"NUTRIENT MANAGEMENT FOR SUSTAINABLE RICE PRODUCTION IN THE BLACK SOILS OF KERALA"

By

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THESIS

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DECLARATION

I hereby declare that the thesis **entitled "Nutrient management for sustainable rice production in the black soils of Kerala"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that the thesis entitled "**Nutrient management for sustainable rice production in the black soils of Kerala**" is a record of research work done independently by **Mr. Danish Tamuly** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma diploma, associateship, fellowship to him.

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ABBREVIATIONS

B	Boron
$BaCl_2$	Barium Chloride
BD	Bulk density
Ca	Calcium
CD	Critical Difference
Cu	Copper
EC	Electrical Conductivity
EDTA	Ethylene Diamine Tetra Acetic Acid
Fe	Iron
FP	Farmers' Practice
g	Gram
GRD	General Recommendations of KAU
ha	Hectare
HCl	Hydrochloric Acid
K	Potassium
KAU	Kerala Agricultural University
Kg	Kilogram
m	metre
M	Molar
Mg	Magnesium
mg	milligram
ml	millilitre
Mn	Manganese
MWHC	Maximum Water Holding Capacity
N	Nitrogen
OC	Organic Carbon
P	Phosphorus
PD	Particle Density
pH	Hydrogem ion concentration
%	Percentage
S	Sulphur
Si	Silicon
STCR	Soil Test Crop Response Correlation
STL	Soil Test Laboratory
T	Targeted yield
t	Tonne
Zn	Zinc

Dedicated to
Deuta-Ma
and Friends

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Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.) is an important food crop for a large proportion of the world's population. Total rice production will need to increase to feed an increasing world population. Rice is produced under both upland and lowland ecosystems. Supplying essential nutrients in adequate rates, sources, application methods, and application times are important factors that influences the productivity and sustainability of rice. This study emphasizes the current, research-based knowledge of nutrient management with regard to efficiency and sustainability of rice production and identifies the areas for additional research to bridge information gaps. A summation of best management practices should help scientists develop practical and integrated recommendations that improve nutrient use efficiency for rice production systems.

The focus on producing more during the green revolution ensured food security to the teeming millions but it also led to degradation of natural resources and reduction in the total factor productivity. Soil- a very precious natural resource had to bear the major brunt of this degradation (physical, chemical and biological). The emphasis on application of major nutrients, particularly nitrogen has resulted in widespread deficiency of secondary and micronutrients *e.g* sulphur, zinc and boron.Since the only alternative is to increase the intensity of agricultural productivity with practically no scope of area expansion, there is an urgency of developing efficient nutrient management strategies for sustaining higher crop productivity and soil heath under intensive agricultural systems.

Soil testing is considered as a reliable tool for making fertilizer recommendation for the various crops grown in a particular location. The soil test value can be interpreted and fertilizer recommendations made by adopting different techniques. The most common and widely used method followed in Kerala is by testing the soil and giving fertilizer recommendation. The traditional method that is followed in Kerala is by sampling the top 15 cm layer of soil. The recommendations so far available are general in nature.

Location specific and crop specific recommendation is to be formulated, taking into consideration the agro climatic, edaphic and local farming situations.

General fertilizer recommendations are based on multi-locational trials conducted with graded doses of N, P and K fertilizers and their economic evaluation to arrive at an optimum dose for a particular crop. The general recommendations hold good under medium soil fertility conditions. In this approach the variation in soil fertility is not taken into consideration, and hence, under high or low soil fertility conditions the applied nutrients are a wasteful expenditure or insufficient, respectively. In both the cases, optimum fertilizer use efficiency cannot be achieved. In soil test laboratory recommendation approach the medium soil fertility is equated with general recommended dose. In case of low and very low, and high and very high fertility categories, the fertilizer doses are increased or decreased by 25 to 50 per cent of the general recommended dose as per the situation. At present most of the fertilizer recommendations issued from soil testing laboratories in India are based on this approach. The rating were developed in 1965 for old varieties of crops. Unfortunately, since then these ratings are the same irrespective of types of soils and varieties of crops.

The fertility gradient field experimental technique of Ramamoorthy *et al* (1967) for evolving soil test based fertilizer recommendations (STCR approach) to crops to applied nutrients is studied on the representative soils, where, variations in soil fertility had earlier been created by applying different amounts of fertilizer nutrients to the preceding crop. Besides balanced nutrition of growing crops, this approach gives due consideration to soil fertility and strikes a real balance between the nutrients already available in the soil and those required by the crops to achieve a predetermined yield target. The practice of fertilizing crops on the basis of yield targets is precise, meaningful and eco-friendly and it needs to be popularized among farmers to obtain higher productivity and profitability.

The black soil area is considered as one of the most productive areas for rice cultivation in Kerala. These soils are locally known as Poonthalpadam due to the deep slushy nature of the soil during the major part of the year. Poonthalpadam soil is located in patches in Chittur taluk of Palakkad district. These soils cover an area of approximately 2000 ha (Padmaja *et al.*,1994) in Chittur taluk and is mainly located in the Palakkad gap of Western Ghats. Though the black soil in Kerala is comparatively productive, certain yield limiting factors, especially poor physical condition due to high exchangeable sodium percentage and nutrient imbalance may adversely affect the yield of the crop (Krishnakumar, 1978; George, 1981 and Padmaja et al., 1994). Recently a detailed study on the nutrient management plan for the soils of Palakkad was done by Narayanankutty *et al.*, (2008). They have reported that deficiency of zinc is widespread in several geological zones. The general fertilizer recommendation for medium duration variety of rice is 90:45:45 N, P_2O_5 and K_2O Kg ha^{-1} along with 5 t FYM ha^{-1} (KAU, 2010). This recommendation does not take into account the different fertility levels of soils and different farming practices prevalent in different regions. Soil test recommendation of the state Soil Testing Laboratory also do not take into account the soil type, crop and its rooting pattern. Though STCR studies have been conducted in the rice growing laterite soils of the state, such studies had not been undertaken in the black soils of Kerala for want of the studies on nutrient imbalances and interaction in this soil. Hence the possibility of adoption of this scientific approach to fertilizer recommendation as conceived by Truog (1960) and experimentally proved by Ramamoorthy et al., (1967) can be utilized for sustainable rice production in these soils also. This can be made possible only from a thorough knowledge about the behaviour of these black soils during rice cultivation. Hence the present study was proposed with the following objectives

1. To find out the best suited nutrient management system of rice.
2. To know the influence of zinc on the growth and yield of rice.
3. To predict the yield of rice based on the nutrient content of soil, plant and yield attributes.

Review of Literature

2. REVIEW OF LITERATURE

Literature on various nutrient management aspects on rice production, influence of zinc on the growth and yield as well as mineral nutrition of rice are reviewed in this chapter.

2.1 Nutrient management systems of rice

Fertilizer had vital role in production and productivity of any crop, but continuous and imbalance use of high analysis chemical fertilizers badly influenced production potential and soil health. Subsequently, most of the productive soil becomes unproductive. Increase in fertilizer use efficiency must be ensured to achieve sustainable production (Tolanur and Badanur 2003 ; Laxminarayana 2006). Use of chemical fertilizers in combination with organic manure was found to be essential to improve the soil health (Bajpai *et al.* 2006).

Nambiar and Abrol (1989) also concluded from the results of long term fertility experiments that the integrated use of organic manures and chemical fertilizers provided more stable rice production in the intensive farming system. The grain yield data brought out by Stalin *et al.* (2006), emphasized the need for conjunctive use of organic manures (6.25 t ha^{-1}green manure in *kharif* and 12.5 t ha^{-1} FYM in *rabi* with inorganic NPK fertilizers (125:50:50: kg NPK ha^{-1}) in *kharif* and 150:60:60 kg NPK ha^{-1} in *rabi*.

Hedge (1992) emphasized on the importance of integrated nutrient management. It was recognized that inorganic fertilizers are not a complete substitute for organic manures and vice versa and their role are complementary (Swarup and Wanjari 2000). The system that included organic sources acted both as macro and micronutrient sources and increased the efficiency of inorganic fertilizers (Pandey *et al.* 2007) and ultimately sustained soil health and productivity in the long run (Mohanty *et al.*1992).

Tripathi *et al.* (2004) reported that the combined use of green manuring with daincha and 75% recommended dose of fertilizers recorded higher yield (42.56q ha^{-1}) than that of 100% recommended dose of fertilizers (39.83q ha^{-1}) in the absence of green manuring. Hence, it was concluded that green manuring either with sunhemp or dhaincha saved upto 25% of chemical fertilizers with an additional improvement in soil health.

Surekha *et al.*(2004) opined that partial substitution through organic sources such as green manures and paddy straw improved the rice productivity showing both direct and residual effects as well as soil quality parameters under intensive rice-rice system.

Singh and Singh (2004) reported that the combined use of soil test based NPK fertilizers and S with FYM and green manuring resulted in an increase of 21 q ha^{-1} of additional grain yield over the existing farmer's practice. It was also put forth that application of 75% RDF, FYM (5t ha^{-1}) and green manuring also increased grain yield of rice to the tune of 10 q ha^{-1}.

Doshi. *et al.* (2004) investigated the effect of nitrogen at different levels and reported that the grain and straw yield of rice was signicantly increased. The maximum grain and straw yield were obtained with 180 kg N ha^{-1} dose. The increase in grain and straw yield at this level was 38.99 and 40.45%, respectively over control.

An increase in pH caused significant decrease in Zn, Ca, Mg, P and K concentrations but increased the Na content. Zinc application, apart from increasing tissue Zn content, elevated Ca:Na and K:Na ratio resulting in improved growth and yield of rice under soil sodicity and alkalinity (Singh and Singh 2005)

Singh *et al.* (2006) were of the opinion that integration of soil test based inorganic fertilizers coupled with FYM and green manuring sustained upland rice grain productivity to the tune of 3.36 t ha^{-1} at farmer's field of Jharkhand where the soil was impoverished of their fertility due to many soil related constraints.

Bajpai *et al.*(2006) opined that sustainability and high productivity of rice–wheat cropping system was possible by providing 50% of the recommended N through green manure as *Sesbania aculeate* to the rice crop and rest of the 50% of N through chemical fertilizers followed by 100% NPK to wheat through chemical fertilizers. He also elucidated that if green manuring was not possible then 25% N substituted through FYM or rice straw incorporation without any adverse effect on soil properties and grain yield.

Laxminarayana (2006) found that the application of 5 t ha^{-1} poultry manure along with optimum dose of NPK recorded highest grain yield for all the three seasons. It was closely followed by the application of NPK+ pig manure and NPK+FYM. Among the applied treatments, the highest yield response (46.80 %) was recorded with the integrated application of optimum doses of NPK and poultry manure, followed by NPK + FYM (40.10%). It was also put forth that, organics and fertilizers were not only complementary but also synergistic since organic inputs had beneficial effects beyond their nutritional components and enhanced the efficiency of the applied mineral fertilizers.

The study carried out by Desai *et al.*(2009) indicated that application of N and P fertilizer [either based on soil test value or 100% RDF or 100% RDF + 50 kg K ha^{-1} or 100% N+ 50% P with PSB (phosphate solubilizing bacteria) to both the crops] was essential for harvesting higher biomass, but as far as sustenance of soil health, in terms of, higher organic carbon and available major and micronutrients, application of organic manures either alone or in combination with inorganic fertilizer was quite worthy to be considered in present day context

Combined application of urea and farmyard manure showed superiority over recommended fertilizer application as reported by Chaudhary and Thakur (2007). Gill *et al.*,(2008) evaluated the effect of different combinations of organic and inorganic fertilizers on a rice-wheat crop rotation and reported saving of 50% chemical fertilizers for same average yield of wheat and rice, if integrated nutrient management with green manuring is practiced. Yadav and Kumar (2009) also reported that substitution of 50% N through farmyard manure and *Sesbania* green manuring to rice gave equal or more yields than 100% NPK fertilizers alone. Investigation by Kharub and Chander (2010) found that the rice productivity was highest (7.13 t ha^{-1}) in the treatment where 75% N supplied through inorganic source and 25% through farmyard manure in rice.

Surekha and Rao (2009) observed that organic sources with moderate C/N ratio and high lignin content (green gram) resulted in higher rice yield compared to wide and narrow C/N ratio sources with low lignin content (straw and dhaincha). Soil quality parameters showed significant improvement with organic sources over chemical fertilizers alone and maximum benefit was from paddy straw.

Prasad *et al.*, (2010) conducted a long term experiment to develop integrated nutrient management system for maize- wheat cropping system in alfisol. He reported that, grain yield of maize, wheat and the system under 50% N through FYM + 50% through chemical fertilizers was significantly higher than that under 100% chemical fertilizers applied to both the crops and was on par with 25% N through FYM and 75% through inorganic sources.

Datta and Singh (2010) reported that the application of 10 t cattle manure ha^{-1} had an enhancement in total production to the tune of 2.06-2.28 t ha^{-1} over control in the cropping system, but the dose of 5 t cattle manure ha^{-1} in combination with NPK raised the production in the range of 1.07-1.99 t ha^{-1}.

Field study carried out by Gogoi *et al.* (2010) revealed that application of 50% recommended dose of fertilizers (RDF) along with 50% N through FYM significantly increased yield attributing parameters, such as effective tiller numbers m^{-2}, panicle length, filled grains $panicle^{-1}$ and test weight of seeds of rice, besides maximizing the straw (7.1 tonnes ha^{-1}) and grain (4.1 tonnes ha^{-1}) yield of *kharif* rice.

Green manuring or adding of rice residues or farmyard manure offers the twin benefits of soil quality and fertility enhancement while meeting a part of nutrient need of crops, not only sustains the higher yields of crops but also cuts the expensive fertilizers on the other hand (Urkurkar *et al.*, 2010).

2.2 Mineral nutrition

Since centuries, it was known that roots of terrestrial plants obtain nourishment from the soil. During the first-half of the nineteenth century, it was found that plants need certain chemical elements referred to as essential elements and that elements are absorbed by roots principally as inorganic ions. These inorganic ions in the soils were derived mostly from mineral constituents of the soil. The term mineral nutrient was generally used to refer to an inorganic ion obtained from the soil and required for plant growth. The process of absorption, translocation and assimilation of nutrients by the plants was known as mineral nutrition (Tisdale *et al*, 1993).

2.2.1 Nitrogen:

Nitrogen was found to be a vitally important plant nutrient and is the most frequently deficient of all nutrients. Nitrogen deficiency was considered as one of the most important nutritional disorders in lowland rice producing areas around the world (Fageria and Baligar 2001). Nitrogen was recorded as an essential component of different protein and is present in many other compounds of great physiological importance in plant metabolism such as nucleotides, phosphatides, alkaloids, enzymes, hormones vitamins and other growth substances and so a basic constituent of life. Nitrogen was found to be an integral part of Chlorophyll.

Bulk of nitrogen was present in organic form and therefore total N content in soils was closely related to organic matter content, which in mineral soils varied from traces to 20-30% (Prasad and Power, 1997). Therefore, total N content in soils could vary from traces to 1-2% depending upon the C:N ratio of soil organic matter. Due to high temperature in tropics and subtropics organic matter content in soil in these regions was found to be lower than in temperate region. Prasad (2007 a) reported that total N content in Indian soils (0-15 cm layer) varied from 0.02 – 0.1%.

De Datta *et al* (1988) reported that for wet direct seeded rice, the rates of N fertilizer ranged from 60-120 kg N ha^{-1} for wet and dry seasons in Philippines. Singh *et al* (2007) observed the N response of wet direct seeded rice up to 120 kg N ha^{-1} where applied N fertilizer increased grain yield by 62% compared to no N (control). Beyond 120 kg N ha^{-1}, no increase in grain yield was obtained but its application resulted in more production of rice straw. These results are in concurrence with findings of Singh et *al.,* (1998) who reported that the maximum average grain yield of 7700 kg ha^{-1} of 20 lowland rice genotype was obtained at 150 to 200 kg ha^{-1} at the International Rice Research Institute in the Philippines.

Ghosh (2007) observed that nitrogen application results in maximum nitrogen use efficiency (27.12 kg grain kg^{-1} N), nitrogen uptake (0.46 kg ha^{-1}) and nitrogen recovery (16.81%). Oo *et al.,* (2007) indicated that the increase in the grain yield due to application of 100 and 150 kg N ha^{-1} over control was 1.99 t ha^{-1} and 1.95 t ha^{-1} and in term of percentage increase was 49.5 and 48.5% respectively. Further increase in the rate of nitrogen to 150 kg ha^{-1} decreased the grain yield slightly. Bhindu and Subramanian (2008) reported that the 150 kg N ha^{-1} applied in four splits led to the highest crop uptake of nitrogen (271 kg ha^{-1}) than the other Nitrogen levels. According to Sathiya and Ramesh (2009) the different split doses of nitrogen application of 150 kg ha^{-1} in four splits – $1/6^{th}$ at 15 Days, $1/3^{rd}$ at tillering, $1/3^{rd}$ at panicle initiation and $1/6^{th}$ at flowering recorded higher tillers ($361m^2$), plant height (77 cm), dry matter at flowering (5.20 t ha^{-1}) and grain yield (2827 kg ha^{-1}) of aerobic rice over four equal splits where the grain yield was 2673 kg ha^{-1}. Yadav *et al* (2009) suggested that application of nitrogen in three splits- 1/2 basal, ¼ at tillering and ¼ at panicle initiation produced significantly higher yield, yield attributing traits and protein production.

2.2.2 Phosphorous

The most essential function of P in plants was proved to be in energy storage and transfer. Adenosine di and tri phosphate (ADP and ATP) were known as 'energy currency' within plants. (Tisdale *et al.*, 1993). In rice, a plentiful supply of P in the early stages promoted energy growth because such a high supply increased the content of nucleic acids and phospholipids. Nucleic acids could actually promote heading in rice as they controlled vegetative growth through protein biosynthesis and reproductive growth through flower initiation (Fujiwara, 1964). An analysis of 3.65 million soil samples from different states of India showed that 42% of soil samples were low, 38% medium and 20% high in available P. Thus nearly 80% of Indian soils are low to medium in available P and need adequate P fertilization (Tandon, 2004)

Majumdar (1971) observed that there is significant increase in number of productive tillers and test weight due to P application. Favourable influence of P application on tillering was also observed by Nair *et al* (1972) and Choudhary *et al* (1978). Phosphorous manuring increased early tiller formation, the greater part of which ultimately provided more grains of heavier weight and also stimulated early and synchronous flowering (Bhattacharya and Chatterjee, 1978). Slaton *et al* (2002) reported that the availability of phosphorous when the soil pH ranged from 6.0 to 6.5. When pH is less than 6.0 the potential for P deficiency for most crops increases. Prasad (2007b) reported that organic manures can supply 2-7 kg P_2O_5 tonne^{-1} and when supplied @ 10 t ha^{-1} could meet most P requirements of crop.

Saleque *et al* 2001 reported that the P deficiency in soil does not only affect the P nutrition of rice, but may also affect the uptake of other nutrients, especially that of K and Mg. The concentration of P in rice straw or grain increased or decreased, obviously, with an increase or decrease in the available P level in soil.

2.2.3 Potassium

Potassium like N, P and most other nutrients did not form co-ordinated compounds in the plant. Instead it existed as the K^+ ion, either in solute ion or bounded to negative charges such as organic radical R-COO. As a result of its strict ionic nature, K^+ had function particularly related to the ionic strength of the solution within cells (Tisdale *et al.*, 1993). Potassium was found to be actively taken up from the soil solution by plant roots. The concentration of Potassium in vegetable tissue usually ranged from 1 to 4 % on dry matter basis. Thus plant requirement for available potassium was quite high. Potassium apparently did not form integral part of any plant component and its function is catalytic in nature.

It was found to be essential for the physiological functions of carbohydrate metabolism and synthesis of protein, control and regulation of various mineral elements, neutralization of physiologically important organic acids, activation of various enzymes, formation of the growth of meristematic tissue and adjustment of stomatal movement and water relation (Tisdale *et al.*, 1993). Potassium was regarded as indispensable to the growth and grain production of rice. Tanaka *et al.*, (1997) reported that the rice plant was characterized by its high capacity of absorbing as well as exhausting K and thereby tried to maintain the K concentration of the plant at a constant level. When the K concentration of rice plant was forced to be low, its relative growth increment reduced drastically. A positive response of rice to k application was observed by Su (1976)

Significant increase in rice height with increase in the levels of K was observed by Vijayan and Sridharan (1972) and Venkatasubbaiah (1982). A positive correlation between K application and leaf area index in rice was observed by Mandal and Dasmahapatra (1983). Potassium checks the chlorophyll degradation and promoted the synthesis of both chlorophyll 'a' and 'b' increase in the rate of translocation of amino acid to the grain and higher protein formation due to K fertilization was reported by Mengel *et al.*, (1981). John *et al.*, (2004) revealed that potassium has been found to influence the use efficiency of other nutrients. The ill effect of Fe can be reduced by K fertilization. High level of K is reported to decrease Fe uptake and helps maintain K/Fe ratio in plants. Higher rate of K application increased efficiency of N, P and Zn in laterite soils of Kerala (Bridgit, 1999 and Deepa 2002). Mansoor *et al.*, (2008) found that the efficient potash uptake by rice when potash was applied at maximum tillering stage (25 DAT) and at panicle initiation stage (45 DAT).

2.2.4 Calcium

Calcium was well known for its role in cell elongation and cell division (Bustrom, 1968). Calcium restricted permeability and makes the cell membrane stable. This is achieved by the absorption of Ca^{+2} to negatively charged phosphate group of the lipids of the membrane (Caldwell and Haung, 1982). An important function of calcium was the activation of number of enzymes including cyclic nucleotide, phosphodiesterase, adenylate cyclase, membrane bound Ca^{+2}-ATPase and NAD-kinase, which it performs in association with calmodulin. Calmodulin, a polypeptiode of 148 aminoacids, was found to be heat stable and sensitive to pH. It was able to form a compact structure binding four Ca ions (Klee et al., 1980; Cheung, 1982).

A fairly large amount of Ca was found to be present in soil as exchangeable Ca on silicate minerals in soils having pH 6.0 or above. Exchangeable Ca in soils ranged from <25 mg kg^{-1} to more than 5000 mg kg^{-1} and Ca in soil solution ranged from 68 to 778 mg kg-1 (Prasad and Power, 1997). Calcium in the exchange complex in acid soil was replaced by H^+ ions. Also as the soil acidity increased, the proportion of exchangeable Al increased and Al toxicity was probably the major limiting factor to plant growth and crop production in strongly acid soils (Foy, 1992). Alam *et al.*, (2002) found that the application of calcium phosphate and calcium sulphate to rice increased N, P, K and Ca and decreased Na and Mg concentrations when compared to control plants grown on all soil types.

2.2.5 Magnesium

Similar to K, Mg^{+2} was found to be a counter ion for H^+ flux across the thylakoid membrane which involved in activation of RuBP carboxylase and thus controlled the CO_2 fixation in photosynthesis (Fang *et al 1995*; Cakmak and Engels, 2002). Magnesium was considered as a cofactor in almost all enzymes involved in photophosphorylation. It might had formed a bridge between the pyrophosphate structure of ATP and ADP and the enzyme molecule (Mengel and Kirkby, 1987). Magnesium fertilization had a significant effect on the K, Mg, Zn and Mn content in grain (Brohi *et al.*, 2000).

Choudhury and Khanif (2002) reported that the application of Mg fertilizer increased grain and straw yields of rice and Mg and K uptake significantly. Singh and Singh (2005) reported that the application of MgSO4 @ 10 kg ha^{-1} promoted the absorption and translocation of Zn, Ca, P, K and that of Mg itself whereas Na accumulation was inhibited. Kobayashi *et al.,* (2005) found that in rice, the excess Mg treatment increased the Mg content of shoots and roots, and the potassium and chloride contents of roots, but slightly decreased the Ca and K contents of shoots.

2.2.6 Sulphur

Sulphur was recognized as the fourth major nutrient in addition to nitrogen, phosphorous and potassium. Hedge and Babu (2007) reported that sulphur ranks thirteenth in terms of abundance in the earth's crust and thus had a limitation in agriculture all over the world..

Sulphur was found to be required by crops in amount comparable to P which formed the amino acid Cysteine (27% S), Cystine (26% S) and methionine (21% S), hence essential for protein production, Chlorophyll formation, activation of enzymes and in the formation of glucosides and glucosinolates. It was also needed for the synthesis of amino acids and the oxidation of intermediates of the citric acid cycle.

The mean total S content of Indian soils was estimated to be about 30- 300 mg kg^{-1} (Anandanarayan *et al.*, 1988). Tandon (1986) and Nair (1995) reported S deficiency in more than 80% of soil. Nair (1995) also reported that 56% of samples collected from alluvial soil and 13% of the samples collected from brown hydromorphic soil in Kerala was categorized sulphur deficient. Tandon and Messic (2002) reported that the total S content of surface soils in India varied from 19 to 9750 ppm. Sheela *et al.*, (2006) and John *et al.*, (2005) reported that 70 % of the soil samples collected from different parts of four districts viz. Palghat, Thrissur, Kollam and Trivandrum were grouped as S deficient.

Rice plant required 1.67 kg sulphur to produce one tone hulled grain (Suzuki 1977). For rice, the S removal varied from 7 to 35 kg ha^{-1} (Lakshmanan and Prasad, 2004). For a crop yielding 4 to 6 Mg ha^{-1} the S removal by rice is about 3 to 3.5 kg S Mg^{-1} of unhulled rice.

Application of S up to 60 kg ha^{-1} increased the growth attributes and yield of rice (Singh *et al.,* 1993 and Raju *et al.*, 1995). However, Liu *et al.,* (1989) reported that application of sulphur retarded organic matter accumulation in paddy soil, increased available phosphorous and sulphur and released potasssium from the clay crystal lattice. Douli and Pradhan (2007) reported that the soil sulphur content decreased with the increase in depth and is mainly due to a decrease in organic carbon content. Similar result with respect to change in sulphur contents with depth was also reported by Pramanic and Douli (2001).

Sulphur application was known to reduce plant content of Iron by reducing leaf sap pH and increasing chlorophyll content (Singh 1970 and Pillai 1972). Singh *et al.,* (1990) was of the view that steady supply of sulphur from elemental sulphur ensured better growth. Nanawaty *et al.,* (1973) showed that the content of chlorophyll, water soluble protein and peroxidase in rice were significantly reduced under condition of sulphur deficiency. Bhuvanesswari and Sreeramchandhrasekharan (2006) noticed that the highest grain (5065 kg ha^{-1}) and straw (7524 kg ha^{-1}) yields and uptake N, P, K and S were obtained with the application of 40 kg S ha^{-1}. Oo et al (2007) reported that the application of 20 kg S ha^{-1} increased significantly P concentration in grain and straw over control but remained on par with 40 and 60 kg S ha^{-1}. Basumatary and Talukdar (2007) found that integrated use of 30 kg S ha^{-1} along with FYM of 1.5 or 3.0 t ha^{-1} resulted in the highest seed and straw yield, uptake of N, P, K and protein content of rice than that of a single application of sulphur or FYM alone.

2.2.7 Silicon

The amount of silicon to correct Si deficiency in the soil and to obtain optimum rice yield was 1500, 1120 and 0 kg ha^{-1} for low (<6 mg $litre^{-1}$), medium (6 to 24 mg $litre^{-1}$), and high (>24 mg $litre^{-1}$) level of soil Si, respectively. Silicon in the straw was classified as high when Si concentration was >34 g kg^{-1}, medium when between 17 and 34, and low when <17 g kg^{-1} (3.4 and 1.7%, respectively). (Korndorfer *et al.*, 2001).

Calcium oxide, silicon oxide, lignin and hemicellulose contents increased and total N and MgO contents decreased with increasing applications of silica. Silica applications gave increased ripened grain percentage and 1000-grain weight (Lee *et al.*, 1990).

Sumida (1992) reported that the main limiting factor to silica uptake by rice plants with abundant N is the ability of paddy fields at later growth stages. At earlier growth stages, a great deal of ammonia remaining in paddy soil and high N content of rice plants limit the silica uptake.

