied by Preman (2015) and found that individual soil application of Mg, Zn and B with POP N, P, K gave higher plant height at harvest compared to the individual foliar feeding of same nutrients.

Singh (2001) reported that addition of magnesium in wheat showed a positive effecton height of the plant at maximum tillering and maturity stages. The height of the plant increased up to 30 kg Mg ha^{-1} and thereafter decreased @ Mg level of 45 kg ha^{-1}. El- Zanaty *et al.* (2012) studied the effect of magnesium sulphate fertilization in wheat and found that soil application of $MgSO_4$ @ 60 kg ha^{-1} or 5 g L^{-1} foliar spray gave maximum plant height.

In a maize based cropping system study by Noor *et al.* (2015) opined that the height of maize plant was the highest when Mg was applied @ 20 kg ha^{-1} with the recommended fertilizer and 2t $CaCO_3$ ha^{-1}. Ertiftik and Zengin (2017) reported that maize plants supplied with Mg and K @ 40 kg ha^{-1} registered the highest plant height during 2009, while during 2010 the highest plant height was obtained by application of 40 and 80 kg ha^{-1} Mg and K.

2.1.2 Tiller number

The tiller count in rice was enhanced when Mg and Zn were applied together (singh and singh, 2005). In a study by Raj *et al.* (2013) on integrated nutrient management in rice, it was found that magnesium sulphate application at 20 kg ha^{-1} with recommended dose of N, P, K @ 90-45-15 kg ha^{-1}, FYM and lime top dressing registered maximum tillers m^{-2} during kharif season.

Rani (2014) observed that in rice, combined application of Mg, B and silica with POP N, P, K produced the highest number of tillers m^{-2} at 30 DAS. The tiller numbers $plant^{-1}$ in rice was the highest when bio-fertilizer was applied in combination with ground magnesium limestone (GML) or biofertilizer alone (Panhwar *et al.*, 2014).

In an experiment to find the efficiency of foliar and soil applied nutrients in irrigated rice, Preman (2015) found that individual foliar spray of Mg and Zn along with POP N, P, K produced more tillers than individual soil application of Mg and Zn together with POP N, P, and K.

Singh (2001) reported that the number of tillers plant^{-1} in wheat improved with increase in magnesium dose up to 30 kg ha^{-1}. El- Metwally *et al.* (2011) reported that combined foliar spray of magnesium sulphate and copper sulphate in wheat resulted in 21.68 % increase in number of tillers plant^{-1}. Hossain *et al.* (2011) observed that in wheat, Mg application with B, recommended N, P, K and lime top dressing produced maximum tillers m^{-2} which was on par with the treatment that received Mg, recommended N, P, K and lime.

Noor *et al.* (2015) opined that in maize, the highest tiller number was obtained when Mg @ 20 kg ha^{-1} was applied with recommended N, P, K and 2t $CaCO_3$ ha^{-1}.

2.1.3 Leaf Area Index

Raj *et al.* (2013) reported that the LAI of rice was the highest when $MgSO_4$ @ 20 kg ha^{-1} was added in addition with NPK @ 90-45-15 kg ha^{-1}, FYM @ 5 t ha^{-1} and lime top dressing. In a study conducted by Rani (2014) found that combined application of magnesium, boron and silica with recommended dose of N, P, K resulted in the highest LAI in rice.

Preman (2015) opined that combined soil application of Mg, Zn and B with POP N, P, K and combined foliar spray of Mg, Zn and B with POP N, P, K developed significantly higher LAI in rice.

2.2 EFFECT OF MAGNESIUM ON PHYSIOLOGICAL PARAMETERS

2.2.1 Chlorophyll content

Preman (2015) found that combined foliar application of Mg, Zn and B along with recommended N, P, K resulted in the highest chlorophyll a content at 60 DAT in irrigated rice. Kobayashi *et al.* (2012) noticed that Chlorophyll concentration in rice seedlings decreases due to magnesium deficiency. Involvement of magnesium in chlorophyll synthesis was considered to be one of the important factor causing the decrease in chlorophyll content.

Rani (2014) revealed that application of higher dose of magnesium had no effect on chlorophyll a content in rice, while chlorophyll b and total chlorophyll were slightly influenced by magnesium application. The experiment conducted in rice by Moreira *et al.* (2015) reported higher chlorophyll content when plants were supplied with 4.0 mM Mg. They reported on average 20% higher total chlorophyll content with 4.0 mM Mg over 0.25 mM Mg.

El- Metwally, *et al.* (2010) studied the effect of magnesium and copper foliar fertilization on growth of wheat and found that foliar spraying with magnesium (Mg) and copper (Cu) either as single nutrient or in combination significantly affected chlorophyll content with 7-29% increment over control. The chlorophyll content was maximum at the highest level of magnesium and copper.

$MgSO_4$ supplied @ 0.5 mM had higher chlorophyll concentration in maize than Mg deficient control plants. The chlorophyll concentration in maize was significantly influenced by Mg deficiency. It was also noticed that chlorophyll content increases with magnesium resupply to deficient plants (Jezek *et al.*, 2015). Application of Mg in maize @ levels >50 mg kg^{-1} resulted in significantly higher chlorophyll a, chlorophyll b and total chlorophyll content (Chen *et al.*, 2017).

2.2.2 Days to Flowering

Singh and Singh (2005) noticed an enhancement in flowering and heading of rice in alkali soils with the supply of magnesium. The best treatment with respect to flowering was application of $MgSO_4$ @ 10kg ha^{-1} along with zinc.

Shaygany *et al.* (2012) observed that application of macro nutrients (N,P,K,Ca and Mg) and micro nutrients through foliar spray favorably influenced the flowering time and heading time in rice. Five foliar sprays of macro and micro nutrients decreased the number of days to flowering by 10 days.

2.2.3 Root shoot ratio

Singh and Singh (2005) reported that addition of magnesium with zinc in alkali soils stimulated shoot to root ratio of rice. The root length was increased by 4 cm due to the application of $MgSO_4$ @ 10 kg ha^{-1}. Ding *et al.* (2006) investigated the effect of Mg concentration on root and shoot growth in rice. Plants with low magnesium concentration had higher root to shoot ratio at 40 days after transplanting. The dry weight of shoot at 70 DAT was found the highest with medium to high concentration of Mg.

The reduction in root growth of rice due to the supply of lower levels of magnesium was reported by Moreira *et al.* (2015).

2.3 EFFECT OF MAGNESIUM ON YIELD ATTRIBUTES

In a study conducted by Chang and Sung (2004) in rice, it was found that application of fused magnesium phosphate (FMP) or lime improved the panicles ha^{-1}, number of grains $panicle^{-1}$ and 1000 grains weight. However, higher levels of FMP decreased number of panicles ha^{-1} compared to lower levels of FMP. Singh and Singh, (2005) indicated that application of $MgSO_4$ @ 10 kg ha^{-1} with $ZnSO_4$ @ 25 kg ha^{-1} in rice resulted in the development of 9 cm long panicles, while plants without any magnesium addition had panicle length only between 6 to7 cm. The spikelet sterility was markedly affected by magnesium and addition of Mg in rice reduced the number of chaffy grains and increased filled grains $panicle^{-1}$. They also reported an increase of 2 to 3.4 g in 1000 grain weight due to magnesium supply.

Addition of 40 kg Mg ha^{-1} registered the highest panicle length, panicle weight, test weight, harvest index and lowest sterility percentage in hybrid rice and it was statistically on par with addition of 20 kg Mg ha^{-1} (Srivastava *et al.,* 2006). In direct seeded rice, panicles m^{-2} and 1000 grain weight were found the highest when plants were sprayed with macro (N, P, K, Ca and Mg) and micro nutrients five times during the growth period (Shaygany *et al*., 2012).

In rice maximum panicles m^{-2}, panicle weight, DMP, and number of fertile grains $panicle^{-1}$ during both kharif as well as rabi seasons were registered by the application of $MgSO_4$ @ 20 kg ha^{-1} along with NPK @ 90-45-15 kg ha^{-1}, FYM @ 5 t ha^{-1} and lime @ 250 kg ha^{-1}. But there were no significant difference in thousand grain weight among the treatments (Raj *et al*., 2013). Preman (2015) reported that spikelets $panicle^{-1}$ in rice was the highest with combined foliar application of Mg, Zn and B along with POP recommendations of N, P, K, while thousand grain weight was the highest with individual application of Mg and Zn along with POP NPK.

Hossain *et al.* (2011) observed that the yield attributes of wheat were favourably influenced by the application of Mg. Maximum spikes m^{-2}, grains $spike^{-1}$, 1000 grain weight and harvest index were recorded for wheat where Mg was applied along with B, lime and recommended dose of N, P, K. The treatment received recommended dose of N, P, K alone recorded the lowest yield attributes. El-Metwally *et al.* (2011) reported that grains number $spike^{-1}$, grain weight $spike^{-1}$ and 1000 grain weight were the highest in combined foliar application of $MgSO_4$ and $CuSO_4$ in wheat.

Singh (2001) indicated that in maize, when Mg levels were increased from 0-30 kg ha^{-1}, the number of grain ear^{-1} and 1000 grain weight were increased, but further increase in Mg level to 45 kg ha^{-1} decreased the yield attributes. Noor *et al.* (2015) studied the effect of applied Mg on maize as well as residual effect of Mg on rice in a maize based cropping system and found that application of Mg @ 20 kg ha^{-1} along with recommended N, P, K and 2t $CaCO_3$ ha^{-1} produced the highest cob length, number of grains cob^{-1} and thousand grain weight. It was found that yield attributes of maize increased with increase in Mg level up to 20 kg ha^{-1} and decreased with further increase in Mg level. Residual Mg also influenced yield attributes of rice followed by maize and filled grains panicle and 1000 grain weight were the highest in rice when maize plants were fertilized with Mg @ 20 kg ha^{-1} along with recommended N, P, K and $CaCO_3$ @ 2 t ha^{-1}. In an experiment conducted for two years by Ertiftik and Zengin (2017), to elucidate the effects of K and Mg in maize, it was revealed that Mg @ 40 kg ha^{-1} along with K @ 80 kg ha^{-1} significantly improved the ear length, number of grains ear $^{-1}$ and grain weight ear $^{-1}$. But the grain: ear ratio and thousand grain weight were not significantly influenced by K, Mg and KxMg in both the years.

2.4 EFFECT OF MAGNESIUM ON YIELD

Choudary and Khanif (2001) studied the effects of Mg and N fertilization on rice yield in two soils (Guar and Hutan series). Grain yield response to added Mg was quadratic in both the soils and grain yield was the highest with Mg @ 26 kg ha^{-1} and N @ 120 kg ha^{-1} in Guar series and Mg @ 20 kg ha^{-1} and N @ 80 kg ha^{-1} in Hutan series respectively. They also reported an increase in straw yield due to magnesium application. The significant effect of Mg on the yield of rice was reported by Singh and Singh (2005). In hybrid rice, application of Mg @ 40 kg ha^{-1} resulted in maximum grain yield and it was statistically on par with 20 kg Mg ha^{-1}. The straw yield was not significantly affected by magnesium application (Srivastava *et al.*, 2006). Biswas *et al.* (2013) investigated effect of different levels of magnesium sulphate ($MgSO_4$) on yield of paddy and found application of $MgSO_4$ @ 3.0 g m^{-2} recorded the highest grain yield and it was 17% higher over control. Application of $MgSO_4$ @ 1.5 g m^{-2} produced 6.4 % higher grain yield than control.

According to Raj *et al.* (2013) application of magnesium sulphate @ 20 kg ha^{-1} with recommended dose of NPK (90-45-15 kg ha^{-1}), farm yard manure (5 t ha^{-1}) and lime top dressing (250 kg ha^{-1}) registered the highest grain yields in kharif and rabi (7570 and 3883 kg ha^{-1} respectively). Preman (2015) claimed that combined application of Mg, Zn and B in soil produced the highest grain yield in rice. Similarly joint foliar application of these nutrients also showed substantial increase in grain yield.

Brohi *et al.* (2000) observed that magnesium addition had significant effect on straw yield of rice and addition of 60 kg Mg ha^{-1} registered the highest straw yield. Rani and Latha (2017) found that the highest straw yield of 8.27 t ha^{-1} was associated with the application of magnesium in rice and it was on par with calcium silicate application. Magnesium application increased straw yield of rice on an average by 720 kg ha^{-1}.

Application of Mg @ 30 kg ha^{-1} registered the highest grain and straw yield in wheat (Singh, 2001). Increase in grain yield of wheat under sandy soil conditions by foliar spray of magnesium sulphate and copper sulphate was registered by El-Metwally *et al.* (2011). According to Hossain *et al.* (2011) wheat plants supplied with Mg, B, lime and recommended N, P, K gave the highest grain yield (4.88 t ha^{-1}) and straw yield (8.35t ha^{-1}). The second highest grain yield (4.02 t ha^{-1}) was obtained when Mg and lime supplied with recommended fertilizer and control recorded the lowest grain yield and straw yield.

Szulc *et al.* (2008) found that maize cob yield increased with magnesium fertilization. Incorporation of 25 kg Mg ha^{-1} in rows resulted in the highest cob yield and the treatment without magnesium fertilization (control) recorded the lowest cob yield. According to Noor *et al.* (2015) the response of maize to Mg was quadratic in nature and the maximum yield of 10,507 kg ha^{-1} was obtained with application of 19 kg Mg ha^{-1}. Ertiftik and Zengin (2017) reported that in maize, application of Mg @ 40 kg ha^{-1} along with K @ 80 kg ha^{-1} gave the highest grain yield (17.867 kg ha^{-1}).

2.5 EFFECT OF MAGNESIUM ON NUTRIENT AVAILABILITY IN SOIL

2.5.1 Primary Nutrients

Rani (2000) reported that available N and P in soil were significantly lower when Mg was applied along with muriate of potash in rice, while available K in soil at harvest was higher when higher doses of Mg or gypsm applied with muriate of potash. Chang and Sung (2004) revealed that application of higher levels of fused magnesium phosphate (FMP) in rice recorded maximum P and K content in soil. According to Latheef (2013) application of $MgSo_4$ in rice registered lower available

K in soil. Preman (2015) reported that available K in soil was the highest with soil application of 80 kg $MgSO_4$ ha^{-1} in rice.

A study formulated by Noor *et al.* (2015) in a maize based cropping system revealed that the total N and available P were the highest when Mg @ 20 kg ha^{-1} was applied along with recommended dose of N, P, K and 2t ha^{-1} $CaCO_3$.

2.5.2 Secondary Nutrients

Rani (2000) observed that application of gypsum in rice showed higher available Ca in soil, but treatments that received Mg had significantly lower available Ca. The Mg availability in soil increased with magnesium fertilization and application of gypsum increased the available S in soil. According to Chang and Sung (2004), Ca and Mg in soil was the highest with application of fused magnesium phosphate (FMP) in rice. Preman (2015) reported that combined soil application of Mg, B and Zn resulted in higher available Ca in the soil, the available S in soil was the highest with application of $MgSO_4$ @ 80 kg ha^{-1}.

Noor *et al.* (2015) found that Ca and Mg in soil were the highest when Mg @ 30 kg ha^{-1} was applied with recommended dose of N, P, K and $CaCO_3$ @ 2 t ha^{-1}, while available S was the highest (16 mg kg^{-1}) when Mg @ 20 kg ha^{-1} was applied with recommended dose of N, P, K and $CaCO_3$ @ 2 t ha^{-1}.

2.6 EFFECT OF MAGNESIUM ON NUTRIENT UPTAKE

2.6.1 Uptake of Primary Nutrients

Application of magnesium in rice enhanced the uptake of P and K in grain as well as K uptake in straw (Brohi *et al.*, 2000). Choudary and Khanif (2001) revealed that Mg application can stimulate uptake of N by whole rice plant (grain and straw). Raj *et al.* (2013) reported that uptake of N, P and K by rice during kharif and rabi seasons were the highest with application of $MgSO_4$ @ 20 kg ha^{-1} along with recommended N, P, K, farm yard manure and lime top dressing. Latheef (2013) reported that foliar application of 1% $MgSO_4$ recorded the highest plant P content @ 30 DAT and grain N at harvest, while MgSO4 @ 40 kg ha^{-1} gave the highest plant P content at 60 DAT and grain P at harvest. He also observed that K content of the plant was the lowest with foliar spray of 0.5 % $MgSO_4$. Preman (2015) revealed that combined foliar application of Mg, B and Zn produced the highest N content in rice grain, while N and P content in straw was the highest with combined soil application of Mg, B and Zn.

El- Metwally *et al.* (2011) opined that application of $MgSO_4$ @ 16 kg ha^{-1} along with 4 kg $CuSO_4$ ha^{-1} recorded the highest N, P and K content in wheat grain.

2.6.2 Uptake of Secondary Nutrients

Sahrawat *et al.* (1999) revealed that Ca and Mg status of rice plants were increased by the application of Mg. According to Brohi *et al.* (2000), uptake of Mg by both grain and straw in rice was enhanced by magnesium fertilization and Mg content in straw was increased from 1422 ppm (control) to 2255 ppm due to the application of Mg @ 80 kg ha^{-1}. The increase in uptake of Mg by rice due to Mg fertilization was reported by Choudary and Khanif (2001). Latheef (2013) reported that magnesium fertilization in rice had remarkable effect on plant Mg content at 30 DAT, 60 DAT and at harvest, the Mg content was the highest when $MgSO_4$ was applied @ 80 kg ha^{-1} along with POP N, P, K. He also observed that Ca content in plant was the lowest when $MgSO_4$ was applied @ 40 kg ha^{-1}. Preman (2015) revealed that supply of Mg either through soil or foliar registered higher plant Mg content in rice.

Wheat plants sprayed with 16 kg $MgSO_4$ ha^{-1} along with 4 kg $CuSO_4$ ha^{-1} had maximum Ca and Mg content at 75 days after sowing and it also recorded the highest Mg content in grain and straw at harvest (El- Metwally *et al.*, 2011).

2.7 EFFECT OF MAGNESIUM ON CROP QUALITY

2.7.1 Starch

Application of Mg @ 45 kg ha^{-1} registered the highest starch content of 70.8 % and 70.5 % respectively in first and second year in wheat and control the lowest (Singh, 2001). The Mg applied @ 45 kg ha^{-1} caused about 5% increase in grain starch compared to control.

2.7.2 Protein

The grain protein content of wheat was the highest when Mg was applied @ 45 kg ha^{-1} during first year and @ 30 kg ha^{-1} during second year (Singh, 2001).

El- Metwally *et al.* (2011) reported that the protein in wheat grain was the highest (15.45 %) when plants were sprayed with 16 kg $MgSO_4$ ha^{-1} + 4 kg $CuSO_4$ ha^{-1} and control registered the lowest (6.37%). Ertiftik and Zengin (2017) reported that protein content (%) in maize grain was the highest when Mg @ 40 kg ha^{-1} and K @ 80 kg ha^{-1} were applied in both the years (9.94% and 9.38%).

