INTEGRATION OF NUTRITIONAL INPUTS FOR IMPROVING RICE PRODUCTIVITY IN LATERITE SOILS

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture

Kerala Agricultural University

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COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2003

DECLARATION

I hereby declare that the thesis entitled **"Integration of nutritional inputs for improving rice productivity in laterite soils"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled " **Integration of nutritional inputs for improving rice productivity in laterite soils"** is a record of research work done independently by **Mr. Jinnappa Halingali** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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ACKNOWLEDGEMENT

I wish to place on record my deep sense of immeasurable gratitude and unbound full indebtedness to Dr. K.E. Usha, chairperson of the advisory committee and Assistant Professor (SS), Agronomy, campus development, Vellanikkara, for her invaluable guidance, untiring interest, esteemed advise and immense help rendered through out the course of this investigation and without which this would have been a futile attempt.

No words can truly represent my profound gratitude and indebtedness to Dr.C.T.Abraham Professor and Head, Department of Agronomy, College of Horticulture, Vellanikkara and member of my advisory committee, for his ardent interest, valuable suggestion, critical scrutiny of the manuscript and ever willing help which has helped a lot for the improvement of this work.

It is my pleasant privilege to oblige Dr.U.Jaikumaran, Associate Professor and head, Agricultural Research Station, Mannuthy and member of my advisory committee for his expert counsel, sharp and constructive criticism and providing me the facilities for the conduct of the field work at the station.

I convey my heart felt thanks to Dr. Betty Bastin, Assistant Professor (SS), Soil Science and Agricultural Chemistry, Vellanikkara and my advisory committee member for all sort of help rendered by her for the completion of this research.

I can truly represent my profound gratitude and indebtedness to Dr. N.N Potty, retired Professor and Head, Department of Agronomy, College of Horticulture, Vellanikkara, for suggestion this experiment, his ardent interest, valuable suggestions and ever wiling help for the completion of this work.

I take this opportunity to express my heartfelt gratitude to Dr.K.A.Mariam, Associate Professor, Soil Science and

Agricultural Chemistry, Vellanikkara for carrying out the chemical analysis.

I grate fully acknowledge the help rendered by Dr. S. Krishnan, Assistant Professor, and Department of Agricultural Statistics for his relentless support in the statistical analysis and interpretation of the data.

I take this opportunity to express my gratitude to Dr. jose matthew, Dr.P.S.John, Dr.Mercy george, Dr. K. E. Savithri, Dr. George thomas, Dr. A. Latha, Dr. P. Gopinathan and Dr. Meera .v. menon of the department of Agronomy for their unbounded support offered at different stages of the study.

Words cannot express my gratitude to Dr. Babu. m. philip and other staff, campus development, Vellanikkara, for their wholehearted support and help given in times of need. I offer my sincere thanks to Dr. T. K. Bridgit, Assistant Professor (Agronomy), Agronomic Research Station, Chalakkudy and Dr. P. A. Joseph Assistant Professor (Agronomy), ARS, Mannuthy for valuable help and suggestions during the study.

I am thankfull to my friends Sanjeev, Ajay, Vijay, Prakash, Srinivas, Nanayya, Mahadev, Chandrasshekhar, Roshni, Venkatesh, Karthikayan, Nagaraj, Rajan, Sindhu, Pradeep, Gopinath, Bhavani, Roy, Bijily, Priya, Preetha, Pamila, Sreeja, Anuja, Shahidha, Swapna and Vanishree for their valuable help, constant inspiration and moral support.

I wish to express my sincere gratitude to seniors Bhoopathi, Hani, Vidya and Sulekha, my classmates Ponnaiyan, Murugan, Mahadev, Rajesh, Sinish, Shobana and Resmy and my junior Binimol for their whole hearted support.

I am extremely thankful to Sri. Basheer, Joy computers, Ms. lalitha and family for the neat typing, setting and printing of the menuscript.

The award of KAU junior fellowship is thankfully acknowledged.

I am forever beholden to my mother, father, brothers, uncle and aunty for their constant prayer, personal sacrifice, affection and tolerance throughout the period of my course.

Above all I bow my head before the god almighty, for his blessings and I am fully satisfied that I could do as much as this in this field.

Jinnappa Halingali

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INTRODUCTION

INTRODUCTION

Limited availability of additional land for crop production along with declining yield of major food crops, have raised concerns about agriculture's ability to feed a world population expected to exceed 7.5 billion by the year 2020. Decreasing soil fertility and declining nutrient use efficiency have also become international problems, which hinder the sustainability of agricultural production at current levels.

Rice production and productivity face a critical decline today. Decreasing area, lack of response to fertilizers and decrease in nutrient use efficiency has driven rice culture to a precarious situation. We have reached a stage at which we are not able to exploit the potential yield of a variety. Kerala, which is chronically short in food grain production, is confronted with a serious problem of retaining even the small area under rice. The rice area, which is fast shrinking into Kuttanad, Kole lands and Chittoor area of Palakkad, witnessed a sharp fall from 8.74 lakh ha in 1972 - 1973 to 4.31 lakh ha in 1996 – 97. The productivity is declining but the product price remains static. Hence, increasing the production efficiency is the only way to improve the situation.