2.2.8 Zinc

Zinc was reported to be involved in enzymatic activities, but it was not known whether it acted as functional, structural or regulatory cofactor. Zinc is important in the synthesis of tryptophan, a component of some proteins and a compound needed for the production of growth hormones (auxins) such as indole acetic acid. Reduced growth hormone production in Zn deficient plants caused shortening of internodes and smaller than normal leaves. Zinc was involved in chlorophyll synthesis, enzyme activation and cell membrane integrity (Havlin *et al.*,2006). Indian soils were generally low in Zn and as much as half of the country soils were categorized to be Zn deficient (Singh, 2009). Total and available Zn content in Indian soils ranged between 7-2960 mg kg^{-1} and 0.1-24.6 mg kg^{-1}, respectively with an average deficiency of 12 to 87 % (Singh, 2000)

Abdul *et al.*, (1988) reported that application of Zn enhanced N concentration and uptake in straw and unhusked grain and increased Zn concentration. Zinc application increased chlorophyll and increased the tissue concentration of Zn, Ca, Mg, K and P, whereas Na content decreased. Zinc modified the elemental composition of plant tissues favourably and thereby accelerated plant growth and yield.

Prasad *et al.*, (2010) reported that application of zinc significantly enhanced the mean grain and straw yield of rice from 3.73 to 4.00 and 6.66 to 7.04 t ha^{-1}. He also concluded that, incorporation of 50% crop residues along with a starter dose of 5-10 kg Zn ha^{-1} can sustain crop productivity and maintain soil health. Moreover, the combined use of crop residues and zinc enhanced the nutrient uptake by crops.

Singh *et al.*, (1999) also observed that application of Zn at the rate of 5.0 mg Zn kg^{-1} increased the dry matter yield of rice significantly and was rated as the most optimum and economical rate. Patel and Rathod (2004) reported that Zn-enriched poultry manure and biogas slurry improved average wheat grain yield by about 68 and 49 %, respectively over control (18.15 q ha^{-1}), whereas the same was higher by 33 and 18% over straight Zn application (22.29 q ha^{-1}), respectively. The zinc level applied at the rate of 25 kg zinc sulphate ha^{-1} gave 31.77% higher yield over 12.50 kg levels (Sinsinwar, *et al.*,2004)

Experiment carried out on rice crop by Srinivas *et al.*, 2010 revealed that significantly higher grain yield of 5.55 t ha^{-1} and 5.59 t ha^{-1} during wet and dry seasons, respectively was obtained with 100% recommended dose of NPK + Zn + S along with FYM at 5 t ha^{-1}, where $ZnSO_4$ @ 40 kg ha^{-1} was applied to supply both Zinc and Sulphur.

Srivastava and Singh (2007) reported that Zn application to a Zn-deficient soil corrected the visual symptoms of Zn deficiency and significantly increased the total biomass, grain yields and the harvest index of rice, as well as the Zn concentration in the grain and the uptake of Zn by the straw and the grains. The calculated panicle-emergence index had a positive correlation with the grain yield of rice. The Zn-EDTA treatment, in spite of supplying the lowest amount of Zn, as well as leading to the lowest rate of Zn uptake, produced the highest yields in comparison to other sources viz. Zinc sulphate ($ZnSO_4$), Zn-enriched farmyard manure (Zn-FYM), Zn-tetra ammonia complex sorbed on FYM [$Zn(NH_3)_4$-FYM] and Zn-ethylenediamine tetra acetate (Zn-EDTA). Therefore Zn-EDTA was the most efficient source of Zn for lowland rice production.

2.2.9 Copper

Copper was found to be required for lignin synthesis (and thus cellular defence mechanism) and is a constituent of ascorbic acid, the enzyme oxidase and phenolase and plastocyanin. As a regulatory factor in enzyme reaction (effector, stabilizer and inhibitor). It played a key role in nitrogen, protein, hormone metabolism, photosynthesis, respiration, pollen formation and fertilization (Dobermann and Fairhurst, 2000). According to Chaudhury and Khanif (2002), single or combined application of Cu and Mg significantly increased rice yield and agronomic efficiency.

In a greenhouse trial, flooded rice cv. INCA grown on organic, humic gley and poorly humic gley soil was given 0, 0.75, 1.5, 2.25 or 3.0 mg Cu kg^{-1} soil. Cu decreased shoot dry matter production, with no difference between rates. Among the macronutrients, only Mg and S were influenced by Cu application. Copper application had significant effects on Cu, Zn, Fe and Mn uptake with no effect on B uptake. The effect of Cu on rice plants differed among soil types, with the organic matter content being the main discriminatory feature (Bertoni *et al.*, 1996).

2.2.10 Iron

Iron stress was investigated as the second most important micronutrient disorder after zinc in India. Both deficiency as well as toxicity of iron occured in rice depending upon the soil type and rice growing ecosystem. Rice plants grown in solution containing more than 200 ppm Fe showed Fe toxicity symptoms and yield reduced and the uptake of other essential elements decreased (Saerayossakul, 1968). Due to the high content of the element in the soil, rice plants absorbed very large amount of Fe (Anon., 1994). High yielding varieties tended to deposit two kg of Fe per ha on their roots which encapacitated the root system (Marykutty *et al.*, 1993). Pathirana *et al.*, (1995) found that Fe uptake was positively correlated with Fe concentration and deposition was greater in roots than shoots. Das *et al.*, (1997) reported that Fe content of plants significantly decreased in heavy textured soils indicating a positive influence of the soil clay content towards reducing Fe content in the plant. Iron is required for electron transport in photosynthesis and is a constituent of iron porphyrins and ferredoxins, both of which are essential components in the light phase of photosynthesis. Iron had a role as an important electron acceptor in redox reactions and an activator of several enzymes (eg., catalase, succinic dehydrogenase and aconitase) (Dobermann and Fairhurst, 2000).

Iron deficiency chlorosis occured in high pH calcareous soils under upland conditions and limited the yield of upland rice on permeable coarse textured soils. Different approaches to correct iron deficiency stress in rice included foliar sprays of inorganic iron compounds including iron chelates, application of potassium salts, growing transgenic and Fe-efficient cultivars (MTU-17, IET 1444 and Basmati-1-63). Excessive availability of iron in lateritic soils of Orissa, West Bengal, sub-montane soils of Punjab, Himachal Pradesh, North Eastern region and coastal soil of Kerala caused iron toxicity in rice. Singh (2009) reported that iron content in Indian soils was high, ranging from 4000-273000 mg kg^{-1} and that of available iron 0.36-174 mg kg^{-1} soil.

Olaleye *et al.*, (2001) found that dry matter yield, number of tillers per pot and height of the two rice cultivars decreased with increasing Fe^{2+}. Mehraban *et al.,* (2008) reported that maximum plant growth of rice occured at iron concentration of 10 and 50 mg L^{-1} and growth reductrion due to iron toxicity was observed at iron concentration of 250 and 500 mg $L^{-1.}$

2.2.11 Manganese

Manganese served as an activator of several enzymes. Rice has a high degree of tolerance for high Mn concentration in its tissue. Cheng and Quellete, (1971) reported that critical tissue content for Mn toxicity was 7000 ppm. Hariguchi and Kitagishi (1976) reported that more than 60% of Mn contained in the plant leaves is in chloroplast. Manganese along with Fe and Cu takes part as indispensable roles in electron transport system. According to De Datta (1981) the critical limits of deficiency and toxicity of Mn in rice plants are 20 ppm and 2500 ppm, respectively. Manganese in Indian soil is adequate varying from 37 to 11500 mg kg^{-1} and available status 0.6-164 mg kg^{-1} to support optimum crop growth (Singh *et al.,* 1995). Tandano and Yoshida (1978) suggested that a high Mn content in rice tissue was frequently associated with high yields; possibly indicating that a high Mn content in the plant was associated with various favourable soil conditions.

2.2.12 Boron

Boron had primary role in cell wall biosynthesis and structure and plasma membrane integrity. It was essential for carbohydrate metabolism, sugar transport, lignifications, nucleotide synthesis and respiration. It was relatively immobile in rice plants. Since boron was not retranslocated to new growth, deficiency symptoms would appear first on young leaves. Boron removal by rice was in the range of 0.01- 0.1 kg B t^{-1} grain yield. A rice crop yielding 6 t ha^{-1} removed 0.09 kg B ha^{-1} of which >60% remained in straw at maturity (Dobermann and Fairhurst, 2000). Soil boron approximation increased boron, copper, phosphorus and potassium concentration but reduced the concentration of iron. It was also shown that in soils with high levels of boron, zinc application may reduce the adverse effects of Boron toxicity and increased rice yields (Hossein *et al.,* 2005).

Soil treated with boron showed a significant effect on the growth and yield of the crop. Two kg boron ha^{-1} produced the highest straw (10.01 g pot^{-1}) and grain (9.69 g pot^{-1}) yields and maximum uptake of nitrogen, phosphorus and potassium (193, 29, and 208 mg pot^{-1}) by the rice plants. The treatment (2 kg B ha^{-1}) increased about 139 to 149 % more straw and grain respectively over the control (Kabir *et al* , 2007)

Materials and Methods

3. MATERIALS AND METHODS

A detailed study was undertaken to identify the best nutritional management practice for rice cultivation in the black soils of Kerala. For this purpose a farmer's field was selected at Vandithavalam, Chittur taluk, Palakkad district. Rice crop (kharif) was raised during June 2009 to October 2009. This soil showed similarities to the soil order vertisols (SSO, 2007)

Chittur lies in the eastern side of Palakkad (Plate 1). The field is located at 10^0 38' 03.88" N latitude, 76^0 44' 53.90" E longitude at an elevation of 129 m from the mean sea level.

3.1 Experimental details

The selected field was divided into three blocks and each block into eleven treatment plots. The different field operations are shown in appendix 1. The experimental details are furnished below.

Design	-	RBD (Randomized Block Design)
Treatments	-	Eleven
Replication	-	Three
Total number of plots	-	33
Plot size	-	40 m^2
Test crop	-	Rice
Variety	-	Uma
Spacing	-	20cm x 15cm.
Date of transplanting	-	25^{th} June 2010.
Date of harvest	-	19^{th} October 2010.

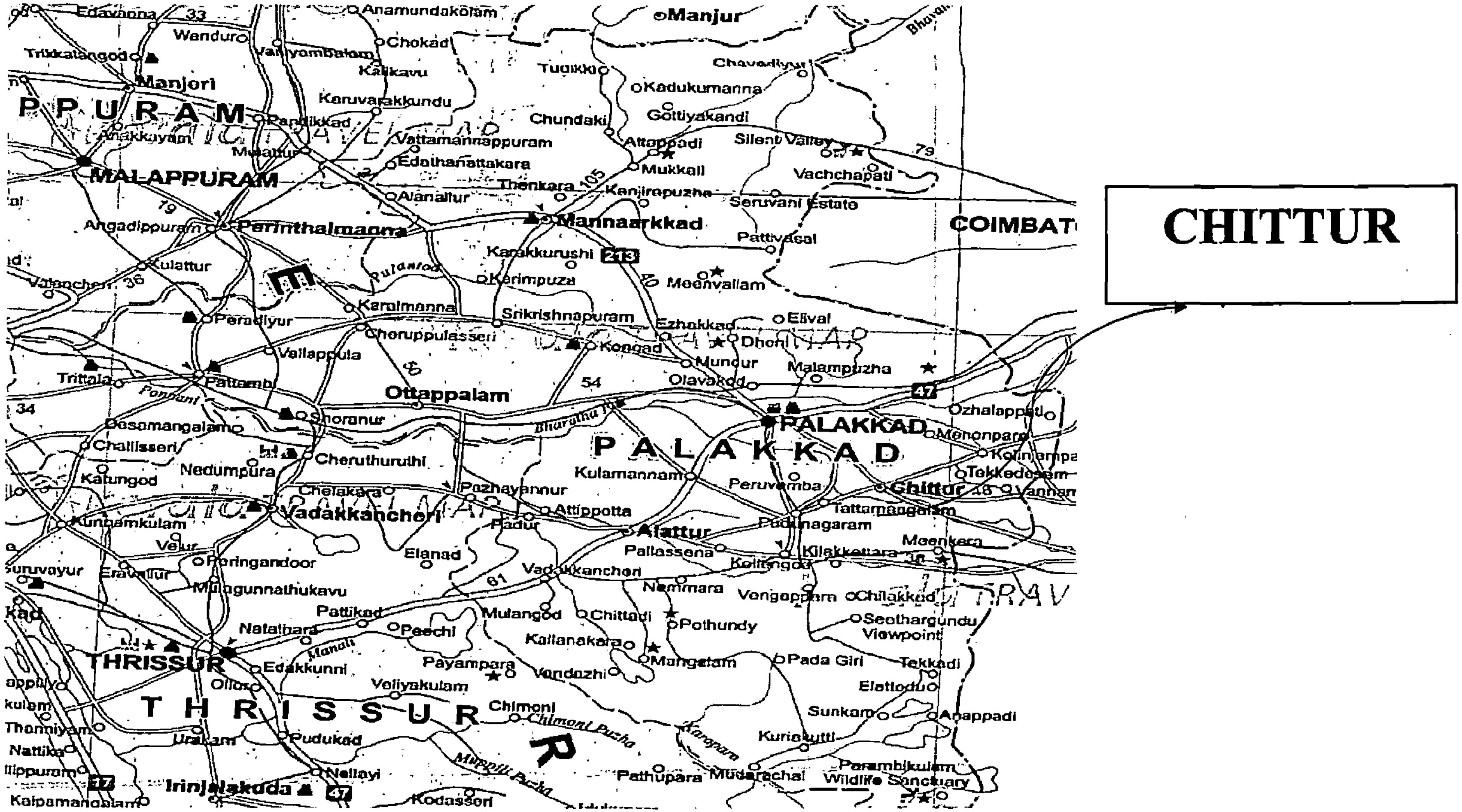

Plate 1. Location of the experiment

3.2 Treatments

The details of treatments are shown in Table 1. The quantities of fertilizer and manures applied in each treatment are given in Table 2.

Table 1. Details of treatments

Treatments No	Treatment details
T_1	Control
T_2	Farmer's practice (F.P)
T_3	Recommendation of KAU (KAU)
T_4	Soil Test Laboratory recommendation (STL)
T_5	STCR recommendation (STCR)
T_6	STCR recommendation+ FYM 5 t/ha.
T_7	T2+ Zinc Sulphate @ 25kg/ha (FP+$ZnSO_4$)
T_8	T3+ Zinc Sulphate @ 25 kg/ha (KAU+ $ZnSO_4$)
T_9	T4 + Zinc Sulphate @ 25kg/ha (STL+ $ZnSO_4$)
T_{10}	T5+ Zinc Sulphate @ 25kg/ha (STCR+ $ZnSO_4$)
T_{11}	T6+ Zinc Sulphate @ 25kg/ha. (STCR+IPNS+ $ZnSO_4$)

A brief description of each treatment is given below.

1. T1- Absolute control. No fertilizers and organic manure were added.
2. T2- The quantities of fertilizers and manures was applied as per the practice of the farmer.
3. T3- KAU recommended dose of fertilizer. This represented the quantities as per package of practices. (KAU, 2010).
4. T4- Soil Test Laboratory recommendation.
5. T5- Here the fertilizers as per the prescription equations developed by STCR centre, Vellanikkara.

   FN = 37.5T - 0.17SN

$FP_2O_5 = 20.16T - 4.69\ SP$

$FK_2O = 52T-1.37SK$

Where, FN = Nitrogen dose in Kg ha^{-1} which is added through fertilizer.

FP_2O_5= P_2O_5 dose in kg ha^{-1} which is added through fertilizer.

FK_2O = K_2O dose in kg ha^{-1} which is added through fertilizer.

T= yield target in t ha^{-1} (8 t ha^{-1})

SN= Soil available nitrogen in kg ha^{-1}.

SP = Soil available phosphorous in kg ha^{-1}

SK= Soil available potassium in kg ha^{-1}.

6. T6- Fertilizer recommendation developed by STCR centre, Vellanikkara along with application of FYM @ 5 t/ha.
   FN= 37.5T--0.17SN--0.31ON
   FP_20_5= 20.16T--4.69SP--2.25OP
   FK_2O= 52T--1.37SK--0.72OK
   T= Yield (8 t ha^{-1})
   SN= Soil available nitrogen kg ha^{-1}
   SP= Soil available phosphorous kg ha^{-1}
   SK= Soil available potassium kg ha^{-1}
   0N= Nitrogen contribution from FYM kg ha^{-1}
   OP = Phosphorous contribution from FYM kg ha^{-1}
   OK= Potassium contribution from FYM kg ha^{-1}
7. T7- Farmers practice (T_2) of fertilizer application along with application of zinc sulphate @ 25 kg ha^{-1}.
8. T8- KAU recommendation (T_3) along with application of zinc sulphate @ 25 kg ha^{-1}.
9. T9- Soil Test Laboratory recommendation (STL) (T_4) along with application of zinc sulphate @ 25 kg ha^{-1}.

10. T10- Fertilizer recommendation developed by STCR centre Vellanikkara (T_5) along with application of zinc sulphate @ 25 kg ha^{-1}
11. T11- Soil test based fertilizer recommendation developed by STCR + FYM (T_6) along with application of zinc sulphate @ 25 kg ha^{-1}. The contribution from the FYM with the specific composition (Table-5) was considered here while computing the fertilizer doses of N, P and K.

Table 2. Rate of application of fertilizers and manures in the experimental site.

Treatments	Urea (kg ha^{-1})	Rajphos/factomphos (kg ha^{-1})	Muriate of potash (kg ha^{-1})	FYM (t ha^{-1})	Zinc Sulphate (kg ha^{-1})
T_1 -control	0	0	0	0	0
T_2 -Farmer's practice	57.50	250.00 (factomphos)	187.50	5	0
T_3- KAU	196	250	75	5	0
T_4-STL	189.66	292.66	70.66	5	0
T_5- STCR	537.33	748	341	0	0
T_6- STCR+FYM	509	640.33	311.33	5	0
T_7- F.P + $ZnSO_4$	57.50	250.00 (factomphos)	187.50	5	0
T_8- KAU+ $ZnSO_4$	196	250	75	5	25
T_9- STL+ $ZnSO_4$	189.66	292.66	70.66	5	25
T_{10}- STCR+ $ZnSO_4$	537.33	748	341	0	25
T_{11}-STCR+ $ZnSO_4$+FYM	509	640.33	311.33	5	25

Elemental S @ 4.5 kg/ha was applied to the treatments where zinc sulphate was not applied except absolute control.

Table 3. Quantities of major nutrients and micronutrient applied through fertilizers.

Treatments	Nutrients (kg ha^{-1})			
	N	P_2O_5	K_2O	Zn
T_1 –control	0	0	0	0
T_2 -Farmer's practice	107.50	50.00	112.50	0
T_3- KAU	90.00	45.00	45.00	0
T_4-STL	87.30	52.65	42.30	0
T_5- STCR	247.20	135.00	205.00	0
T_6- STCR+FYM	234.00	115.26	187.00	0
T_7- F.P + $ZnSO_4$	107.50	50.00	112.50	9.1
T_8- KAU+ $ZnSO_4$	90.00	45.00	45.00	9.1
T_9- STL+ $ZnSO_4$	87.30	52.65	42.30	9.1
T_{10}- STCR+ $ZnSO_4$	247.20	135.00	205.00	9.1
T_{11}-STCR+ $ZnSO_4$+FYM	234.00	115.26	187.00	9.1

3.3 Field layout

The layout (Plate 2.) and the land preparation (Plate 3.) after the incorporation of FYM were completed and the treatments were allocated (Fig.1.)

N

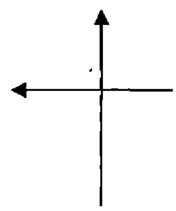

Fig.1. Allocation of treatments in the experimental site.

I	II	III
T_7	T_3	T_9
T_1	T_{11}	T_3
T_{11}	T_7	T_6
T_4	T_6	T_2
T_9	T_{10}	T_8
T_8	T_1	T_7
T_2	T_5	T_4
T_6	T_8	T_5
T_5	T_2	T_{10}
T_3	T_9	T_1
T_{10}	T_4	T_{11}

3.4 Application of manures and fertilizers

Farm yard manure was applied in all the plots except control (T_1), STCR (T_5) and STCR along with zinc sulphate (T_{10}). Fertilizer application is shown in plate 4. Fertilizers were also applied as per the treatments (Table 2). Half of nitrogen, full phosphorous and half of potassium were applied as basal dose. The remaining half of nitrogen and potassium were applied at the active tillering stage of the crop. Zinc sulphate was applied 20 days after transplanting. Sulphur application was done to the plots which did not receive zinc sulphate except control (T_1). The nutrient contents of fertilizers and organic manures are being furnished in appendix 2.

Plate 2. Layout of the experiment

Plate. 3. Land preparation

Plate. 4. Fertilizer application

3.5 Management practices

Management practices like irrigation, weeding, pest and disease control were carried out as per the package of practices recommendations for the various tereatments (KAU, 2010).

3.6 Observations recorded

3.6.1 Initial soil analysis

The basic properties of soils were studied before the conduct of the experiment. Soil samples were collected from 0-15 cm depth, processed and analyzed for the physico-chemical properties like single value constants, soil texture, pH, EC, CEC, organic carbon, available nutrients, N, P, K, Ca, Mg, S, Si, Na and micronutrients, Zn, Cu, Fe, Mn and B. The methods employed for soil analysis is given in Table -6

3.6.2 Soil analysis during the cropping period

Soil samples were collected and analysed at critical growth stages of crop viz maximum tillering, panicle initiation, flowering and after harvest for the available nutrients, N, P, K, Ca, Mg, S, and micronutrients, Zn, Cu, Fe, Mn, B, Na and Si. The methods employed for soil analysis is given in Table -4

Table 4. Methods for soil analysis

Parameter	Methods	Reference
Particle density, bulk density and Pore space	Keen- Raczkowski brass cup	Piper (1942)
Mechanical composition	International pipette method	
pH and Electrical conductivity	1:2.5 soil water suspension – pH meter & conductivity meter	Jackson (1958)
Cation exchange capacity	Saturation with NH_4^+ ions.	
Organic carbon	Wet oxidation	Walkley and Black (1934)
Nitrogen	Alkaline permanganometry	Subbiah and Asija (1956)
Phosphorous	Olsen extractant (0.5 M $NaHCO_3$ at pH 8.5)	Watanabe and Olsen. (1965)
Potassium and sodium	Neutral normal ammonium acetate extraction - flame photometer	Jackson (1958)
Calcium and magnesium	Neutral normal ammonium acetate extraction - atomic absorption spectrophotometer	
Available sulphur	$BaCl_2$ - Nephelometer	Chesnin and Yien (1951)
Available silicon	0.5 M acetic acid extraction - spectrophotometer (630 nm).	Korndorfer *et al*, (2001)
Available micronutrients (Zn, Cu, Fe, Mn)	DTPA extraction - atomic absorption spectrophotometer	Lindsay and Norvell (1978)
Available boron	Hot water extraction - spectrophotometer.	Jackson (1958)

3.6.3 Biometric observations

The different yield attributes such as height of the plant, number of leaves and tillers per plant and total dry matter yield was recorded at the maximum tillering, panicle initiation, flowering and harvest stages.

3.6.4 Plant analysis

Plant samples were collected by uprooting two hills randomly from each treatment at different growth stages viz. maximum tillering, panicle initiation, flowering and harvest. The fresh weight of the whole plant was recorded after removing the soil. The plant samples were oven dried to constant weight at 70^0C, ground, digested and analysed for the contents of N, P, K, Ca, Mg, S, and micronutrients, Fe, Mn, Zn, Cu, B and Na and Si. Grain samples after harvest were collected from various treatments and they were dried to constant weight 70^0C and then powdered. These samples were analysed for the contents of N, P, K, Ca, Mg, S, and micronutrients, Fe, Mn, Zn, Cu, B, Na and Si,. The methodology adopted to determine the above parameters are as detailed below in Table 5

Table 5. Methods for plant analysis

Parameter	Methods	Reference
Nitrogen	Sulphuric acid digestion - Microkjeldahl distillation.	Jackson (1958)
Phosphorous	Nitric-perchloric acid digest (2:1) - spectrophotometer.	Hesse (1971)
Potassium	Nitric-perchloric acid digest (2:1) - flame photometer.	
Calcium and magnesium	Nitric-perchloric acid digest (2:1) - atomic absorption spectrophotometer	Jackson (1958)
Sulphur	Turbidimetric – nephelometer	Hart (1961)
Sodium	Nitric-perchloric acid digest (2:1) - flame photometer.	Hesse (1971)
Iron, manganese, zinc and copper	Nitric-perchloric acid digest (2:1) - atomic absorption spectrophotometer	Jackson (1958)
Total boron	Nitric-perchloric acid digest (2:1) – spectrophotometer	"
Total silicon	Rapid micro-determination method	Nayar *et al* (1975)

3.6.5 Nutrient uptake

Based on the contents of nutrients at harvest and the dry weights of the straw and grain, the total uptake of different nutrients were computed.

3.7 Economic analysis of treatments

The cost of various inputs and the prevailing labour charges in the locality were taken together and gross expenditure was computed and expressed in rupees per hectare. The income from grain and straw at the time of harvest based on the then market price was taken as total receipts for computing gross returns and expressed in rupees per hectare. Benefit: cost ratio was worked out by dividing the gross return with total expenditure per hectare. The details of market prices are furnished in appendix 3.

3.8 Statistical analysis

Data were subjected to analysis of variance using statistical package 'MSTAT-C' package (Freed, 2006). Whenever the F test was significant (at 5 % level) multiple comparision among the treatments were done with Duncan's Multiple Range test (DMRT). Correlation studies of data were carried out using SPSS package.

Results

4. RESULTS

The results of the present study on "Nutrient management for sustainable rice production in black soils of Kerala'' are presented under different headings in this chapter:

Table 4.1. Initial properties of soil

The basic properties of soils were studied before the conduct of the experiment. Soil samples were collected at 0-15 cm depth, processed and analyzed for the physico-chemical properties like single value constants, soil texture, pH, EC, CEC, organic carbon, available nutrients, N, P, K, Na, Ca, Mg, S, micronutrients, Zn, Cu, Fe, Mn, B, Na and Si. The results of the initial soil properties are shown in Table-6

The bulk density and particle density (Mg $c.c^{-3}$) of the soil was 1.31 and 1.98 respectively. The maximum water holding capacity of the soil was 24.330 (%), the pore space (%) was 34.500. With regards to soil texture, the percentage sand, silt and clay were respectively 10.120, 18.710 and 71.160. The pH of the soil was 6.400. The electrical conductivity (dSm^{-1}) of the soil was 0.100. The cation exchange capacity (CEC) of the soil was found to be 11.38 cmol (p+) kg^{-1}. The organic carbon content of the soil was 0.740 %.

Among the major nutrients, the available N (kg ha^{-1}) was found to be 310.500. The available P content (kg ha^{-1}) was 5.670 while, the available K (kg ha^{-1}) was found to be 154.360.

Among the secondary nutrients (mg kg^{-1}), Ca was found to be 1792.010, Mg 484.270 and S was found to be 32.770. In the case of micronutrients (mg kg^{-1}), available Fe content was 333.730, followed by Mn 54.390, Cu 5.010, Zn 0.900 and B 0.200.