2.7.3 Magnesium content

Brohi *et al.* (2000) conducted an experiment on rice grown in artificial siltation soil and observed that grain Mg content increased with successive increases in Mg levels from 0-80 kg ha^{-1} , while there were no significant difference among the Mg levels. Rani (2014) reported that combined application of Mg, B and silica recorded the highest grain Mg content in rice and control, the lowest. According to Preman, (2015) the grain Mg content of rice was the highest (0.077%) with combined foliar application of Mg, B and Zn

Singh (2001) reported that magnesium fertilization can enhance grain Mg uptake and application of Mg @ 45 kg ha^{-1} registered the highest Mg uptake in wheat and control, the lowest. He also observed the effect of K and Mg interaction on grain Mg content and the interaction effect of K @ 80 kg ha^{-1} and Mg @ 45 kg ha^{-1} was found superior to all other treatments. Abunyewa and Quarshie (2004) revealed that Mg uptake by maize grain was quite low even though relatively high levels of magnesium were applied. In an experiment conducted by El- Metwally *et al.* (2011) found that application of magnesium sulphate, copper sulphate or both of them significantly improved grain magnesium content (%) in wheat. Treatments received 16 kg $MgSO_4$ ha^{-1} + 2 kg $CuSO_4$ ha^{-1} and 16 kg $MgSO_4$ ha^{-1} + 4 kg $CuSO_4$ ha^{-1} were produced the highest Mg content (0.35 and 0.35 %) and control plants recorded the lowest value (0.26 %).

2.8 ECONOMICS

Application of 40 kg ha^{-1} Mg and2 kg ha^{-1} B showed marked increase in gross return and net return due to higher grain yield in rice. The B:C ratio was maximum with 20 kg Mg ha^{-1} and 1 kg B ha^{-1} which decreased with further increase in their levels (Srivastava *et al.*, 2006).

The economic analysis of an investigation conducted by Raj *et al.* (2013) in rice revealed that application of magnesium sulphate @ 20 kg ha^{-1} with recommended NPK, FYM and lime top dressing registered the highest gross returns and grain yield. The combined application of Mg, B and silica produced the highest gross return in rice (Rani, 2014). According to Preman (2015) combined application of Mg, B and Zn (soil or foliar) in rice showed higher B:C ratio than package of practices recommendations.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation entitled "Magnesium sulphate fertilization for yield enhancement in direct seeded rice" was conducted in farmer's field at Kalliyoor Panchayat, Thiruvananthapuram district, from May to September 2017. The objectives of the present investigation were to determine the optimum dose, time and method of application of magnesium sulphate for growth and yield enhancement in rice. The materials used and methods adopted for the study is briefly described in this chapter.

3.1. GENERAL DETAILS

3.1.1. Location

The experiment was conducted in farmer's field at Kalliyoor Panchayat, Nemom block, Thiruvananthapuram district, Kerala, India situated at 8° 26.762'N latitude, 77° 0.136' E longitude and 29 m above mean sea level (MSL).

3.1.2. Climate

A warm humid tropical climate prevailed over the experimental area. The rainfall received during the crop growing season extending from May to September 2017 was 734.5 mm. The mean maximum and minimum temperatures ranged between 30.4 ^{0}C to 32.3 ^{0}C and 23.7 ^{0}C to 25.2 ^{0}C respectively. The mean weekly weather parameters prevailed during the experimental period is given in Appendix I and Fig.1.

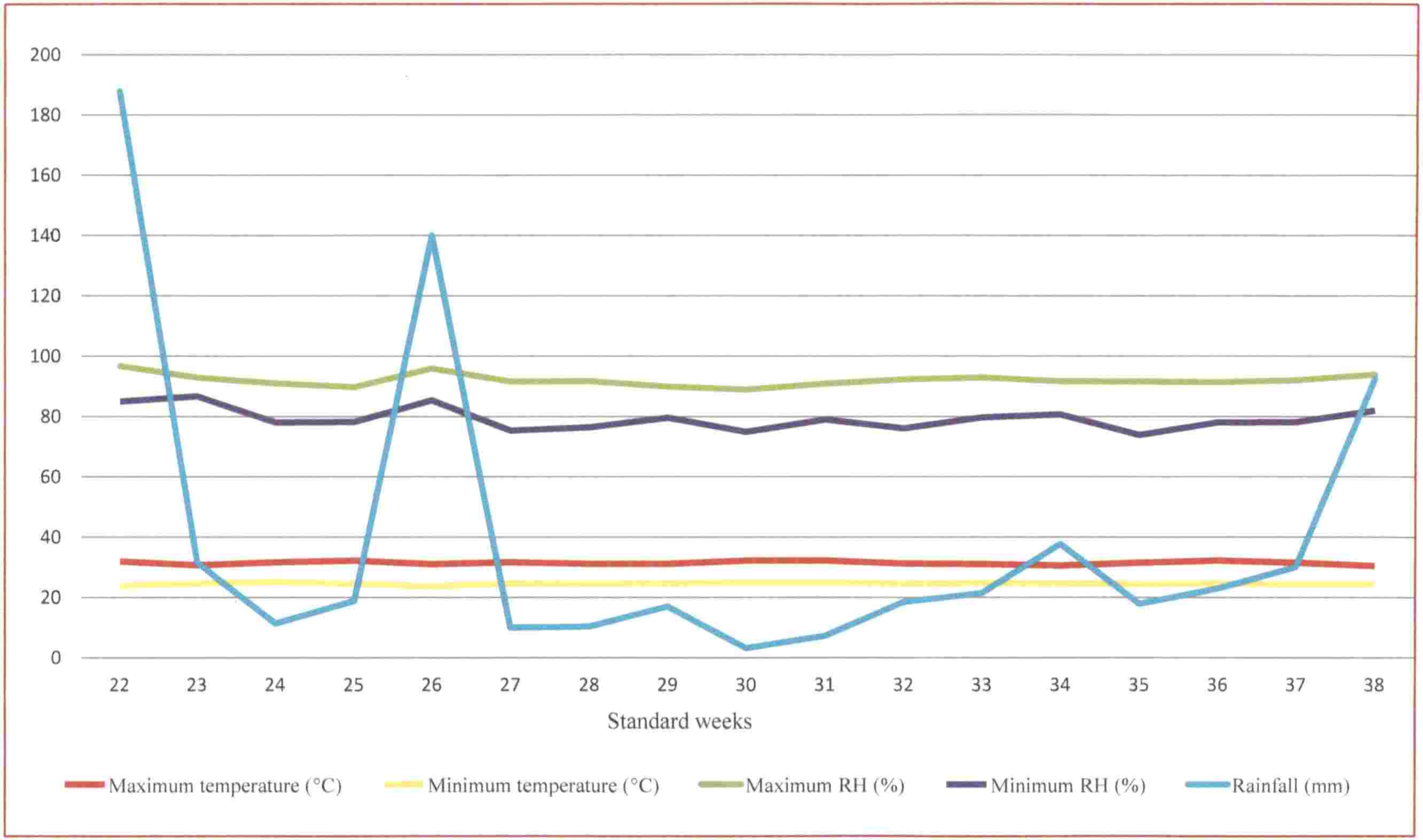

Fig.1 Weather parameters during cropping period (May 2017 -September 2017)

3.1.3. Cropping Season

The experiment was conducted during *Virippu* season (first crop) from May 2017 to September 2017.

3.1.4. Soil

The soil of the experimental field is well drained sandy clay loam. Before conducting the experiment a composite soil sample was drawn and pH, soil texture, electrical conductivity, organic carbon, available nutrients such as N, P, K, Ca, Mg and S were analyzed following the standard procedure.

Soil is acidic in reaction, high in organic carbon and medium in available N and K and high in P. The Initial soil properties of experimental site are presented in Table 1.

3.1.5 Cropping History of the Field

The experimental site was under continuous cultivation of rice for more than 12 years.

3.2. MATERIALS

3.2.1. Crop Variety

The variety used for the study was Sreyas (MO 22), a medium duration (115-120 days), medium bold red kernel variety released from Rice Research Station, Moncompu, Alappuzha, Kerala, India. Sreyas is moderately resistant to sheath blight, sheath rot, bacterial leaf blight and false smut.

Table1. Initial soil properties of experimental site.

Sl. No.	Parameter	Content
A. Mechanical composition		
1	Coarse sand (%)	47.52
2	Fine sand (%)	12.10
3	Silt (%)	7.93
4	Clay (%)	32.40
B. Physico-chemical chemical properties		
1	Soil reaction (PH)	5.30 (strongly acidic)
2	Electrical conductivity (dSm^{-1})	0.20
3	Organic carbon (%)	1.10 (high)
4	Available nitrogen (kg ha^{-1})	288.80 (medium)
5	Available phosphorus (kg ha^{-1})	38.72 (high)
6	Available potassium (kg ha^{-1})	238.60 (medium)
7	Available calcium (mg kg^{-1})	375.90 (sufficient)
8	Available magnesium (mg kg^{-1})	137.35 (sufficient)
9	Available sulphur (mg kg^{-1})	5.90 (sufficient)

3.2.2. Source of seed

The paddy seeds for the study were procured from Rice Research Station, Moncompu, Alappuzha, Kerala.

3.2.3. Manures and Fertilizers

Well decomposed farmyard manure (FYM) with 0.49% N, 0.2% P_2O_5 and 0.5% K_2O was used as organic source. The fertilizers used for the study were urea (46% N), factomphos (20% N, 20% P_2O_5 and 15% S) and muriate of potash (60% K_2O).

3.3. METHODS

3.3.1. Design and Layout

Design	: Randomized Block Design (RBD)
Treatments	: 14
Replications	: 3
Season	: *Virippu* 2017
Plot size (Gross)	: 5 m x 4 m
Plot size (Net)	: 4.5 m x 3.5 m
Total number of plots	: 42

The layout of the experiment site is given in Fig.2.

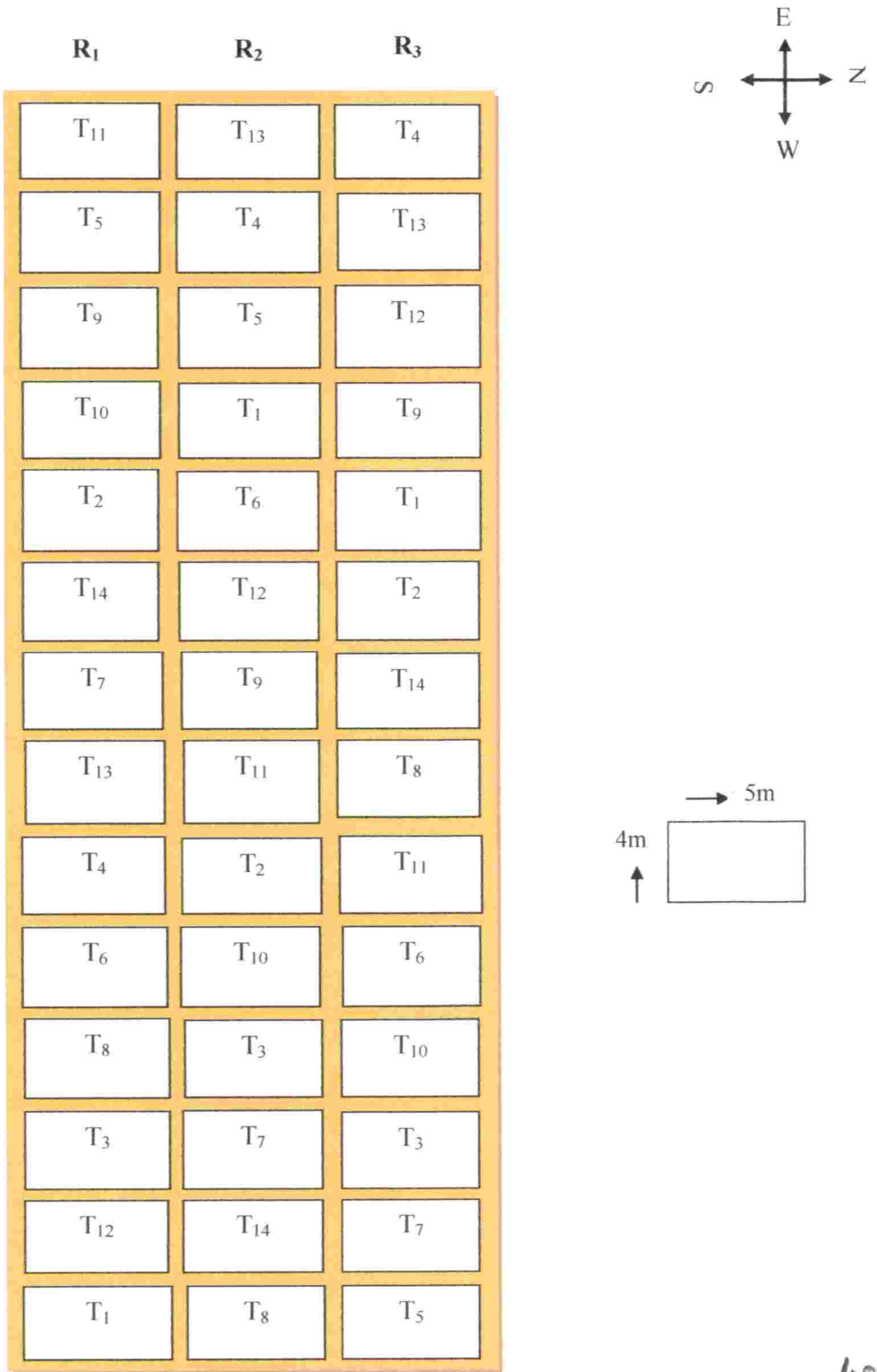

Fig.2. Layout of the experimental field

3.3.2. Treatments

T_1: Magnesium sulphate @ 20 kg ha^{-1} at 20 days after sowing (DAS)

T_2: Magnesium sulphate @ 30 kg ha^{-1} at 20 DAS

T_3: Magnesium sulphate @ 40 kg ha^{-1} at 20 DAS

T_4: Magnesium sulphate @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS

T_5: Magnesium sulphate @ 30 kg ha^{-1} in two equal splits at 20 and 40 DAS

T_6: Magnesium sulphate @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS

T_7: Magnesium sulphate @ 10 kg ha^{-1} at 20 DAS and 1 % Magnesium sulphate as foliar at 40 DAS

T_8: Magnesium sulphate @ 15 kg ha^{-1} at 20 DAS and 1 % Magnesium sulphate as foliar at 40 DAS

T_9: Magnesium sulphate @ 20 kg ha^{-1} at 20 DAS and 1 % Magnesium sulphate as foliar at 40 DAS

T_{10}: Magnesium sulphate @ 10 kg ha^{-1} at 20 DAS and 2 % Magnesium sulphate as foliar at 40 DAS

T_{11}: Magnesium sulphate @ 15 kg ha^{-1} at 20 DAS and 2 % Magnesium sulphate as foliar at 40 DAS

T_{12}: Magnesium sulphate @ 20 kg ha^{-1} at 20 DAS and 2 % Magnesium sulphate as foliar at 40 DAS

T_{13}: Magnesium sulphate @ 80 kg ha^{-1} as basal (*adhoc* recommendations of Kerala Agricultural University (KAU)).

T_{14}: Control (Kerala Agricultural University Package of Practices Recommendations crops (KAU PoP) - without Mg).

3.3.3. Field Preparation and Layout

The experimental area was thoroughly ploughed twice with power tiller and was uniformly levelled. After levelling, the individual plots were laidout as per the

Plate 1. Layout of the experimental field

Plate 2. General view of field

technical programme. Raised bunds of 20 cm height and channels of 30 cm width were taken around each plot and 50 cm wide channels were taken along the length of each block between the replications to facilitate irrigation and drainage.

3.3.4. Seeds and Sowing

Healthy seeds were soaked in water for 24 hours (h). After 24 h, seeds were drained and incubated in gunny bags for sprouting. The sprouted seeds were broadcasted @ 100 kg ha^{-1} in individual plot maintained at saturated condition on 31/05/2017.

3.3.5. Application of lime

Recommended dose of lime (600 kg ha^{-1}) was uniformly applied to all plots in two splits (350 kg ha^{1} at the time of last ploughing and 250 kg ha^{-1} at one month after sowing).

3.3.6. Application of Manures and Fertilizers

The crop was uniformly fertilized with recommended dose of FYM @ 5 t ha^{-1} and chemical fertilizers, N: P_2O_5: K_2O @ 90: 45: 45 kg ha^{-1} as per Package of Practices Recommendations crops (KAU, 2016). The entire dose of FYM was incorporated at the time of last ploughing. The fertilizers were applied in three splits; one third N and K and half P at 15 days after sowing (DAS), one third N and K and P at 35 DAS and remaining one third N and K at 55 DAS. $MgSO_4$ was applied as per treatments.

Seedling stage

Maximum tillering stage

Maturity stage

Harvest stage

Plate 3. Different growth stages of rice in the field

3.3.7. Water Management

Water management was carried out as per Package of Practices Recommendations crops (KAU, 2016).

3.3.8. Weed Management

The experimental area was kept free of weeds with the post emergence application of Metsulfuron ethyl + Chlorimuron ethyl (Almix 20% WP) @ 0.004 kg ai ha^{-1} at 20 DAS followed by one hand weeding at 40 DAS.

3.3.9. Plant Protection

Two sprays of malathion (750 mL ha^{-1}) were given against rice bug at flowering and milky stage of the crop. No serious incidence of diseases was noticed during the crop period.

3.3.10. Harvest

The crop was harvested on 26/09/2017. The net plot area were harvested separately, threshed and winnowed. The weight of grain and straw from individual plots were recorded separately and expressed in kg ha^{-1} on dry weight basis.

3.4. OBSERVATIONS

3.4.1. Growth parameters

3.4.1.1. Plant Height

Ten plants were selected randomly and height of the plant was measured in cm from ground level to the tip of the top most leaf at active tillering and panicle initiation stages, and from the base of the plant to the tip of the ear head at harvest stage.

3.4.1.2. Tillers m^{-2}

Tiller count was recorded randomly from two spots of 0.25 m^2 at active tillering, panicle initiation and harvest stages by using a quadrate of size 0.5 m x 0.5 m from the net plot area of each treatment and expressed in number m^{-2}.

3.4.1.3. Leaf Area Index

The leaf length and breadth of the fourth leaf from top were measured from 10 randomly selected primary tillers at panicle initiation stage. Palanisamy and Gomez (1974) suggested a method for LAI.

Leaf area = K (L×B)

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

L = Leaf length (cm)

B = Maximum breadth of the leaf (cm)

LAI was calculated as follows

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

3.4.1.4. Dry Matter Production (DMP)

At harvest stage, five plants were randomly selected and uprooted from the area demarcated for destructive sampling outside the net plot area leaving the border rows. The plant samples were first air dried and then oven dried at 70$\pm$5°C till the attainment of a constant weight. The total DMP was computed and was expressed in kg ha^{-1}.