The average yield of rice in the state is only 2032 kg ha^{-1} as against 4404 kg ha^{-1} in Tamilnadu (Siddiq, 2000). The problem of low yield expression is of particular significance in the laterite soils of Kerala since the laterites occupy more than 60 per cent of rice soils in the state. Experiments undertaken to find out the factors limiting response to inputs have shown that high content of iron in the soil and its enhanced uptake (Potty *et al.*, 1992) are the prime causes. The low realized yields for the recommended high yielding varieties necessitate identification of technologies for maximising the productivity in the cultivator's field. Intensive investigations on the yield limiting influences of rice in laterite soils have also revealed the high accumulation of iron in the plant and chlorophyll instability (Bridgit and Potty, 1992). Musthafa (1995) found that widening N: Fe ratio of the plant is conducive for higher realized yields.

Long-term manurial trials at RARS, Pattambi showed that even a total substitution of fertilizer with organic manure could not increase the rice yield. Results further showed that continuous application of organic manure like glyricidia has lead to lowest levels of yield. Hence, it is high time to think how far organic farming can be a blind adoption as is conceived today.

Combined use of organics and fertilizers is a workable way to save the cost of production. The manures like cow dung and poultry manure along with fertilizers help in maintaining the soil fertility and rhizosphere environment by improving the physico-chemical properties of paddy soils without hindering the production of the succeeding crop (Tiwari and Tripathi, 1998). Integrated nutrient management involving the intelligent use of organic, chemical and microbial sources will sustain optimum yields, improve the soil health and provide crop nutrition packages which are technically sound, economically attractive, practically feasible and environmentally safe.

It is also observed that the high yielding varieties grown at present are responding to higher levels of NPK than what is recommended. Bridgit (1999) suggested the enhancement of K levels and inclusion of S in the nutritional management for higher yields and nutrient use efficiency. Crop removal is found to be far more than what is supplied. The fertility of the soil is thus getting eroded. So the input requirement should be decided to exploit the yield potential by maintaining the soil fertility.

Fertilizer management has been identified as a practice of applying NPK and rarely amelioration of acidity with lime. As far as the acid soils of Kerala are considered, it is seen that the excess absorption, especially of micronutrients inhibits the yield.

Removal of larger quantities of silica, especially from the laterite soils, has also led to soil degradation. Rice is a known silica accumulator. Several beneficial effects have been attributed to silica in the physiology of the rice plants. It is found that the silica gets deposited on the cell walls of the stem, thereby increasing the culm strength and preventing the tendency to lodge. The increase in silica content of the cells also results in increased resistance of the plants to pests and diseases. Further more, silica is said to regulate the rate of transpiration, there by enabling the plant to withstand the drought conditions better.

As an attempt to standardize the proportionate use of manures and fertilizers along with beneficial elements, the study on "Integration of nutritional inputs for improving rice productivity in laterite soils" was undertaken with the following objectives:

i. To develop cost effective, high yield and sustainable production technology for rice by identifying the components of good management.

ii. to find out the extent of substitution of inorganic with organic materials to overcome the ill effects of chemical farming.

iii. to develop the management practices to prevent the soil degradation through over removal of N and K and

iv. to improve the nutrient use efficiency.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Laterite soils account for more than 60 per cent of the rice soils in Kerala. The productivity and fertilizer responsiveness of rice in these soils are low compared to other soils of the state.

It is highly essential to arrive at a nutrient management system, which integrates organic and inorganic sources at an optimum level to ensure high crop productivity and ecosystem stability. The literature pertaining to the study has been reviewed under the following subheads.

2.1. Yield limiting factors of laterite soils

Evaluation of rice varieties in different soil types of Kerala revealed that the varieties having a potential to produce 10 t ha^{-1} failed to yield even 4 t ha^{-1} (KAU, 1990). The poor nutrient use efficiency was not due to the inadequacy of the major nutrients but due to the higher uptake of native elements like Fe and Mn (Bridgit, 1999).

Marykutty *et al.* (1992) reported that Ca+Mg/K ratio was the determinant factor in deciding the yield expression of rice in laterite soils. The trend of increasing yield could be observed when the ratio got narrowed.

Pushparajah (1998) opined that the deficiency of cat ions was the major constraint for crop production in laterite soils. Intensive leaching leads to the deficiency of N, P, K, Mg, Zn and other bases in these soils. Fixation of P also shows the deficiency of phosphorus.

Bridgit *et al.* (1993) were of the opinion that the unfavourable cationic relation was the yield limiting component in laterite soils. Jacob (1987) reported that the contents of organic carbon and N, CEC and C: N ratio was low in laterite soils. She also observed very low total reserves of CaO, MgO, K_2O and P_2O_5.

Rajagopal *et al.* (1977) found that the available Mn content of Kerala soils ranged from 0.2 to 20 ppm. According to Patnaik (1971), low productivity of laterite and allied soils generally could be attributed to low pH, low base saturation , low available P and high P fixing capacity and toxicity of Fe and Al. He further reported that moderate to high acidity of laterite soils also causes serious problems in major rice growing areas.