The available Na (mg kg^{-1}) content of the soil was found to be 108.330 and the Si content (mg kg^{-1}) was found to be 24.330

Table 6. Initial properties of soil

Sl no.	Properties	Values
1	Bulk density (Mg c.c^{-3})	1.310
2	Particle density (Mg c.c^{-3})	1.980
3	Maximum water holding capacity (%)	24.33
4	Pore space (%)	34.50
5	Volume expansion (%)	9.240
6	Clay (%)	10.12
7	Silt (%)	18.71
8	Sand (%)	71.16
9	pH	6.400
10	EC (dSm^{-1})	0.100
11	CEC [cmol (p^{+})kg^{-1}	11.38
12	Organic carbon (%)	0.740
Available nutrients		
13	Nitrogen (kg ha^{-1})	310.5
14	Phosphorous (kg ha^{-1})	5.670
15	Potassium (kg ha^{-1})	154.4
16	Sodium (mg kg^{-1})	108.3
17	Calcium (mg kg^{-1})	1792
18	Magnesium (mg kg^{-1})	484.2
19	Sulphur (mg kg^{-1})	32.77
20	Silicon (mg kg^{-1})	24.33
21	Zinc (mg kg^{-1})	0.900
22	Copper (mg kg^{-1})	5.010
23	Iron (mg kg^{-1})	333.7
24	Manganese (mg kg^{-1})	54.39
25	Boron (mg kg^{-1})	0.200

4.2 Soil analysis during the cropping period.

Soil samples were collected and analysed at the critical growth stages of crop viz maximum tillering (Plate 5, 6, 7 and 8), panicle initiation, flowering and after harvest, for available nutrients, N, P, K, Ca, Mg, S, micronutrients, Fe, Mn, Zn, Cu, B, Na and Si.

4.2.1. Effect of treatments on soil properties at the maximum tillering stage of the crop.

The available nutrient content of soil at maximum tillering stage is shown in Table 7

Among the major nutrients, available N content (kg ha^{-1}) ranged between 372.30 (T_4, STL) and 560.96 (T_1, control). There was no significant difference among the treatments. The available P content (kg ha^{-1}) ranged from 20.80 (T_5, STCR and T_7, F.P+$ZnSO_4$) to 27.60 (T_2, FP). Here also the treatments did not show any significant difference. The lowest and highest available K content (kg ha^{-1}) was obtained in T_7, F.P+$ZnSO_4$ (67.20) and T_{11}, STCR+ $ZnSO_4$+FYM (141.86) respectively. Significant difference was observed between the treatments. The treatment T_1, control (82.13), T_2, FP (89.60), T_4 STL (89.60), T_6, STCR+FYM (134.40), T_8, KAU+$ZnSO_4$ (82.13), T_9, STL+ $ZnSO_4$ (82.13), T_{10}, STCR+$ZnSO_4$ (89.60) and T_{11}, STCR+$ZnSO_4$+FYM (141.86) were on par.

Among the secondary nutrients, higher values were obtained for Ca followed by Mg and S in soil. The available Ca (mg kg^{-1}) was found to be lowest in T_3, KAU (543.33) and highest in T_8, KAU+$ZnSO_4$ (772.50). The treatments T_1, control (647.50), T_2, FP (638.33), T_4, STL (673.33), T_5, STCR (639.58), T_6, STCR+FYM (697.50), T_8, KAU+$ZnSO_4$ (772.50) T_{10}, STCR+$ZnSO_4$ (670.83) and T_{11}, STCR+$ZnSO_4$+FYM (635.41) were on par. The available Mg content (mg kg^{-1}) ranged from 385.61 (T_5, STCR) to 454.16 (T_7, FP+$ZnSO_4$). There was no significant difference between the treatments. As for available S, the content (kg ha^{-1}) ranged between 65.04 (T_{11}, STCR+$ZnSO_4$+FYM) and 83.50 (T_6, STCR+FYM) but the treatments did not show significant difference.

Plate 5. Crop at the maximum tillering stage

Plate 6. Crop at the flowering stage

Plate 7. Crop at the panicle initiation stage

Plate 8. Crop at the harvest stage

Table 7: Effect of treatments on soil properties at the maximum tillering stage of the crop.

Treatments	N Kg/ha	P Kg/ha	K Kg/ha	Ca (mg kg^{-1})	Mg (mgkg^{1})	S (mgkg^{1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	560.96^{a}	22.80^{a}	82.13^{abc}	647.50^{ab}	430.02^{a}	69.15^{a}	765.10^{ab}	108.40^{a}	4.94^{c}	5.11^{ab}	0.44^{a}	46.66^{a}	18.15^{b}
T_2 -Farmer's practice	449.57^{a}	27.60^{a}	89.60^{abc}	638.33^{ab}	409.03^{a}	73.75^{a}	866.58^{a}	121.40^{a}	5.76^{bc}	6.05^{ab}	0.30^{a}	46.66^{a}	26.78^{b}
T_3- KAU	423.48^{a}	21.20^{a}	74.66^{bc}	543.33^{b}	402.72^{a}	66.06^{a}	830.04^{a}	105.55^{a}	5.46^{c}	5.66^{ab}	0.20^{a}	36.66^{a}	20.98^{b}
T_4-STL	372.30^{a}	24.40^{a}	89.60^{abc}	673.33^{ab}	406.19^{a}	76.81^{a}	863.95^{a}	118.06^{a}	6.76^{abc}	6.00^{ab}	0.14^{a}	36.66^{a}	18.60^{b}
T_5- STCR	447.57^{a}	20.80^{a}	74.66^{bc}	639.58^{ab}	385.61^{a}	76.72^{a}	770.50^{ab}	92.95^{a}	5.23^{c}	5.01^{ab}	0.32^{a}	40.00^{a}	24.10^{b}
T_6- STCR+FYM	488.71^{a}	22.80^{a}	134.40^{ab}	697.50^{ab}	389.58^{a}	83.50^{a}	619.24^{b}	97.73^{a}	5.58^{bc}	4.38^{b}	0.17^{a}	46.66^{a}	27.08^{b}
T_7- F.P + $ZnSO_4$	451.58^{a}	20.80^{a}	67.20^{c}	592.08^{b}	454.16^{a}	77.14^{a}	944.70^{a}	110.04^{a}	8.96^{abc}	6.15^{ab}	0.38^{a}	50.00^{a}	19.19^{b}
T_8- KAU+ $ZnSO_4$	530.86^{a}	26.40^{a}	82.13^{abc}	772.50^{a}	402.50^{a}	71.91^{a}	855.70^{a}	110.55^{a}	7.47^{abc}	6.15^{ab}	0.36^{a}	43.33^{a}	47.91^{a}
T_9- STL+ $ZnSO_4$	430.51^{a}	24.00^{a}	82.13^{abc}	602.08^{b}	409.70^{a}	68.05^{a}	824.53^{a}	111.74^{a}	10.06^{a}	6.20^{ab}	0.21^{a}	36.66^{a}	31.69^{b}
T_{10}- STCR+ $ZnSO_4$	485.70^{a}	24.60^{a}	89.60^{abc}	670.83^{ab}	421.54^{a}	70.43^{a}	796.31^{ab}	125.05^{a}	9.81^{ab}	6.38^{a}	0.63^{a}	43.33^{a}	24.25^{b}
T_{11}- STCR+$ZnSO_4$+FYM	556.95^{a}	26.00^{a}	141.86^{a}	635.41^{ab}	417.75^{a}	65.04^{a}	771.83^{ab}	124.02^{a}	7.00^{abc}	5.50^{ab}	0.22^{a}	33.33^{a}	47.02^{a}
CD (0.05)	NS	NS	57.97	140.9	NS	NS	171.7	NS	3.75	1.67	NS	NS	14.83

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Among micronutrients, highest value was obtained for Fe followed by Mn, Zn, Cu and B in the soil. The available Fe content (mg kg^{-1}) ranged between 619.24 (T_6, STCR+FYM) and 866.58 (T_2, FP). All the treatments were on par except T_6. The available Mn (mg kg^{-1}) ranged between 92.95 (T_5, STCR) and 125.05 (T_{10}, STCR+$ZnSO_4$). There was however no significant difference among the treatments. The available Zn content (mg kg^{-1}) ranged between 4.94 (T_1, control) and 10.06 (T_9, STL+$ZnSO_4$). There was significant difference among the treatments. The treatments T_4, STL (6.76), T_7, FP+$ZnSO_4$ (8.96), T_8, KAU+$ZnSO_4$ (7.47), T_{10}, STCR+$ZnSO_4$ (9.81) and T_{11}, STCR+$ZnSO_4$+FYM (7.00) were on par. The available Cu content (mg kg^{-1}) ranged from 4.38 (T_6, STCR+FYM) to 6.38 (T_{10}, STCR+$ZnSO_4$). All the treatments were on par except T_6 (4.38). Available B content (mg kg^{-1}) ranged between 0.14 (T_4, STL) and 0.63 (T_{10}, STCR+$ZnSO_4$).

The available Na content (mg kg^{-1}) ranged between 33.33 (T_{11}, STCR+$ZnSO_4$+FYM) and 50.00 (T_7, FP+$ZnSO_4$). There was no significant difference among the treatments. The available Si content (mg kg^{-1}) was lowest in control and it ranged between 40.66 (T_1, control) and 107.33 (T_8). There was significant difference between the treatments. Treatments T_5, STCR (77.66), T_8, KAU+$ZnSO_4$+FYM (107.33), T_9, STL+$ZnSO_4$+FYM (71.00) and T_{11}, STCR+$ZnSO_4$+FYM (105.33) were on par.

4.2.2. Effect of treatments on soil properties at panicle initiation stage.

The available nutrient content of soil at PI stage is shown in Table 8

Among the major nutrients, available N content (kg ha^{-1}) varied significantly from 216.41 (T_8, KAU+$ZnSO_4$) to 290.70 (T_9, STL+$ZnSO_4$). Treatments T_1, control (257.33), T_2, FP (237.94), T_3, KAU (272.40), T_4, STL (258.40), T_6, STCR+FYM (234.71), T_9, STL+ $ZnSO_4$ (290.70), T_{10}, STCR+ $ZnSO_4$ (265.94) and T_{11}, STCR+ $ZnSO_4$+FYM (245.48) were on par. The available P content (kg ha^{-1}) was lowest in T_6, STCR+FYM (12.89) and highest in T_1, control (25.78). Treatments T_1, control (25.78), T_2, FP (20.95), T_3, KAU (18.80), T_4, STL (19.33), T_9, STL+ $ZnSO_4$ (18.26) and T_{11}, STCR+$ZnSO_4$+FYM (20.95) were on par. The available K content (kg ha^{-1}) ranged from 63.46 (T_8, KAU+ $ZnSO_4$) to 149.33 (T_{11}, STCR+$ZnSO_4$+FYM). Significant difference was observed between the treatments. But the treatments T_1, control (102.66), T_2, FP (100.80), T_5, STCR (87.73), T_6, STCR+FYM (112.00), T_9, STL+ $ZnSO_4$ (87.73), T_{10}, STCR+$ZnSO_4$ (138.13) and T_{11}, STCR+$ZnSO_4$+FYM (149.33) were on par.

Among the secondary nutrients, available Ca (mg kg^{-1}) content ranged between 713.73 (T_3, KAU) and 1082.75 (T_6, STCR+FYM). The treatments differed significantly. Among the treatments, T_1, control (992.48), T_2, FP (858.30), T_4, STL (841.28), T_5, STCR (840.13), T_6, STCR+FYM (1082.75), T_8, KAU+$ZnSO_4$ (791.15), T_9, STL+$ZnSO_4$ (766.10), T_{10}, STCR+$ZnSO_4$ (766.75) and T_{11}, STCR+$ZnSO_4$+FYM (748.91) were on par. The available Mg content (mg kg^{-1}) was highest in T_6, STCR+FYM (665.57) and lowest in T_9, STL+ $ZnSO_4$ (413.64). The available S content (mg kg^{-1}) was highest (100.72) in T_{10}, STCR+$ZnSO_4$. It was lowest in T_4, STL (70.53). But the treatments did not differ significantly.

Table 8: Effect of treatments on soil properties at panicle initiation stage.

Treatments	N Kg/ha	P Kg/ha	K Kg/ha	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	257.33^{ab}	25.78^{a}	102.66^{abc}	992.48^{ab}	446.70^{b}	80.28^{a}	457.90^{a}	68.29^{ab}	4.10^{a}	4.18^{a}	0.19^{ab}	65.83^{abc}	11.75^{b}
T_2 -Farmer's practice	237.94^{ab}	20.95^{ab}	100.80^{abc}	858.30^{ab}	442.14^{b}	78.02^{a}	450.66^{a}	79.05^{ab}	3.65^{a}	3.41^{a}	0.11^{b}	56.66^{abcd}	23.51^{ab}
T_3- KAU	272.40^{ab}	18.80^{abc}	82.13^{bc}	713.73^{b}	427.42^{b}	79.52^{a}	143.12^{a}	30.49^{b}	3.65^{a}	3.45^{a}	0.15^{ab}	50.00^{bcd}	41.81^{a}
T_4-STL	258.40^{ab}	19.33^{abc}	65.33^{c}	841.28^{ab}	418.59^{b}	70.53^{a}	346.37^{a}	57.94^{ab}	4.30^{a}	4.37^{a}	0.09^{b}	45.83^{d}	20.23^{b}
T_5- STCR	230.41^{b}	13.96^{bc}	87.73^{abc}	840.13^{ab}	459.54^{b}	78.65^{a}	506.02^{a}	102.53^{a}	4.97^{a}	4.39^{a}	0.18^{ab}	56.66^{abcd}	39.88^{a}
T_6- STCR+FYM	234.71^{ab}	12.89^{c}	112.00^{abc}	1082.75^{a}	665.57^{a}	81.28^{a}	124.98^{a}	29.59^{b}	3.58^{a}	2.97^{a}	0.10^{b}	66.66^{ab}	23.36^{ab}
T_7- F.P + $ZnSO_4$	222.87^{b}	17.72^{bc}	80.26^{bc}	729.00^{b}	429.74^{b}	80.28^{a}	599.55^{a}	101.78^{a}	6.42^{a}	5.20^{a}	0.08^{b}	55.00^{abcd}	15.17^{b}
T_8- KAU+ $ZnSO_4$	216.41^{b}	15.04^{bc}	63.46^{c}	791.15^{ab}	469.12^{b}	87.43^{a}	417.05^{a}	79.76^{ab}	5.33^{a}	4.13^{a}	0.16^{ab}	71.66^{a}	20.23^{b}
T_9- STL+ $ZnSO_4$	290.70^{a}	18.26^{abc}	87.73^{abc}	766.10^{ab}	413.64^{b}	81.20^{a}	395.38^{a}	60.77^{a}	6.18^{a}	4.52^{a}	0.28^{a}	53.33^{bcd}	26.04^{ab}
T_{10}- STCR+ $ZnSO_4$	265.94^{ab}	17.72^{bc}	138.13^{ab}	766.75^{ab}	441.40^{b}	100.72^{a}	134.23^{a}	34.70^{b}	4.30^{a}	4.12^{a}	0.11^{b}	48.33^{cd}	18.45^{b}
T_{11}-STCR+$ZnSO_4$+FYM	245.48^{ab}	20.95^{ab}	149.33^{a}	748.91^{ab}	448.14^{b}	88.39^{a}	292.46^{a}	79.10^{ab}	4.46^{a}	3.44^{a}	0.11^{b}	49.16^{bcd}	26.93^{ab}
CD (0.05)	49.79	6.83	56.98	302	180.4	NS	NS	48.37	NS	NS	0.12	15.41	17.22

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Among the micronutrients, the lowest and highest available Fe content (mg kg^{-1}) was found in T_6, STCR+FYM (124.98) and T_7, FP+ZnSO4 (599.55) respectively. The available Mn content (mg kg^{-1}) ranged between 29.59 (T_6, STCR+FYM) and 102.53 (T_5, STCR). The treatments T_1, control (68.29), T_2, FP (79.05), T_4, STL (57.94), T_5, STCR (102.53), T_7, FP+$ZnSO_4$ (101.78), T_8, KAU+$ZnSO_4$ (79.76), T_9, STL+$ZnSO_4$ (60.77) and T_{11}, STCR+$ZnSO_4$+FYM (79.10) were on par. Available Zn content (mg kg^{-1}) ranged between 3.58 (T_6, STCR+FYM) and 6.18 (T_9, STL+ $ZnSO_4$). There was no significant difference between the treatments. The available Cu content (mg kg^{-1}) was lowest in T_6, STCR+FYM (2.97) and highest in T_7, FP+$ZnSO_4$ (5.20).The available B content (mg kg^{-1}) ranged from .08 (T_7, FP+ZnSO4) to 0.28 (T_9, STL+$ZnSO_4$). Treatments T_1, control (0.19), T_3, KAU (0.15), T_5, STCR (0.18) T_8, KAU+$ZnSO_4$ (0.16) and T_9, STL+ $ZnSO_4$ (0.28) were on par.

Regarding the available Si content (mg kg^{-1}), the range was between 11.75 (T_1, control) and 41.81 (T_3, KAU). Significant difference was observed among the treatments. The treatments T_2, FP (23.51), T_3, KAU (41.81), T_5, STCR (39.88), T_6, STCR+FYM (23.36), T_9, STL+ $ZnSO_4$ (26.04) and T_{11}, STCR+$ZnSO_4$+FYM (26.93) were on par. The available Na content (mg kg^{-1}) ranged between 45.83 (T_4, STL) and 71.66 (T_8, KAU+$ZnSO_4$). The treatments T_1, control (65.83), T_2, FP (56.66), T_5, STCR (56.66) T_6, STCR+FYM (66.66), T_7, FP+ $ZnSO_4$ (55.00) and T_8, KAU+$ZnSO_4$ (71.66) were on par.

4.2.3. Effect of treatments on soil properties at flowering stage.

The available nutrient status at flowering stage are shown in Table 9

Among the major nutrients, the available N (kg ha^{-1}) ranged from 231.48 (T_{10}, STCR+$ZnSO_4$) to 345.61 (T_5, STCR). There was significant difference between the treatments. The available P (kg ha^{-1}) content ranged between 11.73 (T_2, FP) and 21.54 (T_5, STCR). There was no significant difference among the treatments. The available

Table 9: Effect of treatments on soil properties at flowering stage.

Treatments	N Kg/ha	P Kg/ha	K Kg/ha	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	279.94^{ab}	16.00^{a}	89.60^{d}	2248.33^{a}	420.64^{a}	56.66^{bc}	237.56^{ab}	64.15^{ab}	3.54^{b}	3.25^{b}	0.53^{a}	68.33^{a}	21.87^{ab}
T_2 -Farmer's practice	241.17^{ab}	11.73^{a}	97.06^{cd}	2333.33^{a}	438.45^{a}	52.87^{bc}	247.10^{ab}	71.71^{ab}	3.42^{b}	3.94^{ab}	0.49^{a}	76.66^{a}	39.58^{ab}
T_3- KAU	265.94^{ab}	17.06^{a}	112.00^{bcd}	1786.66^{a}	414.53^{a}	79.83^{ab}	92.45^{b}	29.70^{b}	3.81^{ab}	4.42^{ab}	1.02^{a}	66.66^{a}	26.93^{ab}
T_4-STL	296.09^{ab}	16.64^{a}	93.33^{d}	2115.00^{a}	432.02^{a}	76.17^{ab}	99.00^{b}	35.65^{b}	3.97^{ab}	4.73^{ab}	0.33^{a}	70.00^{a}	28.27^{ab}
T_5- STCR	345.61^{a}	21.54^{a}	168.00^{a}	2131.66^{a}	441.49^{a}	70.80^{abc}	151.46^{ab}	48.11^{ab}	3.56^{b}	4.44^{ab}	0.45^{a}	73.33^{a}	19.49^{ab}
T_6- STCR+FYM	244.40^{ab}	13.86^{a}	138.13^{ab}	1510.00^{a}	430.47^{a}	61.63^{abc}	231.30^{ab}	77.40^{ab}	4.14^{ab}	3.90^{ab}	0.11^{a}	75.00^{a}	15.62^{b}
T_7- F.P + $ZnSO_4$	248.71^{ab}	18.34^{a}	97.06^{cd}	1966.66^{a}	442.34^{a}	80.89^{ab}	317.72^{a}	88.41^{a}	4.66^{ab}	3.41^{ab}	0.63^{a}	78.33^{a}	23.95^{ab}
T_8- KAU+ $ZnSO_4$	260.56^{ab}	16.21^{a}	100.80^{bcd}	1730.00^{a}	429.83^{a}	55.55^{bc}	90.65^{b}	26.00^{b}	4.33^{ab}	4.84^{a}	1.14^{a}	81.66^{a}	20.53^{ab}
T_9- STL+ $ZnSO_4$	265.94^{ab}	20.05^{a}	104.53^{bcd}	1546.66^{a}	400.26^{a}	71.99^{abc}	180.45^{ab}	48.78^{ab}	5.54^{a}	4.20^{ab}	0.68^{a}	66.66^{a}	20.08^{ab}
T_{10}- STCR+ $ZnSO_4$	231.48^{a}	19.20^{a}	134.40^{abc}	2055.00^{a}	406.88^{a}	46.39^{c}	170.35^{ab}	49.60^{ab}	4.76^{ab}	3.42^{ab}	0.41^{a}	80.00^{a}	45.68^{a}
T_{11}STCR+$ZnSO_4$+FYM	258.40^{ab}	20.26^{a}	134.40^{abc}	1913.33^{a}	417.29^{a}	84.99^{a}	214.46^{ab}	58.89^{ab}	3.43^{b}	3.90^{ab}	0.73^{a}	70.00^{a}	30.35^{ab}
CD (0.05)	93.40	NS	34.46	NS	NS	24.62	172.6	44.92	1.65	1.33	NS	NS	23.19

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K content (kg ha^{-1}) ranged between 89.60 (T_1, control) and 168.00 (T_5, STCR). The treatments T_5, STCR (168.00), T_6, STCR+FYM (138.13), T_{10}, STCR+$ZnSO_4$ (134.40) and T_{11}, STCR+FYM+ $ZnSO_4$ (134.40) were on par. The available K content was highest in STCR treatment 168.00 (T_5) followed by STCR+FYM treatment (T_6) with 138.13.

Among the secondary nutrients, the available Ca content (mg kg^{-1}) ranged between 1510.00 (T_6, STCR+FYM) and 2333.33 (T_2, FP). There was no significant difference between the treatments. The available Mg content (mg kg^{-1}) ranged between 400.26 (T_9, STL+$ZnSO_4$) and T_7, FP+$ZnSO_4$ (442.34). There was significant difference among the treatments. The available S content (mg kg^{-1}) was lowest in T_{10}, STCR+$ZnSO_4$ (46.39) and highest in T_{11}, STCR+$ZnSO_4$+FYM (84.99). There was significant difference between the treatments. The treatments T_3, KAU (79.83), T_4, STL (76.17), T_5, STCR (70.80), T_6, STCR+FYM (61.63), T_7, FP+$ZnSO_4$ (80.89), T_9, STL+ $ZnSO_4$ (71.99) and T_{11}, STCR+$ZnSO_4$+FYM (84.99) were on par.

Among the micronutrients, the available Fe content (mg kg^{-1}) was found to be lowest in T_8, KAU+$ZnSO_4$ (90.65) and highest in T_7, F.P+ZnSO4 (317.72). All the treatments were on par except T_3 (KAU) and T_8 (KAU+$ZnSO_4$). The available Mn content (mg kg^{-1}) was lowest in T_8, KAU+$ZnSO_4$ (26.00) and highest in T_7, FP+ $ZnSO_4$ (88.41). The treatments T_1, control (64.15), T_2, FP (71.71), T_5, STCR (48.11), T_6, STCR+FYM (77.40), T_7, FP+$ZnSO_4$ (88.41), T_9, STL+ $ZnSO_4$ (48.78), T_{10}, STCR+$ZnSO_4$ (49.60) and T_{11}, STCR+$ZnSO_4$+FYM (58.89) were on par. The available Zn content (mg kg^{-1}) varied from 3.42 (T_2, FP) to 5.54 (T_9, STL+$ZnSO_4$). There was significant difference among the treatments. The treatments T_3, KAU (3.81), T_4, STL (3.97), T_6, STCR+ $ZnSO_4$ (4.14), T_7, FP+$ZnSO_4$ (4.66), T_8, KAU+$ZnSO_4$ (4.33), T_9, STL+ $ZnSO_4$ (5.54), and T_{10}, STCR+$ZnSO_4$ (4.76) were on par. The available Cu content (mg kg^{-1}) ranged from 3.25 (T_1, control) to 4.84 (T_8, KAU+$ZnSO_4$). All the treatments were on par except T_1, control. The available B content (mg kg^{-1}) ranged from 0.11 (T_6, STCR+FYM) to 1.14 (T_8, KAU+$ZnSO_4$). There was no significant difference among the treatments.

The available Na (mg kg^{-1}) content was found to be lowest in T_3, KAU and T_9, STL+ $ZnSO_4$ (66.66) while it was highest in T_8, KAU+$ZnSO_4$ (81.66). The treatment did not differ significantly. The available Si content (mg kg^{-1}) ranged from 15.62 (T_6, STCR+FYM) and 45.68 (T_{10}, STCR+$ZnSO_4$). All the treatments were on par except T_6 (STCR+FYM).

4.2.4. Effect of treatments on soil properties at harvesting stage.

The available nutrient status at harvest stage is shown in Table 10.

Among the major nutrients, the available N (kg ha^{-1}) ranged between 240.62 (T_3, KAU) to 335.55 (T_{11}, STCR+$ZnSO_4$+FYM). All the treatments were on par except T_3 (KAU). The available P content (kg ha^{-1}) varied between 23.10 (T_5, STCR) and 35.79 (T_8, KAU+$ZnSO_4$). All the treatments were on par except T_5, STCR and T_{11}, STCR+$ZnSO_4$+FYM. The available K content (kg ha^{-1}) ranged between 78.40 (T_1, control) and 141.86 (T_{10}, STCR+$ZnSO_4$). The treatment T_4, STL (104.53), T_5, STCR (104.53), T_6, STCR+FYM (126.93), T_9, STL+ $ZnSO_4$ (115.73), T_{10}, STCR+$ZnSO_4$ (141.86) and T_{11}, STCR+$ZnSO_4$+FYM (130.66) were on par.

Among the secondary nutrients, available Ca (mg kg^{-1}) ranged between 875.15 (T_{11}, STCR+$ZnSO_4$+FYM) and 1211:16 (T_1, control). All the treatments except T_{11}, STCR+$ZnSO_4$+FYM were on par. The available Mg content (mg kg^{-1}) ranged between 153.87 (T_9, STL+ $ZnSO_4$) and 178.83 (T_{11}, STCR+$ZnSO_4$). There was no significant difference among the treatments. Available S content (mg kg^{-1}) was lowest in T_2, FP (49.39) and highest in T_7, FP+$ZnSO_4$ (77.14). There was however no significant difference among the treatments.

Among micronutrients, the available Fe content (mg kg^{-1}) ranged between 74.70 (T_3, KAU) and 151.28 (T_5, STCR). There was no significant difference among the treatments. The available Mn content (mg kg^{-1}) was lowest in T_8, KAU+ $ZnSO_4$ (15.56) and highest in T_7, FP+$ZnSO_4$ (24.35). The treatments did not show significant difference. The available Zn content (mg kg^{-1}) ranged between 1.96 (T_5, STCR) and 5.62 (T_{11}, STCR+$ZnSO_4$+FYM) respectively. The treatments T_1, control (3.36), T_2, FP (3.23), T_3, KAU+FYM (4.02), T_6, STCR+FYM (3.60), T_7, FP+$ZnSO_4$ (4.20), T_9, STL+ $ZnSO_4$ (4.21), T_{10}, STCR+$ZnSO_4$ (3.77) and T_{11}, STCR+$ZnSO_4$+FYM (5.62) were on par. The available Cu content (mg kg^{-1}) was lowest in T_3, KAU (3.27) and highest in T_{11}, STCR+FYM+ $ZnSO_4$ (4.26). All the treatments except T_3 (KAU+FYM) were on par. The available B content (mg kg^{-1}) ranged between 0.84 (T_{11}, STCR+$ZnSO_4$+FYM) and 1.66 (T_1, control). There was no significant difference among the treatments.

The available Na content (mg kg^{-1}) ranged between 63.33 (T_3, KAU) and 83.33 (T_6, STCR+FYM). All the treatments were on par except T_3, KAU (63.33) and T_{11}, STCR+$ZnSO_4$+FYM (66.66). The available Si content (mg kg^{-1}) ranged between 13.83 (T_1, control) and 29.91 (T_7, FP+$ZnSO_4$). The treatments T_2, FP (17.56), T_3, KAU (20.38), T_4, STL (16.96), T_5, STCR (20.23), T_6, STCR+FYM (18.60), T_7, FP+$ZnSO_4$ (29.91), T_8, KAU+$ZnSO_4$ (22.91) and T_{10}, STCR+$ZnSO_4$ (27.67) were on par.