3.4.2 Physiological parameters

3.4.2.1. Days to 50% flowering

Number of days from sowing till the date when approximately 50 per cent of the plants flowered were counted and recorded.

3.4.2.2. Chlorophyll content

The chlorophyll content of the leaves was estimated at panicle initiation and boot leaf stages by DMSO (Dimethyl Sulphoxide) method. The first fully opened leaves from top were selected as index leaves and were removed from the plants sampled for chemical analysis. A weighed quantity of sample (0.5 g) was taken and cut into small bits. These bits were put in test tubes and incubated overnight at room temperature, after pouring 10 ml DMSO: 80% acetone mixture (1:1 v/v) and the absorbance at 663 and 645 nm were measured in spectrophotometer.

The amount of pigments were estimated and expressed in mg g^{-1} of fresh weight using the formula suggested by Yoshida *et al*. (1976).

Chlorophyll a = (12.7 × A663 – 2.69 × A645) × V/ (1000× W)

Chlorophyll b = (22.9 × A645 – 4.63 × A663) × V/ (1000 × W)

Total chlorophyll = (8.02 × A 663 + 20.2 × A645) × V/ (1000 × W)

A = Absorbance at specific wavelengths
V = Final volume of aliquot (L)
W = Fresh weight of the sample (g)

3.4.2.3. Root shoot ratio

At flowering stage five plants were randomly selected from the area demarcated for destructive sampling outside the net plot area leaving the border rows. The hills were carefully uprooted without causing any damage to the roots and washed thoroughly with water. Root and shoot were separated and air dried, then oven dried at 70±5°C till the attainment of a constant weight and ratio of weight of roots to shoots were worked out.

3.4.3. Yield Components

3.4.3.1. Productive Tillers

The number of productive tillers was recorded from two spots of 0.25 m^2 each at random; using a quadrate and mean values were calculated accordingly.

3.4.3.2. Panicle Weight

Ten panicles were selected randomly from each treatment plot and were sun dried till a constant weight was attained, weighed using an electronic balance and expressed as g panicle^{-1}.

3.4.3.3. Filled Grains Panicle^{-1}

From the ten randomly selected panicles total numbers of filled grains was counted and mean number panicle^{-1} was calculated.

3.4.3.4. Sterility Percentage

From the selected panicles, the number of unfilled grains was recorded and sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.4.3.5. Thousand Grain Weight

From each plot thousand grains were drawn at random, sun dried and weighed at 14 per cent moisture content and expressed in g.

3.4.3.6. Grain Yield

Grains were harvested from each net plot area separately, dried in sun to a moisture content of 14 per cent and its weight was recorded and expressed in t ha^{-1}.

3.4.3.7. Straw Yield

Dry weight of harvested straw from the net plot area was recorded after sun drying for three consecutive days and expressed in t ha^{-1}.

3.4.3.8. Harvest Index

The harvest index was estimated using the following formula suggested by Donald and Hamblin (1976).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.4. Chemical Analysis

3.4.4.1. Soil Analysis

The soil samples for doing analysis were drawn to a depth of 15 cm from four different spots in each plot, shade dried, ground and composite samples were prepared by quartering.

3.4.4.1.1. Organic Carbon

The composite soil samples prepared were passed through 0. 2 mm sieve and analyzed for organic carbon by rapid titration method (Walkley and Black, 1934).

3.4.4.1.2. Available Nitrogen

Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956).

3.4.4.1.3. Available Phosphorus

Available phosphorus of the soil was determined by Dickman and Brays molybdenum blue method using spectrophotometer (Jackson, 1973).

3.4.4.1.3. Available Potassium

Available potassium content of the soil was determined using neutral normal ammonium acetate and estimated using flame photometer (Jackson, 1973).

3.4.4.1.4. Available Calcium and Magnesium

The available calcium and magnesium content in the soil were determined by ammonium acetate method and estimated using atomic absorption spectrophotometer (Hesse, 1971).

3.4.4.1.5. Available Sulphur

The available Sulphur in the soil was determined using calcium chloride extraction and estimated by turbidimetry (Chesnin and Yien 1950).

3.4.4.2. Plant Analysis

The plant samples at active tillering, panicle initiation and at harvest stages were analysed for the total N, P, K, Ca, Mg and S content. The samples were dried in a hot air oven at 70±5°C to constant weight, ground and used for analysis. The required quantities of samples were weighed out accurately and were subjected to acid extraction and N, P, K, Ca, Mg and S content were determined.

3.4.4.2.1. Total Nitrogen Content

Total nitrogen content was estimated by modified microkjheldal method (Jackson, 1973).

3.4.4.2.2. Total Phosphorus Content

Total phosphorus content was found out using Vanadomolybdate phosphoric yellow colour method (Jackson, 1973).

3.4.4.2.3. Total Potassium content

Total potassium content was estimated using flame photometer (Jackson, 1973).

3.4.4.2.3. Total Calcium and Magnesium Content

Total calcium and magnesium content was determined by diacid digestion and estimated using Atomic Absorption Specrtrometry (Piper, 1966).

3.4.4.2.4. Total Sulphur Content

Total sulphur content was estimated using diacid digestion and determined by turbidimetry method (Chesnin and Yien 1950).

3.4.4.2.4.5. Nutrient Uptake

The uptake of nutrients were estimated by multiplying nutrient content of the sample and respective dry weight of plant samples and expressed in kg ha^{-1}.

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient content (\%) x Total dry matter production (kg ha}^{-1})}{100}$$

3.4.4.3. Quality Attributes

3.4.4.3.1. Starch

Starch content of grain was estimated by the cyanide method suggested by Aminoff *et al.* (1970).

3.4.4.3.2. Protein

The protein content in grain was calculated by multiplying the nitrogen content of the grain with the factor 6.25 and was expressed in percentage (Simpson *et al.*, 1965).

3.4.4.3.2. Magnesium

Magnesium content of grain was found by Versanate titration method (Hesse, 1971).

3.4.5. Economic Analysis

The economics of cultivation was estimated based on the cost of cultivation and the prevailing market price of the produce.

3.4.5.1. Net Income

Net income was computed using the formula

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

3.4.5.2. Benefit Cost Ratio

Benefit cost ratio was computed using the formula

$$BCR = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.4.6. Statistical Analysis

The data generated from the experiment were statistically analyzed using Analysis of Variance technique for Randomized Block Design (Cochran and Cox, 1965) and the significance was tested using F test. Wherever the F values were found significant, critical difference was calculated at five per cent probability level.

RESULTS

4. RESULTS

Investigation entitled "Magnesium sulphate fertilization for yield enhancement in direct seeded rice" was conducted in farmer's field at Kalliyoor Panchayat, Thiruvananthapuram district from May 2017 to September 2017 with the objective to determine the optimum dose, time and method of application of magnesium sulphate for growth and yield enhancement in direct seeded rice. The results obtained from the experiment are presented below.

4.1 GROWTH PARAMETERS

4.1.1 Plant Height

The mean data on plant height at maximum tillering, panicle initiation and at harvest are presented in Table 2.

At maximum tillering stage, the height of the plant was the highest in T_2 ($MgSO_4$ @ 30 kg ha^{-1} at 20 DAS) which was on par with all other treatments except T_4, T_6, T_8 and T_{14} and the lowest in T_4 ($MgSO_4$ @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS).

At panicle initiation stage, the treatments differed significantly. The treatment T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar) recorded the highest plant height which was on par with T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) and the lowest in T_8 ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar).

Plant height at harvest was not found influenced by the treatments.

Table 2. Effect of magnesium sulphate fertilization on plant height, cm

Treatments	Plant height		
	Maximum tillering	Panicle initiation	Harvest
T_1	51.27	88.60	127.27
T_2	52.73	91.27	125.97
T_3	48.87	90.97	125.07
T_4	45.10	88.83	128.83
T_5	52.43	91.80	126.63
T_6	47. 87	89.40	128.07
T_7	49.80	90.43	128.20
T_8	46.20	85.70	126.10
T_9	49.90	94.70	123.83
T_{10}	51.10	99.90	126.00
T_{11}	49.00	86.20	126.03
T_{12}	50.17	89.53	123.80
T_{13}	49.67	86.73	125.33
T_{14}	46.30	91.50	126.07
SE m (±)	1.564	2.463	3.726
CD (0.05)	4.552	7.163	NS

4.1.2 Tillers m^{-2}

The data on tillers m^{-2} at various growth stages are presented in Table 3.

At maximum tillering stage, T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) produced the highest tillers m^{-2}, which was on par with all other treatments except T_1, T_3, T_{11} and T_{14} and the lowest in T_{14} (control- KAU PoP without Mg).

At panicle initiation stage, tillers m^{-2} was the highest in T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) which was on par with all other treatments except T_2, T_5, T_{11}, T_{13}, and T_{14} and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

At harvest stage, tillers m^{-2} was the highest in T_4 ($MgSO_4$ @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with all other treatments except T_1, T_2, T_{11}, and T_{14} and the lowest in T_{11} ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar).

4.1.3 Leaf Area Index (LAI)

The data on leaf area index (LAI) at panicle initiation stage is presented in Table 4.

At panicle initiation stage, T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) recorded the highest LAI which was on par with T_3, T_5, and T_9 and the lowest in T_{14} (control- KAU PoP without Mg).

Table 3. Effect of magnesium sulphate fertilization on tillers m^{-2}

Treatments	Tillers m^{-2}		
	Maximum tillering	Panicle initiation	Harvest
T_1	539.67	676.00	553.67
T_2	577.33	671.00	560.33
T_3	540.67	680.67	590.67
T_4	598.33	702.67	616.00
T_5	571.00	672.00	586.00
T_6	557.33	697.33	607.0 0
T_7	557.00	683.33	574.00
T_8	572.67	698.33	614.33
T_9	608.00	713.67	607.00
T_{10}	604.33	703.33	579.00
T_{11}	535.67	664.00	534.00
T_{12}	558.33	702.00	579.00
T_{13}	602.33	650.33	569.33
T_{14}	533.67	655.33	566.00
SE m (±)	17.635	13.299	16.587
CD (0.05)	51.280	38.672	48.229

Table 4. Effect of magnesium sulphate fertilization on leaf area index (LAI) at panicle initiation stage

Treatments	Leaf Area Index (LAI)
T_1	4.38
T_2	4.29
T_3	4.94
T_4	4.48
T_5	5.06
T_6	5.39
T_7	4.72
T_8	4.73
T_9	5.08
T_{10}	4.05
T_{11}	4.19
T_{12}	4.11
T_{13}	3.94
T_{14}	3.78
SE m (±)	0.156
CD (0.05)	0.453

4.2 PHYSIOLOGICAL PARAMETERS

4.2.1 Days to 50 % Flowering

The data on days to 50 % flowering are given in Table 5.

Days to 50 % flowering was significantly influenced by the treatments and flowering was the earliest in T_6 ($MgSO_4$ @ 40 kg ha-^{1} in two equal splits at 20 and 40 DAS) which was on par with T_2, T_4, and T_5, and late in T_{14} (control- KAU PoP without Mg).

4.2.2 Root Shoot Ratio

The data on root shoot ratio at flowering stage is given in Table 5.

The root shoot ratio was the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) and was on par with T_3, T_5, and T_{12} and the lowest in T_{14} (control- KAU PoP without Mg).

4.2.3 Chlorophyll Content

The data on chlorophyll content at panicle initiation and boot leaf stages are presented in Table 6.

At panicle initiation stage, chlorophyll a was the highest in T_{12} ($MgSO_4$ @ 20 kg ha-^{1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar), which was on par with T_6 and the lowest in T_{14} (control- KAU PoP without Mg). The chlorophyll b was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar), which was on par with all other treatments except T_5, T_6, T_{13} and T_{14} and the lowest in T_{14} (control- KAU PoP without Mg). The total chlorophyll content was the highest in T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar), which was on

Table 5. Effect of magnesium sulphate fertilization on days to 50 % flowering and root shoot ratio

Treatments	Days	Root shoot ratio
T_1	83.33	0.143
T_2	81.67	0.155
T_3	84.67	0.169
T_4	83.00	0.101
T_5	77.67	0.163
T_6	75.67	0.197
T_7	85.00	0.155
T_8	86.67	0.144
T_9	85.33	0.156
T_{10}	86.67	0.092
T_{11}	85.33	0.121
T_{12}	83.33	0.180
T_{13}	90.67	0.153
T_{14}	95.67	0.079
SE m (±)	2.511	0.012
CD (0.05)	7.300	0.035

Table 6. Effect of magnesium sulphate fertilization on Chlorophyll content, mg g^{-1} FW

Treatments	Panicle initiation			Boot leaf stage		
	Chlorophyll a	Chlorophyll b	Total chlorophyll	Chlorophyll a	Chlorophyll b	Total chlorophyll
T_1	0.484	0.551	1.035	0.503	0.550	1.053
T_2	0.486	0.536	1.022	0.496	0.543	1.039
T_3	0.493	0.536	1.028	0.509	0.596	1.105
T_4	0.495	0.485	0.980	0.496	0.552	1.048
T_5	0.497	0.422	0.919	0.498	0.576	1.074
T_6	0.527	0.453	0.980	0.572	0.455	1.027
T_7	0.484	0.484	0.968	0.497	0.625	1.122
T_8	0.485	0.542	1.027	0.505	0.643	1.148
T_9	0.504	0.546	1.050	0.514	0.592	1.106
T_{10}	0.487	0.556	1.043	0.603	0.751	1.354
T_{11}	0.489	0.503	0.993	0.506	0.553	1.059
T_{12}	0.549	0.484	1.033	0.575	0.530	1.105
T_{13}	0.496	0.417	0.913	0.502	0.515	1.017
T_{14}	0.469	0.403	0.872	0.476	0.523	1.006
SE m (±)	0.0136	0.0340	0.0329	0.0192	0.0268	0.0316
CD (0.05)	0.0397	0.0988	0.0957	0.0561	0.0779	0.0921

par with all other treatments except T_5, T_{13} and T_{14} and the lowest in T_{14} (control- KAU PoP without Mg).

At boot leaf stage, chlorophyll a was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar), which was on par with T_6 and T_{12} and T_{14} (control- KAU PoP without Mg) recorded the lowest value. The chlorophyll b content was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar), which was statistically superior to all other treatments and the lowest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS). The total chlorophyll content was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar), which was statistically superior to all other treatments and the lowest was in T_{14} (control- KAU PoP without Mg).

4.3 YIELD ATTRIBUTES AND YIELD

4.3.1 Productive Tillers m^{-2}

The data on productive tillers m^{-2} are given in Table 7. The highest number of productive tillers m^{-2} (578) was recorded in T_8 ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar) which was on par with all other treatments except T_1, T_{11}, T_{13}, and T_{14} and the lowest was in T_{14} (control- KAU PoP without Mg).

4.3.2 Panicle Weight (g)

The data on panicle weight are presented in Table 7. The panicle weight was the highest (2.89 g) in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with all other treatments except T_1, T_2, T_{13}, and T_{14} and the lowest in T_{14} (control- KAU PoP without Mg).

Table 7. Effect of magnesium sulphate fertilization on productive tillers m^{-2}, panicle weight, filled grains $panicle^{-1}$, sterility percentage and thousand grain weight

Treatments	Productive tillers m^{-2}	Panicle weight (g)	Number of filled grains $panicle^{-1}$	Sterility percentage	Thousan d grain weight (g)	Dry matter production ($t\ ha^{-1}$)
T_1	534.33	2.53	122.07	15.38	27.80	19.82
T_2	559.00	2.63	122.53	15.10	28.30	20.57
T_3	564.67	2.67	124.73	16.04	28.17	20.20
T_4	576.67	2.82	126.53	14.88	28.27	21.03
T_5	548.33	2.74	125.47	16.12	29.13	20.14
T_6	577.67	2.89	133.20	13.27	29.77	20.65
T_7	559.00	2.69	123.40	14.79	28.90	20.60
T_8	578.00	2.79	127.20	17.05	28.93	20.35
T_9	576.67	2.85	129.73	12.77	29.43	21.00
T_{10}	554.67	2.67	130.73	15.54	29.93	20.31
T_{11}	543.67	2.71	119.13	15.40	29.30	21.05
T_{12}	545.67	2.67	126.47	13.43	28.23	20.11
T_{13}	536.00	2.47	121.00	17.31	29.90	19.62
T_{14}	530.33	2.45	118.53	15.95	27.50	19.05
SE m ($\pm$)	11.583	0.081	2.672	1.033	0.527	0.416
CD (0.05)	33.678	0.237	7.769	NS	1.533	1.211

4.3.3 Number of Filled Grains Panicle^{-1}

The data on number of filled grains panicle^{-1} are presented in Table 7. The number of filled grains panicle^{-1} was the highest (133.2) in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with T_4, T_5, T_6, T_8, T_9, T_{10} and T_{12} and the lowest in T_{14} (control).

4.3.4 Sterility Percentage

The sterility percentage was not significantly influenced by the treatments (Table 7).

4.3.5 Thousand Grain Weight (g)

The data on thousand grain weight are given in Table 7. The thousand grain weight was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar) which was on par with T_5, T_6, T_7, T_8, T_9, T_{11} and T_{13} and the lowest in T_{14} (control- KAU PoP without Mg).

4.3.6 Grain Yield (kg ha^{-1})

The data on grain yield are given in Table 8. The highest grain yield (9.6 t ha^{-1}) was registered in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) and was on par with T_2, T_4, T_5, T_7, T_8, T_9, and T_{10}. The grain yield was the lowest (7253.3 kg ha^{-1}) in T_{14} (control- KAU PoP without Mg), which was on par with T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

Table 8. Effect of magnesium sulphate fertilization on grain yield, straw yield and harvest index

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index
T_1	8.67	11.15	0.436
T_2	8.99	11.58	0.437
T_3	8.43	11.77	0.417
T_4	9.47	11.55	0.451
T_5	9.03	11.11	0.448
T_6	9.60	11.05	0.463
T_7	8.87	11.73	0.430
T_8	8.82	11.53	0.432
T_9	9.50	11.50	0.452
T_{10}	9.09	11.21	0.447
T_{11}	8.69	12.35	0.414
T_{12}	7.98	12.12	0.398
T_{13}	7.26	12.35	0.370
T_{14}	7.25	11.79	0.381
SE m ($\pm$)	0.300	0.534	0.014
CD (0.05)	0.872	NS	0.042

4.3.7 Straw Yield (kg ha^{-1})

The straw yield was not significantly influenced by treatments (Table 8).

4.3.8 Dry Matter Production at harvest (kg ha^{-1})

The data on dry matter production are presented in Table 8. The DMP at harvest was the highest (21.05 t ha^{-1}) in T_{11} ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar) which was on par with all other treatments except T_1, T_{13}, and T_{14} and the lowest in T_{14} (control- KAU PoP without Mg).