2.2. *Mineral nutrition and nutrient interactions influencing rice growth*

As far as rice is concerned, the stage of growth is important as it decides the physiological requirement of each element. In addition to the specific functions of each nutrient, the interacting influences of the different nutrients absorbed by the rice plant have to be considered. The nutrient ratios and their balances in the plant system would be more important than the content of individual elements absorbed when the soil contents of these elements are either at deficient or toxic levels.

2.2.1. Nitrogen

An adequate supply of N is associated with vigorous vegetative growth, a deep green colour and carbohydrate utilization (Tisdale *et al.*, 1995). Rice plant requires a large amount of N at the early and mid tillering stages to maximize the number of panicles. The number of tillers produced was also correlated positively with the concentration of NH_4^+ in the soil (Lai Ding *et al.*, 1993).

Nitrogen content at the panicle initiation stage increases the spikelet number per panicle and some N is required at the ripening stage (De Datta, 1981). Short statured and long duration rice responded to high dose of N under low fertility condition (Gupta and O'toole, 1986). Increase in grain yield with higher rates, up to 180 kg ha^{-1} N, was observed Singh and Om (1993) and Monapara *et al.* (1993).

Elaward and Green (1979) reported that the yield decreased when the rate of N was more than the optimum. Due to the synergistic effect, application of Si had the potential to raise the optimum N rate, thus enhancing the productivity of existing lowland rice. Wagava and Kashima (1963) observed that when Si was applied, the percentage of nitrogen in every part of rice plant was decreased.

Mitsui and Takatoh (1963) suggested that Si application lowered the N content in the leaves of rice plant, but had little or no effect on plant K contents. Padmaja and Varghese (1972) found that the application of Si as sodium silicate reduced the nitrogen uptake. They also revealed that when Si was combined with Ca or Mg or both, the capacity of these nutrients for increasing the nitrogen uptake was reduced.

Mistui and Ishii (1938) indicated that the photosynthetic efficiency of a single leaf per area was positively correlated to the leaf content of total N than to chlorophyll. Photosynthetic rate was saturated at the level of 3-4% N in the leaf blade (Tanaka, 1960).

Plant N content in rice is maximum at the early growth stage and subsequently decreased with the advancement of age (Rao and Murthy, 1975). Rao *et al.* (1974) reported a lag period in the N uptake of dry sown rice during 40-90 days after seeding resulting in a deep decrease in N content.

Patiram and Singh (1993) stated that continuous application of N tended to decrease pH, available P_2O_5, Exchangeable Ca^{++}, Mg^{++} and K^+ and increased the exchangeable Al^{++}.

2.2.2. Phosphorus

Phosphorus is associated with the root development, early flowering and active tillering (De Geus, 1954). An adequate supply of P is associated with greater strength of cereal straw (Tisdale *et al.*, 1995). Phosphorus manuring increases early tiller formation, the greater part of which ultimately produce more grains of heavier weight and also stimulates early and synchronized flowering (Bhattacharya and Chatterjee, 1978). Favourable influence of P application on tillering was also observed by Nair *et al.* (1972), Bhattacharya *et al.* (1978) and

Choudhary *et al.* (1978). However, Alexander *et al.* (1973), Kalyanikutty and Morachan (1974) and Suseelan *et al.* (1978) have reported the lack of any response to P application on tillering.

Majumdar (1971) observed that there is significant increase in the number of productive tillers and test weight due to P application. Contradictory reports are available on the effect of P on rice grain yields. Favourable responses have been reported Mohanty and Patnaik (1974), Kalyanikutty and Morachan (1974), Ittiyaverah *et al.* (1979) and Kalita and Baroova (1994). However, several workers have reported that mean grain yields were not significantly affected by P fertilizers (Dargan and Chillar, 1978, Dargan *et al.*, 1980 and Rao and Kumar, 1994). Sindhu (2002) reported that reducing the dose of P and withholding basal application of S could increase the influence of silica and improve the yield.

2.2.3. Potassium

Potassium is indispensable to the growth and grain production of rice. Tanaka *et al.* (1977) reported that the rice plant was characterized by its high capacity of absorbing as well as exhausting K and thereby tending to maintain the K concentration in a plant at a constant level. When the K concentration in the rice plant was forced to be low, its relative growth increment decreased drastically. A positive response of rice to K application was observed by Su (1976).

Vijayan and Sreedharan (1972) and Venkatasubbaih *et al.* (1982) observed significant increase in rice plant height with increase in the levels of K. Also, a positive correlation between K application and leaf area index of rice was observed Mandal and Dasmahapatra (1983). Increase in the chlorophyll content in the flag leaf due to K application was observed Ray and Choudhari (1960). Potassium checks the chlorophyll degradation and promotes the synthesis of both chlorophyll 'a' and 'b'. The increase in the rate of translocation of amino acids to the grain and protein formation was reported by Mengel *et al.* (1981) and Ray and Choudhari (1960).

Potassium application positively influences the yield attributes in rice. Potassium absorbed at the maximum tillering stage increased the number of panicles, spikelets per panicle and the weight of grain (Su, 1976, Mandal and Dasmahapatra, 1983). Verma *et al.* (1979) observed longer panicles with increased K rates while Vijayan and Sreedharan (1972) reported greater number of spikelets per panicle. Higher grain and straw yields were reported by Gurmani *et al.* (1984). Gosh *et al.* (1994) also reported the similar results.