4.3. Biometric observation.

The different yield attributes such as height of the plant, number of leaves and tillers per plant and total dry matter production was recorded at the maximum tillering, PI, flowering and harvest stages.

4.3.1. Effect of treatments on height of the plant per hill.

The height of the plant at critical stages of crop growth as affected by different treatments is given in Table 11. It was seen that there was significant

Table 11: Effect of treatments on height of plant.

Treatments	Plant height per hill (cm)			
	Maximum tillering	Panicle initiation	Flowering	Harvest
T_1 control	69.80^{c}	69.60^{c}	86.13^{ab}	83.60^{ab}
T_2 -Farmer's practice	83.06^{ab}	87.26^{ab}	83.86^{b}	86.60^{ab}
T_3- KAU	76.13^{bc}	82.06^{bc}	91.80^{ab}	82.06^{b}
T_4-STL	75.80^{bc}	86.06^{ab}	90.40^{ab}	87.33^{ab}
T_5- STCR	83.00^{ab}	97.86^{a}	90.33^{ab}	86.80^{ab}
T_6- STCR+FYM	83.33^{ab}	90.06^{ab}	92.93^{a}	84.60^{ab}
T_7- F.P + $ZnSO_4$	79.46^{ab}	81.20^{bc}	89.33^{ab}	91.93^{a}
T_8- KAU+ $ZnSO_4$	80.93^{ab}	82.46^{bc}	83.86^{b}	83.86^{ab}
T_9- STL+ $ZnSO_4$	79.73^{ab}	82.20^{bc}	87.66^{ab}	85.66^{ab}
T_{10}- STCR+ $ZnSO_4$	80.73^{ab}	93.86^{ab}	94.46^{a}	87.40^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	87.73^{a}	99.46^{a}	88.53^{ab}	85.86^{ab}
CD (0.05)	7.713	12.12	7.771	8.089

difference in plant height among the treatments in all the stages. In general, the plant height

increased from maximum tillering to flowering stage for all treatments and there after decreased towards the harvest.

At the maximum tillering stage, plant height (cm) ranged from 69.80 (T_1, control) to 87.73 (T_{11}, STCR+$ZnSO_4$+FYM). The treatments T_2, FP (83.06), T_5, STCR (83.00), T_6, STCR+FYM (83.33), T_7, FP+$ZnSO_4$ (79.46), T_8, KAU+$ZnSO_4$ (80.93), T_9, STL+ $ZnSO_4$ (79.73), T_{10}, STCR+$ZnSO_4$ (80.73) and T_{11}, STCR+$ZnSO_4$ (87.73) were on par.

At the panicle initiation stage, plant height (cm) ranged from 69.60 (T_1, control) to 99.46 (T_{11}, STCR+$ZnSO_4$+FYM). The treatments T_2, FP (87.26), T_4, STL (86.06), T_5, STCR (97.86), T_6, STCR+FYM (90.06), T_{10}, STCR+$ZnSO_4$ (93.86) were on par.

At flowering stage, plant height (cm) was highest in T_{10}, STCR+ $ZnSO_4$ (94.46) and lowest in T_2, FP+FYM and T_8, KAU+ $ZnSO_4$ (83.86). All the treatments were on par except T_2, FP and T_8, KAU+$ZnSO_4$.

At harvest stage, plant height (cm) ranged from 82.06 (T_3, KAU) to 91.93 (T_7, FP+$ZnSO_4$). There was significant difference among treatments.

4.3.2. Effect of treatments on number of leaves of plant per hill.

The number of leaves per hill at different growth stages of the crop is furnished in Table 12. It is seen that there was significant difference between the treatments at maximum tillering and flowering stage. No significant difference was observed among the treatments at PI stage and harvest stage.

At the maximum tillering stage, the number of leaves varied between 24.55 (T_1, control) and 33.04 (T_{10}, STCR+ $ZnSO_4$). There was significant difference among the treatments. Except T_1, control and T_3, KAU all the treatments were on par.

Table 12: Effect of treatments on number of leaves of plant.

Treatments	Number of leaves per hill			
	Maximum tillering	Panicle initiation	Flowering	Harvest
T_1 control	24.55[b]	39.33[a]	41.16[b]	25.00[a]
T_2 -Farmer's practice	30.28[ab]	50.83[a]	48.00[ab]	32.00[a]
T_3- KAU	24.95[b]	55.33[a]	51.33[ab]	24.66[a]
T_4-STL	30.07[ab]	51.00[a]	55.66[ab]	30.66[a]
T_5- STCR	31.43[ab]	56.83[a]	64.50[ab]	29.50[a]
T_6- STCR+FYM	29.87[ab]	50.66[a]	69.83[a]	30.16[a]
T_7- F.P + $ZnSO_4$	31.32[ab]	54.66[a]	44.83[ab]	32.33[a]
T_8- KAU+ $ZnSO_4$	29.24[ab]	52.83[a]	48.00[ab]	38.50[a]
T_9- STL+ $ZnSO_4$	27.66[ab]	42.00[a]	46.50[ab]	32.16[a]
T_{10}- STCR+ $ZnSO_4$	33.04[a]	52.00[a]	62.66[ab]	27.83[a]
T_{11}-STCR+ $ZnSO_4$+FYM	29.65[ab]	51.50[a]	60.33[ab]	26.50[a]
CD (0.05)	6.965	NS	22.62	NS

At the PI stage, the number of leaves was lowest in T_1, control (39.33) and highest in T_5, STCR (56.83). There was however no significant difference among the treatments.

At the flowering stage, the number of leaves ranged between 41.16 (T_1, control) and 69.83 (T_6, STCR+FYM). There was significant difference among the treatments.

At the harvest stage, the number of leaves varied between 24.66 (T_3, KAU) and 38.50 (T_8, KAU+$ZnSO_4$). No significant difference was observed between the treatments.

4.3.3. Effect of treatments on number of tillers of plant per hill.

The number of tillers per hill at different growth stages is furnished in Table 13. The number of tillers differed significantly among treatments during maximum tillering and flowering stage. There was no significant difference among the treatments at PI and harvest stage.

At the maximum tillering stage, the number of tillers ranged between 7.50 (T_3, KAU) and 11.66 (T_{11}, STCR+$ZnSO_4$+FYM). There was significant difference among the treatments.

At the PI stage, the number of tillers ranged between 8.5 (T_1, control) and 12.66 (T_{10}, STCR+FYM). There was however no significant difference among the treatments.

At the flowering stage, the number of tillers ranged between 8.50 (T_1, control) and 16.00 (T_5, STCR). There was significant difference among the treatments. All the treatments were on par except T_1, control and T_8, KAU+$ZnSO_4$.

At the harvest stage, the number of tillers ranged between 9.5 (T_1, control) and 13.66 (T_8, KAU+$ZnSO_4$). The treatments showed no significant difference.

Table 13: Effect of treatments on number of tillers of plant.

Treatments	Number of tillers per hill			
	Maximum tillering	Panicle initiation	Flowering	Harvest
T_1 control	9.66[ab]	8.50[a]	8.50[c]	9.50[a]
T_2 -Farmer's practice	11.16[ab]	10.33[a]	10.83[abc]	10.00[a]
T_3- KAU	7.50[b]	9.83[a]	12.66[abc]	10.50[a]
T_4-STL	10.50[ab]	10.00[a]	10.66[abc]	10.50[a]
T_5- STCR	11.33[ab]	12.50[a]	16.00[a]	12.16[a]
T_6- STCR+FYM	10.00[ab]	9.66[a]	15.16[ab]	12.00[a]
T_7- F.P + $ZnSO_4$	12.83[a]	11.00[a]	11.00[abc]	12.33[a]
T_8- KAU+ $ZnSO_4$	9.66[ab]	10.83[a]	9.33[bc]	13.66[a]
T_9- STL+ $ZnSO_4$	9.16[ab]	11.16[a]	9.66[abc]	11.00[a]
T_{10}- STCR+ $ZnSO_4$	10.50[ab]	12.66[a]	13.16[abc]	9.66[a]
T_{11}-STCR+ $ZnSO_4$+FYM	11.66[a]	12.33[a]	13.83[abc]	10.16[a]
CD (0.05)	3.391	NS	5.514	NS

4.3.4. Effect of treatments on total dry matter yield of plant.

The total dry matter yield was obtained for the different treatments. The effect of treatment on the total dry matter yield is shown in Table-14.

The total dry matter yield was highest in T_2, FP+FYM (6688.54) and lowest in T_{10}, STCR+ $ZnSO_4$ (3779.05) There was significant difference among the treatments. The treatments T_2, FP (6688.54), T_3, KAU (6133.97), T_4, STL (6389.19), T_6, STCR+FYM (6046.28) and T_9, STL+ $ZnSO_4$ (6427.35) were on par.

4.4. Plant nutrient status during the cropping period

Plant samples were collected and analysed for the content of N, P, K, Ca, Mg, S, Na, Si and micronutrients, Fe, Mn, Zn, Cu and B at maximum tillering, panicle initiation, flowering and harvest stages.

4.4.1. Effect of treatments on plant nutrient content at the maximum tillering stage of the crop

The details of total nutrient content in rice plants are presented in Table 15. The treatments differed significantly with respect to N, P, Ca, S, Fe, Cu, B and Si. Significant difference was not shown by treatments with respect to K, Mg, Na, Zn and Mn.

Among major nutrients, the N concentration (%) in rice plants ranged from 1.86 (T_1, control) to 3.22 (T_{11}, STCR+FYM+$ZnSO_4$). The treatments T_3, KAU (2.66), T_5, STCR (2.61), T_6, STCR+FYM (2.87), T_7, FP+$ZnSO_4$ (2.84) T_9, STL+ $ZnSO_4$ (2.38), T_{10}, STCR+$ZnSO_4$ (2.52) and T_{11}, STCR+FYM+$ZnSO_4$ (3.22) were on par. The P content ranged between 0.09 (T_4, STL) and 0.17 (T_{11}, STCR+FYM+$ZnSO_4$). The treatments, T_1, control (0.11), T_2 FP+FYM (0.11), T_6, STCR+FYM (0.13), T_7, FP+$ZnSO_4$ (0.15), T_9, STL+$ZnSO_4$ (0.14) and T_{11}, STCR+$ZnSO_4$+FYM (0.17) were on par. The Potassium content was lowest in T_2, FP (1.29) and highest in T_{11},

Table 14: Effect of treatments on total dry matter yield of plant.

Treatments	Total dry matter (kg ha^{-1})
T_1 control	5155.97[de]
T_2 -Farmer's practice	6688.54[a]
T_3- KAU	6133.97[abc]
T_4-STL	6389.19[ab]
T_5- STCR	3686.03[f]
T_6- STCR+FYM	6046.28[abc]
T_7- F.P + $ZnSO_4$	5651.83[bcd]
T_8- KAU+ $ZnSO_4$	4560.91[e]
T_9- STL+ $ZnSO_4$	6427.35[ab]
T_{10}- STCR+ $ZnSO_4$	3779.05[f]
T_{11}-STCR+ $ZnSO_4$+FYM	5479.18[cd]
CD (0.05)	750.30

Table 15: Effect of treatments on plant nutrient content at the maximum tillering stage of the crop

Treatments	N (%)	P (%)	K (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	1.86^{c}	0.11^{ab}	2.16^{a}	2546.66^{ab}	6350.33^{a}	5517.03^{h}	7373.00^{a}	775.50^{a}	172.00^{a}	42.66^{ab}	65.12a^{b}	2916.66^{a}	3932.08^{b}
T_2 -Farmer's practice	2.00^{bc}	0.11^{ab}	1.29^{a}	2396.66^{b}	6382.33^{a}	32564.53^{b}	6086.50^{ab}	839.33^{a}	209.33^{a}	37.66^{abcd}	71.60^{ab}	3750.00^{a}	6925.82^{b}
T_3- KAU	2.66^{abc}	0.10^{b}	2.41^{a}	3308.33^{a}	7860.00^{a}	9169.85^{gh}	3181.16^{ab}	755.50^{a}	173.00^{a}	30.00^{bcd}	48.14^{b}	2916.66^{a}	3842.71^{b}
T_4-STL	2.31^{bc}	0.09^{b}	1.37^{a}	2670.00^{ab}	7738.33^{a}	14028.25^{ef}	5015.75^{ab}	654.50^{a}	311.33^{a}	42.66^{ab}	83.95^{ab}	3750.00^{a}	13360.14^{a}
T_5- STCR	2.61^{abc}	0.10^{b}	2.16^{a}	2860.00^{ab}	5605.00^{a}	16863.18^{de}	5231.83^{ab}	777.00^{a}	239.66^{a}	46.00^{a}	114.19^{a}	5000.00^{a}	6970.50^{b}
T_6- STCR+FYM	2.87^{ab}	0.13^{ab}	2.16^{a}	2380.00^{b}	7131.00^{a}	47867.53^{a}	5251.16^{ab}	763.16^{a}	173.00^{a}	36.00^{abcd}	79.32^{ab}	2500.00^{a}	3753.35^{b}
T_7- F.P + $ZnSO_4$	2.84^{ab}	0.15^{ab}	1.58^{a}	3265.00^{a}	7358.50^{a}	11419.16^{fg}	4461.00^{ab}	751.83^{a}	196.00^{a}	42.33^{abc}	59.87^{b}	8333.33^{a}	5853.44^{b}
T_8- KAU+ $ZnSO_4$	1.96^{c}	0.10^{b}	1.41^{a}	2673.33^{ab}	6365.66^{a}	28534.63^{c}	4692.16^{ab}	659.66^{a}	249.66^{a}	32.66^{abcd}	76.23^{ab}	2916.66^{a}	7283.28^{b}
T_9- STL+ $ZnSO_4$	2.38^{abc}	0.14^{ab}	2.00^{a}	2783.33^{ab}	6859.66^{a}	32204.37^{b}	4998.33^{ab}	617.83^{a}	357.33^{a}	26.66^{d}	75.00^{ab}	2500.00^{a}	3529.93^{b}
T_{10}- STCR+ $ZnSO_4$	2.52^{abc}	0.10^{b}	1.70^{a}	2755.00^{ab}	7672.33^{a}	20103.04^{d}	5428.83^{ab}	665.83^{a}	195.00^{a}	32.66^{abcd}	90.43^{ab}	4166.66^{a}	5093.83^{b}
T_{11}-STCR+ $ZnSO_4$+FYM	3.22^{a}	0.17^{a}	2.58^{a}	3345.00^{a}	8055.00^{a}	6074.72^{h}	3055.16^{b}	837.50^{a}	208.00^{a}	27.33^{cd}	48.76^{b}	2916.66^{a}	5451.29^{b}
CD (0.05)	0.77	0.05	NS	737.4	NS	3854	3640	NS	NS	13.31	45.64	NS	4073

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STCR+$ZnSO_4$+FYM (2.58). However, the treatments did not show any significant difference.

Regarding the secondary nutrient Ca, the content (mg kg^{-1}) ranged from 2380.00 (T_6, STCR+FYM) to 3345.00 (T_{11}, STCR+$ZnSO_4$+FYM). All the treatments were on par except T_2, FP and T_6, STCR+FYM. The Mg content (mg kg^{-1}) ranged between 5605.00 (T_5, STCR) and 8055.00 (T_{11}, STCR+FYM+$ZnSO_4$). There was no significant difference among the treatments. Total sulphur content (mg kg^{-1}) ranged between 6074.72 (T_{11}, STCR+FYM+$ZnSO_4$) and 47867.53 (T_6, STCR+FYM). The treatments T_2, FP (32564.53) T_3, KAU (33849.85) and T_9, STL+ $ZnSO_4$ (34204.37) were on par.

Among the micronutrients, the total Fe content (mg kg^{-1}) ranged between 3055.16 (T_{11}, STCR+$ZnSO_4$+FYM) and 7373.00 (T_1, control). All treatments except T_{11}, STCR+$ZnSO_4$+FYM were on par. The total Mn content (mg kg^{-1}) ranged from 617.83 (T_9, STL+ $ZnSO_4$) to 2872.50 (T_3, KAU). There was no significant difference among the treatments. The total Zn content (mg kg^{-1}) ranged between 172.00 (T_1, control) and 357.33 (T_9, STL+$ZnSO_4$). The treatments did not show any significant difference. The total Cu content (mg kg^{-1}) varied from 26.66 (T_9, STL+$ZnSO_4$) to 1704.50 (T_4, STL). The total B content (mg kg^{-1}) was lowest in T_3, KAU (481.14) and highest in T_5, STCR (114.19). The treatments T_1, control (65.12), T_2, FP (71.60), T_4, STL (83.95), T_5, STCR (114.19), T_6, STCR+FYM (79.32), T_8, KAU+$ZnSO_4$ (76.23), T_9, STL+ $ZnSO_4$ (75.00) and T_{10}, STCR+$ZnSO_4$ (90.43) were on par.

The total Na content (mg kg^{-1}) was lowest in T_6, STCR+FYM (2500.00) and T_9, STL+ $ZnSO_4$ (2500.00), while highest in T_7, FP+$ZnSO_4$ (8333.00). There was no significant difference among the treatments. The total Si content (mg kg^{-1}) varied from 3529.93 (T_9, STL+ $ZnSO_4$) to 13360.14 (T_4, STL).

4.4.2. Effect of treatments on plant nutrient content at panicle initiation stage of the crop

The details of total nutrient content in rice plants are presented in Table 16. The treatments differed significantly with respect to N, P, K, S, Na, Si, Zn, Cu, Mn, and B. No significant difference was shown by treatments with regards to Ca, Mg and Fe.

Among the major nutrients, the total N concentration (%) in rice plants ranged from 1.40 (T_1, control) to 2.52 (T_9, STL+$ZnSO_4$). There was significant difference among the treatments. The total P content (%) varied from 0.09 (T_1, control) to 0.17 (T_9, STL+$ZnSO_4$). The treatments T_2, FP (0.13), T_3, KAU (0.12), T_5, STCR (0.13), T_6, STCR+FYM (0.14), T_7, FP+ZnSO4 (0.12), T_9, STL+$ZnSO_4$ (0.17), T_{10}, STCR+$ZnSO_4$ (0.12) and T_{11}, STCR+$ZnSO_4$+FYM (0.13) were on par. Total potassium content (%) in the plant ranged between 1.51 (T_1, control) and 2.92 (T_9, STL+ $ZnSO_4$+FYM). The treatments T_3, KAU+FYM (2.21), T_5, STCR (2.71), T_6, STCR+FYM (2.91), T_9, STL+ $ZnSO_4$ (3.11), T_{10}, STCR+$ZnSO_4$ (2.43) and T_{11}, STCR+$ZnSO_4$+FYM (2.58) were on par.

Among secondary nutrients, total calcium content (mg kg^{-1}) was lowest in T_2, FP (2288.33) and highest in T_3, KAU (13993.30). There was no significant difference among the treatments. Total magnesium content (mg kg^{-1}) varied from 1573.00 (T_1, control) to 2648.00 (T_6, STCR+FYM). The treatments did not show any significant difference. The total S content (mg kg^{-1}) ranged from 3983.42 (T_2, FP) to 14698.85 (T_6, STCR+FYM). Treatments T_6, STCR+FYM (14698.85) and T_{10}, STCR+$ZnSO_4$ (11366.05) was on par.

Among micronutrients, the total Fe content (mg kg^{-1}) ranged from 986.50 (T_{10}, STCR+$ZnSO_4$) to 2717.66 (T_9, STL+$ZnSO_4$). The treatments did not differ significantly. Total Mn content (mg kg^{-1}) ranged from 335.50 (T_1, control) to 1236.83 (T_3, KAU). Treatments T_3, KAU (1236.83), T_5, STCR (745.33), T_6, STCR+FYM (742.25), T_7, FP+$ZnSO_4$ (732.75), T_{10}, STCR+$ZnSO_4$ (909.66) and T_{11}, STCR+$ZnSO_4$+FYM (728.16) were on par. The total Zn content (mg kg^{-1})

Table 16: Effect of treatments on plant nutrient content at panicle initiation stage of the crop.

Treatments	N (%)	P (%)	K (%)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	S ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	B ($mg\ kg^{-1}$)	Na ($mg\ kg^{-1}$)	Si ($mg\ kg^{-1}$)
T_1 control	1.40^{b}	0.09^{b}	1.51^{d}	3850.00^{a}	1573.00^{a}	5497.13^{bc}	2181.00^{a}	335.50^{b}	107.00^{b}	27.25^{ab}	48.97^{ab}	2500.00^{ab}	5861.08^{ab}
T_2 -Farmer's practice	2.47^{a}	0.13^{ab}	1.73^{cd}	2288.33^{a}	2443.00^{a}	3983.42^{c}	1090.16^{a}	595.50^{b}	109.66^{b}	26.66^{ab}	79.67^{a}	2916.66^{a}	6165.55^{ab}
T_3- KAU	2.19^{ab}	0.12^{ab}	2.21^{abcd}	3993.3^{a}	1616.00^{a}	5683.02^{bc}	1147.16^{a}	1236.83^{a}	451.66^{a}	32.33^{ab}	57.01^{ab}	2500.00^{ab}	3349.19^{b}
T_4-STL	1.54^{ab}	0.11^{b}	1.90^{bcd}	2800.00^{a}	2028.66^{a}	6081.36^{bc}	1087.83^{a}	418.66^{b}	86.66^{b}	20.66^{b}	76.02^{ab}	2083.33^{b}	6317.79^{ab}
T_5- STCR	2.14^{ab}	0.13^{ab}	2.71^{abc}	3116.66^{a}	2592.00^{a}	5523.68^{bc}	1148.00^{a}	745.33^{ab}	137.33^{b}	29.66^{ab}	39.47^{ab}	2500.00^{ab}	8449.09^{ab}
T_6- STCR+FYM	2.33^{ab}	0.14^{ab}	2.91^{ab}	3595.00^{a}	2648.00^{a}	14698.8^{a}	1065.25^{a}	742.25^{ab}	91.66^{b}	27.75^{ab}	38.74^{b}	2500.00^{ab}	8905.80^{a}
T_7- F.P + $ZnSO_4$	2.10^{ab}	0.12^{ab}	1.73^{cd}	3431.66^{a}	2619.00^{a}	5138.62^{bc}	2399.66^{a}	732.75^{ab}	127.66^{b}	37.50^{a}	56.28^{ab}	2916.66^{a}	7307.35^{ab}
T_8- KAU+ $ZnSO_4$	1.86^{ab}	0.11^{b}	1.95^{bcd}	3368.33^{a}	1931.00^{a}	4966.00^{bc}	1776.83^{a}	479.33^{b}	99.33^{b}	21.83^{b}	53.36^{ab}	2500.00^{ab}	6165.55^{ab}
T_9- STL+ $ZnSO_4$	2.52^{a}	0.17^{a}	3.11^{a}	3331.66^{a}	2319.33^{a}	5603.35^{bc}	2717.66^{a}	547.33^{b}	126.33^{b}	25.16^{ab}	62.86^{ab}	2500.00^{ab}	8677.45^{ab}
T_{10}- STCR+ $ZnSO_4$	2.33^{ab}	0.12^{ab}	2.43^{abcd}	3250.0^{a}	1981.66^{a}	11366^{ab}	986.50^{a}	909.66^{ab}	319.3^{ab}	29.00^{ab}	74.56^{ab}	2500.00^{ab}	7535.68^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	2.10^{ab}	0.13^{ab}	2.58^{abcd}	2751.66^{a}	2553.33^{a}	7321.51^{bc}	2138.00^{a}	728.16^{ab}	142.00^{b}	31.00^{ab}	4.20^{ab}	2500.00^{ab}	8677.45^{ab}
CD (0.05)	0.84	0.05	0.95	NS	NS	5731	NS	452.00	250.9	12.52	35.26	631.1	3351.00

ranged between 91.66 (T_6, STCR+FYM) and 451.67 (T_3, KAU). Treatments T_3, KAU (451.66) and T_{10}, STCR+$ZnSO_4$ (319.33) was on par. The total Cu content (mg kg^{-1}) ranged between 20.66 (T_4, STL) and 131.21 (T_3, KAU). The total B content (mg kg^{-1}) varied from 38.74 (T_6, STCR+FYM) to 79.67 (T_2, FP). Except T_6 (STCR+FYM) all the treatments were on par.

Total sodium content (mg kg^{-1}) ranged between 2083.33 (T_4, STL) and 2916.66 (T_2, FP and T_7, FP+ZnSO4). All the treatments were on par except T_4 (STL). The total Si content (mg kg^{-1}) ranged from 3349.19 (T_3, KAU) to 8905.80 (T_6, STCR+FYM). Except T_3 (KAU) all the treatments were on par.

4.4.3. Effect of treatments on plant nutrient content at flowering stage of the crop

The details of total nutrient content in rice plants are presented in Table 17. The treatments differed significantly with respect to N, P, K, Mg, S, Na, Si Cu and Fe. The treatments did not show significant difference with respect to Ca, Zn, Mn and B.

Among major nutrients, the total nitrogen content (%) ranged between 0.65 (T_4, STL) and 1.89 (T_9, STL+$ZnSO_4$). None of the treatments were on par. The total P content (%) ranged between 0.15 (T_{11}, STCR+FYM+$ZnSO_4$) and 0.47 (T_6, STCR+FYM). None of the treatments were on par. Total K content (%) was lowest in T_3, KAU (1.20) and highest in T_6, STCR+FYM (3.33) and the treatments differed significantly.

Regarding the secondary nutrients, total Ca content (mg kg^{-1}) ranged between 1510.00 (T_6, STCR+FYM) and 2248.33 (T_1, control). There was no significant difference among treatments. Total Mg content (mg kg^{-1}) ranged between 2375.00

Table 17: Effect of treatments on plant nutrient content at flowering stage of the crop.