4.3.9 Harvest Index

The data on harvest index are presented in Table 8. Harvest index was significantly influenced by the treatments. The harvest index was the highest (0.463) in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with all other treatments except T_3, T_{11}, T_{12}, T_{13}, and T_{14}. The harvest index was the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

4.4 AVAILABLE NUTRIENTS

4.4.1 Available Nitrogen

The data on available N in soil at maximum tillering, panicle initiation and at harvest are given in Table 9.

At maximum tillering stage, available N in soil was not found influenced by the treatments.

Table 9. Effect of magnesium sulphate fertilization on available N in soil, kg ha^{-1}

Treatments	Available N		
	Maximum tillering	Panicle initiation	Harvest
T_1	204.68	322.88	183.24
T_2	222.70	329.15	202.06
T_3	219.99	297.79	183.24
T_4	203.88	322.88	189.52
T_5	216.43	285.25	183.25
T_6	200.55	266.43	162.34
T_7	216.43	291.52	183.24
T_8	216.43	285.25	176.97
T_9	222.70	291.52	183.25
T_{10}	216.43	310.34	163.10
T_{11}	216.43	310.34	158.16
T_{12}	210.16	278.98	164.43
T_{13}	203.89	304.06	170.70
T_{14}	227.43	341.69	195.79
SE m (±)	18.551	14.566	8.942
CD (0.05)	NS	42.354	25.999

At panicle initiation stage, the soil available N status was the highest in T_{14} (control- KAU PoP without Mg) which was on par with T_1, T_2, T_4, T_{10}, T_{11} and T_{13} and the lowest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS).

At harvest stage, the soil available N status was the highest in T_2 ($MgSO_4$ @ 30 kg ha^1 at 20 DAS) which was on par with all other treatments except T_6, T_{10}, T_{11}, T_{12}, and T_{13} and the lowest in T_{11} ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar).

4.4.2 Available Phosphorus

The data on available P in soil at maximum tillering, panicle initiation and at harvest are given in Table 10.

At maximum tillering stage, available P in soil was not found influenced by the treatments.

At panicle initiation stage, the soil available P status was the highest in T_1 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS) which was on par with all the treatments except T_2, T_3, T_5, T_6, T_{10}, and T_{12} and the lowest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar).

At harvest stage, the soil available P status was the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) which was on par with all the treatments except T_1, T_3, T_{10} and T_{12} and the lowest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar).

4.4.3 Available Potassium

The data on available K in soil at maximum tillering, panicle initiation and at harvest are given in Table 11.

Table 10. Effect of magnesium sulphate fertilization on available P in soil, kg ha^{-1}

Treatments	Available P		
	Maximum tillering	Panicle initiation	Harvest
T_1	35.14	45.90	27.70
T_2	39.70	41.48	30.73
T_3	37.35	39.95	27.53
T_4	37.00	44.30	30.75
T_5	39.95	41.26	30.28
T_6	36.96	40.16	34.13
T_7	35.65	42.62	30.97
T_8	36.73	43.01	31.65
T_9	35.32	41.75	30.56
T_{10}	39.60	41.01	29.64
T_{11}	41.30	44.10	33.92
T_{12}	36.18	39.68	27.15
T_{13}	40.2	45.59	33.06
T_{14}	42.09	45.15	33.39
SE m (±)	2.229	1.454	1.523
CD (0.05)	NS	4.230	4.427

Table 11. Effect of magnesium sulphate fertilization on available K in soil, kg ha^{-1}

Treatments	Available K		
	Maximum tillering	Panicle initiation	Harvest
T_1	184.92	185.73	119.88
T_2	181.13	199.97	132.39
T_3	173.54	182.67	112.52
T_4	186.87	198.13	119.18
T_5	190.85	205.02	135.62
T_6	192.36	199.97	132.26
T_7	196.62	204.62	125.34
T_8	182.92	206.58	140.88
T_9	200.77	202.52	138.14
T_{10}	197.34	207.37	159.76
T_{11}	199.75	239.67	150.94
T_{12}	190.73	199.74	122.99
T_{13}	169.57	183.24	118.23
T_{14}	219.35	240.12	152.76
SE m (±)	6.140	11.609	17.555
CD (0.05)	17.853	33.755	NS

At maximum tillering stage, the available K status was the highest in T_{14} (control- KAU PoP without Mg) which was significantly superior to all other treatments and the lowest was in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

At panicle initiation stage, the available K status in soil was the highest in T_{14} (control- KAU PoP without Mg) which was on par with T_8, T_{10}, and T_{11} and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

The available K status of soil was not found influenced by treatments at harvest stage.

4.4.4 Calcium

The data on available Ca in soil at maximum tillering, panicle initiation and at harvest are given in Table 12.

At maximum tillering stage, available Ca in soil was the highest in T_{14} (control- KAU PoP without Mg) which was significantly superior to all other treatments and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

At panicle initiation stage, T_{14} (control- KAU PoP without Mg) recorded the highest value which was on par with T_4, T_7 and T_{11} and the lowest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar).

The available Ca status of the soil was the highest in T_7 ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ as foliar at 40 DAS) at harvest stage, which was on par with T_8, T_{11}, and T_{14} and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

Table 12. Effect of magnesium sulphate fertilization on available Ca in soil, mg kg^{-1}

Treatments	Available Ca		
	Maximum tillering	Panicle initiation	Harvest
T_1	373.33	462.90	331.62
T_2	336.28	472.15	322.77
T_3	361.20	454.47	314.72
T_4	369.94	510.66	338.77
T_5	399.30	448.55	359.28
T_6	386.96	466.95	350.82
T_7	364.28	509.45	393.92
T_8	398.07	463.10	373.87
T_9	396.82	470.45	353.06
T_{10}	374.63	479.00	334.77
T_{11}	313.50	499.40	376.87
T_{12}	363.70	420.95	343.72
T_{13}	279.85	441.30	301.32
T_{14}	459.25	533.15	383.85
SE m (±)	14.701	15.724	10.511
CD (0.05)	42.746	45.719	30.562

4.4.5 Magnesium

The data on available Mg in soil at maximum tillering, panicle initiation and at harvest are given in Table 13.

At maximum tillering stage, available Mg in soil was the highest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) which was on par with T_3 and the lowest in T_{14} (control- KAU PoP without Mg).

At panicle initiation stage, available Mg in soil was the highest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) which was on par with T_2, and T_3 and the lowest in T_{14} (control- KAU PoP without Mg).

The available Mg status of the soil was the highest in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) at harvest stage, which was on par with T_1, T_2, T_5 and T_6 and the lowest in T_{14} (control- KAU PoP without Mg).

4.4.6 Sulphur

The data on available S in soil at maximum tillering, panicle initiation and at harvest are given in Table 14.

At maximum tillering stage, available S in soil was the highest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal), which was on par with T_2, T_3 and T_6 and the lowest in T_{14} (control- KAU PoP without Mg).

At panicle initiation stage, available S in soil was the highest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal), which was on par with T_3, and T_6 and the lowest in T_{14} (control- KAU PoP without Mg).

Table 13. Effect of magnesium sulphate fertilization on available Mg in soil, mg kg^{-1}

Treatments	Available Mg		
	Maximum tillering	Panicle initiation	Harvest
T_1	185.68	228.40	168.40
T_2	203.46	266.85	189.66
T_3	217.93	271.55	194.78
T_4	164.93	206.70	152.46
T_5	184.50	213.40	171.28
T_6	183.10	227.50	165.01
T_7	158.67	213.00	151.67
T_8	157.70	215.30	149.31
T_9	159.37	214 25	154.25
T_{10}	155.42	210.60	150.60
T_{11}	161.87	229.90	162.07
T_{12}	159.11	213.80	153.80
T_{13}	248.21	280.65	146.27
T_{14}	149.73	180.75	127.20
SE m (±)	12.342	16.561	11.065
CD (0.05)	35.885	48.155	32.173

Table 14. Effect of magnesium sulphate fertilization on available S in soil, mg kg^{-1}

Treatments	Available S		
	Maximum tillering	Panicle initiation	Harvest
T_1	8.06	14.07	7.89
T_2	8.99	15.11	8.43
T_3	9.06	16.70	10.55
T_4	6.50	13.86	6.92
T_5	7.45	13.88	9.78
T_6	8.94	16.46	10.15
T_7	5.99	12.58	9.13
T_8	7.74	13.20	9.20
T_9	8.25	14.93	9.76
T_{10}	6.41	13.91	7.29
T_{11}	7.41	11.65	6.76
T_{12}	8.57	14.67	5.76
T_{13}	10.41	18.49	11.02
T_{14}	5.02	10.23	5.02
SE m (±)	0.564	0.788	0.615
CD (0.05)	1.641	2.292	1.787

At harvest stage, available S in soil was the highest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) which was on par with T_3, T_5, T_6 and T_9 and the lowest in T_{14} (control- KAU PoP without Mg).

4.5 NUTRIENT UPTAKE

4.5.1 Nitrogen

The data on nitrogen uptake at maximum tillering, panicle initiation and at harvest are presented in Table15.

At maximum tillering stage, N uptake by the plant was not significantly influenced by the treatments.

At panicle initiation stage, T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) recorded the highest N uptake, which was on par with T_4, T_7, T_9 and T_{13}. The lowest N uptake was in T_{14} (control- KAU PoP without Mg).

At harvest stage, N uptake by the plant was the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) which was on par with T_4, T_7, T_9 and T_{12} and the lowest in T_{14} (control- KAU PoP without Mg).

4.5.2 Phosphorus

The data on phosphorus uptake by the crop at maximum tillering, panicle initiation and at harvest are shown in Table16.

At maximum tillering stage, T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) recorded the highest P uptake, which was on par with T_1 and T_{13} and the lowest in T_{14} (control- KAU PoP without Mg).

Table 15. Effect of magnesium sulphate fertilization on N uptake, kg ha^{-1}

Treatments	N uptake		
	Maximum tillering	Panicle initiation	Harvest
T_1	56.17	123.82	146.31
T_2	58.35	111.68	159.72
T_3	60.45	120.57	168.63
T_4	54.62	125.43	186.05
T_5	54.64	122.33	174.78
T_6	54.40	135.11	204.66
T_7	55.55	124.67	182.33
T_8	57.04	121.54	161.69
T_9	53.91	127.20	196.68
T_{10}	54.53	114.99	170.59
T_{11}	56.99	122.45	179.37
T_{12}	53.95	113.92	182.40
T_{13}	57.81	127.21	142.31
T_{14}	50.00	108.15	137.26
SE m (±)	1.929	3.767	7.735
CD (0.05)	NS	10.954	22.489

Table 16. Effect of magnesium sulphate fertilization on P uptake, kg ha^{-1}

Treatments	P uptake		
	Maximum tillering	Panicle initiation	Harvest
T_1	16.32	30.25	49.54
T_2	15.71	31.82	49.41
T_3	19.04	35.52	50.29
T_4	10.98	33.77	48.30
T_5	10.34	31.03	50.89
T_6	12.00	28.55	55.10
T_7	11.95	27.21	45.60
T_8	15.69	28.11	32.60
T_9	12.63	28.82	46.28
T_{10}	10.13	26.92	44.85
T_{11}	14.92	28.59	38.42
T_{12}	11.49	28.59	42.66
T_{13}	17.51	19.15	31.02
T_{14}	9.19	22.14	49.64
SE m (±)	1.097	1.430	3.147
CD (0.05)	3.188	4.159	9.152

At panicle initiation stage, P uptake was the highest in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS), which was on par with T_2 and T_4 and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

At harvest stage, P uptake by the plant was the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) which was on par with all treatments except T_7, T_8, T_{10}, T_{11}, T_{12}, and T_{13} where T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) recording the lowest uptake.

4.5.3 Potassium

The data on potassium uptake by the crop at maximum tillering, panicle initiation and at harvest are presented in Table17.

At maximum tillering stage, K uptake by the plant was the highest in T_{14} (control- KAU PoP without Mg) which was on par with T_4, T_7, T_8, T_{10}, T_{11} and T_{12} and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

At panicle initiation stage, T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar) recorded the highest K uptake, which was on par with all other treatments except T_2, T_4, T_6, T_7, T_8, T_9, and T_{10} and lowest in T_4 ($MgSO_4$ @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS).

At harvest T_{14} (control- KAU PoP without Mg) recorded the highest K uptake which was on par with all other treatments except T_6, T_7, T_8, T_9 and T_{13} where T_{13} ($MgSO_4$ @ 80 kg ha^{-1} as basal) recording the lowest.

4.5.4 Calcium

The data on calcium uptake by the crop at maximum tillering, panicle initiation and at harvest are presented in Table18.

Table 17. Effect of magnesium sulphate fertilization on K uptake, kg ha^{-1}

Treatments	K uptake		
	Maximum tillering	Panicle initiation	Harvest
T_1	73.99	135.63	183.67
T_2	73.68	124.07	186.11
T_3	63.62	137.24	188.88
T_4	81.20	118.67	176.10
T_5	63.24	136.56	177.41
T_6	69.87	120.45	156.69
T_7	80.23	123.99	169.24
T_8	89.86	128.19	144.15
T_9	67.02	119.98	160.88
T_{10}	88.92	121.41	197.96
T_{11}	90.24	138.42	187.18
T_{12}	83.71	145.76	206.91
T_{13}	54.52	139.85	125.49
T_{14}	91.96	141.39	207.67
SE m (±)	4.717	5.412	11.382
CD (0.05)	13.716	15.736	33.095

Table 18. Effect of magnesium sulphate fertilization on Ca uptake, kg ha^{-1}

Treatments	Ca uptake		
	Maximum tillering	Panicle initiation	Harvest
T_1	7.57	15.03	18.65
T_2	9.99	14.49	19.20
T_3	8.60	13.74	21.04
T_4	9.16	14.25	21.48
T_5	8.98	14.32	16.80
T_6	7.99	12.47	15.92
T_7	9.65	12.24	18.13
T_8	9.60	13.96	16.42
T_9	8.97	13.17	21.60
T_{10}	8.30	13.83	20.62
T_{11}	9.79	12.28	19.36
T_{12}	7.64	13.12	17.44
T_{13}	7.34	12.57	16.53
T_{14}	10.96	13.50	16.65
SE m (±)	0.590	0.294	0.634
CD (0.05)	1.717	0.856	1.842

At maximum tillering stage, Ca uptake was the highest in T_{14} (control- KAU PoP without Mg), which was on par with T_2, T_7, T_8, and T_{11} and the lowest in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal).

At panicle initiation stage, T_1 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS) recorded the highest Ca uptake, which was on par with T_2, T_4, and T_5 and the lowest in T_7 ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar).

At harvest, T_9 ($MgSO_4$@ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) recorded the highest uptake which was on par with T_3, T_4 and T_{10} and the lowest in T_6 ($MgSO_4$ @ 40 kg ha-^{1} in two equal splits at 20 and 40 DAS).

4.5.5 Magnesium

The data on magnesium uptake by the crop at maximum tillering, panicle initiation and at harvest are presented in Table 19.

At maximum tillering stage, Mg uptake was the highest in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS), which was on par with T_1, T_2, and T_7 and the lowest in T_{14} (control- KAU PoP without Mg)

At panicle initiation stage, T_6 ($MgSO_4$ @ 40 kg ha-^{1} in two equal splits at 20 and 40 DAS) recorded the highest Mg uptake, which was on par with all the treatments except T_4, T_8, T_{11}, T_{12}, T_{13}, and T_{14} where T_{14} (control- KAU PoP without Mg) recording the lowest.

At harvest, Mg uptake by the plant was the highest in T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) which was on par with T_2, T_4, T_6, T_7, and T_{10} and the lowest in T_{14} (control- KAU PoP without Mg).

Tale 19. Effect of magnesium sulphate fertilization on Mg uptake, kg ha^{-1}

Treatments	Mg uptake		
	Maximum tillering	Panicle initiation	Harvest
T_1	4.93	9.56	12.95
T_2	5.20	10.67	14.73
T_3	5.62	9.80	12.83
T_4	4.25	9.07	15.01
T_5	4.22	10.22	12.51
T_6	4.55	10.99	14.98
T_7	4.95	9.89	14.49
T_8	4.56	9.26	13.71
T_9	4.43	10.17	16.51
T_{10}	4.24	10.52	14.60
T_{11}	4.28	9.05	12.04
T_{12}	4.62	9.48	12.19
T_{13}	4.13	8.76	11.83
T_{14}	4.11	8.17	11.50
SE m (±)	0.246	0.491	0.726
CD (0.05)	0.714	1.427	2.111

4.5.6 Sulphur

The data on sulphur uptake by the crop at maximum tillering, panicle initiation and at harvest are presented in Table 20.

At maximum tillering stage, S uptake by the plant was not found influenced by the treatments.

At panicle initiation stage, S uptake was the highest in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) which was significantly superior to all other treatments and the lowest in T_{14} (control- KAU PoP without Mg).

At harvest, T_{13} ($MgSO_4$ @ 80 kg ha^{-1} as basal) recorded the highest S uptake which was on par with T_3, T_5 and T_6 and the lowest in T_{14} (control- KAU PoP without Mg).

4.6 QUALITY ATTRIBUTES

4.6.1 Starch

The starch content of grain was not significantly influenced by the treatments (Table 21)

4.6.2 Protein

The data on protein content of grain are presented in Table 21. Protein content in grain was the highest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar) which was on par with T_5, T_6, T_7, T_8, T_9, T_{10}, and T_{11} and the lowest in T_{14} (control- KAU PoP without Mg).

Table 20. Effect of magnesium sulphate fertilization on S uptake, kg ha^{-1}

Treatments	S uptake		
	Maximum tillering	Panicle initiation	Harvest
T_1	4.66	10.83	11.43
T_2	4.22	11.40	11.76
T_3	5.26	13.46	14.16
T_4	4.26	9.08	11.71
T_5	4.31	8.20	13.29
T_6	4.12	8.35	13.28
T_7	4.17	8.67	9.37
T_8	4.69	8.97	9.54
T_9	4.45	7.36	9.95
T_{10}	4.56	7.51	10.06
T_{11}	3.88	7.60	12.61
T_{12}	4.34	7.60	11.37
T_{13}	4.18	11.61	14.65
T_{14}	4.03	7.02	8.17
SE m (±)	0.347	0.522	0.515
CD (0.05)	NS	1.518	1.498

Table 21. Effect of magnesium sulphate fertilization on starch, protein and magnesium content of grain

Treatments	Starch (%)	Protein (%)	Magnesium (%)
T_1	64.08	6.11	0.053
T_2	60.25	6.49	0.055
T_3	64.61	6.20	0.065
T_4	59.67	6.26	0.055
T_5	61.68	6.88	0.066
T_6	61.05	7.25	0.073
T_7	59.13	7.05	0.063
T_8	65.05	6.93	0.065
T_9	60.97	7.11	0.070
T_{10}	60.85	7.02	0.075
T_{11}	61.23	7.12	0.045
T_{12}	64.02	7.49	0.065
T_{13}	61.32	5.64	0.058
T_{14}	64.44	5.57	0.043
SE m (±)	5.424	0.234	0.005
CD (0.05)	NS	0.679	0.014

4.6.3 Magnesium content

The data on magnesium content of grain are presented in Table 21. The magnesium content in grain was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar) which was on par with T_3, T_5, T_6, T_7, T_8, T_9 and T_{12} and the lowest in T_{14} (control- KAU PoP without Mg).