Mikkelsen and Patrick (1968) indicated that 75 per cent of the total amount of potassium was absorbed prior to the booting stage and no absorption took place from grain forming to grain filling. Noguchi (1940) reported an increase in the lignin content of the rice stem with increased application of K. Mitra *et al.* (1990) evaluated the effects of higher level of K (0 to 160 kg ha^{-1}) on rice in an iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increased K application.

Takijima *et al.* (1959) noticed an increase in the uptake of potassium by the application of silica. Islam and Saha (1969) reported that the application of silica along with other nutrients in the culture solution has decreased the potassium uptake of rice plants. This is due to more absorption of Ca and Mg ions promoted by Si application.

Padmaja and Verghese (1972) found that the percentage of potash in the grain and straw was maximum in those treatments, which included silica. Bridgit (1999) reported that the application of silica @ 250 kg ha^{-1} limited K removal by the crop within the level of application.

Agarwal (1980) also observed significant increase in the yield by the application of K_2O up to 80 kg ha^{-1}. According to Vijayan and Sreedharan (1972) application of graded levels of K increased the height of the plants, percentage of filled grains and thousand grain weights. They also found that the application of 120 kg ha^{-1} of K level had recorded the maximum grain and straw production.

Venkatasubbiah *et al.* (1982) indicated that significant increase in the yield of grain and straw were obtained for applied potassium. According to them, the effect of potash application was more on grain yield compared to straw yield. According to Bridgit (1999), increasing levels of K significantly increased the height of the plant at panicle initiation, flowering, and harvesting stages but increasing the level of K_2O beyond 120 kg ha^{-1} did not have any effect. She also found that the application of K @ 120 and 180 kg ha^{-1} significantly increased the panicle weight, filled grains per panicle and grain weight as compared to 60 kg K_2O ha^{-1}.

Mitra *et al.* (1990) reported that Fe toxicity symptoms decreased with increasing K application in an iron toxic laterite soil. Chan (1997) reported that K application increased the root growth, the number of roots, regrowth capacity and the uptake of N, P, K, Ca and Mg in rice, but the effect was dependent on the cultivars.

2.2.4. Calcium

Calcium stimulated the absorption of P and K (Tanaka, 1960; Jacobson *et al.*, 1961 and Erdei and Zsoldos, 1977) and accelerated more effectively the translocation of photosynthetic products compared to K and Mg.

Application of lime increased the rice yield by rectifying the ill effects of Fe and Al (Sahu, 1968; Dixit and Sharma, 1993 and Laskar, 1990). Liming in acid soil has been found to be beneficial in increasing the availability of P and reducing the toxic levels of Al, Mn and Fe (Hati *et al.*, 1979 and Mongia and Bandyopadhyay, 1993).

Verma and Tripati (1987) reported that the application of lime under flooded condition increased the rice yield, Mn content and decreased the Fe content. Marykutty (1986) found that Ca application, though raised the pH, could not bring down Fe content below the critical level of 300 ppm in rice in laterite soil. Mandal and Sinha (1968) could not found any effect of liming on the potassium in the content of plant in acid red loam soils.

2.2.5. Magnesium

Magnesium application was found to increase the grain yield in rice (Mani *et al.*, 1993; Muralidharan and Jose, 1993; Verghese and Jose, 1993). Takijima *et al.* (1970) noted that Si application resulted increased uptake of Mg by rice. Magnesium absorbed into rice plant was easily mobile in retranslocation and the distribution of Mg in the panicle was more following P and K (Ishizuka and Tanaka, 1959).

2.2.6. Sulphur

Sulphur has been reported to increase K absorption and productivity of oil seeds crops by Daliparthy (1994). Prabhakumari (1992) observed antagonistic relationship between K and S content in coconut.

Kumar and Singh (1994) observed an increase in total potassium in sulphur deficient plants because of improper utilization of potassium. Singh *et al.* (1993) reported that the application of 'S' upto 60 kg ha^{-1} increased the growth attributes and the yield of rice. Sulphur application is known to reduce the plant content of iron by reducing the leaf sap pH and increasing the chlorophyll content (Pillai, 1972).

2.2.7. Iron

Iron is an important micronutrient. But its excess concentration affects the growth and yield of rice in laterite soils of Kerala. Howeler (1973) indicated that iron induced deficiency of P, K, Ca and Mg could occur due to the relatively high level of iron in soil solution. He also found that the root became coated with the iron oxide and reduces the root's capacity to absorb enough plant nutrients from an already deficient environment. IRRI (1972) reports showed that the excess iron lead to bronzing in laterite soils of India, Ceylon, Thailand, Malaysia and Cambodia.

According to Patnaik (1971), low productivity of laterite and allied soils can generally be attributed to low pH, low base saturation, low available P and high P fixing capacity and toxicity of Fe and Al. Potty *et al.* (1992) revealed that higher absorption of iron by rice is the cause of low yield as well as poor input use efficiency in laterite soils. Singh (1992) found that Fe toxicity caused formation of fewer panicles and filled grains, delayed crop maturity and yield reduction of 2 t ha^{-1}. High nitrogen absorption and resultant narrow N/Fe ratio leads to low productivity of rice.