Treatments	N (%)	P (%)	K (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	0.98^{b}	0.24^{b}	1.54^{b}	2248.33^{a}	2511.66^{ab}	6201.54^{b}	2730.66^{ab}	390.50^{a}	121.66^{a}	17.00^{b}	55.21^{a}	4666.66^{ab}	5328.25^{c}
T_2 -Farmer's practice	1.02^{b}	0.21^{b}	1.33^{b}	2333.33^{a}	2866.00^{ab}	10153.51^{ab}	1397.50^{b}	485.50^{a}	148.66^{a}	16.33^{b}	57.77^{a}	5000.00^{a}	4871.55^{c}
T_3- KAU	0.74^{b}	0.20^{b}	1.20^{b}	1786.66^{a}	2397.33^{b}	13193.493^{ab}	2721.00^{ab}	413.33^{a}	110.66^{a}	12.83^{b}	72.08^{a}	4000.00^{b}	1035.04^{a}
T_4-STL	0.65^{b}	0.19^{b}	1.16^{b}	2115.00^{a}	2417.00^{ab}	15321.47^{ab}	1740.50^{ab}	360.16^{a}	95.33^{a}	7.66^{b}	98.67^{a}	4000.00^{b}	6622.26^{abc}
T_5- STCR	1.02^{b}	0.24^{b}	1.58^{b}	2131.66^{a}	2942.66^{ab}	13740.69^{ab}	2947.50^{ab}	601.00^{a}	122.66^{a}	22.00^{b}	68.50^{a}	4666.66^{ab}	7078.97^{abc}
T_6- STCR+FYM	2.10^{a}	0.47^{a}	3.33^{a}	1510.00^{a}	2695.00^{ab}	13983.88^{ab}	1623.66^{ab}	489.16^{a}	83.00^{a}	15.25^{b}	81.28^{a}	4000.00^{b}	7535.37^{abc}
T_7- F.P + $ZnSO_4$	1.12^{b}	0.27^{b}	1.50^{b}	166.66^{a}	3062.00^{a}	6383.94^{b}	4306.83^{a}	548.66^{a}	149.66^{a}	18.16^{b}	67.48^{a}	5333.33^{a}	7424.54^{abc}
T_8- KAU+ $ZnSO_4$	0.74^{b}	0.21^{b}	1.54^{b}	1730.00^{a}	2375.00^{b}	6505.54^{b}	2194.16^{ab}	394.16^{a}	146.33^{a}	19.6^{b}	73.10^{a}	4666.66^{ab}	5480.49^{bc}
T_9- STL+ $ZnSO_4$	1.89^{a}	0.30^{b}	3.54^{a}	1546.66^{a}	2441.66^{ab}	18604.65^{a}	1350.66^{b}	387.66^{a}	95.33^{a}	13.50^{b}	80.77^{a}	4000.00^{b}	7307.32^{abc}
T_{10}- STCR+ $ZnSO_4$	1.02^{b}	0.16^{b}	1.37^{b}	2055.00^{a}	2745.33^{ab}	7903.93.^{ab}	2513.00^{ab}	589.33^{a}	113.66^{a}	17.66^{b}	74.64^{a}	4000.00^{b}	9279.87^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	0.70^{b}	0.15^{b}	1.33^{b}	1913.33^{a}	2799.33^{ab}	16415.86^{ab}	2694.83^{ab}	628.50^{a}	122.66^{a}	46.33^{a}	80.77^{a}	4000.00^{b}	9389.77^{a}
CD (0.05)	0.68	0.15	1.68	NS	563.4	9910	2415	NS	NS	23.33	NS	750.10	3388

(T_8, KAU+$ZnSO_4$) and 3062.00 (T_7, FP+$ZnSO_4$). Treatments T_1, control (2511.66), T_2, FP (2866.00), T_4, STL (2417.00) T_5, STCR (2942.66), T_6, STCR+FYM (2695.00), T_7, FP+$ZnSO_4$ (3062.00), T_9, STL+$ZnSO_4$ (2441.66) T_{10}, STCR+$ZnSO_4$ (2745.33) and T_{11}, STCR+$ZnSO_4$+FYM (2799.33) were on par. Total sulphur content (mg kg^{-1}) in rice plant was lowest in T_1, control (6201.54) and highest in T_9, STL+ $ZnSO_4$ (18604.654). Except T_1, control, T_7, FP+ZnSO4 and T_8, KAU+$ZnSO_4$ all the treatments were on par.

Total Fe content (mg kg^{-1}) ranged between 1350.66 (T9, STL+$ZnSO_4$) and 4306.83 (T_7, FP+ZnSO4). Except T_2, (FP) and T_9, STL+$ZnSO_4$ all the treatments were on par. The total Mn content (mg kg^{-1}) ranged between 363.16 (T_4, STL) and 628.50 (T_{11}, STCR+$ZnSO_4$+FYM). There was no significant difference among the treatments. In total Zn content (mg kg^{-1}), the highest and least value was obtained in T_7, FP+$ZnSO_4$ (149.67) and T_6, STCR+FYM (83.00) respectively. There was no significant difference among the treatments. Total Cu content (mg kg^{-1}) varied from 7.66 (T_4, STL) to 46.33 (T_{11}, STCR+FYM+$ZnSO_4$). Total B content (mg kg^{-1}) ranged between 55.21 (T_1, control) and 98.67 (T_4, STL). The B content however did not show any significant difference among treatments.

The sodium content (mg kg^{-1}) ranged from 4000.00 (T_3, KAU, T_4, STL, T_6, STCR+FYM, T_9, STL+$ZnSO_4$, T_{10}, STCR+$ZnSO_4$ and T_{11}, STCR+FYM+$ZnSO_4$) to 5333.33 (T_7, FP+ZnSO4). Treatments T_1, control (4666.66), T_2, FP (5000.00), T_5, STCR (4666.66), T_7, FP+$ZnSO_4$ (5333.33) and T_8, KAU+$ZnSO_4$ (4666.66) were on par. The total Si content (mg kg^{-1}) ranged between 4871.55 (T_2, FP) and 9389.77 (T_{11}, STCR+FYM+$ZnSO_4$). Treatment T_4, STL (6622.26), T_5, STCR (7078.97) T_6, STCR+FYM (7535.37), T_7, FP+$ZnSO_4$ (7424.54) T_9, STL+$ZnSO_4$ (7307.32) T_{10}, STCR+$ZnSO_4$ (9279.87) were on par.

4.4.4. Effect of treatments on plant nutrient content at harvest stage of the crop

The details of total nutrient content in rice plants are presented in Table 18. Treatments differed significantly with respect to N, P, Mg, S, Zn, Mn and Si. There was no significant difference among treatments with respect to K, Ca, Na, Fe, Cu and B.

Among the major nutrients, total nitrogen content (%) ranged from 0.46 (T_1, control) to 1.07 (T_7, FP+$ZnSO_4$). The treatments T_2, FP (0.65) T_3, KAU (0.79), T_5, STCR (0.88), T_6, STCR+FYM (0.84), T_7, FP+$ZnSO_4$ (1.07), T_9, STL+$ZnSO_4$ (0.88), T_{10}, STCR+$ZnSO_4$ (1.02) and T_{11}, STCR+$ZnSO_4$+FYM (0.93) were on par. The total P content (%) ranged between 0.1 (T_6, STCR+FYM) and 0.18 (T_{11}, STCR+$ZnSO_4$+FYM). There was significant difference among the treatments. All the treatments were on par except T_6, STCR+FYM and T_8, KAU+$ZnSO_4$. The total K content (%) was lowest in T_1, control (1.25) and T_2, FP (1.25) and highest in T_{10}, STCR+$ZnSO_4$ (1.70) and T_{11}, STCR+$ZnSO_4$+FYM (1.70). Treatments however did not differ significantly.

Among the secondary nutrients, total Ca content (mg kg^{-1}) ranged between 1696.66 (T_{10}, STCR+$ZnSO_4$) and 6776.66 (T_5, STCR). Treatments did not differ significantly. Total Mg content (mg kg^{-1}) was highest in T_9, STL+$ZnSO_4$ (2430.33) and lowest in T_4, STL (1459.00). Except T_4 (STL) all the treatments were on par. Total sulphur content (mg kg^{-1}) was highest in T_{11}, STCR+$ZnSO_4$+FYM (18604.65) which was on par with T_9, STL+$ZnSO_4$ (3997.34). The lowest value was obtained in T_7, FP+ZnSO4 (2217.79).

Among micronutrients, total Fe content (mg kg^{-1}) ranged between 2106 (T_9, STL+$ZnSO_4$) and 4458 (T_8, KAU+$ZnSO_4$). Total Mn content (mg kg-1) ranged between 352 (T_4, STL) and 538.67 (T_7, FP+$ZnSO_4$). Except T_1 (control), T_4 (STL) and T_{11} (STCR+$ZnSO_4$+FYM) all the treatments were on par. Total Zn content (mg kg^{-1}) varied between 111.33 (T_6, STCR+FYM) and 209.67 (T_7, FP+$ZnSO_4$). There exists significant difference among the treatments.

Table 18: Effect of treatments on plant nutrient content at harvest stage of the crop.

Treatments	N (%)	P (%)	K (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	0.46^{c}	0.16^{ab}	1.25^{a}	1825.00^{a}	1821.00^{ab}	2257.63^{b}	2616.33^{a}	357.16^{b}	126.33^{ab}	21.50^{a}	51.61^{a}	7500.00^{a}	5512.82^{a}
T_2 -Farmer's practice	0.65^{abc}	0.14^{abc}	1.25^{a}	1685.00^{a}	2099.00^{ab}	2616.20^{b}	3510.83^{a}	410.83^{ab}	142.33^{ab}	21.83^{a}	47.26^{a}	10208.33^{a}	1794.87^{ab}
T_3- KAU	0.79^{abc}	0.13^{abc}	1.54^{a}	2011.66^{a}	1800.33^{ab}	3579.01^{b}	2541.66^{a}	413.66^{ab}	181.00^{ab}	19.50^{a}	32.75^{a}	6250.00^{a}	2179.48^{ab}
T_4-STL	0.56^{bc}	0.12^{abc}	1.41^{a}	2323.33^{a}	1459.00^{b}	2722.44^{b}	3895.83^{a}	352.00^{b}	115.33^{b}	23.33^{a}	54.31^{a}	7500.00^{a}	512.82^{b}
T_5- STCR	0.88^{abc}	0.15^{abc}	1.66^{a}	6776.66^{a}	1844.33^{ab}	3539.17^{b}	2832.33^{a}	449.83^{ab}	134.00^{ab}	23.00^{a}	49.33^{a}	5833.33^{a}	2307.69^{ab}
T_6- STCR+FYM	0.84^{abc}	0.10^{c}	1.41^{a}	2125.00^{a}	2076.66^{ab}	3054.44^{b}	3292.00^{a}	470.33^{ab}	111.33^{b}	17.66^{a}	37.72^{a}	7291.66^{a}	2435.89^{ab}
T_7- F.P + $ZnSO_4$	1.07^{a}	0.14^{abc}	1.37^{a}	3010.00^{a}	2401.33^{a}	2217.79^{b}	3364.50^{a}	538.66^{a}	209.66^{a}	17.25^{a}	53.89^{a}	6041.66^{a}	2692.30^{ab}
T_8- KAU+ $ZnSO_4$	0.51^{c}	0.10^{bc}	1.41^{a}	3734.16^{a}	2079.66^{ab}	2954.84^{b}	4458.00^{a}	371.00^{ab}	166.66^{ab}	19.66^{a}	42.28^{a}	7500.00^{a}	769.23^{b}
T_9- STL+ $ZnSO_4$	0.88^{abc}	0.12^{abc}	1.37^{a}	3731.66^{a}	2430.33^{a}	3997.34^{ab}	2446.00^{a}	453.66^{ab}	142.33^{ab}	16.33^{a}	70.89^{a}	4583.33^{a}	1666.66^{ab}
T_{10}- STCR+ $ZnSO_4$	1.02^{ab}	0.16^{a}	1.70^{a}	1696.66^{a}	1994.66^{ab}	3034.52^{b}	2106.00^{a}	419.16^{ab}	126.33^{ab}	17.16^{a}	44.77^{a}	9583.33^{a}	1794.87^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	0.93^{abc}	0.18^{a}	1.70^{a}	2133.33^{a}	2087.33^{ab}	9395.74^{a}	2664.66^{a}	363.50^{b}	156.33^{ab}	34.00^{a}	81.67^{a}	6458.33^{a}	2051.28^{ab}
CD (0.05)	0.42	0.05	NS	NS	747.6	5480	NS	148.2	79.70	NS	NS	NS	3939

All the treatments were on par except T_4 (STL) and T_6 (STCR+FYM). The total Cu content (mg kg^{-1}) ranged from 17.16 (T_{10}, STCR+$ZnSO_4$) to 77.16 (T_7, FP+ZnSO4). Total B content (mg kg^{-1}) was lowest in T_3, KAU (32.75) and highest in T_{11}, STCR+$ZnSO_4$+FYM (81.67). The content of plant Cu, Fe, and B did not differ significantly among the treatments.

The total sodium content (mg kg^{-1}) was highest in T_2, FP (10208.33) and lowest in T_9, STL+$ZnSO_4$ (4583.33). There was no significant difference among the treatments. The total Si content (mg kg^{-1}) was lowest in T_4, STL (512.82) and highest in T_1, control (5512.82). Except T_4 (STL) and T_8 (KAU+$ZnSO_4$) all the treatments were on par.

4.4.5. Effect of treatments on nutrient content of grain at harvest stage of the crop

The details of total nutrient content in rice grain are presented in Table 19. It showed that the content of N, K, Ca, Na, Si, Fe, Mn, Cu and B differed significantly among treatments. The treatments did not differ significantly with respect to P, Mg, S, Fe, and Zn.

The total N concentration (%) was highest in T_7, FP+$ZnSO_4$ (1.55) and lowest in T_6, STCR+FYM (1.04). Treatments T_1, control (1.21), T_2, FP (1.21), T_3, KAU (1.45), T_5, STCR (1.25), T_7, FP+$ZnSO_4$ (1.55), T_8, KAU+$ZnSO_4$ (1.25), T_9, STL+$ZnSO_4$ (1.31) and T_{11}, STCR+$ZnSO_4$+FYM (1.31) were on par. Total P concentration (%) was highest in T_7, FP+ZnSO4 (0.28) and the lowest in T_{10}, STCR+$ZnSO_4$ (0.19). There was no significant difference among the treatments. Total K content (%) ranged from 0.27 (T_1, control) to 0.50 (T_3, KAU). Treatments T_2, FP (0.41), T_3, KAU (0.50), T_4, STL (0.43) and T_{10}, STCR+$ZnSO_4$ (0.37) were on par.

Regarding secondary nutrients, total Ca content (mg kg^{-1}) varied from 4489.58 (T_7, FP+$ZnSO_4$) to 17427.08 (T_4, STL). There was significant difference among the treatments. All the treatments were on par except T_3 (KAU) and T_7 (FP+$ZnSO_4$). Total Mg content (mg kg^{-1}) varied from 1314.95 (T_5, STCR) to

Table 19: Effect of treatment on grain nutrient content at harvest stage of the crop.

Treatments	N (%)	P (%)	K (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Na (mg kg^{-1})	Si (mg kg^{-1})
T_1 control	1.21^{abc}	0.23^{a}	0.27^{c}	6781.25^{ab}	1329.20^{a}	1329.20^{a}	398.83^{a}	77.50^{c}	140.71^{a}	12.66^{ab}	356.55^{c}	666.66^{ab}	3974.35^{ab}
T_2 -Farmer's practice	1.21^{abc}	0.23^{a}	0.41^{abc}	7061.66^{ab}	1740.18^{a}	1740.18^{a}	487.10^{a}	134.66^{ab}	273.63^{a}	38.83^{a}	547.26^{abc}	1333.33^{ab}	1923.07^{ab}
T_3- KAU	1.45^{ab}	0.23^{a}	0.50^{a}	4625.00^{b}	1357.33^{a}	1357.33^{a}	403.83^{a}	96.66^{bc}	153.16^{a}	12.00^{ab}	559.70^{abc}	433.33^{b}	2820.51^{ab}
T_4-STL	1.08^{bc}	0.21^{a}	0.43^{ab}	17427.08^{a}	1316.63^{a}	1316.63^{a}	684.50^{a}	93.83^{bc}	149.96^{a}	7.33^{b}	555.55^{abc}	933.33^{ab}	2051.28^{ab}
T_5- STCR	1.25^{abc}	0.23^{a}	0.31^{bc}	7562.50^{ab}	1314.95^{a}	1314.95^{a}	494.83^{a}	96.66^{bc}	127.73^{a}	7.16^{b}	563.85^{abc}	766.66^{ab}	1666.66^{ab}
T_6- STCR+FYM	1.04^{c}	0.24^{a}	0.29^{bc}	8989.58^{ab}	1682.61^{a}	1682.61^{a}	543.00^{a}	111.83^{abc}	125.51^{a}	8.33^{ab}	485.07^{abc}	900.00^{ab}	5512.82^{a}
T_7- F.P + $ZnSO_4$	1.55^{a}	0.28^{a}	0.29^{bc}	4489.58^{b}	1362.03^{a}	1362.03^{a}	311.75^{a}	100.00^{bc}	115.33^{a}	15.33^{ab}	522.38^{abc}	1800.00^{a}	2820.51^{ab}
T_8- KAU+ $ZnSO_4$	1.25^{abc}	0.25^{a}	0.29^{bc}	7875.00^{ab}	1435.00^{a}	1435.00^{a}	855.50^{a}	82.33^{c}	127.51^{a}	10.33^{ab}	447.76^{bc}	933.33^{ab}	2435.89^{ab}
T_9- STL+ $ZnSO_4$	1.31^{abc}	0.26^{a}	0.29^{bc}	8479.16^{ab}	1443.80^{a}	1443.81^{a}	529.33^{a}	102.83^{bc}	123.48^{a}	9.00^{ab}	493.36^{abc}	1033.33^{ab}	769.23^{b}
T_{10}- STCR+ $ZnSO_4$	1.15^{bc}	0.19^{a}	0.37^{abc}	9479.16^{ab}	1658.96^{a}	1658.96^{a}	506.83a	126.83^{abc}	235.80^{a}	10.5^{ab}	692.37^{a}	1166.66^{ab}	2564.10^{ab}
T_{11}-STCR+ $ZnSO_4$+FYM	1.31^{abc}	0.27^{a}	0.33^{bc}	6916.66^{ab}	1651.36^{a}	1651.36^{a}	530.50^{a}	158.33^{a}	133.23^{a}	8.83^{ab}	617.74^{ab}	1533.33^{ab}	2500.00^{ab}
CD (0.05)	0.34	NS	0.14	9631.00	NS	NS	NS	43.22	NS	26.7	202.8	1049	4032

1740.18 (T_2, FP). Total S content (mg kg^{-1}) ranged between 1314.95 (T_5, STCR) and 1682.61 (T_6, STCR+FYM). The content of Mg and S in grain did not show any significant difference among treatments.

Among micronutrients, the total Fe content (mg kg^{-1}) was highest in T_{11}, STCR+$ZnSO_4$+FYM (530.50) and lowest in T_7, FP+ZnSO4 (311.75). The total manganese content (mg kg^{-1}) varied between 77.50 (T_1, control) and 158.33 (T_{11}, STCR+FYM+$ZnSO_4$). Treatments T_2, FP (134.66), T_6, STCR+FYM (111.83), T_{10}, STCR+$ZnSO_4$ (126.83) and T_{11}, STCR+$ZnSO_4$+FYM (158.33) were on par. Total Zn content (mg kg^{-1}) ranged between 115.33 (T_7, FP+ZnSO4) and 273.63 (T_2, FP). Zinc content however did not show any significant difference among the treatments. The total Cu content (mg kg^{-1}) ranged from 7.16 (T_5, STCR) to 38.83 (T_2, FP). There was significant difference among the treatments. All the treatments were on par except T_4 (STL) and T_5 (STCR). The boron content (mg kg^{-1}) was highest in T_{10}, STCR+$ZnSO_4$ (692.37 mg kg^{-1}) and lowest in T_1, control (356.55 mg kg^{-1}). There existed significant difference among the treatments. The treatments were on par except T_1, control and T_8, KAU+$ZnSO_4$.

The highest grain sodium content (mg kg^{-1}) was found to be in T_7, FP+$ZnSO_4$ (1800.00) and the lowest in T_3, KAU (433.33). All treatments were on par except T_3 (KAU).The total grain Si content (mg kg^{-1}) ranged between 769.23 (T_9, STL+$ZnSO_4$) and 5512.82 (T_6, STCR+FYM). All the treatments were on par except T_9 (STL+$ZnSO_4$).

4.5. Nutrient uptake

4.5.1. Effect of treatments on the nutrient uptake of crop

Effect of treatment on nutrient uptake of crop is shown in Table 20.

Among the major nutrients, the total uptake of N (kg ha^{-1}) was highest in T_7, FP+$ZnSO_4$ (149.40) and lowest in T_8, KAU+$ZnSO_4$ (75.54). The treatments T_2, FP (120.50), T_3, KAU (131.99), T_4, STL (99.95), T_6, STCR+FYM (118.21),

Table 20: Effect of treatments on the nutrient uptake of crop.

Treatments	N Kg/ha	P Kg/ha	K Kg/ha	Ca Kg/ha	Mg Kg/ha	S Kg/ha	Fe Kg/ha	Mn Kg/ha	Zn Kg/ha	Cu Kg/ha	B Kg/ha	Na Kg/ha	Si Kg/ha
T_1 control	80.32^{c}	19.43^{bcd}	80.20^{c}	38.05^{b}	15.19^{cd}	17.48^{d}	14.23^{c}	2.26^{bc}	1.28^{b}	0.16^{ab}	8.23^{cde}	43.57^{ab}	42.22^{ab}
T_2 -Farmer's practice	120.50^{abc}	24.38^{ab}	115.66^{abc}	54.23^{ab}	25.70^{a}	29.42^{abcd}	48.77^{a}	3.78^{abc}	2.73^{a}	0.40^{ab}	14.07^{a}	81.91^{a}	24.47^{ab}
T_3- KAU	131.99^{ab}	22.61^{ab}	141.61^{ab}	39.31^{b}	19.81^{abc}	31.98^{abc}	19.15^{c}	3.55^{abc}	2.07^{ab}	$0..19^{ab}$	9.35^{bcde}	51.1^{ab}	27.17^{ab}
T_4-STL	99.95^{abc}	20.48^{abc}	123.39^{abc}	110.30^{a}	18.51^{bc}	26.07^{abcd}	35.71^{abc}	3.17^{abc}	1.60^{b}	0.20^{ab}	11.12^{abcd}	56.25^{ab}	14.28^{b}
T_5- STCR	83.67^{bc}	15.20^{cd}	92.00^{bc}	55.90^{ab}	12.21^{d}	21.23^{cd}	14.65^{c}	2.48^{bc}	1.07^{b}	0.14^{b}	6.40^{e}	30.09^{b}	17.25^{b}
T_6- STCR+FYM	118.21^{abc}	19.84^{bcd}	123.35^{abc}	61.51^{ab}	24.44^{ab}	31.84^{abc}	28.59^{abc}	4.23^{a}	1.48^{b}	0.18^{ab}	11.39^{abc}	60.08^{ab}	46.99^{a}
T_7- F.P + $ZnSO_4$	149.40^{a}	23.47^{ab}	113^{abc}	41.62^{b}	23.96^{ab}	22.68^{bcd}	24.94^{bc}	4.44^{a}	2.06^{ab}	0.65^{a}	10.09^{abcde}	52.29^{ab}	31.69^{ab}
T_8- KAU+ $ZnSO_4$	75.54^{c}	14.95^{cd}	80.93^{c}	48.40^{b}	16.01^{cd}	20.16^{cd}	23.66^{bc}	2.11^{c}	1.33^{b}	0.13^{b}	7.88^{cde}	41.29^{ab}	13.44^{b}
T_9- STL+ $ZnSO_4$	135.25^{a}	23.23^{ab}	116.37^{abc}	72.19^{ab}	25.49^{a}	36.35^{a}	20.76^{bc}	3.88^{ab}	1.70^{b}	0.16^{ab}	12.9^{ab}	39.27^{ab}	17.14^{b}
T_{10}- STCR+ $ZnSO_4$	81.86^{bc}	13.52^{d}	93.83^{abc}	39.29^{b}	14.52^{cd}	19.44^{cd}	14.44^{c}	2.41^{bc}	1.32^{b}	0.11^{b}	6.92^{de}	51.40^{ab}	16.37^{b}
T_{11}-STCR+ $ZnSO_4$+FYM	133.10^{ab}	26.91^{a}	142.69^{a}	49.69^{ab}	23.12^{ab}	35.36^{ab}	44.18^{ab}	3.43^{abc}	1.78^{ab}	0.27^{ab}	13.98^{a}	53.85^{ab}	27.87^{ab}
CD (0.05)	45.30	6.03	43.51	54.60	5.57	11.95	21.32	1.48	0.92	0.44	3.92	40.46	25.45

T_7, FP+$ZnSO_4$ (149.40), T_9, STL+$ZnSO_4$ (135.25) and T_{11}, STCR+$ZnSO_4$+FYM (133.10) were on par. Total uptake of P (kg ha^{-1}) ranged between 13.52 (T_{10}, STCR+$ZnSO_4$) and 26.91 (T_{11}, STCR+$ZnSO_4$+FYM). There was significant difference among the treatments. The treatments T_2, FP+FYM, T_3, KAU, T_4, STL, T_7, FP+$ZnSO_4$, T_9, STL+$ZnSO_4$ and T_{11}, STCR+$ZnSO_4$+FYM were on par. Total K uptake (kg ha^{-1}) was highest in T_{11}, STCR+$ZnSO_4$+FYM (142.69) and lowest in T_1, control (80.20). There was significant difference among the treatments except T_1, control and T_8, KAU+$ZnSO_4$.

Among the secondary nutrients total uptake (kg ha^{-1}) of Ca ranged between 38.05 (T_1, control) and 110.30 (T_4, STL). All the treatments were on par except T_3, KAU and T_{10}, STCR+$ZnSO_4$. Total Mg uptake (kg ha^{-1}) varied from 12.21 (T_5, STCR) to 25.70 (T_2, FP). The treatments T_2, FP (25.70), T_3, KAU (19.81), T_6, STCR+FYM (24.44), T_7, FP+$ZnSO_4$ (23.96), T_9, STL+$ZnSO_4$ (25.49) and T_{11}, STCR+$ZnSO_4$+FYM (23.12) were on par. The highest total S uptake (kg ha^{-1}) was obtained in T_9, STL+$ZnSO_4$ (36.35) and the lowest in T_1, control (17.48). The treatments T_2 (FP), T_3 (KAU), T_4 (STL), T_6 (STCR+FYM), T_9 (STL+$ZnSO_4$) and T_{11} (STCR+$ZnSO_4$+FYM) were on par.

Among the micronutrients, the total Fe uptake (kg ha^{-1}) was highest in T_2, FP (48.77) and lowest in T_1, control (14.23). Treatments T_2, FP (48.77), T_4, STL (35.71), T_6, STCR+FYM (28.59) and T_{11}, STCR+FYM+$ZnSO_4$ (44.18) were on par. Total Mn uptake (kg ha^{-1}) ranged between 2.11 (T_8, KAU+$ZnSO_4$) and 4.44 (T_7, FP+$ZnSO_4$). All the treatments were on par except T_1 (control), T_5 (STCR), T_8 (KAU+$ZnSO_4$) and T_{10} (STCR+$ZnSO_4$). Total uptake of Zn (kg ha^{-1}) ranged between 1.28 (T_1, control) and 2.73 (T_2, FP). There was significant difference among the treatments. The treatments T_2 (FP), T_3 (KAU), T_7 (FP+$ZnSO_4$) and T_{11} (STCR+FYM+$ZnSO_4$) were on par. Total Cu uptake (kg ha^{-1}) was highest in T_7, FP+ZnSO4+FYM (0.65) and lowest in T_{10}, STCR+$ZnSO_4$ (0.11). All the other treatments were on par except T_5 (STCR), T_8 (KAU+$ZnSO_4$) and T_{10} (STCR+$ZnSO_4$). The total uptake of B (kg ha^{-1}) ranged from 6.40 (T_5, STCR) to 14.07 (T_2, FP). Treatments T_2, FP+FYM (14.07), T_4, STL (11.12), T_6,

STCR+FYM (11.39), T_7, FP+$ZnSO_4$ (10.09), T_9 STL+$ZnSO_4$+FYM (12.90) and T_{11}, STCR+$ZnSO_4$+FYM (13.98) were on par.

The total Na uptake (kg ha^{-1}) ranged from 30.09 (T_5, STCR) to 81.91 (T_2, FP+FYM). All the treatments were on par except T_5, STCR. The total Si uptake (kg ha^{-1}) ranged between 13.44 (T_8, KAU+$ZnSO_4$) and 46.99 (T_6, STCR+FYM). There was significant difference among the treatments. The treatments T_1 (control), T_2 (FP+FYM), T_3 (KAU), T_6 (STCR+FYM), T_7 (FP+$ZnSO_4$) and T_{11} (STCR+$ZnSO_4$+FYM) were on par.

4.6. Correlation studies

The simple correlations between yield contributing factors and grain and straw yield were worked out based on the data obtained for the different treatments.