4.7 ECONOMIC ANALYSIS

The data on gross income, net income and benefit cost ratio (B:C ratio) are given in Table 22.

4.7.1 Gross Income

The highest gross income (253960 ₹ ha^{-1}) was recorded in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with all other treatments except T_3, T_{12}, T_{13} and T_{14} where T_{14} (control- KAU PoP without Mg) recording the lowest (202206 ₹ ha^{-1})

4.7.2 Net Income

The net income was also the highest in T_6 (169554 ₹ ha^{-1}) was recorded in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with all other treatments except T_3, T_{12}, T_{13} and T_{14}, where T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) recording the lowest (119673 ₹ ha^{-1}).

Table 22. Effect of magnesium sulphate fertilization on economics of cultivation

Treatments	Total cost (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	B:C ratio
T_1	83226	232800	149574	2.80
T_2	83416	241472	158056	2.90
T_3	83606	229226	145620	2.74
T_4	84026	252545	168519	3.00
T_5	84216	240939	156723	2.86
T_6	84406	253960	169554	3.01
T_7	85631	239133	153502	2.80
T_8	85726	237367	151641	2.77
T_9	85821	253000	167179	2.95
T_{10}	85726	242925	157199	2.83
T_{11}	85821	237059	151238	2.76
T_{12}	85916	220099	134183	2.56
T_{13}	84366	204039	119673	2.42
T_{14}	82046	202206	120161	2.46
SE m (±)		7440.95	7440.95	0.088
CD (0.05)		21635.51	21635.51	0.256

4.7.3 Benefit Cost Ratio

The highest B: C of 3.01 was recorded in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS), which was on par with all other treatments except T_3, T_{12}, T_{13} and T_{14}, where T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) recording the lowest (2.76).

DISCUSSION

5. DISCUSSION

The experimental findings obtained from the investigation entitled "Magnesium sulphate fertilization for yield enhancement in direct seeded rice" to determine the optimum dose, time and method of application of magnesium sulphate for growth and yield enhancement in rice is discussed in this chapter.

5.1 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON GROWTH PARAMETERS

The results of the study revealed that the growth attributes like plant height, tillers m^{-2} and leaf area index were influenced by the dose, time and method of application of magnesium sulphate ($MgSO_4$). Magnesium (Mg) is an essential nutrient for normal and healthy plant growth; the steady supply of Mg might have improved several anatomical and physiological reactions in plants which in turn contributed to increase in size of cells, intercellular spaces and increase in plant height. Increased plant height in rice due to magnesium addition was reported by Singh and Singh (2005). Similar findings were also reported by Singh (2001) and El-Zanaty *et al.* (2012) in wheat.

The plant height was the highest in T_2 ($MgSO_4$ @ 30 kg ha^{-1} at 20 DAS) at maximum tillering stage. The higher Mg uptake in T_2 at maximum tillering stage might have favoured several anatomical and physiological reactions increasing cell size and intercellular spaces, leading to higher plant height. At panicle initiation stage, it was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar). The foliar application of $MgSO_4$ given at 40 DAS had facilitated quick consumption of nutrients by easy penetration through stomata or leaf cuticle and improved plants mineral status and growth. The plant height at harvest was not influenced by treatments as growth in terms of height terminates at harvest stage.

At maximum tillering and panicle initiation stages, T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) produced maximum tillers m^{-2} while at harvest it was the highest in T_4 ($MgSO_4$ @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS). Adequate Mg availability at later growth stages either through foliar feeding of $MgSO_4$ (T_9) or soil application (T_4) might have enhanced nutrient availability resulting in higher tiller number. Even though higher dose of $MgSO_4$ was given as basal in T_{13} (80 kg ha^{-1}), split application of lower dose (20 kg ha^{-1}) was found effective in terms of tiller production. Moreover the uptake of N in T_9 and T_4 were on par with T_6, where the highest uptake of N was observed. The enhanced N uptake might have increased the cytokinin content within tiller nodes and further enhanced the germination of the tiller primordium which might be the reason for more tiller production. The applied Mg might have favourably influenced the N uptake and assimilation in rice as reported by Ding *et al.* (2006) and resulted in more tiller production. Szulc (2013) and Grzebisz (2010) also reported the positive influence of Mg on the uptake and utilization of N. The increase in tiller number as a result of Mg addition in rice was reported by Raj *et al.* (2013).

Significant influence of magnesium nutrition on leaf area index in rice at panicle initiation stage was observed in the current study. The treatment T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) recorded the highest LAI and T_{14} (control- KAU PoP without Mg) the lowest. At panicle initiation stage, uptake of N was the highest in T_6 and it was the lowest in T_{14} (control- KAU PoP without Mg) and this increased nitrogen uptake might have influenced the production of green mass. Mg is considered as an essential nutrient for the uptake of N by crop plants, sufficient quantity of Mg available throughout the growth stages facilitated N uptake and this might be the reason for higher LAI. According to Andrieu *et al.* (1997), supply of Mg resulted in higher nitrate uptake with increased canopy growth. Favourable effect of Mg on LAI of rice was reported by Raj *et al.* (2013), Rani (2014) and Preman (2015).

From the results on growth parameters such as plant height, tillers m^{-2} and leaf area index, it is inferred that steady and continuous supply of magnesium had a direct influence on growth components of rice. The role of Mg in activating more enzymes engaged in numerous biochemical and physiological processes which affecting growth and development of plants (Epstein and Bloom 2004) might be the reason for growth improvement.

5.2 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON PHYSIOLOGICAL PARAMETERS

The physiological parameters such as days to 50 % flowering, chlorophyll content and root shoot ratio were found influenced by Mg application. Flowering was the earliest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) and late in T_{14} (Control- without Mg application). Singh and Singh (2005) observed an enhancement in flowering and heading of rice with the supply of magnesium. Mg is necessary for normal plant growth and split application is found more effective for flowering.

The chlorophyll content at panicle initiation and boot leaf stages were significantly influenced by treatments. At panicle initiation stage, 'chlorophyll a' was the highest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar), 'chlorophyll b' was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar) and total chlorophyll content was the highest in T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar). The control (T_{14} - KAU PoP without Mg) recorded the lowest chlorophyll content at this stage. At boot leaf stage 'chlorophyll a', 'chlorophyll b' and total chlorophyll were the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar), T_{14} (control- KAU PoP without Mg) had the lowest chlorophyll a and total chlorophyll. It is evident from the results that split application of low dose of $MgSO_4$ with foliar feeding is more effective than basal application. An increase in chlorophyll concentration with foliar application of Mg has been shown by Dordas (2009), Teklic *et al.* (2009) and Neuhaus *et al.* (2013). The role of Mg in chlorophyll structure and function is well known. Mg is bound as the central atom of the porphyrin ring structure of chlorophyll and is also involved in the biosynthesis of chlorophyll molecule, ie., Mg chelatase enzyme catalysing the first step of chlorophyll biosynthesis by inserting Mg^{2+} into protoporphyrin IX (Walker and Weinstein 1991). This might be the reason for higher chlorophyll value. Increase in chlorophyll content in rice due to magnesium addition was reported by Moreira *et al.* (2015) and Preman (2015).

The root shoot ratio at flowering was the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) and the lowest in T_{14} (control- KAU PoP without Mg). Mg plays a major role in the partitioning and utilization of carbohydrates between source and sink. When Mg is not adequate in plants, dry matter partitioning to roots decreases, thereby decreases growth of roots (Cakmak *et al.*, 1994a, b), this could be the reason for the lowest root shoot ratio in T_{14} (control- KAU PoP without Mg). The treatments receiving $MgSO_4$ had higher root shoot ratio than control and soil application was found more effective for root growth. However root shoot ratio in T_{13} (*adhoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) was less than that of T_6, this might be due to leaching loss of $MgSO_4$ from the root zone. In T_{13}, high dose of Mg (80 kg ha^{-1}) was given entirely as basal and a very high rainfall (187.9 mm) was received just after the broadcasting of seeds and this might have resulted in loss of Mg from the root zone through leaching. It is well documented that Mg is involved in the allocation of carbohydrate from leaves to sink and Mg deficiency causes accumulation of carbohydrates in shoots and thereby reduces the root growth. The root growth in plants is highly sensitive to Mg supply and availability in soil. Similar findings have been reported by Ericsson and Kahr (1995) and Fischer *et al.* (1998) in a wide range of cultivated species.

5.3 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON YIELD ATTRIBUTES AND YIELD

Results (Tables 7 & 8) revealed that yield attributes like productive tillers m^{-2}, panicle weight, number of filled grains $panicle^{-1}$ and thousand grain weight were found influenced by magnesium application. Tillering being an important trait deciding rice grain yield, the number of productive tillers m^{-2} was the highest in T_8 ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar). The treatment T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) registered the highest panicle weight and number of filled grains $panicle^{-1}$ (Fig.4), T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar) had the highest thousand grain weight. All these parameters were the lowest in T_{14} (control- KAU PoP without Mg). Split application of $MgSO_4$ or foliar application was found more effective than single application in increasing the yield attributes. The treatments receiving $MgSO_4$ produced more panicles and filled grains, might be due to the critical role of Mg in crop growth, photosynthesis processes, respiration and other biochemical and physiological activities (El- Zanaty *et al.*, 2012). Similarly an improvement in grain number with the addition of Mg was reported by Srivastava *et al.* (2006). Shaygany *et al.* (2012) and Chang and Sung (2004) had also observed an increase in yield attributes of rice due to Mg addition. This is in conformity with the findings of Hossain *et al.* (2011) and El-Metwally *et al.* (2011) in wheat.

$MgSO_4$ fertilization had profound influence on grain yield of direct seeded rice. The treatment T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) recorded the highest grain yield and it was on par with T_2, T_4, T_5, T_7, T_8 T_9, and T_{10} (Fig.3). The increased grain yield in these treatments might be due to the formation of more panicles m^{-2}, grains $panicle^{-1}$ and production of bold grains with high test grain weight. The uptake of N, P, Mg and S were also higher in T_6 and this might have also attributed to higher grain yield. Results also revealed the better performance of split

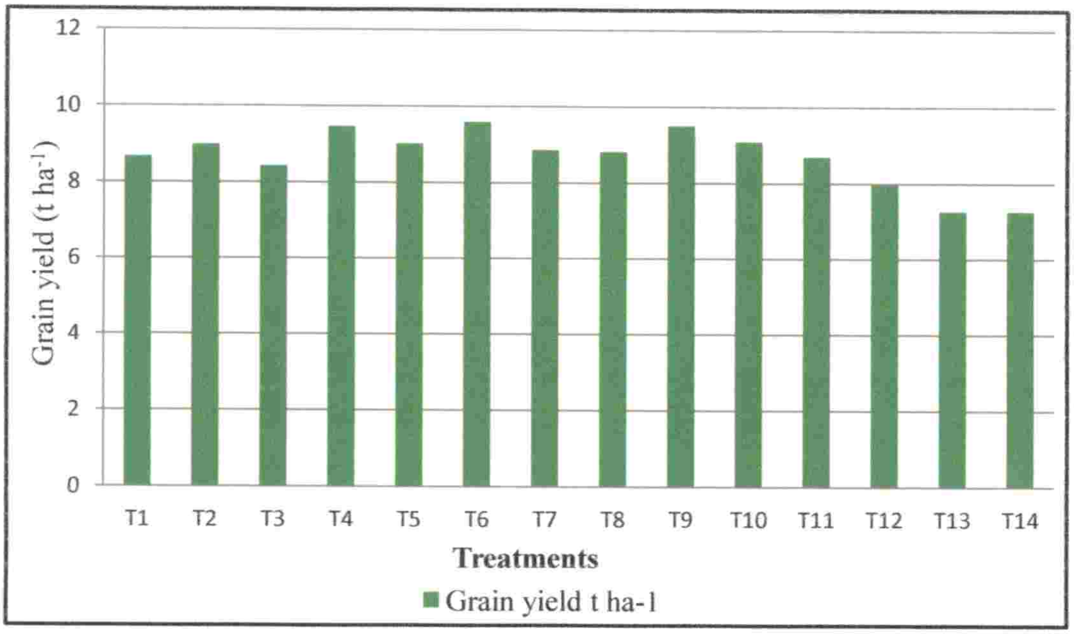

Fig.3 Effect of $MgSO_4$ fertilization on grain yield ($t\ ha^{-1}$)

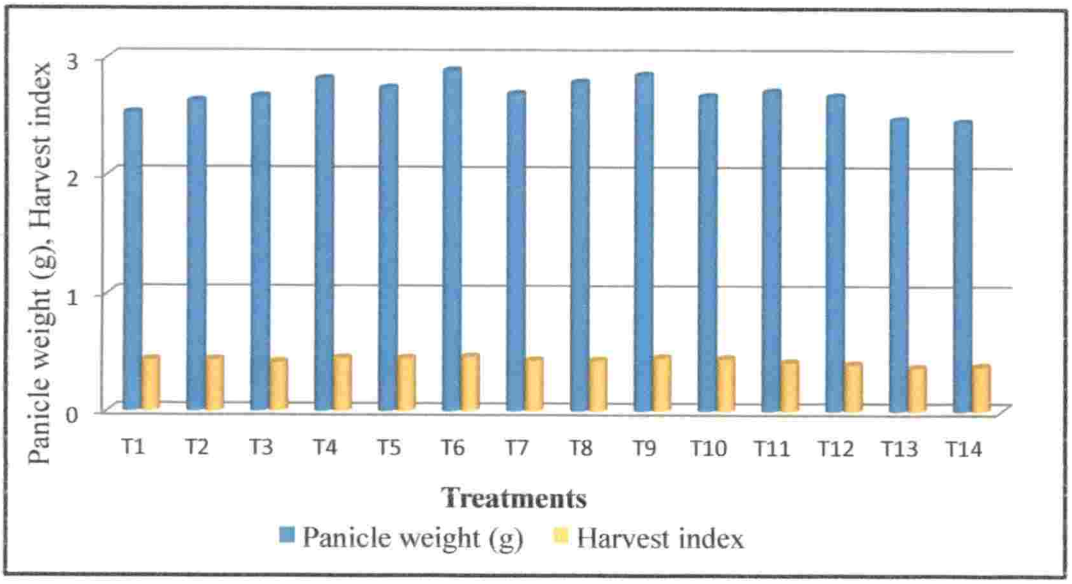

Fig.4 Effect of $MgSO_4$ fertilization on panicle weight (g), harvest index.

application of $MgSO_4$ compared to single application. Compared to control, T_6 recorded a yield enhancement of 32.35%. The dry matter production (DMP) at harvest was the highest in T_{11} ($MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar), T_{14} (control- without Mg application) registered the lowest grain yield and DMP at harvest and T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal)) registered the lowest harvest index (Fig.4). Straw yield was not found influenced by the treatments; harvest index followed the similar trend as that of grain yield. Addition of Mg improved the yield attributes and grain yield, however compared to single application split application of $MgSO_4$ was found effective. Mg performs a major role in the allocation of photo assimilates from leaves into sink organs and it is critical for photosynthesis, enzyme activation, and formation and utilization of ATP in plants (Cakmak *et al.* 1994a; Hermans *et al.* 2005) and this might have contributed to higher grain yield. The significant effect of Mg on the yield of rice was reported by Choudary and Khanif (2001), Singh and Singh (2005) and Preman (2015). Similar observations were also reported by El- Metwally *et al.* (2011) and Hossain *et al.* (2011) in wheat and Szulc *et al.* (2008), Noor *et al.* (2015) and Ertiftika and Zenginb (2017) in maize. In addition to the effect of Mg, the S present in $MgSO_4$ (13%) might have also played a role in yield enhancement as uptake of S was also higher in T_6, for better understanding of this effect we need more research.

On perusal of data on yield attributes and yield, it can be seen that even though 80 kg ha^{-1} $MgSO_4$ was given as basal in T_{13}, yield attributes and yield were low compared to other treatments receiving Mg. This might be due to the fact that the entire dose (80 kg ha^{-1}) of $MgSO_4$ was applied as basal, at that time the rice root system was not well developed to absorb Mg to the maximum extent and the high mobile nature of Mg in the soil caused the leaching of $MgSO_4$ from the root zone. The hydrated radius of Mg is large, it is having a weak binding with soil colloids compared to other cations and therefore highly prone to leaching (Hermans *et al.*, 2004). The data on uptake of Mg revealed that uptake in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) was less compared to other treatments receiving Mg and this might be the reason for decreased yield. Study conducted by Biswas *et al.* (2013) pointed out the significance of lower dose of $MgSO_4$ for yield enhancement in rice. According to Raj *et al.* (2013) magnesium sulphate @ 20 kg ha^{-1} with recommended N, P, K, FYM and lime was the best integrated nutrient management practice for higher grain yield in transplanted rice. Critical analysis of data on yield attributes and yield, it can be seen that irrespective of deficiency or sufficiency of Mg in soil, addition of optimum dose of $MgSO_4$ enhanced the yield attributes and yield in direct seeded rice. In addition split or foliar application ensures continuous and steady availability of Mg. However, the role of S in yield enhancement requires more study as $MgSO_4$ is a chemical combination of Mg and S.

5.4 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON AVAILABLE NUTRIENTS

Results revealed that availability of primary and secondary nutrients in soil at different growth stages were found influenced by treatments. The available nutrient status in soil exhibited an increasing trend from maximum tillering to panicle initiation stage and thereafter it declined at harvest stage. The increase in available nutrients at panicle initiation stage might be due to the split application of fertilizers done one week prior to panicle initiation and also due to the vigorous crop growth resulting in greater root exudation (Dotanita *et al.*, 2014). Available N in soil was the highest in T_{14} (control- KAU PoP without Mg) and T_2 ($MgSO_4$ @ 30 kg ha^1 at 20 DAS) at panicle initiation and harvest stages respectively, while at maximum tillering stage it was not found influenced by treatments (Fig.5). The uptake of N in T_{14} and T_2 were lower and this could be the reason for higher available N in soil. In general compared to initial soil N status, there was a decline in soil N might be due to the enhanced uptake of applied and native N by plants. Application of Mg has the ability to increase N uptake and to decrease losses of fertilizer N, fertilization with Mg enhanced the N uptake and N recovery percentage in rice (Choudhury and Khanif, 2001). According to Rani (2000) available N in soil was significantly lower when Mg was applied along with muriate of potash in rice.

Similarly, available P at maximum tillering stage was not found influenced by treatments. Similar to available N status, it also showed an increase from maximum tillering to panicle initiation stage and thereafter it decreased at harvest. Available P in soil was the highest in T_1 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS) at panicle initiation stage, and in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) at harvest stage (Fig.6). The increase in available P in T_1 might be due to lower P uptake by plants at panicle initiation stage.