The Si content of the rice plant affects the uptake of iron. As the content of Si in the tops increased over the range from 0.2 to 7.0 per cent, decreasing amounts of iron was absorbed (Okuda and Takahashi, 1962). According to Ponnamperuma (1965), sufficient Si supply facilitated the oxygen transport more efficiently from the plant tops to the roots through enlargement on rigidity of gas channels and as a result increased oxidation and subsequent deposition of Fe and Mn on the roots surface, thus excluding them from absorption by the plants. Wallace (1992) found that the application of Si decreased the uptake of Fe in iron rich acid soil. This is because of high concentrations of Si in rice. Plants could serve to create an alkaline rhizosphere that would decrease the availability of the Fe.

2.2.8. Manganese

Somer and Shive (1942) reported that the excess Mn hindered the translocation of Fe by converting it into an insoluble form in the plant roots. A study conducted by Moormann (1963) under acid sulphate soils showed that excess manganese concentration and its increased solubility caused toxicity to the rice plant.

Vorm and Diest (1979) found that Mn uptake decreased with increasing pH and Si had a suppressive effect on Mn uptake. Horiguchi (1988) reported that the alleviation of Mn toxicity by Si was due to the increased oxygen supply of roots causing deposition of Mn on them, the decreased transpiration reducing the

Mn absorption and also the increased tolerance in the plant tissues to an excess amount of Mn.

2.2.9. Zinc

Zinc application improved the grain yield, plant height, tillering, leaf area index, root growth and increased the uptake of N, P, Zn and Fe (Salam and Subramanian, 1993). Bridgit (1999) reported that the application of Si as sodium silicate increased the Zn content of root and shoot of rice.

Ghabrial (1979) could not observe any significant effect on growth and yield attributes by Zn application. Beneficial effect of Zn application on yield was also reported by Singh *et al.*, (1983). Singh and Singh (1987) reported that the application of Zn alone or in combination with N did not show any significant effect on yield but in combination with P significantly increased the yield.

2.2.10. Silica

Rice crop, on an average, removes more than 500 kg ha^{-1} of silica every season. It is also reported that the rice crop becomes deficient if the silica content is less than 6 per cent. An increase in grain and straw yield of rice could be noted due to silica application (Subramanian and Gopalaswami, 1990).

Silica is a beneficial element required specially for rice in soils low in silica. The application of silica increased the yield of a modern rice variety at higher rates of N application (De Datta, 1981). Application of silica up to 1000 kg ha^{-1} had shown increased yield of rice in laterite soils (Potty, 1965). Increase in the dry matter, height, length of ear head and roots due to the application of silica had been reported by Okamoto (1957).

Padmaja and Verghese (1966) found that the application of sodium silicate as soil amendment in laterite soil increased the tillering, height of plants, the depth of penetration of the root system and the proportion of thicker to thinner roots. They also observed that the application of sodium silicate combined with magnesium carbonate increased all the productive factors such as earhead length, thousand grain weight, grain and straw yield. Silica reduced the flowering duration to the extent of 10 days. Early flowering saved time and promoted uniform and early ripening of grain. Grain to straw ratio was highest with Mg in combination with Si while calcium in combination with silica has reduced the proportion of immature to mature earheads.

According to Agarie *et al.* (1992), the maintenance of photosynthetic activity due to Si fertilization could be one of the reasons for the increased dry matter production. According to Tisdale *et al.* (1995) Si increased the top length, number of stems, fresh and dry weight of rice and also increased the photosynthesis because of better light interception. Hosoda and Takota (1957) recorded 14 per cent increase in the yield of rice due to the application of calcium silicate in soils of low SiO_2/Al_2O_3 ratio.

Kumar (1977) observed that the application of 600 kg ha^{-1} of magnesium silicate increased the number of spikelets, number of filled grains and thousand grain weights. Yein *et al.* (1983) suggested that the spreading of rice hull @ 20 t ha^{-1} about one week before planting increased the grain yield from 7.2 to 8.2 t ha^{-1}. Snyder *et al.* (1986) showed that calcium silicate application increased the rice yield on histosols mainly due to the supply of plant available silica and not due to the supply of other nutrients.

According to Bridgit (1999), application of sodium silicate @ 250 kg ha^{-1} in laterite soils significantly increased the yield of grain and the increase was to the tune of 619 kg ha^{-1}. Sodium silicate application at the rate of 500 kg ha^{-1} recorded an increase in grain yield of 632 kg ha^{-1} (Lakshmikanthan, 2000). The immediate increase in yield has also depleted the organic carbon from the soil. Nayar *et al.* (1982) concluded that the silica content and uptake by the plant increased with the progress of growth from transplanting to harvest. Takahashi (1997) reported that rice is a Si accumulator and Si had the fastest uptake rate among the nutrients in solution. He also noted that the rice roots actively absorbed Si and stocked the absorbed Si in the top, mainly, leaf blades and chaffs.

Chandramony and George (1975) found that the application of sodium silicate induces anatomical changes favourable for resistance to lodging for the variety PTB-31. Mathai *et al.* (1981) found that the application of silica @ 250 and 500 kg ha^{-1} as sodium silicate had significant effect in reducing the intensity of pest attack 75 DAS. Studies at IRRI (1991) showed that cells in the epidermal layers of leaves were more closely packed than those in susceptible rice and contributed to physical resistance through enhanced mandibular wear in leaf folder larvae.