4.6.1. Relationship of soil nutrients at different stages of crop growth with grain and straw yield

The correlations of various soil nutrients in the maximum tillering stage, panicle initiation stage, flowering stage and harvest with the grain and straw yield were worked out. The results were presented in Table 21, 22, 23 and 24 respectively. The contents of available nutrients during the maximum tillering and panicle

Table 21: Correlation coefficient of soil nutrients with yield at maximum tillering stage

	Available nutrients at maximum tillering stage														
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		.338	**.358(*)**	.110	.019	.152	.183	.185	-.031	-.028	.239	.122	**.361(*)**	-.227	-.114
P			.115	**.437(*)**	-.073	.012	-.284	.004	.103	.203	**.381(*)**	.327	.082	.193	-.022
K				.237	-.101	-.064	-.142	-.086	.171	-.011	.300	-.061	.193	.105	.221
Ca					.095	-.237	-.117	.127	.225	.134	.147	.116	.142	-.115	-.115
Mg						-.316	-.110	.341	.032	.073	.109	.255	.093	-.088	-.089
S							.253	-.141	-.136	**-.409(*)**	-.065	-.117	.029	-.048	-.163
Na								.118	-.222	-.002	-.018	-.296	-.203	-.030	.108
B									-.016	.160	.013	.137	-.056	-.338	-.311
Zn										**.535(**)**	**.438(*)**	**.414(*)**	-.032	-.077	-.007
Cu											**.503(**)**	**.571(**)**	-.073	.007	.034
Mn												.342	-.006	.055	.014
Fe													-.016	.032	.032
Si														-.251	-.252

Table22: Correlation coefficient of soil nutrients with yield at panicle initiation stage

	Available nutrients at panicle initiation stage														
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		.168	.209	-.161	-.184	.311	-.327	.218	.152	-.120	**-.353(*)**	-.321	.049	.140	-.066
P			.314	-.234	-.062	-.002	-.134	-.006	-.141	.001	-.073	-.017	-.242	.227	.115
K				-.070	.181	**.385(*)**	-.212	-.127	-.168	**-.392(*)**	-.324	**-.450(**)**	-.175	-.147	-.092
Ca					**.440(*)**	-.298	**.397(*)**	.046	-.213	**-.362(*)**	.010	-.086	-.193	.097	.085
Mg						.051	.260	-.173	-.128	-.202	-.112	-.123	-.070	.032	.141
S							-.257	-.063	.118	.068	-.068	-.131	.005	-.227	-.236
Na								.323	.129	.107	.315	.329	**-.385(*)**	.064	-.086
B									-.020	-.046	-.037	-.064	.114	.016	-.239
Zn										**.623(**)**	**.569(**)**	**.625(**)**	-.257	-.071	.049
Cu											**.522(**)**	**.778(**)**	-.159	-.078	.024
Mn												**.877(**)**	-.110	-.033	.052
Fe													-.215	.077	.165
Si														-.071	-.021

**Correlation is significant at 0.01 level (2-tailed); *Correlation is significant at 0.05 level

Table 23: Correlation coefficient of soil nutrients with yield at flowering stage

		Available nutrients at flowering stage													
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		.068	.148	.280	.046	.159	-.121	.013	-.181	.218	.192	.113	-.252	-.195	-.228
P			.077	-.062	-.222	.204	-.173	.118	-.060	.072	.017	.001	.189	-.293	.069
K				-.117	.038	.043	.136	-.031	-.091	-.070	-.045	-.082	.044	**-.472(**)**	-.202
Ca					**-.520(**)**	-.096	-.240	-.029	-.136	.070	.205	.167	.039	-.073	-.259
Mg						.097	**.459(**)**	.012	-.090	.011	-.209	-.188	.052	-.064	-.127
S							-.017	-.271	.022	.082	.022	.068	-.017	.136	**.351(*)**
Na								-.264	.148	-.095	.023	-.015	.048	-.231	-.240
B									-.063	.250	-.246	-.254	.121	-.067	-.133
Zn										.284	-.061	-.097	.057	-.070	.039
Cu											**-.377(*)**	**-.538(**)**	.242	.011	-.004
Mn												**.935(**)**	-.180	.114	.116
Fe													-.168	.102	.146
Si														-.163	.116

Table 24: Correlation coefficient of soil nutrients with yield at harvest stage

		Available nutrients at harvest stage													
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		.053	-.028	.111	.312	**.388(*)**	.206	-.231	.127	**.581(**)**	.252	.172	.011	-.204	-.286
P			-.150	.166	**-.368(*)**	-.081	.107	.246	-.030	-.184	.198	.033	.069	.182	.044
K				-.170	.216	-.006	.199	-.063	.167	-.047	-.184	-.120	-.007	-.087	.190
Ca					.097	.137	.171	.232	-.312	.235	.168	.198	.052	-.202	-.249
Mg						-.269	.253	.064	.291	**.439(*)**	-.080	-.301	-.084	-.143	-.290
S							.039	-.041	-.228	.106	.236	**.384(*)**	-.054	-.178	.070
Na								.182	-.111	.021	-.042	.026	.051	.040	-.058
B									.043	-.067	.319	-.310	-.248	.136	.225
Zn										.322	**.374(*)**	**-.666(**)**	-.133	.218	.226
Cu											**.542(**)**	-.069	-.032	-.096	-.136
Mn												-.241	.014	.035	.082
Fe													.254	-.142	-.176
Si														**-.378(*)**	-.143

**Correlation is significant at 0.01 level (2-tailed) ; *Correlation is significant at 0.05 level

initiation had no correlation with either grain or straw yield. Negative and significant correlation was observed between available K (r= -0.472) content at the flowering stage of the crop and grain yield. While, a positive and significant correlation was observed between available S at flowering stage and straw yield (r=0.351). During the harvest stage of the crop, a negative and significant correlation was observed between available Si (r= -0.378) content and grain yield.

Inter correlation among the different available soil nutrients were also studied. At maximum tillering stage, positive and significant correlation was observed between N and K (r= 0.358), N and Si (r=0.361), P and Ca(r=0.437), P and Mn (r= 0.381), Zn and Cu (r= 0.535), Zn and Mn (r= 0.438), Zn and Fe (r =0.414), Cu and Mn (r =0.503), Cu and Fe (r =0.571). A negative and significant correlation was seen between S and Cu (r = -0.409). The positive and significant correlations among available nutrients at panicle initiation stage are between K and S (r= 0.385), Ca and Mg (r= 0.440), Ca and Na (r= 0.397), Zn and Cu (r= 0.623), Zn and Mn (r= 0.569), Zn and Fe (r= 0.625), Cu and Mn (r= 0.522), Cu and Fe (r= 0.778), Mn and Fe (r= 0.877). The negative and significant correlation were between N and Mn (r= -0.353), K and Cu (r= -0.392), K and Fe (r= -0.450), Ca and Cu (r= -0.362) and between Na and Si (r= -0.385).

At the flowering stage positive and significant correlation was observed between Mg and Na (r = 0.459) and between Mn and Fe (r= 0.935), while negative and significant correlation was seen between Ca and Mg (r= -0.520), Cu and Mn (r=-0.377) and between Cu and Fe (r= -0.538). During the harvest stage, the inter relation among available nutrient was found to be positive and significant between N and S (r= 0.388), N and Cu (r= 0.581), Mg and Cu (r= 0.439), S and Fe (r= 0.384), Zn and Mn (r= 0.374) and between Cu and Mn (r= 0.542). However, negative and significant correlation was observed between P and Mg (r= -0.368) and between Zn and Fe (r= 0 .666).

4.6.2. Relationship of biometric parameters at different stages of crop growth with grain and straw yield

The correlations between biometric parameters like plant height, number of leaves and number of tillers with yield was worked out at different stages of crop growth viz. maximum tillering stage, panicle initiation stage, flowering stage and harvest stage. The observations are provided in Table 25, 26, 27 and 28. None of the parameters were significantly correlated either with grain or straw yield.

Inter correlation study among the biometric parameter revealed that number of leaves was positively and significantly correlated with number of tillers during all the four stages of crop growth. While plant height was positively and significantly correlated with number of leaves at maximum tillering (r= 0.382) and panicle initiation stage (r= 0.351). A positive and significant correlation was also observed between plant height and number of tillers at panicle initiation stage (r= 0.371). Number of leaves and number of tillers were positively and significantly correlated during flowering (r= 0.858) and harvest stages (r= 0.680).

Table 25: Correlation coefficient between biometric parameters and yield at maximum tillering stage

	Plant height	Number of leaves	Number of tillers	Grain yield	Straw yield
Plant height		.381(*)	.248	-.034	.166
Number of leaves			.714(**)	-.205	-.139
Number of tillers				-.126	-.006

Table 26: Correlation coefficient between biometric parameters and yield at panicle initiation stage

	Plant height	Number of leaves	Number of tillers	Grain yield	Straw yield
Plant height		.351(*)	.371(*)	-.156	-.010
Number of leaves			.692(**)	-.042	.170
Number of tillers				-.256	-.067

Table 27: Correlation coefficient between biometric parameters and yield at flowering stage

	Plant height	Number of leaves	Number of tillers	Grain yield	Straw yield
Plant height		.155	.083	-.261	.226
Number of leaves			.858(**)	-.101	.131
Number of tillers				-.083	.170

Table 28: Correlation coefficient between biometric parameters and yield at harvest stage

	Plant height	Number of leaves	Number of tillers	Grain yield	Straw yield
Plant height		-.016	.047	-.112	-.057
Number of leaves			.680(**)	.082	.144
Number of tillers				-.113	-.156

**Correlation is significant at 0.01 level (2-tailed) ; *Correlation is significant at 0.05 level

4.6.3. Relationship of plant nutrients at different stages of crop growth with grain and straw yield

The correlations of various plant nutrients on grain and straw yield was worked out at different stages of the crop growth viz. maximum tillering stage, panicle initiation stage, flowering stage and harvest stage. The results are presented in Table 29, 30, 31 and 32. The plant nutrients during the maximum tillering and panicle initiation stages of crop growth had no significant correlation with either grain or straw yield. There was no significant correlation between grain yield and plant nutrient content at the flowering stage. However, a positive and significant correlation was observed between straw yield with plant Mg content (r= 0.465) and S content (r= 0.515). During the harvest stage, there was no significant correlation between plant nutrient content either with grain or straw yield.

Inter correlations among the different plant nutrients were also studied at different stages of plant growth. At maximum tillering stage, the positive and significant correlation was seen between N and P (r= 0.417), N and K (r= 0.415), N and Ca (r= 0.368), K and Ca (r= 0.364), S and Zn (r= 0.544) and between Cu and Si (r= 0.665) and between S and Mn (r= 0.409), while negative and significant correlation was observed between N and B (r= -0.389), N and Fe (r= -0.503), P and Fe (r= -0.402), P and Si (r= -0.352) Ca and S (r= -0.414) and between Ca and Fe (r= -0.497). At panicle initiation stage, the positive and significant correlation were observed between N and P (r= 0.772), N and K (r= 0.664), N and Mn (r= 0.360) P and K (r= 0.865), K and S (r= 0.381), Ca and Zn (r= 0.571), Ca and Cu (r= 0.696), Ca and Mn (r= 0.640), Zn and Cu (r= 0.581), Zn and Mn (r= 0.853) and between Cu and Mn (r= 0.626). The negative and significant correlations were between Mg and Zn (r= -0.476), Zn and Fe (r= -0.360) and between Cu and Si (r= -0.382).

The positive and significant correlations during flowering stage among the plant nutrients were found between N and P (r= 0.839), N and K (r= 0.883), P and

Table 29: Correlation coefficient of plant nutrients with yield at maximum tillering stage

		Plant nutrients at maximum tillering stage												
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		**.417(*)**	**.415(*)**	**.368(*)**	.150	-.196	-.163	**-.389(*)**	-.065	-.102	-.007	**-.503(**)**	-.187	-.002	.266
P			.261	.312	.068	-.261	.029	-.279	-.191	-.252	-.161	**-.402(*)**	**-.352(*)**	.103	.159
K				**.364(*)**	.202	-.128	-.108	-.301	-.190	-.155	.277	-.168	-.341	-.127	.089
Ca					.290	**-.414(*)**	.234	-.218	-.256	-.101	-.046	**-.497(**)**	-.072	-.115	.148
Mg						-.204	-.103	-.333	-.221	.080	-.034	.002	.122	.001	-.084
S							-.145	-.002	**.544(**)**	-.039	**.409(*)**	.320	-.168	.239	.274
Na								.290	-.022	-.015	-.085	.112	-.139	-.119	-.095
B									.005	.141	-.224	.293	.105	-.276	-.210
Zn										.267	-.018	.255	.087	.151	.184
Cu											-.078	.037	**.665(**)**	.259	.227
Mn												.088	-.157	.110	.167
Fe													-.125	-.015	-.059
Si														.027	-.083

Table 30: Correlation coefficient of plant nutrients with yield at panicle initiation stage

		Plant nutrients at panicle initiation stage												
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		**.772(**)**	**.664(**)**	.114	.195	.285	.051	.201	.297	.059	**.360(*)**	-.263	.110	.084	.223
P			**.865(**)**	.083	.254	.268	-.033	.082	.034	.018	.144	.012	.019	.219	.206
K				.006	.286	**.381(*)**	-.217	-.140	.065	-.004	.193	-.003	.136	-.072	.106
Ca					-.193	-.009	-.031	-.008	**.571(**)**	**.696(**)**	**.640(**)**	-.216	-.164	.065	-.119
Mg						.181	.103	-.310	**-.476(**)**	-.160	-.039	.337	.253	.057	.157
S							-.130	-.082	-.042	-.085	.082	-.029	.170	-.138	.044
Na								.002	-.023	.001	.041	-.051	-.157	.083	.167
B									.257	-.052	.105	-.176	-.065	.122	.028
Zn										**.581(**)**	**.853(**)**	**-.360(*)**	-.055	-.160	-.018
Cu											**.626(**)**	-.047	**-.382(*)**	.134	.164
Mn												-.246	.046	-.125	.011
Fe													.199	.053	.080
Si														-.162	.009

**Correlation is significant at 0.01 level (2-tailed) ; *Correlation is significant at 0.05 level

Table 31: Correlation coefficient of plant nutrients with yield at flowering stage

	Plant nutrients at flowering stage														
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		.839(**)	.883(**)	-.166	.079	.207	-.095	.191	-.116	-.069	.071	-.048	.328	.119	.143
P			.820(**)	-.093	.167	.090	.065	.213	-.002	-.082	.117	.107	.237	.148	.162
K				-.128	.029	.296	-.145	.167	-.081	-.053	.040	-.058	.198	.129	.138
Ca					.600(**)	-.343	.313	-.304	.537(**)	.180	.269	.165	-.084	-.069	-.260
Mg						.465(**)	-.170	.606(**)	.406(*)	.625(**)	.535(**)	.145	-.148	.012	.465(**)
S							-.414(*)	.239	-.105	.269	.062	.019	-.124	.226	.515(**)
Na								-.334	.498(**)	.011	.125	.331	-.238	-.139	-.235
B									-.235	-.013	-.058	.181	.009	.133	.242
Zn										.424(*)	.338	.598(**)	-.153	-.105	-.015
Cu											.357(*)	.447(**)	-.038	-.175	-.038
Mn												.463(**)	.415(*)	-.295	-.071
Fe													-.026	-.272	.075
Si														-.299	-.026

Table 32: Correlation coefficient of plant nutrients with yield at harvest stage

	Plant nutrients at harvest stage														
	N	P	K	Ca	Mg	S	Na	B	Zn	Cu	Mn	Fe	Si	Grain yield	Straw yield
N		.475(**)	.573(**)	-.010	-.027	.161	-.237	.208	.104	-.135	.322	-.133	.046	-.119	.222
P			.431(*)	-.105	-.369(*)	-.020	-.216	.414(*)	-.112	.009	-.171	-.366(*)	-.071	-.163	.053
K				.035	-.249	.030	.033	.065	.080	-.237	-.038	-.348(*)	-.094	-.339	-.035
Ca					.138	.119	-.152	-.077	.027	-.030	.090	.193	-.032	-.220	-.241
Mg						.277	.162	.016	.044	.145	.563(**)	.125	-.127	.082	.059
S							-.086	.058	-.018	-.069	.105	-.072	-.128	-.045	-.117
Na								-.433(*)	.182	.110	.022	.032	.060	-.074	-.049
B									-.259	-.005	-.129	-.173	-.093	.079	.098
Zn										.610(**)	-.098	.084	.247	-.025	.032
Cu											-.078	.091	.014	-.065	.105
Mn												-.087	-.119	.052	.262
Fe													.200	.114	-.022
Si														-.140	-.207

**Correlation is significant at 0.01 level (2-tailed) ; *Correlation is significant at 0.05 level

K (r= 0.820), Ca and Mg (r= 0.600), Ca and Zn (r= 0.537), Mg and S (r= 0.465), Mg and B (r= 0.606) Mg and Zn (r= 0.406), Mg and Cu (r= 0.625), Mg and Mn (r= 0.535), Na and Zn (r= 0.498), Zn and Cu (r= 0.424), Zn and Fe(r= 0.598), Cu and Fe (r= 0.447), Mn and Fe (r= 0.463) and between Mn and Si (r= 0.415). There was no significant negative correlation between plant nutrient content and yield at flowering stage. At the harvest stage, positive and significant correlations among nutrients between N and P (r= 0.475), N and K (r= 0.573), P and K (r= 0.431), P and B (r= 0.414), Mg and Mn (r= 0.563) and between Zn and Cu (r= 0.610). Significant and negative correlation was observed between P and Mg (r= -0.369), P and Fe (r= -0.366), K and Fe (r= -0.348) and between Na and B (r= -0.433)

4.6.4. Correlation between nutrient uptake and grain yield.

Simple correlation coefficients were worked out between nutrient uptake and the grain and straw yield of rice and are presented in Table 33.

The N, P, K, Mg, S, Fe, Mn, Zn and B uptake were significantly and positively correlated with both grain and straw yields. Sodium content was positively and significantly correlated with straw yield (r= 0.418). The correlations of nutrient uptake with grain yield were of the order B (r= 0.709), P (r= 0.665), Mg (r= 0.643), Zn (r= 0.593), Mn (r= 0.522), S (r= 0.517), N (r= 0.510) and K (r= 0.502). Regarding the straw yield, the order observed was K (r= 0.815), Mn (r= 0.777), P (r= 0.725), N (r= 0.708), Mg (r= 0.645), B (r= 0.585) and S (r= 0.527).

Table 33: Correlation coefficient between nutrient uptake and yield.

	Total nutrient uptake (Grain + Straw)														
	N	P	K	Ca	Mg	S	Na	B	Fe	Cu	Zn	Mn	Si	Grain yield	Straw yield
N		.800(**)	.747(**)	.115	.454(**)	.479(**)	.186	.499(**)	.331	.095	.473(**)	.674(**)	.095	.510(**)	.708(**)
P			.697(**)	.230	.492(**)	.553(**)	.193	.687(**)	.457(**)	.271	.553(**)	.539(**)	.129	.665(**)	.725(**)
K				.202	.400(*)	.405(*)	.301	.495(**)	.359(*)	.001	.380(*)	.594(**)	.045	.502(**)	.815(**)
Ca					.240	.254	.024	.341	.436(*)	-.129	-.053	.203	-.042	.302	.335
Mg						.622(**)	.391(*)	.634(**)	.489(**)	.343	.458(**)	.764(**)	.157	.643(**)	.645(**)
S							.181	.580(**)	.280	.129	.339	.492(**)	.003	.517(**)	.527(**)
Na								.185	.328	.354(*)	.531(**)	.298	.098	.297	.418(*)
B									.523(**)	.224	.469(**)	.434(*)	.155	.709(**)	.585(**)
Fe										.260	.411(*)	.299	-.001	.531(**)	.478(**)
Cu											.565(**)	.137	.021	.162	.247
Zn												.332	.050	.593(**)	.471(**)
Mn													.238	.522(**)	.777(**)
Si														.117	.181

**Correlation is significant at 0.01 level (2-tailed) ; *Correlation is significant at 0.05 level

4.6.5. Correlation of soil Ca and Na content with uptake of major nutrients.

The correlation of soil content of Ca and Mg with uptake of major nutrients was worked out. The results are presented in Table 34. It was found that the content of Ca and K were significantly and negatively correlated with the uptake of N (r= -0.380*) and K (r= -0.362*) at the panicle initiation stage. While, the soil content of Na was significantly and negatively correlated with the uptake of K (r= -0.365) at panicle initiation stage and uptake of P (r= -0.328) at harvest stage.

4.6.6. Correlation between nutrient content of grain and yield.

The correlations of nutrient of grain on yield were worked out. The results were presented in Table 35. There was no significant correlation between the grain nutrient content and yield. However, a negative and significant correlation was observed between B (r= -0.392) and grain yield. A positive and significant correlation was observed between B (r= 0.361) and Fe (r= 0.422) with straw yield.

Inter correlations between nutrient contents of grain were also studied. Positive and significant correlation existed between N and P (r= 0.559), P and Na (r= 0.358), K and Zn (r= 0.389), Mg and S (r= 0.996), Mg and Cu (r= 0.635), Mg and Zn (r= 0.587), S and Cu (r= 0.634), S and Zn (r= 0.584), Na and Fe (r= 0.357), Na and Mn (r= 0.386), Fe and Mn (r= 0.739), Cu and Zn (r= 0.697). No negative correlations were observed between the grain nutrient contents.

Table 34: Correlation coefficient of soil Ca and Na content with uptake of major nutrients

Critical growth stages	Nutrients	N	P	K
Maximum tillering	Ca	-0.055	-0.052	-0.067
	Na	-0.207	-0.222	-0.269
Panicle initiation	Ca	**-0.380***	-0.316	**-0.362***
	Na	-0.203	-0.157	**-0.365***
Flowering	Ca	0.110	0.212	0.097
	Na	-0.039	0.046	0.038
Harvest	Ca	-0.261	-0.133	-0.143
	Na	-0.139	**-0.349***	-0.244

Table 35: Correlation between nutrient content of grain and yield.

	Grain nutrient content														
	N	P	K	Ca	Mg	S	Na	B	Fe	Cu	Zn	Mn	Si	Grain yield	Straw yield
N		**.559(**)**	-.036	-.275	-.119	-.123	.255	-.084	.038	.104	.114	.195	-.266	.031	.136
P			-.289	-.101	.180	.162	**.358(*)**	-.323	.109	.103	.023	.154	-.051	.158	.008
K				.057	.134	.142	-.096	.090	-.017	.296	**.389(*)**	.091	.092	.321	.198
Ca					-.038	-.020	.062	.195	-.065	-.049	.021	.044	-.049	.066	.131
Mg						**.996(**)**	.264	.027	.217	**.635(**)**	**.587(**)**	.192	.040	.112	-.069
S							.248	.044	.205	**.634(**)**	**.584(**)**	.178	.025	.114	-.047
Na								.125	**.357(*)**	.063	.028	**.386(*)**	.045	.027	.067
B									.274	-.159	-.063	.284	-.260	-.162	.153
Fe										-.015	-.015	**.739(**)**	-.132	.176	.107
Cu											**.697(**)**	.009	-.015	.294	.014
Zn												-.022	.014	.136	-.062
Mn													-.003	.140	.228
Si														-.022	.077

**Correlation is significant at 0.01 level (2-tailed) ; *Correlation is significant at 0.05 level

4.7. Grain and straw yield.

The straw and grain yield were measured after harvest and the weights of grain and straw were reported in Table 36.

The grain yield (kg ha^{-1}) varied from 2911 (T_{10}, STCR+$ZnSO_4$) to 6033 (T_2, FP). Regarding straw, the highest yield was obtained in T_6, STCR+FYM (7711) and lowest in T_{10}, STCR+$ZnSO_4$ (4811). There was significant difference among the treatments. The treatment T_2, FP (7245), T_3, KAU (7512), T_4, STL (7188), T_6, STCR+FYM (7710), T_7, FP+$ZnSO_4$ (7277), T_9, STL+$ZnSO_4$ (7310) and T_{11}, STCR+FYM+$ZnSO_4$ (7377) were on par.

4.8. Yield prediction

The yield prediction equation based on the nutrient content of soil, plant and yield attributes are presented in Table 37, 38 and 39.

Stepwise regression was carried out to find the key soil nutrients which influence the grain and straw yield at critical growth stages. It was found that grain yield was influenced by nutrients namely N, K, Mg, Na, Cu and Fe at the maximum tillering stage. The straw yield was influenced by S alone. At the panicle initiation stage, N, P, K, Ca, Mg. B, Mn and Fe were the major nutrients influencing straw yield, whereas, N, P, Ca, Na, Zn and Fe were major nutrients influencing straw yield. At the flowering stage Mg and Na was influencing grain yield while, non of the nutrients influenced straw yield. At the harvest stage, grain yield was influenced by N, K and Si while, straw yield was influenced by Na.

Table 36: Effect of treatments on grain and straw yield

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)
T_1 control	4322^{ef}	5222^{bc}
T_2 -Farmer's practice	6032^{a}	7245^{ab}
T_3- KAU	5121^{bc}	7512^{ab}
T_4-STL	5377^{b}	7188^{ab}
T_5- STCR	3111^{g}	4855^{c}
T_6- STCR+FYM	5021^{bcd}	7710^{a}
T_7- F.P + $ZnSO_4$	4555^{de}	7277^{ab}
T_8- KAU+ $ZnSO_4$	4000^{f}	4832^{c}
T_9- STL+ $ZnSO_4$	5333^{b}	7310^{ab}
T_{10}- STCR+ $ZnSO_4$	2910^{g}	4811^{c}
T_{11}-STCR+ $ZnSO_4$+FYM	4777^{cde}	7377^{ab}
CD (0.05)	465	2032

Table 37: Yield prediction equation based on available soil nutrients

Growth stage	Maximum tillering stage	
Dependent variable	Regression equation	
Grain yield	Y= 6342.56-816.18N*+637.67K**-1471.13Mg*-902.55Na*+40.19Cu*-0.193Fe*	(r=0.499)
Straw yield	Y= 5877.29+0.025S*	(r=0.159)
Growth stage	Panicle initiation stage	
Dependent variable	Regression equation	
Grain yield	Y= 7970.22-1412.67N*+38684.06P**-1179.14K*-1043.33Ca*-7555.70Mg*-2.34B**+1.67Mn*-2.29Fe	
Straw yield	Y= 2391.49-2354.45N**+39066.88P**-970.71Ca+17889.75Na**+4.376Zn*-0.56Fe*	(r=0.464)
Growth stage	Flowering stage	
Dependent variable	Regression equation	
Grain yield	Y= 3689.87-8453.17Mg+7180.57Na**	(r=0.180)
Straw yield	No significance	
Growth stage	Harvest stage	
Dependent variable	Regression equation	
Grain yield	Y= 2975.19-1454.02N*+1690.52K*+1320.88Si	(r=0.233)
Straw yield	Y= 5251.97+1723.51Na*	(r=0.136)

**Significant at 0.01 level

* Significant at 0.05 level

Table 38: Yield prediction equation based on plant nutrient content

Growth stage	Maximum tillering stage	
Dependent variable	Regression equation	
Grain yield	Y= 6938.87+3.60N*-8.81K-16.20Na-45.89Zn	(r= 0.237)
Straw yield	No significance	
Growth stage	Panicle initiation stage	
Dependent variable	Regression equation	
Grain yield	No significance	
Straw yield	No significance	
Growth stage	Flowering stage	
Dependent variable	Regression equation	
Grain yield	Y= 5991.30+6.90N*-263.32Cu*-2.05Fe*	(r= 0.255)
Straw yield	No significance	
Growth stage	Harvest stage	
Dependent variable	Regression equation	
Grain yield	Y= 4907.79+0.746Ca-8.90S*-19.60Si*	(r= 0.270)
Straw yield	Y= 8920.44-16.91S*	(r=0.170)

** Significant at 0.01 level

* Significant at 0.05 level

Stepwise regression was carried out to find the key plant nutrients which influence the grain and straw yield at critical growth stages. It was found that at maximum tillering stage grain yield was influenced by plant content of N, K, Na and Zn. The straw yield was however not influenced by any of the plant nutrients at this stage. Both grain as well as straw yield was found not to be influenced by any of the plant nutrient content at panicle initiation stage. At flowering stage, the grain yield was influenced by N, Cu and Fe content in plant. None of the plant nutrients were found to significantly influence the straw yield at flowering stage. The grain yield was influenced by Ca, S and Si while straw yield was found to be influenced by S alone.

Stepwise regression was carried out to find the influence of biometric parameters viz, height of plant, number of leaves and number of tillers per hill on grain as well as straw yield. The straw and grain yield was found to be influenced by height of plant, number of leaves and number of tillers per hill at maximum tillering and panicle initiation stage respectively. There was however no significant influence observed on either grain or straw yield by any of the biometric paramaters at flowering and harvest stage.