Available K in soil was the highest in T_{14} (control- KAU PoP without Mg)) at maximum tillering and panicle initiation stages, while at harvest it was not found influenced by treatments (Fig.7). Results revealed that, all the treatments receiving $MgSO_4$ had lower available K than T_{14} (control- KAU PoP without Mg), might be due to the competitive behaviour of Mg and K. $Mg^{2+}$and K^+ are quite similar in size and charge, hence exchange sites cannot distinguish the difference between the ions (Malvi, 2011) and external supply of magnesium might have decreased available K in the present study. The highest available K was recorded when no Ca and Mg were applied (Kasinath *et al.*, 2014). According to Latheef (2013) application of $MgSO_4$ in rice registered lower available K in soil.

The available Ca was the highest in T_{14} (control- KAU PoP without Mg) at maximum tillering and panicle initiation stages, while at harvest stage it was the highest in T_7 ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ as foliar at 40 DAS) (Fig.8). The higher concentration of Mg in soil shows a depressing effect on available Ca, this might be the possible reason for lower available Ca in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal). The availability of Ca was higher in T_{14} (control- KAU PoP without Mg) where no Mg was applied. According to Jakobsen (1993), antagonistic interaction exists between Mg, K and Ca. The supply of Mg as soil application in treatments might have increased the solution concentration of Mg and which in turn might have suppressed the calcium activity in soil, because of antagonistic interaction between Ca and Mg.

The initial available Mg status of soil (137.35 mg kg^{-1}) was above the critical level of sufficiency (more than 120 mg kg^{-1}) and in general Mg availability in soil slightly increased after the experiment due to the application of $MgSO_4$. Irrespective of deficiency or sufficiency optimum application of Mg fertilizers is required to maintain sufficient quantity of Mg in nutrient solution for obtaining higher yield and quality. The highest available Mg content was observed in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) at maximum tillering and panicle initiation stages, while at harvest it was the highest in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) (Fig.9). The available Mg status of the soil at all stages was the lowest in T_{14} (control- KAU PoP without Mg). Application of higher dose of Mg in T_{13} (80 kg ha^{-1} as basal) might have helped to increase available Mg during the early stages while at harvest stage there was a sharp decrease, might be due to crop uptake and the loss of Mg through leaching. All the treatments receiving Mg had higher available Mg and compared to foliar application, soil application showed more Mg content in soil. According to Jose (2015) soil application of Mg recorded the highest Mg content in soil.

Available S was the highest in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) at all the stages, might be due to the supply of higher dose of $MgSO_4$ (80 kg ha^{-1}). The control (T_{14}- KAU PoP without Mg) registered the lowest available S at all the stages of plant growth and all the treatments receiving $MgSO_4$ gave higher available S content (Fig.10). This is because of the presence of S in $MgSO_4$ (13 %). Similar observations were also reported by Noor *et al.* (2015) and Preman (2015). The application of Mg might have also helped in better

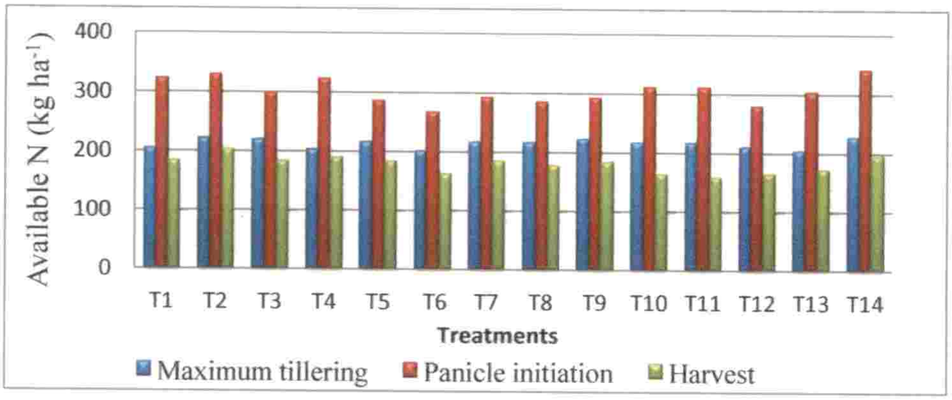

Fig.5 Effect of $MgSO_4$ fertilization on available N (kg ha^{-1})

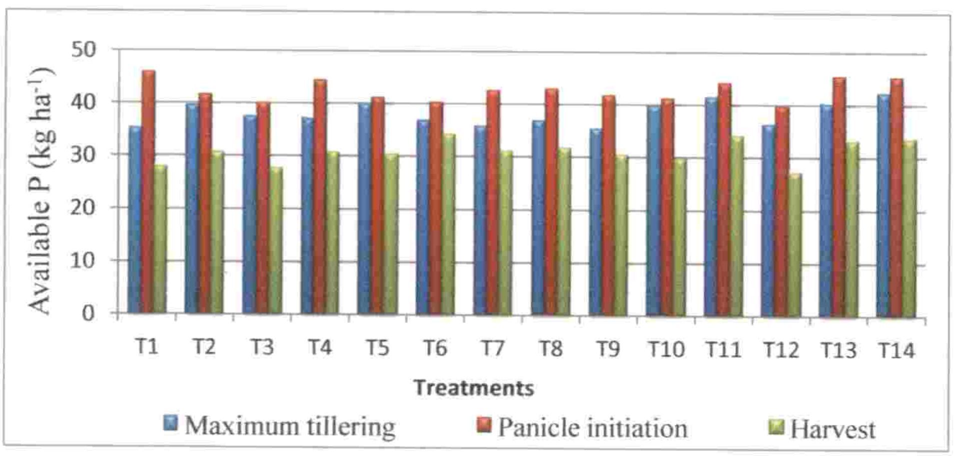

Fig.6 Effect of $MgSO_4$ fertilization on available P (kg ha^{-1})

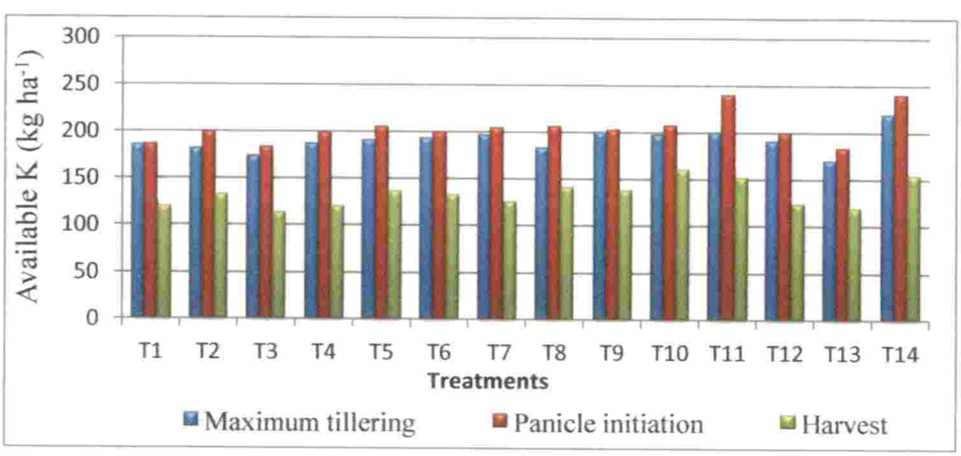

Fig.7 Effect of $MgSO_4$ fertilization on available K (kg ha^{-1})

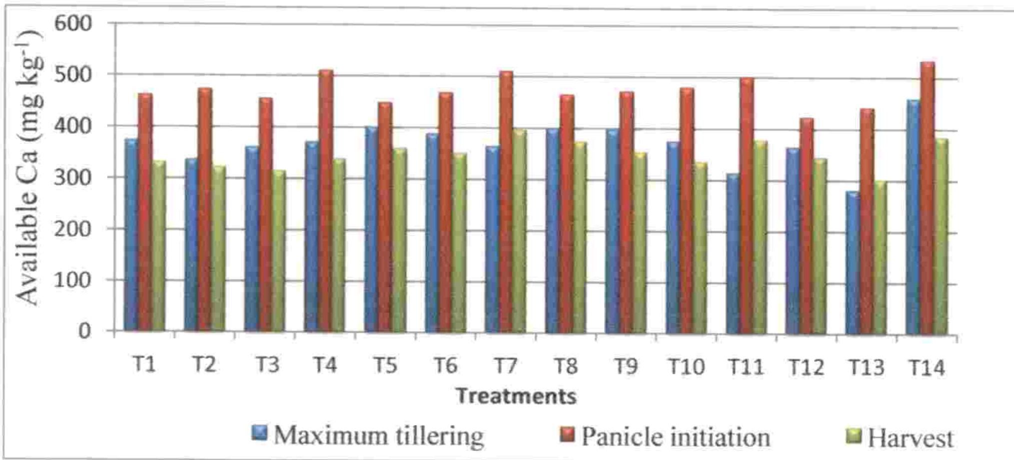

Fig.8 Effect of $MgSO_4$ fertilization on available Ca (mg kg^{-1})

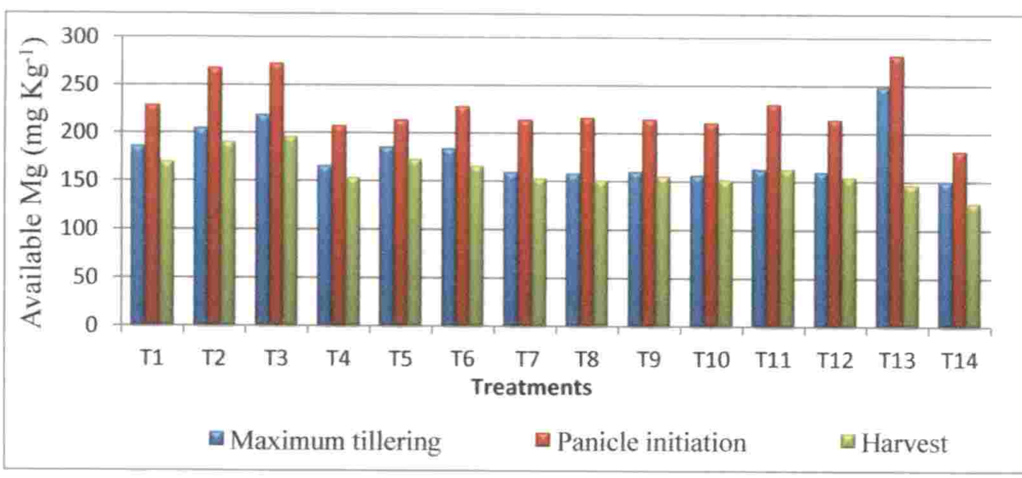

Fig.9 Effect of $MgSO_4$ fertilization on available Mg (mg kg^{-1})

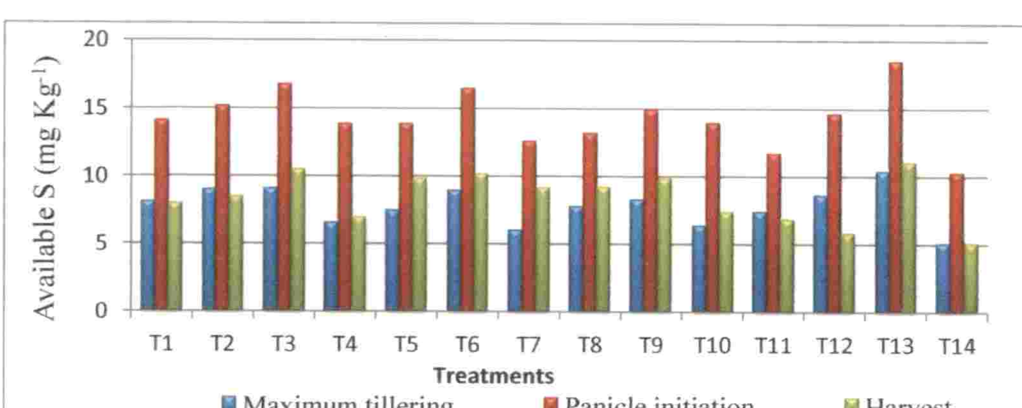

Fig.10 Effect of $MgSO_4$ fertilization on available S (mg kg^{-1})

mineralization of organic sulphur present in the soil and this would have enhanced the S availability in the soil (Losak *et al.*, 2017).

5.4 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON NUTRIENT UPTAKE

The nutrient uptake by crop is a function of nutrient content in dry matter and dry matter yield, it also depends on availability of nutrients from the soil reservoir and from the added sources. The results of the study revealed that uptake of primary and secondary nutrients by rice plant were affectedd by the dose, time and method of application of magnesium sulphate. The N uptake at maximum tillering stage was not influenced by the treatments. At panicle initiation and harvest stages, N uptake by the plant was the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) and the lowest in T_{14} (control- KAU PoP without Mg) (Fig.11). Better root proliferation as evident from the higher root shoot ratio (0.197) in T_6 might have naturally enhanced the absorption of N by the crop, leading to highest N uptake. Magnesium is also having a synergistic interaction with nitrogen, Mg fertilization enhanced the N uptake and N recovery percentage in rice (Choudhury and Khanif, 2001) this might be another possible reason for the lowest N uptake in T_{14} (control-KAU PoP without Mg). Szulc (2013) also reported that in maize, N fertilization with Mg addition increased N uptake and utilization compared to N application alone. Magnesium also has effect on N assimilation as the nitrate reductase and glutamine synthetase enzyme is highly sensitive to the magnesium concentration in shoot and root.

The P uptake was the highest in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) at maximum tillering and panicle initiation stages and in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) at harvest stage (Fig.12). The root shoot ratio, number of tillers m^{-2} and DMP were high in the above treatments and this could be attributed to higher P absorption and uptake by the plants. The K uptake was negatively influenced by Mg fertilization because of the antagonistic interaction between them. At maximum tillering and harvest stages, K uptake by the plant was the highest in T_{14} (control- KAU PoP without Mg), at panicle initiation stage it was the highest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar), probably because these treatments registered lower Mg uptake (Fig.13). It has been accepted that the uptake of K and Mg behave competitively. The depressive effect of Mg on K uptake by rice plants was earlier reported by Fageria (1983). Ding *et al.* (2006) also observed the existence of antagonistic interaction between Mg and K in rice.

At maximum tillering stage, Ca uptake by the plant was the highest in T_{14} (control- KAU PoP without Mg) and the lowest in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) (Fig.14). A decrease in the uptake of Ca due to the application of high dose of Mg (80 $kgha^{-1}$) entirely as basal, was observed at initial stages and this could be due to the antagonistic interaction between Ca and Mg. The same antagonistic effect was reflected in T_{14} (control- KAU PoP without Mg), where Ca uptake was the highest due to the non application of Mg. Fageria (2001) also reported that Mg decreased the uptake of Ca in rice plants. At panicle initiation stage, T_1 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS) recorded the highest Ca uptake, at harvest stage, it was the highest in T_9 ($MgSO_4$@ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) and no clear cut interaction effect was observed during these stages.

The uptake of Mg was significantly influenced by magnesium sulphate fertilization, all the treatments receiving $MgSO_4$ showed higher uptake at all the three stages and it was the lowest in T_{14} (control- KAU PoP without Mg). The highest Mg uptake was recorded in T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) at maximum tillering stage, T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) at panicle initiation stage, T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as

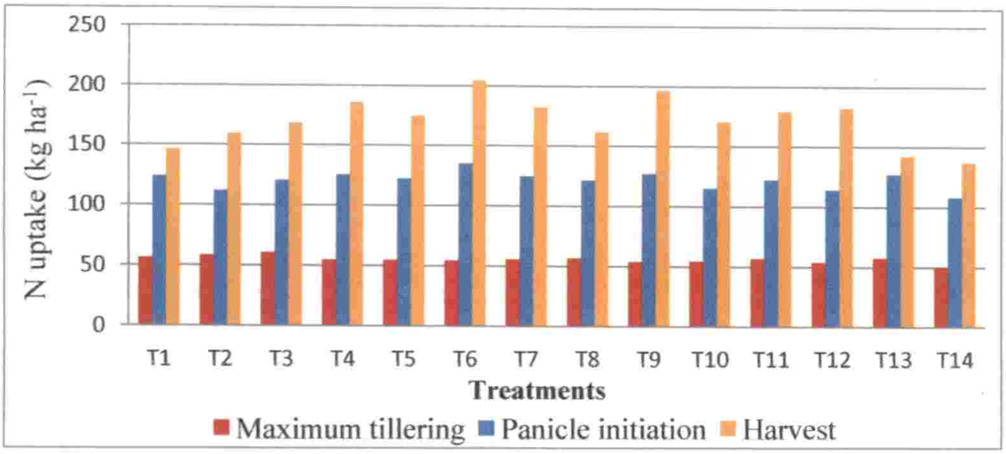

Fig.11 Effect of $MgSO_4$ fertilization on N uptake (kg ha^{-1})

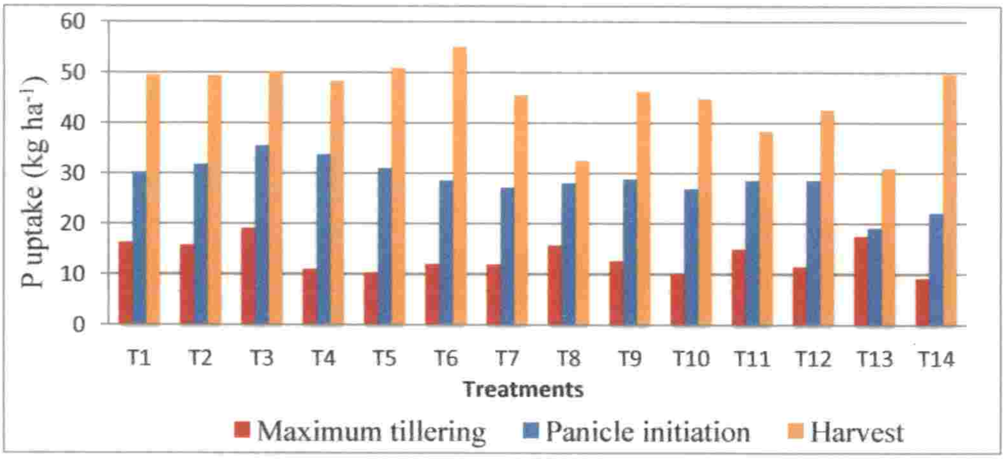

Fig.12 Effect of $MgSO_4$ fertilization on P uptake (kg ha^{-1})