Sawant *et al.* (1994) found that improving Si concentration in rice plants reduces the stem borer incidence. It is believed that the formation of a silicate epidermal layer prevents the physical penetration by insects and makes the plant cells less susceptible to enzymatic degradation by fungal pathogens. Tang and Wang (2000) reported that the silica fertilizer increased the rice yield by an average of 8.5% compared to the control. It is suggested that the silica fertilizer should be applied into the plough horizon to allow the contact with the crop roots.

2.3. Organic manure and rice productivity

The inorganic fertilizer use has depleted the soil and polluted the environment and now some farmers are turning back to organic farming practices. The use of animal wastes, green manures and crop residues becomes important in this context. Farmyard manure of good quantity is perhaps the most valuable organic matter applied to a soil and is the most commonly used organic manure in most countries of the world (Dahama, 1996). Poultry manure is rich in plant nutrients and the content of N, P and K is double than that of farmyard manure (Dobermann and Fairhurst, 2000).

The function of organic manure is not only nutritional but also physiological, since the manure contains vitamins, hormones, phenolic substances and humic acids. Kawata and Soejima (1976) showed that long-term application of compost / FYM to rice fields accelerates the development of superficial roots and are helpful for more respiration and thus nutrient absorption. They also reported that the organic matter accelerated the development of active roots deep into the soil and helped to maintain their activity until late growth stage guarding the plant from early senescence.

Singh and Hariram (1977) reported that organic matter reduced the concentration of P into Fe-P and was more pronounced in laterite soils due to greater reduction of ferric compounds and organic compounds possessing chelating properties.

Patiram and Singh (1993) reported that continuous application of organic manure increased the pH, organic carbon, available P_2O_5, exchangeable Ca, Mg and K of the soil and decreased the exchangeable Al. Similarly, the application of organic manure to the soil increased the availability of Fe, Mn, Zn and Cu in the rhizosphere soil but lower in the availability of N, P, K and organic carbon. (Sekharan *et al.*, 1996). Sharma and Meelu (1975) also found that the continuous application of FYM increased the soil micronutrient status.

Highest grain yield was obtained by the use of poultry manure in rice crop @ 12.5 t ha^{-1} (Budhar *et al.*, 1991). Gupta *et al.* (1995) observed that the highest rice yields were obtained with combined application of poultry manure and P. In addition, the concentration of phosphorus in rice tissue at different stages and P uptake at maturity increased with the application of P and/or manure. However, the highest uptake was recorded with combined application.

Though poultry manure did not perform better than urea after the first year of application, by the second and third year 120 and 180 kg as poultry manure produced significantly higher grain yield than the same rates of urea. Yields decreased with the use of urea but the poultry manure sustained the grain yields of rice (Singh *et al.*, 1996). Rice grown with annual application of 10 t

FYM ha^{-1} gave average unpolished grain yield of 3.66 t ha^{-1} (Kobayashi *et al.*, 1989).

Average yield of rice over a period of 20 years increased from 5.2 t with no FYM to 6.0 t with 20 t FYM and 5.89 t with 30 t ha^{-1} of FYM. A similar trial achieved a yield of 6.6 t ha^{-1} with 40 t FYM/ha (Ohyama, 1989). Ikarashi *et al.* (1990) conducted the experiments with various levels of FYM and plant density. They reported that the plant height was highest with lower plant density and without FYM while the leaf area index was greater with FYM application.

Straw yield was increased while the proportion decreased with FYM application. Farmyard manure @ 10 t ha^{-1} without inorganic fertilizers produced 3.54 t ha^{-1} grain and gave the highest input: cost ratio (Hussain *et al.*, 1991). Applying lot of FYM at the time of transplanting increased the grain yield of rice as much as applying 30 kg N ha^{-1} as fertilizer (Sharma and Mitra, 1991). Chandrakar *et al.* (1990) reported maximum rice grain yield with 5.3 t ha^{-1} sunhemp and 40 kg N ha^{-1} in 1987 and with 8 t ha^{-1} FYM + 40 kg N ha^{-1} in 1988. Application of 80 kg N ha^{-1} was on par with 40 kg N ha^{-1} + 8 t ha^{-1} FYM.

Application of organic manure as wheat straw @ 10 t ha^{-1} saved 50 kg N ha^{-1} and gave the maximum yield of rice. The carry over effect of FYM on the next crop of wheat also showed a similar trend. The benefit : cost ratio was maximum with FYM @ 10 t ha^{-1} + 100 kg N ha^{-1} in wheat and FYM alone in the case of rice (Rajput and Warsi, 1992). Heavy application of cattle manure increased the plant height, number of tillers and grains/panicle but decreased the thousand grain weights and total yield (Jin *et al.*, 1996).

In tall indica rice, an application of cattle manure + NPK fertilizer and cattle manure + green manure + NPK gave the highest grain yield in the kharif and rabi season crops respectively (Anilakumar *et al.*, 1993). Balram *et al.* (1977) reported that the application of N fertilizer, green manure and FYM increased the N content and uptake.