Table 39: Yield prediction equation based on based on biometric parameters

Growth stage	Maximum tillering stage
Dependent variable	Regression equation
Grain yield	No significance
Straw yield	Y= -1343.72+23.76Height of plant*+88.33no of leaves*+48.27no of tillers* (R=0.285)
Growth stage	Panicle initiation stage
Dependent variable	Regression equation
Grain yield	Y= 1580.44+1.92height of plant*+5.16no of leaves*+133.92no of tillers* (R=.247)
Straw yield	No significance
Growth stage	Flowering stage
Dependent variable	Regression equation
Grain yield	No significance
Straw yield	No significance
Growth stage	Harvest stage
Dependent variable	Regression equation
Grain yield	No significance
Straw yield	No significance

** Significant at 0.01 level

* Significant at 0.05 level

4.9. Economic analysis

The economic analysis for the different treatments was shown in Table-40. The highest benefit cost ratio was obtained in T_1, control (1.97) followed by T_2, FP (1.88), whereas, the lowest was obtained in T_{10}, STCR+$ZnSO_4$ (0.59).

Table 40: Economic analysis

	EXPENDITURE (Rs)				(Rs)				Total Profit (Rs)	
Treatments	Fertilizer Cost	Seed Cost	Labour Cost	Total expenditure (C)	Grain Yield	Profit from Grain	Straw Yield	Profit from Straw	(B)	B/C
T1(Control)	0	1750	36877.5	38627.5	4322.02	60508.28	5222.82	15668.46	76176.74	1.97
T2(FP+FYM)	8415.75	1750	46282.50	56448.25	6032.93	84461.02	7245.34	21736.02	106197.00	1.88
T3(KAU+FYM)	9705.31	1750	42075	53530.31	5121.82	71705.48	7512.11	22536.33	94241.81	1.76
T4(STL+FYM)	9866.36	1750	42075	53691.36	5377.81	752893	7188.78	21566.34	96855.68	1.80
T5(STCR)	10568.41	1750	42075	54393.41	3111.21	43556.94	4855.65	14566.95	58123.89	1.07
T6(STCR+FYM)	14703.19	1750	42075	58528.19	5021.28	70297.92	7710.81	23132.43	93430.35	1.60
T7(FP+ZnSO4+FYM)	49028.25	1750.00	46282.50	97060.75	4555.85	63781.90	7277.87	21833.61	85615.51	0.88
T8(KAU+ZnSO4+FYM)	48380.75	1750	42075	92205.75	4000	56000	4832.83	14498.49	70498.49	0.76
T9(STL+ZnSO4+FYM)	48541.80	1750	42075	92366.8	5333.13	74663.82	7310.71	21932.13	96595.95	1.05
T10(STCR+ZnSO4)	49243.64	1750	42075	93068.64	2910.91	40752.74	4811.21	14433.63	55186.37	0.59
T11(STCR+ZnSO4+FYM)	53378.62	1750	42075	97203.62	4777.87	66890.18	7377.67	22133.01	89023.19	0.92

Discussion

5. DISCUSSION

5.1. Initial physico-chemical properties

The pH of the soil was near neutral (6.4) and EC was $0.1 dSm^{-1}$. The comparatively higher content of Na and Ca in the soil has already been reported (Krishnakumar and Koshy 1986; Bridgit 1999). The organic carbon content of the soil was medium (0.74%). Considering the major nutrients, the available N (310.5 kg ha^{-1}) and K (154.36 kg ha^{-1}) was medium, while available P content was low (5.67 kg ha^{-1}). The earlier study conducted by Narayanan, *et al* (2008) had reported that a medium status of available P in the soils of eastern region of Palakad. The same study indicated low levels of available potassium in the above region. The available basic cations viz Ca, Mg and Na were found to be higher in these soils compared to laterites and kole lands. The content of B (0.20 mg kg^{-1}) was found to be deficient, whereas that of Zn (0.90 mg kg^{-1}) was adequate and that of Fe (333.73 mg kg^{-1}) was toxic. The initial status of Fe was more than that of the laterite paddy soils. Similar observations were reported by Bridgit, (1999).

5.2. Effect of treatments on soil properties at critical growth stages.

Among the major nutrients, the available P reduced upto the flowering stage whereas, the available N reduced from maximum tillering stage to panicle initiation stage. This might be due to the uptake corresponding to the high initial vegetative growth during these stages. The content of K reduced at the harvest stage and this might be coinciding with the high uptake during the grain filling stage. There was clear cut difference in the content of available K in STCR treatments during all the critical growth stages. This might be due to the high levels of application of inorganic fertilizers to the STCR treatments. Tandon and Sekhon (1988) related the build up of K in soils as due to the direct addition of K to the available pool of the soil. Among the STCR treatments irrespective of addition of zinc sulphate, it was found that application of FYM increased available K status in the soil (Tables -1, 2 and 4).

The content of available Ca was the highest both among secondary nutrients as well as basic cations (Figure- 1, 4 and7). The values for the available cations generally decreased in the order Ca>Mg>K>Na. The content of Ca in the soil gradually increased from maximum tillering stage to flowering stage and thereafter it decreased towards the harvest irrespective of the treatments. The increase may be due to the low uptake during the initial growth phases along with the release from the native soil deposits. And the decrease in the availability after flowering upto harvest may be due to the uptake at the reproductive or the maturity phase of the crop. The content of Mg remained almost steady throughout the critical growth stages upto flowering and thereafter there was a decrease for all the treatments. The requirement of Mg by the crop from the flowering to harvest might have resulted in the decrease in the content between flowering to harvest stages.

Among micronutrients, the available soil content decreased in the order Fe>Mn> B. The contents of Zn and Cu remained in between Mn and B and occasionally they varied without any uniformity. The available Fe content was found to continuously decrease with the advancement of growth of the crop until harvest (Figure- 2, 5 and 8). During maximum tillering stage , the available Fe content was above the toxic level (619.24 to 944.70 mg kg^{-1}). Such a high content of Fe at critical stages may lead to reduction in growth and yield of crop (Saerayossakul, 1968). The same trend was observed at panicle initiation stage except for treatments T_3 (KAU), T_6 (STCR+FYM) and T_{10} (STCR+$ZnSO_4$). It was found that, those treatments in which zinc was applied showed higher content compared to those in which zinc was not applied. Irrespective of the treatments, the zinc level of the soil remained above the critical level (0.6 mg kg^{-1}).

5.3. Effect of treatments on biometric parameters

The maximum plant height and number of tillers per plant at maximum tillering and panicle initiation stages were recorded for T11 (STCR+$ZnSO_4$ along with FYM 5 t ha^{-1}). Application of adequate nutrients promoted the supply of assimilates from source to sink which would have resulted in increased plant height and number of tillers per hill (Singh and Mandal 1997). The total dry matter yield was highest (12.2 t/ha) in the treatment T11 (STCR+ZnSO4+FYM @ 5t/ha). Yadav and Kumar (2009) also reported that substitution of 50% N through FYM and sesbania green manuring to rice gave equal or more yield than 100% NPK fertilizers alone. Combined application of urea and FYM showed superiority over recommended fertilizer application as reported by Chaudhury and Thakur (2007).

5.4. Effect of treatments on nutrient content of plant at critical stages of crop growth.

Plant samples were collected and analysed for the contents of N, P, K, Ca, Mg, S, micronutrients, Fe, Mn, Zn, Cu B, Na and Si at maximum tillering, panicle initiation, flowering and harvest stages. At maximum tillering stage, the content of major nutrients were of the order N>K>P, but with succeeding growth stages the trend became K>N>P. This may be due to transition from the vegetative stage to the reproductive and harvest stage. A general comparison between T_5 (STCR) with T_6 (STCR+FYM) and T_{10} (STCR+$ZnSO_4$) with T_{11} (STCR+FYM+ $ZnSO_4$) revealed that, the addition of FYM increased the content of major nutrients. In the case of secondary nutrients, a competitive trend was observed between Ca and Mg. The growth stages where plant content of Ca was high viz. panicle initiation and harvest stage, the content of Mg was particularly lower. Similar competitive trend was observed at the maximum tillering and flowering stages where Mg content was higher, while Ca was lower (Figure- 10, 11 and 12). Throughout the growth stages from maximum tillering to harvest (Figure- 11, 14 and 17), the content of Fe remained very high and it was always above the critical level in plants. Due to the high content of the element in the soil, rice plants absorbed very large amount of Fe (Anon., 1994). The content of Na was almost equal or even greater than Ca throughout all the growth stages. During the panicle initiation, flowering and harvest stages the content of Na remained higher than Mg. In all the treatments it was found that the soil Si content was less in these rice soils compared to laterite and Kole lands (Bridgit 1999). This might have resulted in the low Si content in plants (Figure- 12, 15 and 18). This points to the need of silica application to these black soils.

5.5. Nutrient uptake

Application of FYM with fertilizers significantly increased the NPK uptake by the crop than application of fertilizers alone or in combination with zinc sulphate. This can also be attributed to increased efficiency of fertilizers in the presence of FYM resulting in increased uptake (Dwivedi and Thakur 2000). Total N, P, K and Ca uptake in plants increased with the age of the plant. Similar observation was reported by Sarkar and Debnath (1996). The uptake of P was found to be highest for T11 (STCR+$ZnSO_4$ + FYM 5 t ha^{-1}). But if we compare the amount of fertilizers applied to each treatment (Table-4) the percentage of uptake was highest for the farmer's practice. This might be due to application of soluble ammonium phosphate through factomphos as source of P in this treatment.

All the treatements resulted in the high uptake of Na [30.09 (T5, STCR) to 81.91 (T_2, farmer's practice)]. When the different treatments were compared it was found that the uptake of Na was higher than Ca and Mg and at times it was almost equal to K uptake. This may be due to higher content of Na in soil throughout the growth stages.

Among the micronutrients, the uptake was of the order Fe>Mn>Zn>Cu>B. The Fe uptake was found to be the highest. This might be due to high Fe content of the soil during the initial phases of crop growth. Boron, though deficient in the soil was found to be taken up by the crop in adequate amounts. This probably may be attributed to supply of B through FYM in adequate amount for the crop. The Si uptake was found to be less (Figure-20). Though the rice crop is a heavy accumulator of Si, the low soil content might be responsible for the low uptake here. Silicon in plant protects the crop from insect attack. Further, Si is important for maintaining the leaf erect and decrease susceptibility to lodging. In general, the crop was affected mainly by pests like rice stem borer and rice leaf roller, which might be attributed to the low soil Si availability and consequent low uptake.

5.6 Correlation

Correlation between available nutrient status in soil and plant with yield during different growth stages were worked out. For the active growth period of the crop, no significant correlation was obtained. However, during harvest stage when the uptake of the nutrients by the crop was correlated with soil nutrients, significant correlations were obtained. It was observed that presence high quantities of basic cations like Ca and Na in soil during the initial stages like maximum tillering, panicle initiation and flowering has caused the hindrance in the uptake of major nutrients like N, P and K (Figure- 19). In case of Ca, negative and significant correlation was observed with uptake of N ($r= -0.380$) and K ($r= -0.362$) during panicle initiation stage. The high soil Na content has hindered the uptake of K ($r= -0.365$*) at panicle initiation stage while, at harvest stage uptake of P ($r= 0.349$*) was hindered.

Fig1. Available Ca, Mg and Na status at maximum tillering stage

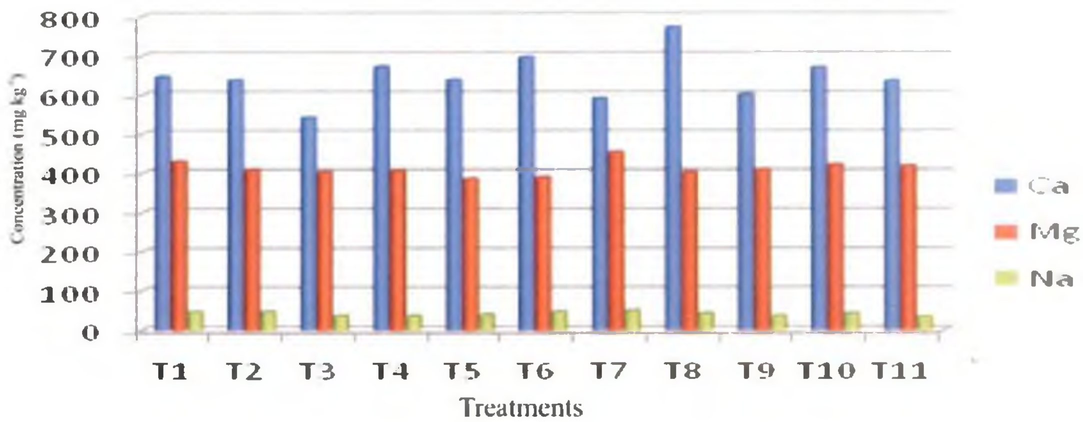


Fig2. Available Fe status at maximum tillering stage

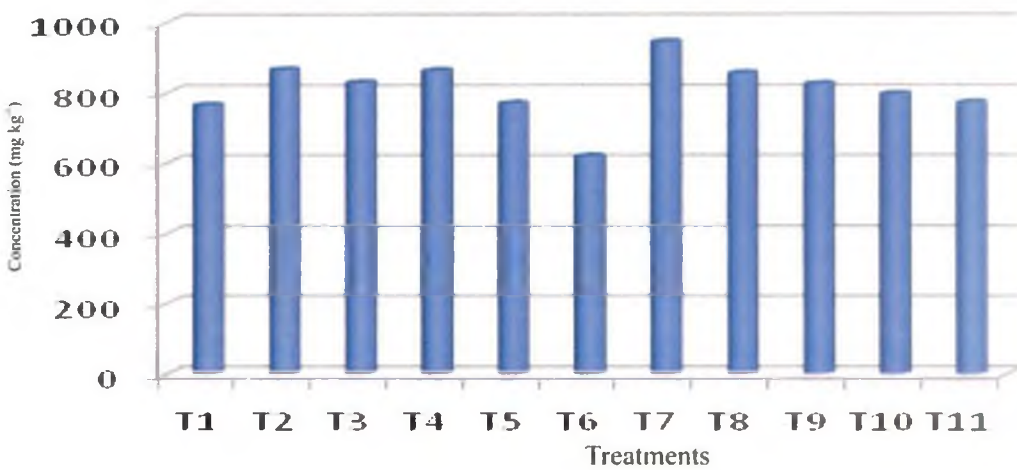
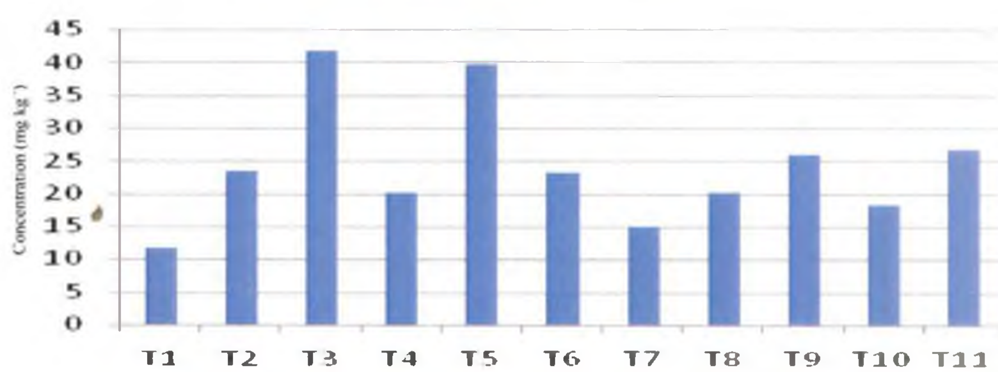


Fig3. Available Silicon status at maximum tillering stage



T_1= Absolute control
T_2= Farmers practice
T_3= KAU recommendation
T_4= STL recommendation
T_5= STCR recommendation
T_6= STCR+FYM @ 5 t ha^{-1}
T_7= T2+ $ZnSO_4$ @ 25 kg ha^{-1}
T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}
T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Fig4. Available Calcium Magnesium and Sodium status at maximum tillering stage

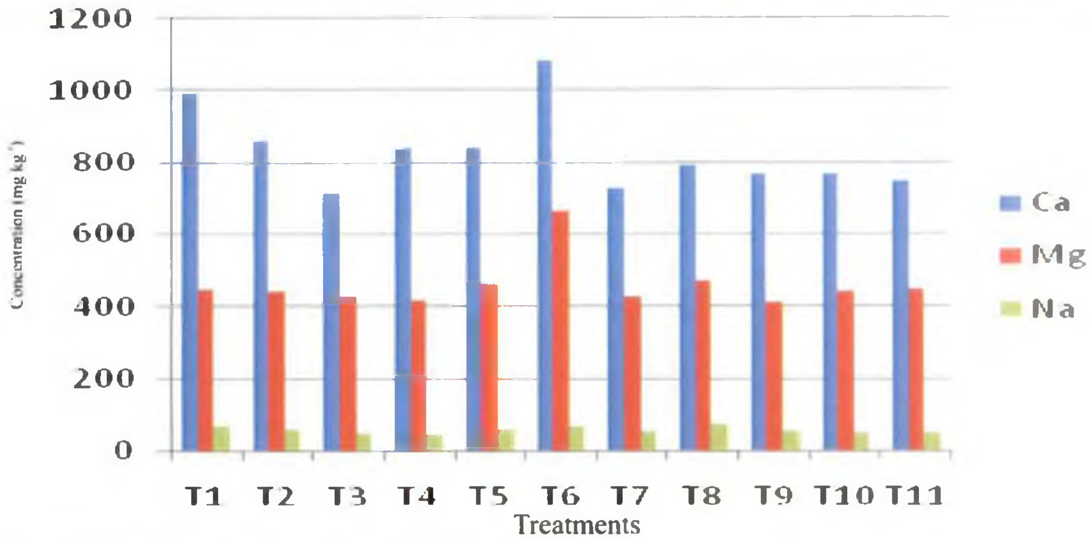


Fig5. Available Iron status at panicle initiation stage

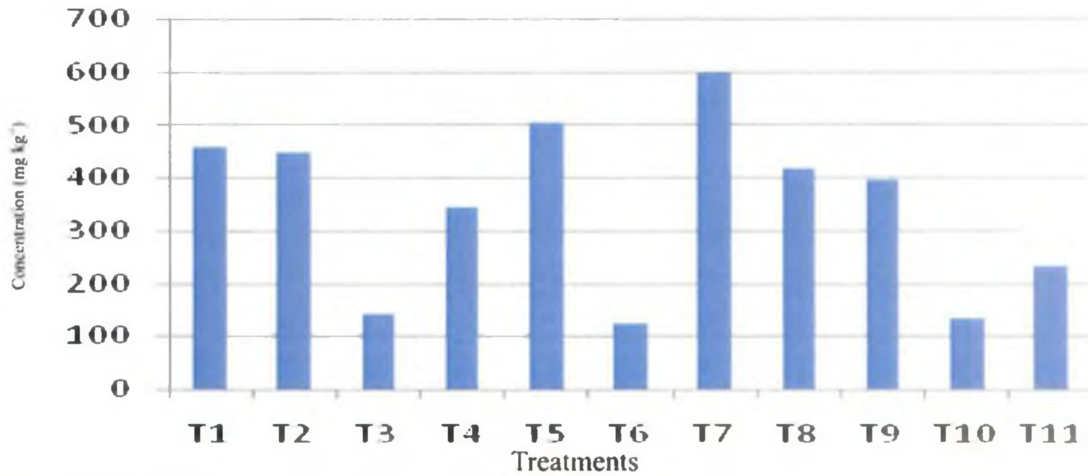
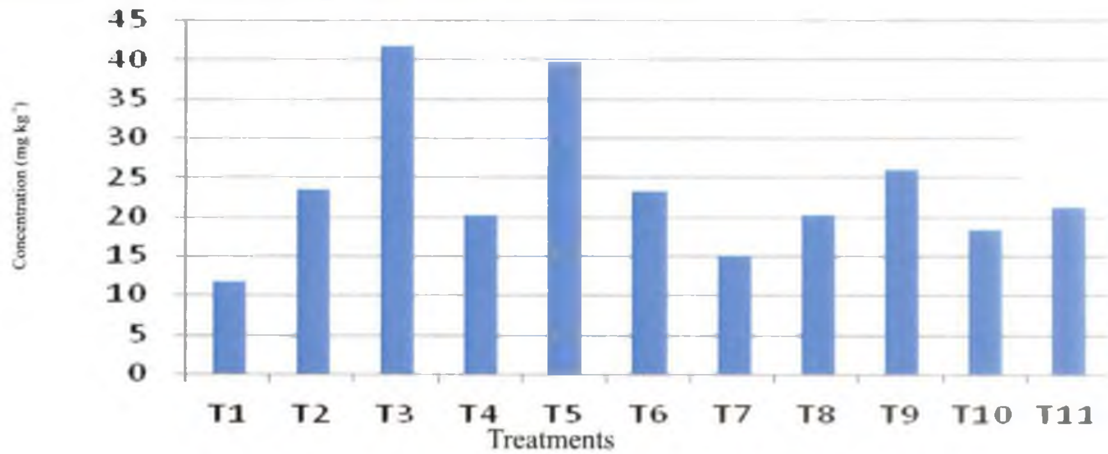


Fig6. Available Silicon status at panicle initiation stage



T_1= Absolute control
T_2= Farmers practice
T_3= KAU recommendation
T_4= STL recommendation
T_5= STCR recommendation
T_6= STCR+FYM @ 5 t ha^{-1}
T_7= T2+ $ZnSO_4$ @ 25 kg ha^{-1}
T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}
T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Fig7. Available Calcium, Magnesium and Sodium staus at flowering stage

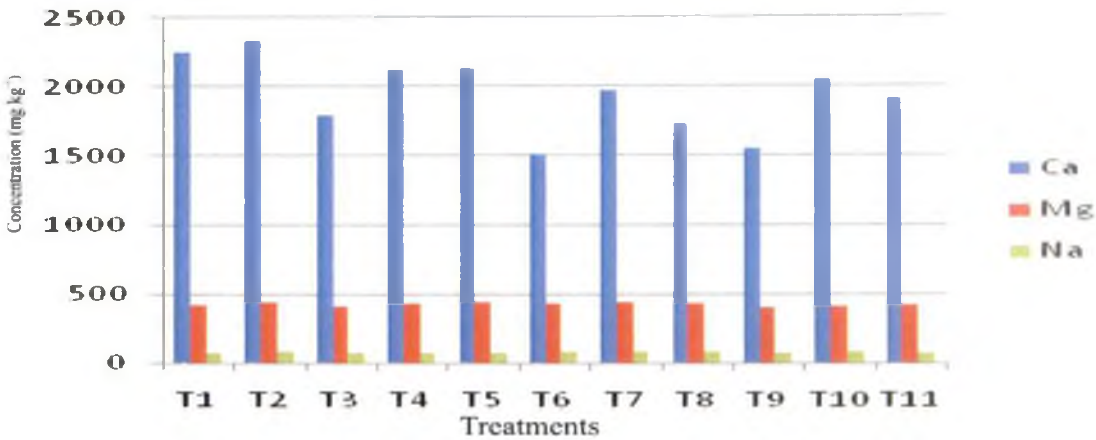


Fig8. Available Iron status at flowering stage

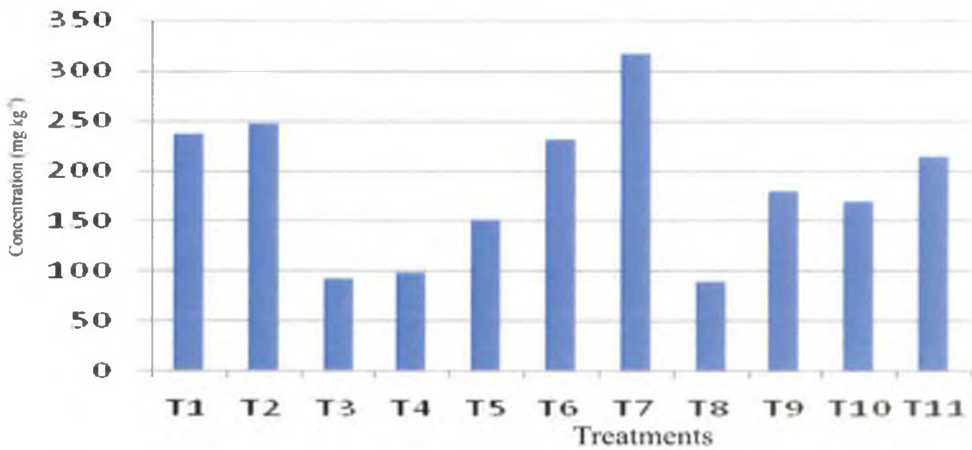
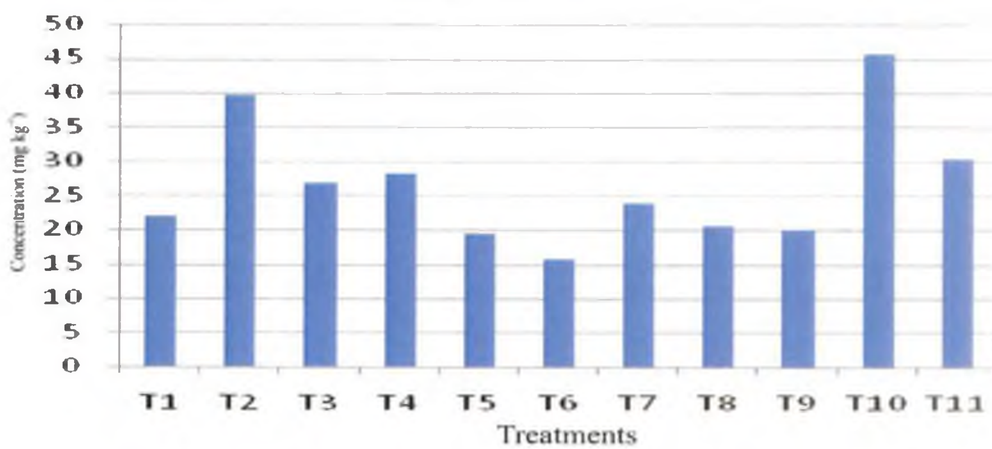


Fig9. Available Silicon status at flowering stage



T_1= Absolute control
T_2= Farmers practice
T_3= KAU recommendation
T_4= STL recommendation
T_5= STCR recommendation
T_6= STCR+FYM @ 5 t ha^{-1}
T_7= T2+ $ZnSO_4$ @ 25 kg ha^{-1}
T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}
T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Fig10. Content of Ca, Mg and Na in plants at maximum tillering stage