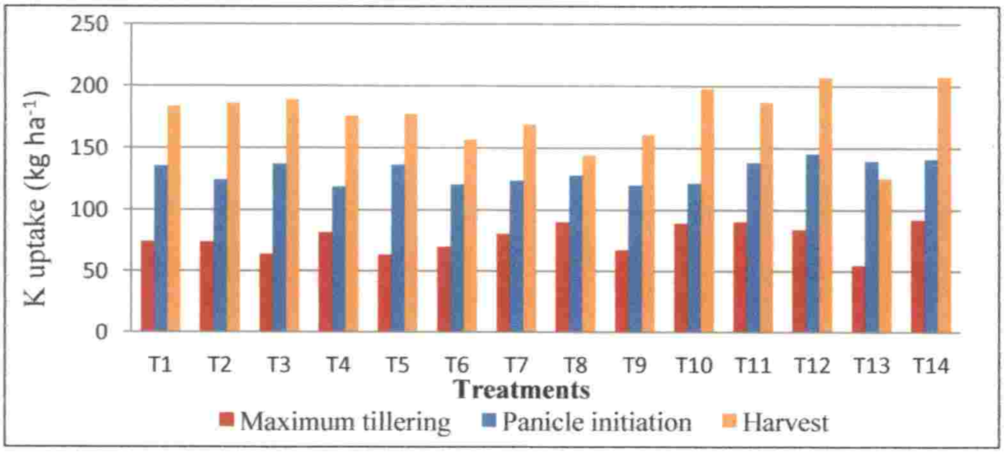

Fig.13 Effect of $MgSO_4$ fertilization on K uptake (kg ha^{-1})

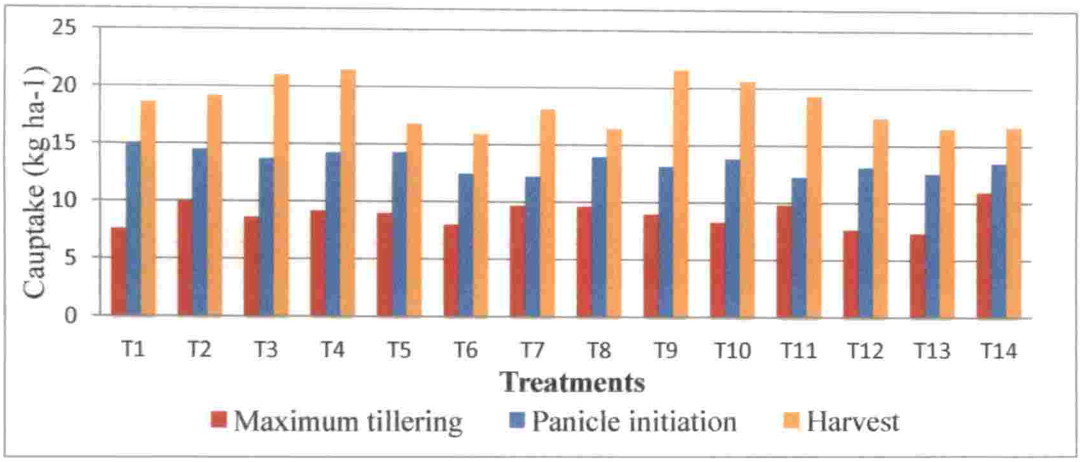

Fig.14 Effect of $MgSO_4$ fertilization on Ca uptake (kg ha^{-1})

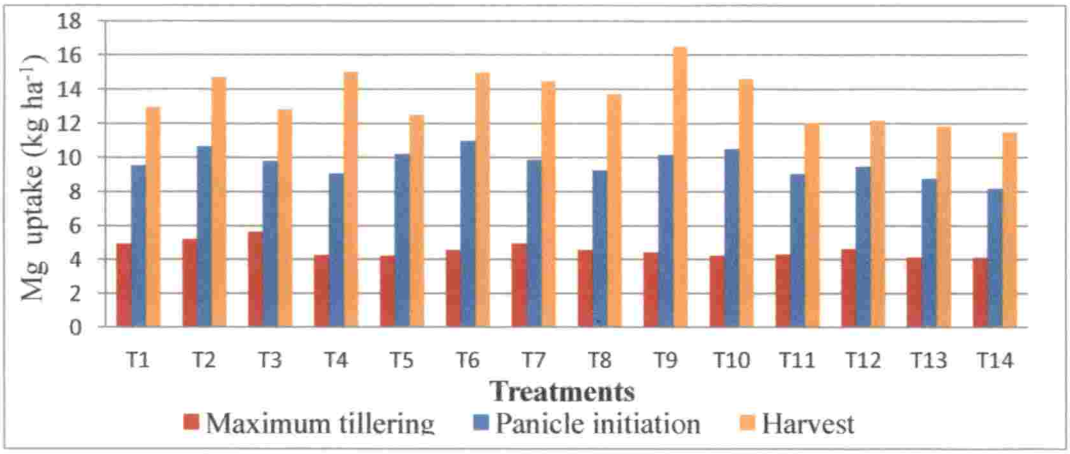

Fig.15 Effect of $MgSO_4$ fertilization on Mg uptake (kg ha^{-1})

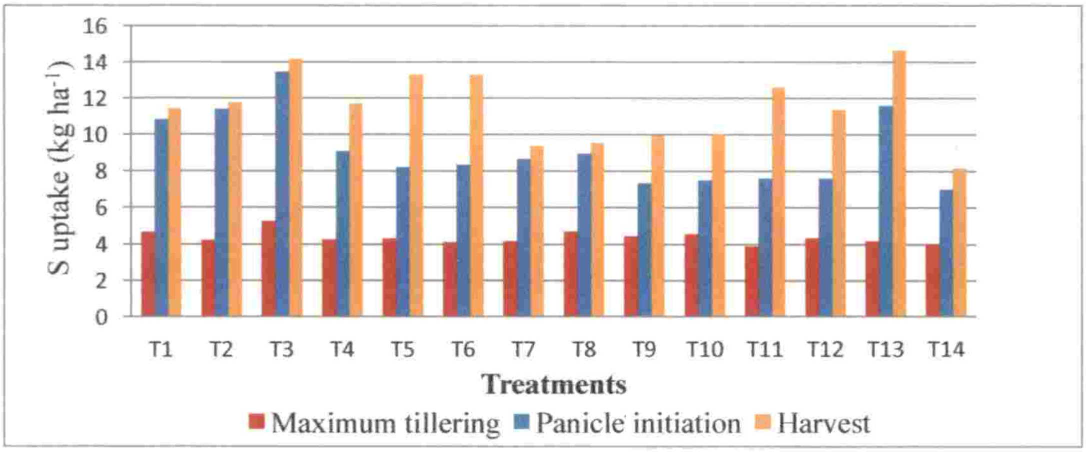

Fig.16 Effect of $MgSO_4$ fertilization on S uptake (kg ha^{-1})

foliar) at harvest (Fig.15). This could be attributed to the enhanced Mg availability due to Mg application in respective treatments. The results shows that compared to foliar application soil application increases the uptake of Mg, might be due to higher quantity of $MgSO_4$ applied in soil treatments than foliar spray. The increase in uptake of Mg by rice due to Mg fertilization was reported by Choudary and Khanif (2001), Brohi *et al.* (2000), and Sahrawat *et al.* (1999).

The S uptake was influenced by treatments both at panicle initiation and harvest stages. At panicle initiation stage T_3 ($MgSO_4$ @ 40 kg ha^{-1} at 20 DAS) recorded the highest S uptake, at harvest stage it was the highest in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) and T_{14} (control- KAU PoP without Mg) registered the lowest uptake (Fig.16). The sulphate from applied magnesium sulphate might have increased the sulphur availability in soil and thereby increased the S uptake by plants. All the treatments receiving magnesium sulphate had higher S uptake, however those treatments with higher doses of $MgSO_4$ (T_3 and T_{13}) registered the highest uptake. Turker and Dikshit (1994) also reported increase in S uptake due to $MgSO_4$ addition.

5.6 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON QUALITY ATTRIBUTES

The quality attributes such as protein and magnesium content in grain were significantly affected by the dose, time and method of application of $MgSO_4$, while starch content in grain was not found influenced by treatments. Protein content in grain was the highest in T_{12} ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar) which was on par with T_6 ($MgSO_4$ @ 40 kg ha-^{1} in two equal splits at 20 and 40 DAS) and T_9 ($MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1% $MgSO_4$ at 40 DAS as foliar) and the lowest in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg

ha^{-1} as basal) (Fig.17). An increase in protein content might be due to increased nitrogen assimilation in plants because nitrogen is a major component of amino acids and proteins. Magnesium has effect on N assimilation as the nitrate reductase and glutamine synthetase enzymes are highly sensitive to the Mg concentration in plants. N fertilization with Mg addition increased the N uptake and utilization compared to N application alone (Szulc, 2013). The total N uptake at harvest was more for T_6 and T_{12}. Foliar application of $MgSO_4$ at later growth stages in T_{12} and T_9 might have increased the Mg content in grain, which in turn resulted in the highest protein content. Moreover Mg is a component of ribosome structure and it stabilizes the particles of ribosome in the configuration necessary for protein synthesis. An increase in grain protein content in wheat by magnesium application was reported by Singh (2001). The protein content was found to be the lowest in T_{13} (*ad hoc* recommendations of KAU- $MgSO_4$ @ 80 kg ha^{-1} as basal) and this might be due to leaching loss of Mg from root zone and due to lower uptake of N and Mg (Tables 15 & 19).

Magnesium fertilization significantly influenced the grain Mg content. Mg content in grain was the highest in T_{10} ($MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2% $MgSO_4$ at 40 DAS as foliar) which was on par with T_3, T_5, T_6, T_7, T_8, T_9 and T_{12} and the lowest in T_{14} (control- KAU PoP without Mg) (Fig.18). All those treatments that received Mg either through soil or as foliar had higher grain Mg content. Similar result has been obtained by Singh (2001). Though only 10 kg $MgSO_4$ ha^{-1} was added in T_{10}, the foliar application at later stage might have improved Mg uptake. As the high yielding varieties crops are lacking Mg, optimum supply of Mg to plants irrespective of deficiency or sufficiency is required to increase the nutrient content and quality of harvested products.

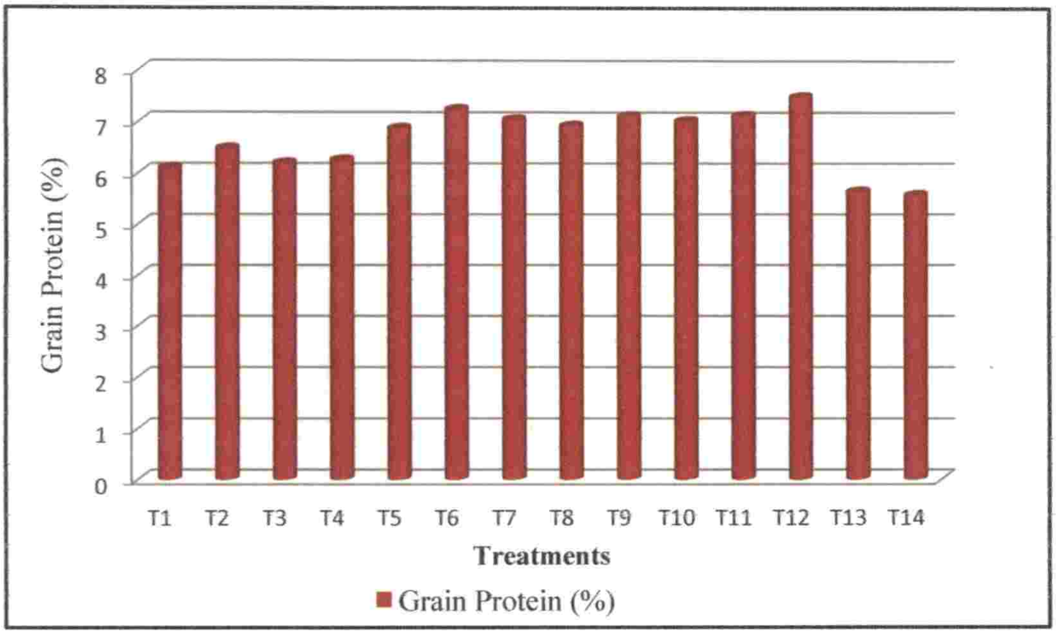

Fig.17 Effect of $MgSO_4$ fertilization grain protein (%)

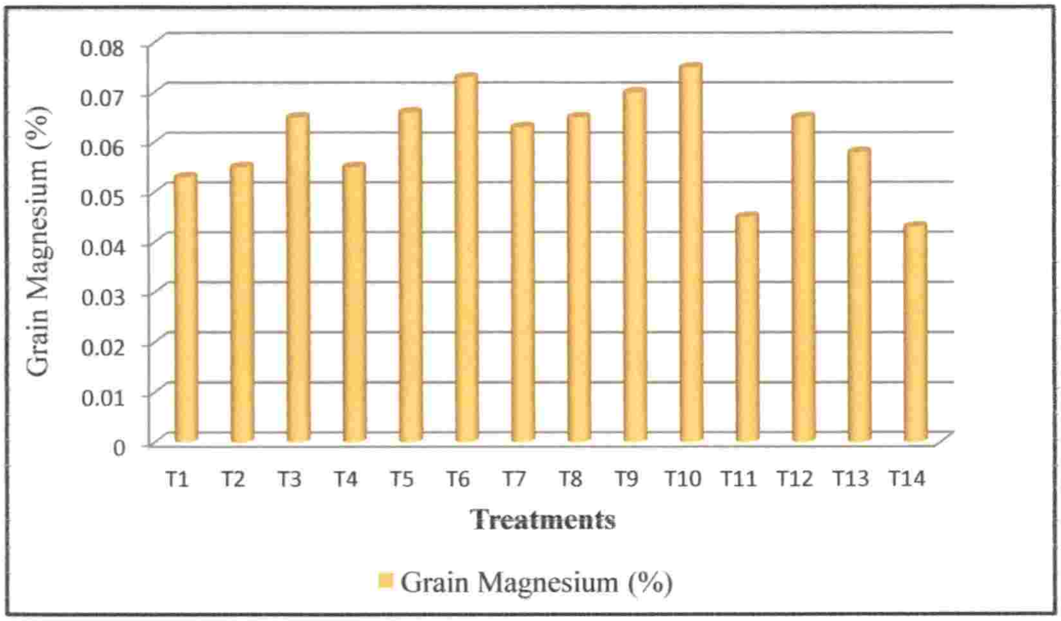

Fig.18 Effect of $MgSO_4$ fertilization grain magnesium (%)

5.7 EFFECT OF MAGNESIUM SULPHATE FERTILIZATION ON ECONOMICS

Economic analysis reveals the feasibility of $MgSO_4$ fertilization in rice crop. The higher monetary returns in treatments receiving $MgSO_4$ could be due to higher grain yield.

The gross income, net income (Fig.19) and B:C ratio (Fig.20) were the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS) which was on par with all other treatments except T_3, T_{12}, T_{13} and T_{14}. The cost of cultivation was higher in foliar spraying compared to soil application, due to the high cost involved in spraying. Though treatment T_9 recorded higher grain yield than T_4, it registered less B:C ratio due to the high cost involved in foliar spraying. The grain yield was the lowest in T_{14} (control- KAU PoP without Mg), while net income and B:C ratio were the lowest in T_{13} (*adhoc* recommendations- $MgSO_4$ @ 80 kg ha^{-1} as basal) might be due to the high cost involved in huge quantity of $MgSO_4$ used (80 kg ha^{-1}). The gross income, net income and B:C ratio of T_6 were 2,53,960 ₹ ha^{-1}, 1,69554 ₹ ha^{-1}, and 3.01 respectively. Srivatava *et al.* (2006) pointed out that application of Mg brought about an increase in B: C ratio because of marked enhancement in grain yield. Khadtare *et al.* (2017) also indicated the higher monetary returns and B:C ratio with $MgSO_4$ application. Considering the net income and B:C ratio, soil application of $MgSO_4$ @ 20 or 40 kg ha^{-1} in two equal splits at 20 and 40 DAS (depending upon Mg availability in soil) can be given as recommendation for farmers for getting higher grain yield.

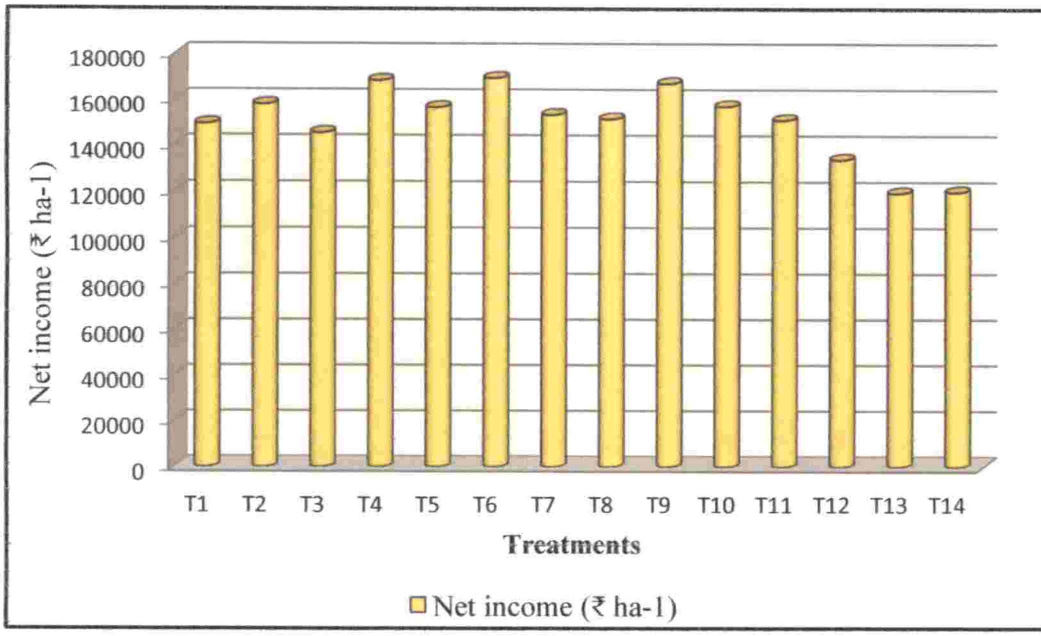

Fig.19 Effect of $MgSO_4$ fertilization on net income (₹ ha-1)

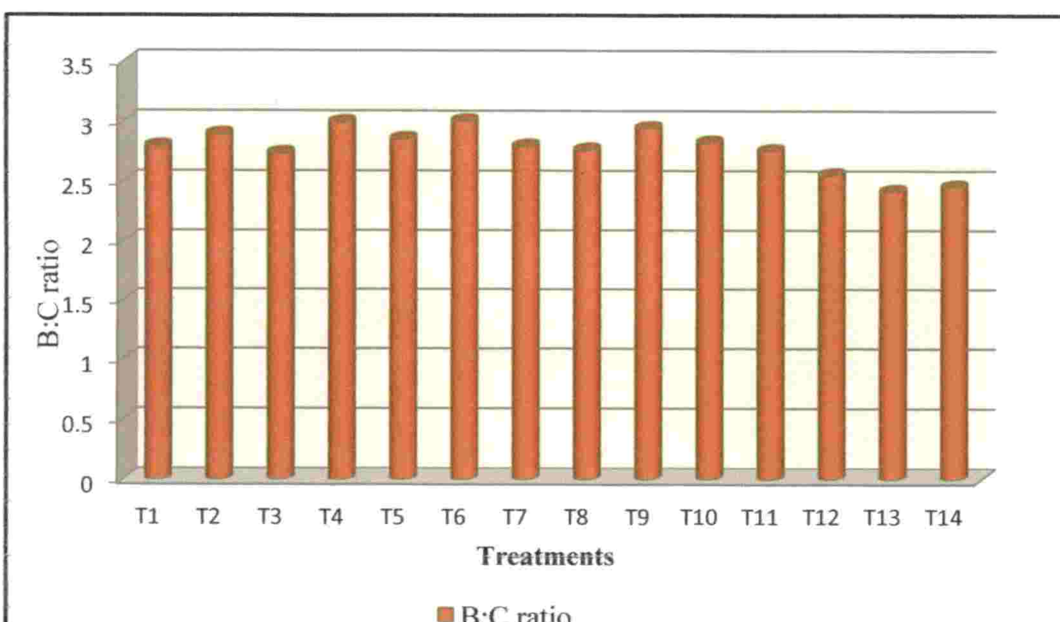

Fig.20 Effect of $MgSO_4$ fertilization on B:C ratio

SUMMARY

6. SUMMARY

The study entitled "Magnesium sulphate fertilization for yield enhancement in direct seeded rice" was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala from 2016 - 2018 July, to determine the optimum dose, time and method of application of magnesium sulphate ($MgSO_4$) for growth and yield enhancement in rice. The salient findings from the study are summarised in this chapter.