Raman *et al.* (1996) found that in the first year of a trial, the yield was highest with inorganic fertilizers only. After three years, the combination of organics and inorganics gave similar yield to the inorganic treatments while after another four years; the combined treatments started giving higher yield than the inorganic source. Farm yard manure was a more effective organic nutrient source than the wheat straw and green manures.

Singh *et al.* (1996) reported significantly higher grain and straw yields of rice and wheat with the application of 10 t ha^{-1} of farmyard manure. In trials with rice cultivars, Jaya and Bymellu and the hybrid KRH-1, the yield was highest with 5 t ha^{-1} FYM followed by 10 t ha^{-1} FYM (Reddy and Shivaraj, 1999b).

Sharma and Mitra (1990) noticed an increase in grain and straw yield of rice due to the application of organic materials. The total uptake of N, P and K increased in brinjal with a higher dose of poultry manure (Prasanna, 1998). According to Singh and Patiram (1977), the yield increase due to organic manure was due to the increase in P uptake. Musthafa (1998) reported that the yield improvement due to the organic manure was by widening of N/Fe ratio in the laterite soils.

2.4. Integrated nutrient management

Application of fertilizers will lead to the braking down of organic matter and loss of organic carbon in the soil. The development of acidity will increase the availability of Fe, Mn etc. which inturn will lead to the toxicity problems and decrease the availability of phosphorus.

Long term manurial trials at RARS, Pattambi showed that even a total substitution of fertilizer with organic manure could not increase the rice yield (Anilakumar *et al*, 1993). Results further showed that continuous application of organic manure like glyricidia had led to lowest levels of yield. Integrated nutrient supply through judicious combination of organic and biological sources along with the inorganic fertilizers has a larger number of agronomic and environmental benefits over organic sources alone and it is a concept that is ecologically sound leading to sustainable agriculture (Swaminathan, 1987). According to Mohanthy *et al.* (1992) the use of chemical fertilizers in conjunction with organic sources such as poultry manure, farmyard manure, green manure etc. restores and sustains soil health and productivity.

In sustained rice production organic manuring plays an important role. The combination of manures and fertilizers is considered to be more productive. The concept of ecological recovery of the soil through balanced use of organic manures and chemical fertilizers was high (Pillai and Kundu, 1990). Singh *et al.* (2000) found that the use of FYM either alone are in combination with chemical fertilizer, sustained much the available NPK and organic carbon in soil after rice – lentil sequence as compared to rest of the treatments.

Liu and Shen (1992) observed that mixed application of inorganics and organics increased the soil organic matter content and improved its quality compared to no fertilizer or inorganic fertilizers. It is estimated that the rain fed lowland rice alone will have to contribute 25-30 per cent increase in production, which will necessitate the development of better production technology, including integrated nutrient management.

A combination of organic and inorganic nutrient sources is a necessary part for any management strategy to sustain productivity of rice growing tracts especially areas with limited resources (Kundu and De Datta, 1988).Udayasoorian *et al.* (1988) studied the effect of continuous application of organic matter and fertilizer on growth and yield of rice under submerged condition and have reported that organic manure addition irrespective of the form in which it is applied, resulted in the accumulation of organic carbon of the soil, increased the CEC and exchangeable cations especially K. Singh and Patiram (1977) reported that FYM application significantly increased the P uptake in acid soils. According to Singh *et al.* (2001) the full recommended dose of N and organic sources applied either alone or in combination with prilled urea increased the grain yield, straw yield, yield attributing characters, nutrient uptake and net return in rice.

In an experiment conducted on INM at RARS, Pattambi, Mathew *et al.* (1994) reported higher plant height and tiller count of rice with the combined use of 10 t ha^{-1} FYM and chemical fertilizers. Babu (1996) observed that the integration of FYM @ 10 t ha^{-1} along with chemical fertilizers could increase the plant height, tiller count, leaf area index, chlorophyll content and dry matter production of medium duration rice variety Pavizham in a study at RRS, Monocompu. He also reported an increased grain yield for the medium duration rice upto 5.6 t ha^{-1} with the combined application of organic manures and chemical fertilizers.

Mondal *et al.* (1994) observed an increase in panicles, number of grains, number of panicles and thousand grain weights in rice with increased NPK rates along with FYM application. Anilakumar *et al.* (1993) obtained 7.6 percentage increases in grain yield of rice by the combined application of FYM and NPK than the application of NPK alone. Singh *et al.* (1996) reported that the substitution of 25 percentage of N through FYM, particularly at higher N rates, increased the rice yield. Gupta *et al.* (2000) reported that sesbania green manure alone was capable of producing and sustaining more than 6 t/ha rice yield equal to more than 120 kg inorganic N.

Roy *et al.* (1997) observed higher grain yield of rice with combined application of NPK @ 90:60:90 kg ha^{-1} along with 10 t FYM. Mandal and Chettri (1998), while studying the effect of integrated nutrient management on productivity and fertility building under rice based cropping system, noticed significantly higher grain yield up to 5.3 t ha^{-1} in rice with 50 per cent of the recommended NPK through chemical fertilizers along with 10 t ha^{-1} FYM. Lal and Mathur (1989) reported that the application of chemical fertilizers in combination with FYM could regulate the nutrient uptake from the soil. The combined use of 12 t of FYM and 80 kg ha^{-1} of nitrogen not only gave the comparable rice yield as that with 120 kg N ha^{-1}, but also contributed a residual effect equivalent to 30 kg each of N and P for the succeeding wheat crop (Meelu, 1981). According to Kumar and Yadav (1995) farm yard manure and susbania green manure were superior to wheat straw for increasing grain yield and NPK uptake in rice.