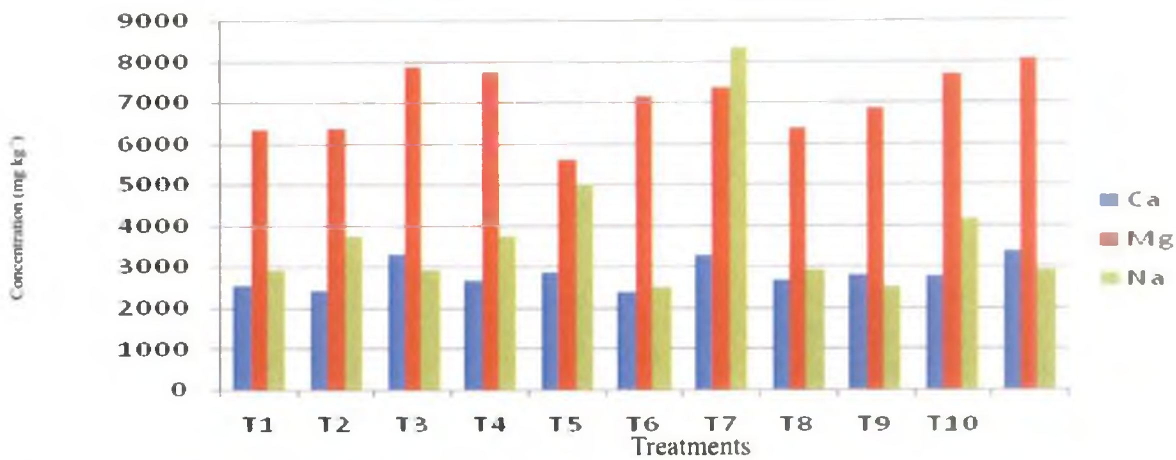


Fig11. Content of Fe in plants at maximum tillering stage

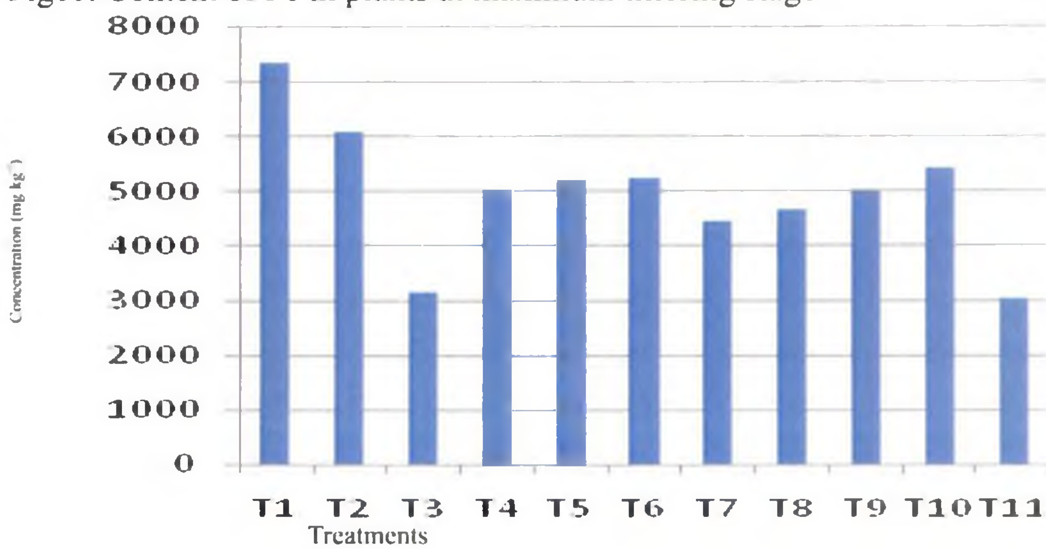
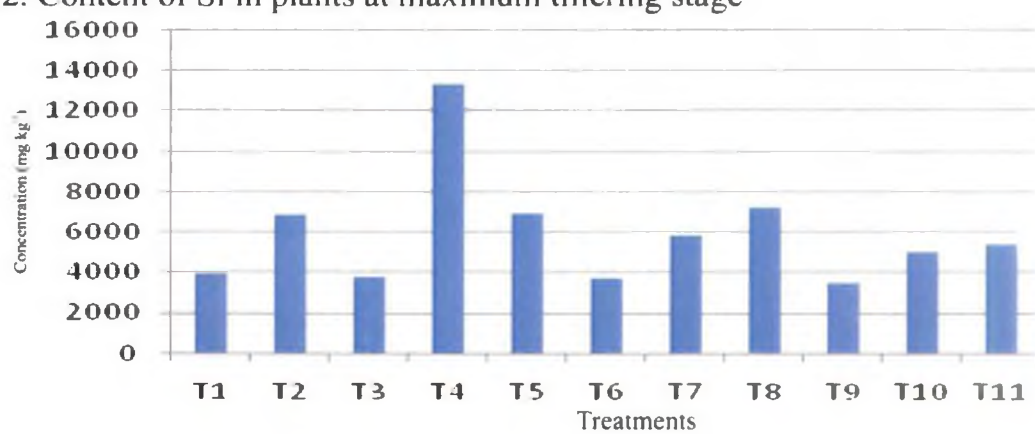


Fig12. Content of Si in plants at maximum tillering stage



T_1= Absolute control

T_2= Farmers practice

T_3= KAU recommendation

T_4= STL recommendation

T_5= STCR recommendation

T_6= STCR+FYM @ 5 t ha^{-1}

T_7= T2+ $ZnSO_4$ @ 25 kg ha^{-1}

T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}

T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}

T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}

T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Fig13. Content of Ca, Mg and Na in plants at panicle initiation stage stage

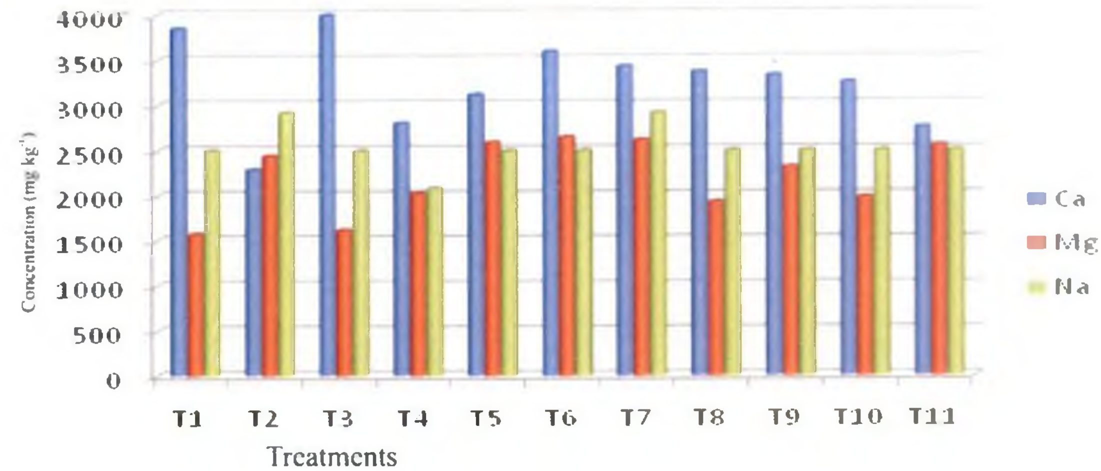


Fig14. Content of Fe in plants at panicle initiation stage stage

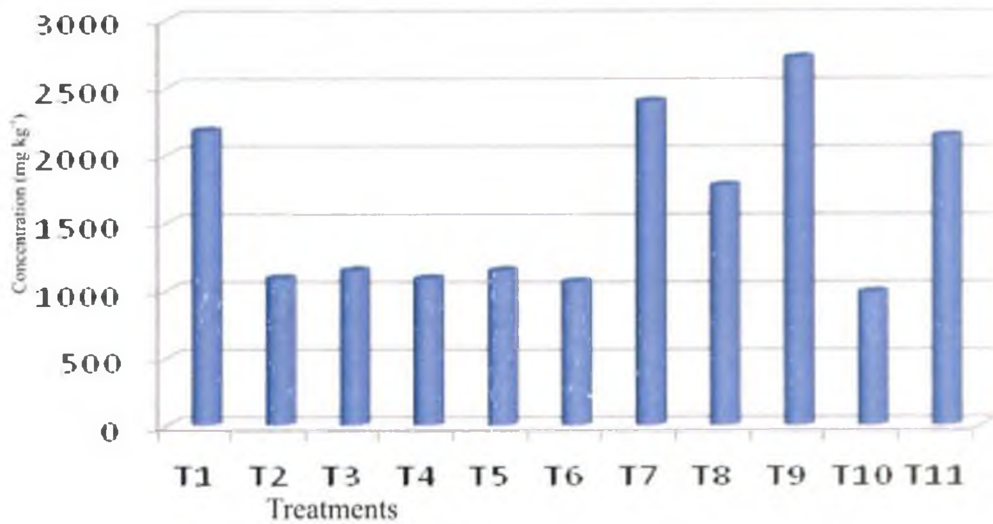
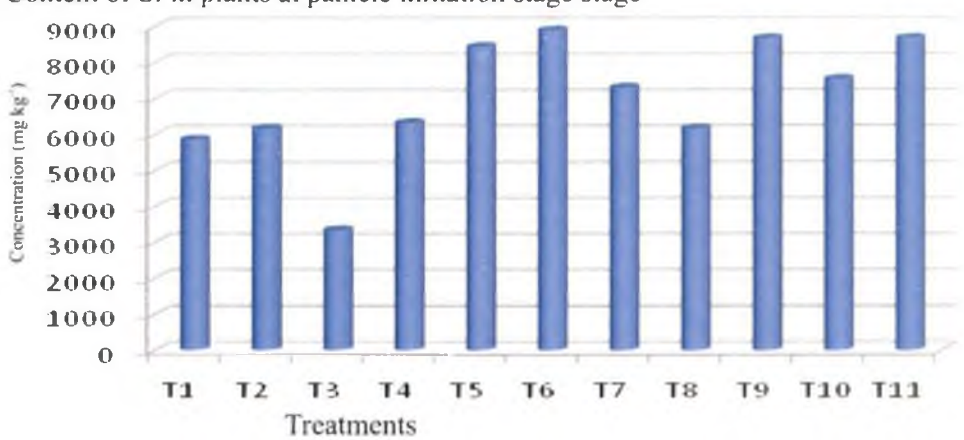


Fig15. Content of Si in plants at panicle initiation stage stage



T_1= Absolute control
T_2= Farmers practice
T_3= KAU recommendation
T_4= STL recommendation
T_5= STCR recommendation
T_6= STCR+FYM @ 5 t ha^{-1}
T_7= T2+ $ZnSO_4$ @ 25 kg ha^{-1}
T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}
T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Fig16. Content of Ca, Mg and Na in plants at flowering stage

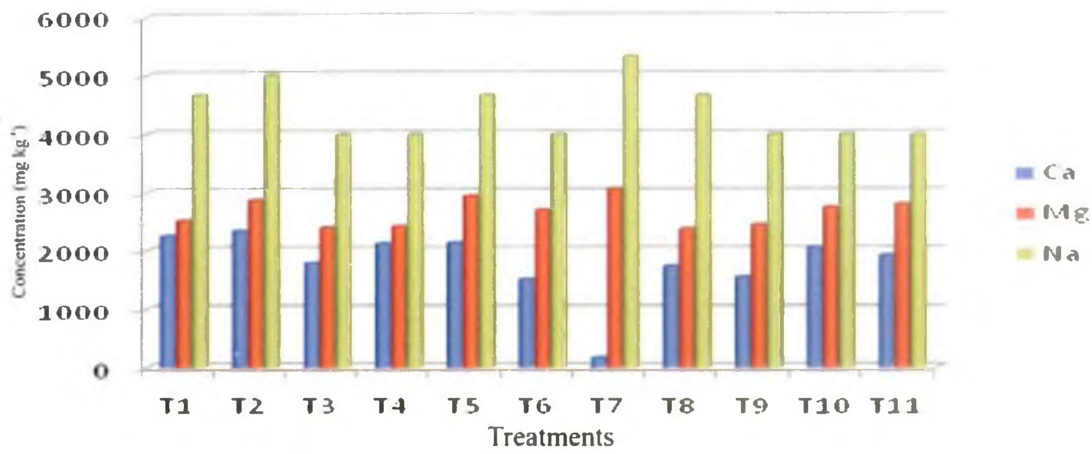


Fig17. Content of Fe in plants at flowering stage

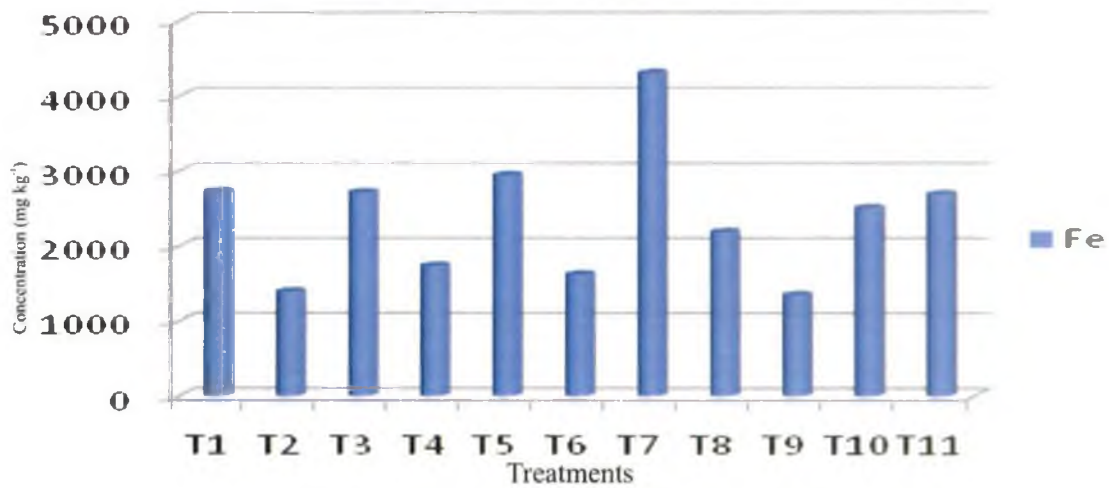
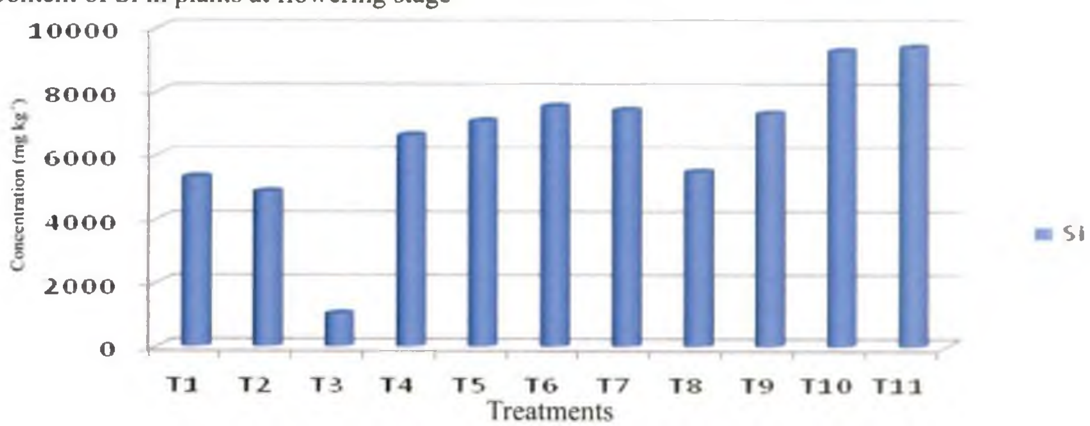


Fig18. Content of Si in plants at flowering stage



T_1= Absolute control
T_2= Farmers practice
T_3= KAU recommendation
T_4= STL recommendation
T_5= STCR recommendation
T_6= STCR+FYM @ 5 t ha^{-1}
T_7= T2+ $ZnSO_4$ @ 25 kg ha^{-1}
T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}
T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Fig19. Uptake of N, P and K as influenced by different treatment

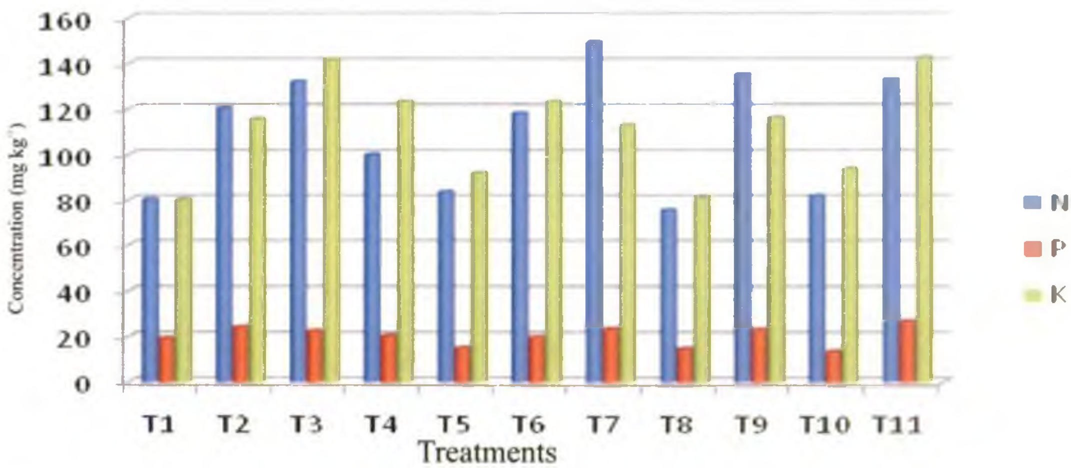
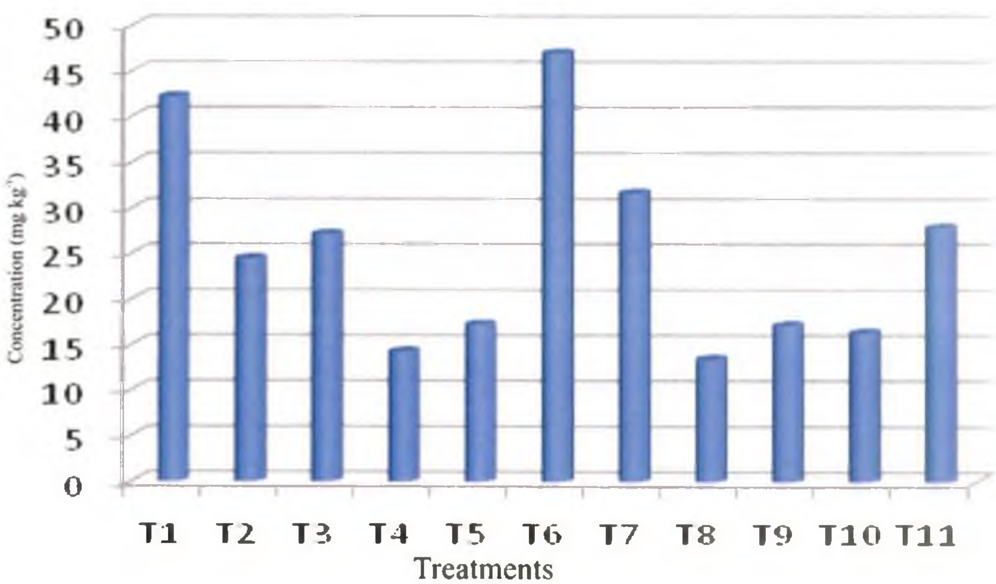


Fig20. Uptake of Si as influenced by different treatment



T_1 = Absolute control
T_2= Farmers practice
T_3= KAU recommendation
T_4= STL recommendation
T_5= STCR recommendation
T_6= STCR+FYM @ 5 t ha^{-1}

T_8= T3+ $ZnSO_4$ @ 25 kg ha^{-1}
T_9= T4+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{10}= T5+ $ZnSO_4$ @ 25 kg ha^{-1}
T_{11}= T6+ $ZnSO_4$ @ 25 kg ha^{-1}

Summary

6. SUMMARY

A sound resource management strategy is fundamental to ensure sustainability of agricultural production. Soil as resource is the key determinant that has to be managed in a scientific manner inorder to keep it sustainable. The study revealed that these soils have a pH 6.4 (slightly acidic) and the texture of the soil was sandy loam. The organic carbon content was 0.74 %. Among the major nutrients, available N and K were medium, while available P was deficient. In the case of basic cations, the contents of Ca was highest followed by Mg and Na. Iron was found to be in toxic level while, B was found to be deficient. Content of zinc was found to be adequate in this soil.

Rice, as test crop was grown to evaluate the characterstics of black soil for increased production on a sustainable basis. Experiment was also taken up to know the effect of zinc on yield of rice as well as to predict the yield based on nutrient content of soil, plant and yield attributes. The field experiment consisted of eleven treatments with three replications. The treatments were as follows- absolute control (T_1), farmer's practice (T_2), recommendation of KAU (T_3), Soil Test Laboratory recommendation of Kerala (T_4), STCR recommendation (T_5), STCR + FYM @ 5 t ha^{-1} (T6), T_2 + zinc sulphate @ 25 kg ha^{-1} (T_7), T_3 + zinc sulphate @ 25 kg ha^{-1} (T8), T_4 + zinc sulphate @ 25 kg ha^{-1} (T_9), T_5+ zinc sulphate @ 25 kg ha^{-1} (T_{10}) and T_6 + zinc sulphate @ 25 kg ha^{-1} (T_{11}). Soil as well as plant nutrient status were recorded at critical growth stages viz, maximum tillering, panicle initiation, flowering and harvest for the content of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B, Na, Si. Biometric parameters such as the height of the plant, number of tillers and number of leaves at critical growth stages were also recorded. Simple correlation co-efficients were worked out for soil nutrients, plant nutrients, grain nutrient and uptake with yield. The results of the experiment are summarized as follows:

- The grain yield showed the maximum in the treatment T_2 (farmer's practice) and the yield was 6.03 t ha^{-1} followed by treatment T_4 (STL recommendation), 5.3 t $ha^{-1.}$
- The straw yield showed the maximum in the treatment T_6 (STCR + FYM @ 5 t ha^{-1}) and the yield was 7.7 t ha^{-1}, followed by T_3 (KAU recommendation), 7.5 t ha^{-1}
- Among the soil available nutrients, the content of Fe was found to be in the toxic range throughout the crop growth.
- Available calcium was found to be higher than Mg and Na throughout the entire growth stages.
- High availability of basic cations like Ca and Na were found to be negatively and significantly correlated with the uptake of major nutrients during critical growth stages.
- The content of available Si in soil was low and the different treatments failed to influence the available Si content of the soil.
- The biometric parameters like plant height, number of tillers and number of leaves were fairly high for STCR treatments with or without zinc sulphate and FYM.
- The treatment T_2 (farmers practice) gave the highest total dry matter production of 6.68 t ha^{-1} and T_{10} (STCR+$ZnSO_4$) the lowest.
- There was an inverse relationship between the plant contents of Ca and Mg at different stages of crop growth.
- The uptake of P (26.91 kg ha^{-1}) and K (142.69) was found to be the
- highest in treatment T_{11} (STCR+FYM+$ZnSO_4$).
- The dose of zinc reduced the grain and straw yield.
- It was found to be difficult to predict the yield based on equations.
- The highest benefit cost ratio was found for absolute control (T_1) that was 1.97.
- The highest B/C ratio for the control indicates that the productivity of these soils can be improved with the use of minimum dose of chemical fertilizers.

FUTURE LINE OF WORK

The productivity of the black soils constrained by the excessive contents of basic cations as well as Fe can be improved by adopting proper drainage as well as integrated nutrient management methods like the application of FYM, crop residues or paddy husk. The improvement in physical condition of the soil as well as the increased supply of Si through incorporation of paddy husk (rich source of Si) has to be explored.

Similar trials have to be conducted in the other black soil areas and the results should be compared.

Also studies have to be taken up to improve the productivity with use of minimum dose of chemical fertilizers alongwith a major share of organic inputs. This should be supplemented with need based micronutrient application. This is especially relevant in a soil where the highest B/C ratio was obtained for control treatment.

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Appendices

Appendix 1. Date of planting and other field operation

Date	Operation done
26-06-2010	Transplanting
08-07-2010	First top dressing
22-07-2010	Second top dressing
18-10-2010	Harvest

Appendix 2. Nutrient content of fertilizers and organic manure

Fertilizers	Nutrient content (%)				
	N	P_2O_5	K_2O	Zinc	Sulphur
Urea	46.00	0.00	0.00	0.00	0.00
Rajphos	0.00	18.00	0.00	0.00	0.00
Muriate of potash	0.00	0.00	60.00	0.00	0.00
Zinc sulphate	0.00	0.00	0.00	36.43	17.86
Organic manure	N	P	K		
Farmyard manure	0.84	0.17	0.49	0.00	0.00

Appendix 3. Details of market prices of inputs and produce

Items	Cost (Rs kg^{-1})
Urea	5.60
Rajphos	5.60
Muriate of potash	5.30
Factomphos	8.40
Farm yard manure	1.00
Zinc sulphate	1624.50
Sulphur powder	434.00
Grain	14.00
Straw	3.00
Labour	
Men	@ Rs 250.00
Women	@ Rs 125.00

"NUTRIENT MANAGEMENT FOR SUSTAINABLE RICE PRODUCTION IN THE BLACK SOILS OF KERALA"

By
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ABSTRACT OF THE THESIS

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ABSTRACT

A field experiment was carried out to find out the best nutrient management system suited for sustainable rice production in black soils of Chittur, Palakkad district. The study also aimed to know the influence of zinc on the yield of rice in such soils. These black soils though fertile, the nutrient imbalances, as well as the poor physical condition may adversely affect the yield of crop. The soil selected for the study had a mean pH value of 6.4 and electrical conductivity of 0.1dSm^{-1}. The organic carbon content was 0.74%. The status of available N, P and K were 310.5, 5.67 and 154.36 kg ha^{-1} respectively. It was found that, except for available P and B, all other soil nutrients were present either in the medium level or adequate.

The field experiment consisted of eleven treatments and three replications each. The treatments were- Absolute control (T_1), farmer's practice (T_2), recommendation of KAU (T_3), Soil Test Laboratory recommendation of Kerala (T_4), STCR recommendation (T_5), STCR + FYM @ 5 t ha-1 (T_6), T_2 + zinc sulphate @ 25 kg ha^{-1} (T_7), T_3 + zinc sulphate @ 25 kg ha^{-1} (T_8), T_4 + zinc sulphate @ 25 kg ha^{-1} (T_9), T_5+ zinc sulphate @ 25 kg ha^{-1} (T_{10}) and T_6 + zinc sulphate @ 25 kg ha^{-1} (T_{11}). Soil as well as plant nutrient status were recorded at critical growth stages viz, maximum tillering, panicle initiation, flowering and harvest stage for the content of N, P, K, Ca, Mg, S Na, Si, Fe, Mn, Zn, Cu and B. Biometric parameters such as the height of the plant, number of tillers and number of leaves at critical growth stages were also recorded. Simple correlation co-efficient were worked out for soil nutrients, plant nutrients, grain nutrient and uptake with yield. Among the available soil nutrients, N content was found to be highest followed by available K and P during different growth stages. Available Ca was higher than Mg during all the growth stages. Among micronutrients, available Zn reduced while B increased from maximum tillering to harvest. A sharp decline in soil Fe content was observed with the advancement of growth stages. Available Na increased while, Si remained almost uniform throughout the different growth stages.

Among plant nutrients, the content of N decreased from maximum tillering stage to harvest. A higher concentration of Mg compared to Ca was observed during maximum tillering stage. The plant content of Fe showed a sharp decrease from maximum tillering to panicle initiation and thereafter increased. The range varied from 5000 mg kg^{-1} at maximum tillering stage to 3000 mg kg^{-1} towards the harvest stage. The plant content of Na increased from panicle initiation to harvest stage while, that of Si declined from flowering to harvest.

The number of leaves and tillers were found to be significantly higher for STCR treatments (with or without FYM) and zinc sulphate at the flowering stage. The highest benefit cost ratio was obtained for T_1 (absolute control). It was also observed that the yield of both grain and straw reduced on addition of $ZnSO_4$. Positive and significant correlation was observed between uptake of almost all the nutrients with grain and straw yield except Ca, Cu and Si. The uptake of the major nutrients, N and K was found to be significantly and negatively correlated to the contents of Na and Ca in soil. This supports the fact that excess amount of basic cations are hindering the uptake of major nutrients. Prediction of yield based on content of soil, plant and yield attributes could not be obtained from the present study.

It can be concluded that black soils of Chittur are fertile. But the productivity of these soils are constrained by factors like high content of basic cations such as calcium and sodium and subsequent low uptake of major nutrients. High plant content of Fe was also observed during the maximum tillering and panicle initiation stages.The content of Si in soil as well as uptake of Si by the crop was also comparatively less. So management practices have to be adopted to reduce the soil content of the basic cations as well as nutrient imbalances in soil and plants by drainage, leaching and incorporation of FYM, crop residues,rice husk etc. The highest B/C ratio for the control indicates that the productivity of these soils can be improved with the use of minimum dose of chemical fertilizers. The interaction between macro and micronutrients have to be examined in detail and further studies have to be conducted for sustainable rice production in these poonthalpadam (black) soils.