The study was conducted in farmer's field at Kalliyoor Panchayat, Thiruvananthapuram district during May to September 2017. The experiment was laid out in randomized block design (RBD) with fourteen treatments and three replications. The variety used was Sreyas (MO 22), a medium duration (115-120 days) variety released from Rice Research Station (RRS), Moncompu, Kerala. The treatments were; T_1 -$MgSO_4$ @ 20 kg ha^{-1} at 20 days after sowing (DAS), T_2 -$MgSO_4$ @ 30 kg ha^{-1} at 20 DAS, T_3 -$MgSO_4$ @ 40 kg ha^{-1} at 20 DAS, T_4 -$MgSO_4$ @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS, T_5 -$MgSO_4$ @ 30 kg ha^{-1} in two equal splits at 20 and 40 DAS, T_6 -$MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS, T_7 -$MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar spray, T_8-$MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar spray, T_9 -$MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar spray, T_{10} -$MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar spray , T_{11}-$MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar spray, T_{12}-$MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar spray, T_{13} -$MgSO_4$ @ 80 kg ha^{-1} as basal (*adhoc* recommendations of Kerala Agricultural University (KAU)), and T_{14}-Control (Package of Practices Recommendations of KAU, without Mg). All the treatments were given a uniform dose of FYM @ 5 t ha^{-1}, lime @ 600 kg ha^{-1} in two splits and NPK @ 90: 45: 45 kg ha^{-1} (KAU POP, 2016).

The observations on growth attributes such as plant height and number of tillers m^{-2} were recorded at maximum tillering, panicle initiation (PI) and harvest stages and leaf area index (LAI) at panicle initiation stage only. $MgSO_4$ fertilization had significant influence on growth parameters of crop. The height of the plant was the highest in T_2 at maximum tillering stage and in T_{10} at panicle initiation stage. At both maximum tillering and panicle initiation stages, tillers m^{-2} were the highest in T_9, while it was the highest in T_4 at harvest stage. The LAI which was recorded only at PI stage was found the highest in T_6.

Magnesium application had significant effect on physiological parameters like days to 50 % flowering, root shoot ratio and chlorophyll content. Early flowering was observed in T_6. Similarly the root- shoot ratio was also found the highest in T_6. Late flowering and the lowest root shoot ratio were observed in T_{14} (control- KAU POP without Mg). Chlorophyll content at panicle initiation and boot leaf stages were significantly higher in Mg applied treatments compared to control. The total chlorophyll content was the highest in T_9 at PI stage and in T_{10} at boot leaf stage. At these two stages, the chlorophyll content was the lowest in T_{14}.

The yield and yield attributing characters such as productive tillers m^{-2}, panicle weight, number of filled grains $panicle^{-1}$ and thousand grain weight were significantly affected by magnesium sulphate fertilization. The yield attributes and grain yield were the lowest in T_{14}. The number of productive tillers m^{-2} was found the highest in T_8 (578); however thousand grain weight was the highest in T_{10} (29.93 g). Regarding the dry matter production (DMP), T_{11} produced the highest DMP at harvest (21050.8 kg ha^{-1}). The panicle weight (2.89 g), filled grains $panicle^{-1}$ (133.2), grain yield (9.6 t ha^{-1}) and harvest index (0.463) were the highest in T_6. The highest grain yield in T_6 was on par with T_2, T_4, T_5, T_7, T_8, T_9, and T_{10}. The lowest grain yield of 7.25 t $ha^{-1}$was observed in T_{14} (control), which was on par with T_{13} (*adhoc* recommendations of KAU- Magnesium sulphate @ 80 kg ha^{-1} as basal). The sterility percentage and straw yield were not found influenced by treatments.

The availability of primary and secondary nutrients in soil and its uptake at maximum tillering, panicle initiation and harvest stages were also found influenced by the treatments. In general the nutrient availability in soil exhibited an increasing trend from maximum tillering to panicle initiation stage and thereafter it decreased at harvest stage. The availability status of Mg and S in soil at harvest was slightly higher than initial due to $MgSO_4$ fertilization. The availability of all nutrients except K and Ca were found higher with Mg application compared to T_{14} where no Mg application was done. The N uptake at panicle initiation and harvest stages and P uptake at harvest stages were the highest in T_6 ($MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS). The uptake of K and Ca showed antagonistic interaction. The Mg and S uptake by the plant was higher with Mg application and it was lower in T_{14} (control- KAU POP without Mg).

Magnesium fertilization had significant influence on quality attributes like protein and Mg content in grain, while starch content of grain was not found influenced by the treatments. The protein and Mg content in grain were the highest in T_{12} and T_{10} respectively and were the lowest in T_{14} (control- KAU POP without Mg).

Economic analysis revealed the superiority of Mg application over T_{14} (control- KAU POP without Mg) as well as the superiority of split application over T_{13} (*adhoc* recommendations- $MgSO_4$ @ 80 kg ha^{-1} as basal). The gross income, net income and B:C ratio were the highest in T_6 (2,53,960 ₹ ha^{-1}, 1,69,554 ₹ ha^{-1} and 3.01 respectively), as against the lowest gross income (2,02,206 ₹ ha^{-1}) in T_{14}, net income and B:C ratio (119673 ₹ ha^{-1} and 2.42 respectively) in T_{13}.

Based on the study, it can be concluded that $MgSO_4$ fertilization significantly enhanced the yield and quality of rice irrespective of method of application. However considering the net income and B:C ratio, soil application of $MgSO_4$ @ 20 or 40 kg ha^{-1} in two equal splits at 20 and 40 DAS (depending upon Mg availability in soil) can be given as recommendation for farmers for getting higher grain yield.

Future line of work

1. A detailed survey of intensively cultivated rice tracts of Kerala should be conducted to assess the Mg availability.
2. Study of Ca-Mg and K-Mg interaction in soil.
3. Detailed investigation to evaluate the efficiency of different sources of Mg.
4. Studies on effect of Mg fertilizers in enhancing yield of other crops.

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7. REFERENCES

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MAGNESIUM SULPHATE FERTILIZATION FOR YIELD ENHANCEMENT IN DIRECT SEEDED RICE

by

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ABSTRACT

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ABSTRACT

The study entitled "Magnesium sulphate fertilization for yield enhancement in direct seeded rice" was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala from 2016 - 2018 July, to determine the optimum dose, time and method of application of magnesium sulphate ($MgSO_4$) for growth and yield enhancement in rice.

The study was conducted in farmer's field at Kalliyoor Panchayat, Thiruvananthapuram district during May to September 2017. The experiment was laid out in randomized block design (RBD) with fourteen treatments and three replications. The variety used was Sreyas (MO 22) released from Rice Research Station, Moncompu, Kerala. The treatments were; T_1 -$MgSO_4$ @ 20 kg ha^{-1} at 20 days after sowing (DAS), T_2 -$MgSO_4$ @ 30 kg ha^{-1} at 20 DAS, T_3 -$MgSO_4$ @ 40 kg ha^{-1} at 20 DAS, T_4 -$MgSO_4$ @ 20 kg ha^{-1} in two equal splits at 20 and 40 DAS, T_5 - $MgSO_4$ @ 30 kg ha^{-1} in two equal splits at 20 and 40 DAS, T_6 - $MgSO_4$ @ 40 kg ha^{-1} in two equal splits at 20 and 40 DAS, T_7 -$MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar spray, T_8- $MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar spray, T_9- $MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 1 % $MgSO_4$ at 40 DAS as foliar spray, T_{10} -$MgSO_4$ @ 10 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar spray , T_{11}-$MgSO_4$ @ 15 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar spray, T_{12}- $MgSO_4$ @ 20 kg ha^{-1} at 20 DAS and 2 % $MgSO_4$ at 40 DAS as foliar spray, T_{13} -$MgSO_4$ @ 80 kg ha^{-1} as basal (*ad hoc* recommendations of Kerala Agricultural University (KAU)) and T_{14}- Control (Package of Practices Recommendations crops 2016 Kerala Agricultural University (KAU PoP) without Mg). All the treatments were given a uniform dose of FYM @ 5 t ha^{-1}, lime @ 600 kg ha^{-1} in two splits and NPK @ 90: 45: 45 kg ha^{-1} (KAU, 2016).

The results revealed that growth attributes like plant height and tillers m^{-2} at maximum tillering, panicle initiation (PI) and harvest stages and the leaf area index (LAI) at panicle initiation stage were significantly influenced by $MgSO_4$ fertilization.

At maximum tillering stage, the height of the plant was the highest in T_2, at panicle initiation stage it was the highest in T_{10}. At both maximum tillering and panicle initiation stages, tillers m^{-2} were the highest in T_9, while at harvest it was the highest in T_4. The LAI at panicle initiation stage was found the highest in T_6.

Early flowering was observed in T_6, similarly the root shoot ratio was also found the highest in T_6. Late flowering and the lowest root shoot ratio were observed in T_{14} (control -KAU PoP without Mg). Chlorophyll content at panicle initiation and boot leaf stages were significantly higher in Mg applied treatments compared to control. The yield and yield attributing characters were also significantly influenced by the dose, time and method of application of $MgSO_4$. The panicle weight (2.89 g), number of filled grains panicle^{-1} (133.2), grain yield (9.6 t ha^{-1}) and harvest index (0.463) were the highest in T_6.

The availability of primary and secondary nutrients in soil and its uptake at maximum tillering, panicle initiation and harvest stages were also influenced by the treatments. The availability of Mg in soil at harvest was slightly increased due to $MgSO_4$ fertilization. The uptake of K and Mg showed an antagonistic interaction and Mg uptake at all stages was lower in control (KAU PoP without Mg). The quality attributes like protein and Mg content in grain were also higher in treatments receiving Mg. Economic analysis showed the significance of Mg application and also its split application over control (KAU PoP without Mg) and T_{13} ($MgSO_4$ @ 80 kg ha^{-1} as basal (*ad hoc* recommendations)). The B:C ratio in T_6 was 3.01 whereas in control it was 2.46 and in T_{13} it was 2.42.

From the study, it can be concluded that $MgSO_4$ fertilization significantly enhanced the yield and quality of rice irrespective of method of application. However considering the net income and B:C ratio, soil application of $MgSO_4$ @ 20 or 40 kg ha^{-1} in two equal splits at 20 and 40 DAS (depending upon Mg availability in soil) can be given as recommendation for farmers for getting higher grain yield.

സംഗ്രഹം

"നെല്ലിൻറെ വിളവ് വർദ്ധിപ്പിക്കാൻ മഗ്നീഷ്യം സൾഫേറ്റ് പോഷണം" എന്ന വിഷയത്തെ സംബന്ധിച്ച ഒരു പഠനം രണ്ടായിരത്തി പതിനേഴ് മെയ്-സെപ്റ്റംബര് വരെയുള്ള കാലയളവിൽ തിരുവനന്തപുരത്തെ കല്ലിയൂർ പഞ്ചായത്തിലെ ഒരു കൃഷിക്കാരൻറെ കൃഷിയിടത്തിൽ വച്ച് നടത്തുകയുണ്ടായി. നെല്ലിൻറെ വളർച്ചയും വിളവും വർധിപ്പിക്കുന്നതിന് മഗ്നീഷ്യം സൾഫേറ്റ് പോഷണത്തിന്റെ ഏറ്റവും ഉചിതമായ അളവ്, സമയം, രീതി എന്നിവ നിശ്ചയിക്കുക ആയിരുന്നു പഠനത്തിൻറെ മുഖ്യ ലക്ഷ്യം. റാൻഡമൈസ്ട് ബ്ലോക്ക് ഡിസൈൻ എന്ന രീതി അവലംബിച്ച് നടത്തിയ പരീക്ഷണത്തിൽ 14 വിവിധ മഗ്നീഷ്യം സൾഫേറ്റ് തലങ്ങൾ പഠനവിധേയമാക്കി. മങ്കോമ്പ് നെല്ല് ഗവേഷണ കേന്ദ്രത്തിൽ നിന്നും വികസിപ്പിച്ചെടുത്ത ശ്രേയസ് എന്ന ഇനം ആണ് പഠനത്തിന് ഉപയോഗിച്ചത്.

മഗ്നീഷ്യം സൾഫേറ്റിന്റെ വിവിധ തലങ്ങൾ താഴെ പറയുന്ന രീതിയിൽ ക്രമീകരിച്ചു.

T_1 – 20 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് നട്ട് 20 ദിവസത്തിന് ശേഷം.

T_2 – 30 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് നട്ട് 20 ദിവസത്തിന് ശേഷം

T_3 – 40 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് നട്ട് 20 ദിവസത്തിന് ശേഷം.

T_4- 20 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് രണ്ട് തുല്യ ഭാഗങ്ങളായി 20 ദിവസത്തിനും 40 ദിവസത്തിനും ശേഷം.

T_5 – 30 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് രണ്ട് തുല്യ ഭാഗങ്ങളായി 20 ദിവസത്തിനും 40 ദിവസത്തിനും ശേഷം.

T_6 – 40 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് രണ്ട് തുല്യ ഭാഗങ്ങളായി 20 ദിവസത്തിനും 40 ദിവസത്തിനും ശേഷം.

T_7 – 10 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് 20 ദിവസത്തിന് ശേഷവും, 1% മഗ്നീഷ്യം സൾഫേറ്റ് സ്പ്രേ 40 ദിവസത്തിന് ശേഷവും.

T_8 – 15 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് 20 ദിവസത്തിന് ശേഷവും, 1% മഗ്നീഷ്യം സൾഫേറ്റ് സ്പ്രേ 40 ദിവസത്തിന് ശേഷവും.

T_9 – 20 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് 20 ദിവസത്തിന് ശേഷവും, 1% മഗ്നീഷ്യം സൾഫേറ്റ് സ്പ്രേ 40 ദിവസത്തിന് ശേഷവും.

T_{10} – 10 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് 20 ദിവസത്തിന് ശേഷവും, 2% മഗ്നീഷ്യം സൾഫേറ്റ് സ്പ്രേ 40 ദിവസത്തിന് ശേഷവും.

T_{11} – 15 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് 20 ദിവസത്തിന് ശേഷവും, 2% മഗ്നീഷ്യം സൾഫേറ്റ് സ്പ്രേ 40 ദിവസത്തിന് ശേഷവും.

T_{12} – 20 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് 20 ദിവസത്തിന് ശേഷവും, 2% മഗ്നീഷ്യം സൾഫേറ്റ് സ്പ്രേ 40 ദിവസത്തിന് ശേഷവും.

T_{13} – 80 കി.ഗ്രാം/ഹെ. മഗ്നീഷ്യം സൾഫേറ്റ് അടിവളം (കേരള കാർഷിക സർവ്വകലാശാല- അഡ്ഹോക് ശുപാര്ശ)

T_{14} – മഗ്നീഷ്യം സൾഫേറ്റ് കൂടാതെ കേരള കാർഷിക സർവ്വകലാശാല ശുപാർശ ചെയ്ത വളപ്രയോഗം(90:45:45 കി. ഗ്രാം/ഹെ. NPK - മഗ്നീഷ്യം നൽകുന്നില്ല)

ഈ പഠനത്തിൽ നിന്നും മഗ്നീഷ്യം സൾഫേറ്റ് പോഷണം എങ്ങിനെ നൽകുന്നു എന്നതിനപ്പുറം അത് നെല്ലിൻറെ വളർച്ചയേയും ഉല്പാദന ഘടകങ്ങളെയും അനുകൂലമാക്കി കൂടുതൽ വിളവും, ധാന്യത്തിന് ഗുണമേന്മയും നല്കുന്നതായി തെളിഞ്ഞു. എന്നിരുന്നാലും കർഷകൻറെ അറ്റാധായവും, വരവ്-ചെലവ് അനുപാതവും കണക്കിലെടുക്കുമ്പോൾ 40 കി. ഗ്രാം മഗ്നീഷ്യം സൾഫേറ്റ് രണ്ട് തുല്യ ഭാഗങ്ങളായി 20 ദിവസത്തിനും 40 ദിവസത്തിനും ശേഷം നൽകുന്നതാണ് ഉല്പാദന വർധനവിനുള്ള ഏറ്റവും നല്ല മാർഗ്ഗം എന്ന് മനസിലായി.

APPENDIX

APPENDIX 1

Weather parameters during cropping period (May 2017 -September 2017)

Standard week	Temperature ^{o}C		RH%		Rainfall mm
	Maximum	Minimum	Max	Min	
22	31.9	23.9	96.8	85	187.9
23	30.8	24.6	92.9	86.7	31.7
24	31.7	25.2	91.0	78.0	11.3
25	32.2	24.4	89.7	78.3	18.9
26	31.1	23.7	95.9	85.4	140.2
27	31.7	24.6	91.6	75.4	10.0
28	31.2	24.5	91.7	76.4	10.3
29	31.2	24.6	89.9	79.6	17.0
30	32.2	25.0	89.0	74.9	3.10
31	32.3	25.0	90.9	79.0	7.20
32	31.3	24.5	92.3	76.1	18.5
33	31.1	24.7	92.9	79.7	21.4
34	30.5	24.6	91.7	80.7	37.7
35	31.5	24.4	91.6	73.9	17.9
36	32.3	24.6	91.4	78.0	22.9
37	31.5	24.2	92.1	78.1	30.0
38	30.4	24.4	94.0	82.0	92.7
39	31.6	24.9	93.3	75.14	55.8