Mishra and Sharma (1997) observed appreciable build up of NPK in the soil with the integrated application of fertilizers and FYM. Deepa (1998) reported higher status of available NPK. According to Lakshmikanthan (2000), sodium silicate application at the rate of 500 kg ha^{-1} recorded an increase in grain yield of 632 kg ha^{-1}. The immediate increase in yield has also depleted the organic carbon from the soil. Soil at harvest with integrated nutrient management, which supplied 50 per cent of the recommended N through FYM and the rest through chemical fertilizers for the rice variety Kanchana. Takur *et al.* (1999) observed an increase in available P and organic carbon but a decrease in the level of soil K in the treatments with organic substances.

Ritamani *et al.* (1999) reported significant increase in the available NPK, uptake of NPK and yield in the treatment receiving both the organic and inorganic sources. Moreover, organic matter treated soil showed a better residual effect as compared to the soil where the chemical fertilizers were applied. The continuous addition of lignite fly ash resulted in significant increase in pH, EC, exchangeable Na, available P, K, Ca, Mg, S and Si in the post harvest soil after the fourth crop of rice. The increase in pH was not significant. The results also confirmed that even after continuous addition of fly ash for three seasons, there was no hazardous level of heavy metal content (Selvakumar *et al.*, 2000).

Anand *et al.* (2000) revealed that the soil organic carbon, available Zn and Mn in receiving fertilizer treatments were significantly lower compared to the treatments involving organic source in Haryana. Reddy and Shivaraj (1999a) reported that the yield of all cultivars was high with FYM in kharif, while in summer, the yield of KRH-1 was highest with the poultry manure followed by FYM and that for Jaya with NPK followed by green manure. FYM reduced the soil pH and salinity, while the poultry manure increased them. Brar *et al.* (1995) reported that 12 t. FYM gave the highest grain yield of 6.7 t for rice in rice-wheat rotation. Soil fertility or residual effects of FYM did not significantly affect wheat grain yields. The application of FYM to rice increased N and P uptake in rice and P and K in wheat.

Application of FYM in conjunction with fertilizers had also been found to increase soil fertility significantly besides increasing rice yield. The organic carbon content and NPK status of soil were reduced by the application of fertilizer alone. (Kumar, 2002). According to Premi (2003), Dhainchia and Sunhemp proved significantly superior to FYM and BGA. Combined use of inorganic sources of N increased the organic carbon content, NPK and decreased the bulk density of the soil. The combined application of FYM @10 t ha^{-1} and @ neem cake (3 t ha^{-1}) to substitute 150 Kg N ha^{-1} in rabi and 8 t FYM ha^{-1} and 5.7 t ha^{-1} of neem cake in kharif were beneficial in achieving the higher nutrient uptake and grain yield.

Vats *et al.* (2001) reported that the yearly application of organic manure @ 15 t ha^{-1} in conjuction with the fertilizers had a pronounced effect in enhancing the efficiency of chemical fertilizers leading to improved crop productivity by 16 to 44 per cent. In addition to yield gains, organic manure had also significantly increased the availability of limiting nutrients in the soil. According to Pandey *et al.* (2001), the complementary use of organics and inorganics were advantageous and substantial amount of fertilizers could be saved for the rice crop by the use of organic manures.

From the above review, the following general trends are noted:

1. High accumulation of Fe and Mn in the soil, removal of silica, higher content of Fe in the plant, chlorophyll instability etc. is some of the yield limiting factors of rice in laterite soils. The potential production of HYV cannot be exploited under such situations.

2. Application of organics alone will not be able to meet the nutrient requirement. Hence, the fertilizers alone will degrade the soil and hence combined application is a workable way to sustain the productivity.

3. Rice responds to higher levels of N and K levels and reduction of P will help to prevent the soil degradation and maintain the soil fertility.

4. Rice is a known silica accumulator and the application of silica has shown increase in the yield of rice.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled "Integration of nutritional inputs for improving rice productivity in laterite soils" was taken up at the College of Horticulture, Vellanikkara during 2001-03.

3.1. Materials

3.1.1. Site, Weather and Soil

The experiment was laid out at the Agricultural Research Station, Mannuthy located at 10° 31' N latitude, 76° 13' E longitude and at an altitude of 40.29 m above sea level.

The area enjoys a typical humid tropical climate. The mean weekly averages of the important meteorological parameters observed during the experimental period are presented in Appendix-I and Fig.1 and 2.

The mean maximum temperature experienced during the period of study was 29.83°C, while the mean minimum temperature was 23.36°C with an average mean of 26.59°C.

The soil type of the experimental area was laterite loamy sand of the Ultisol group with a pH of 5.3 (Appendix-II)

3.1.2. Season

The study was taken up during the first crop season (May – September) of the year 2002.

Fig.1. Weather data during the crop period (5/2002 to 9/2002)

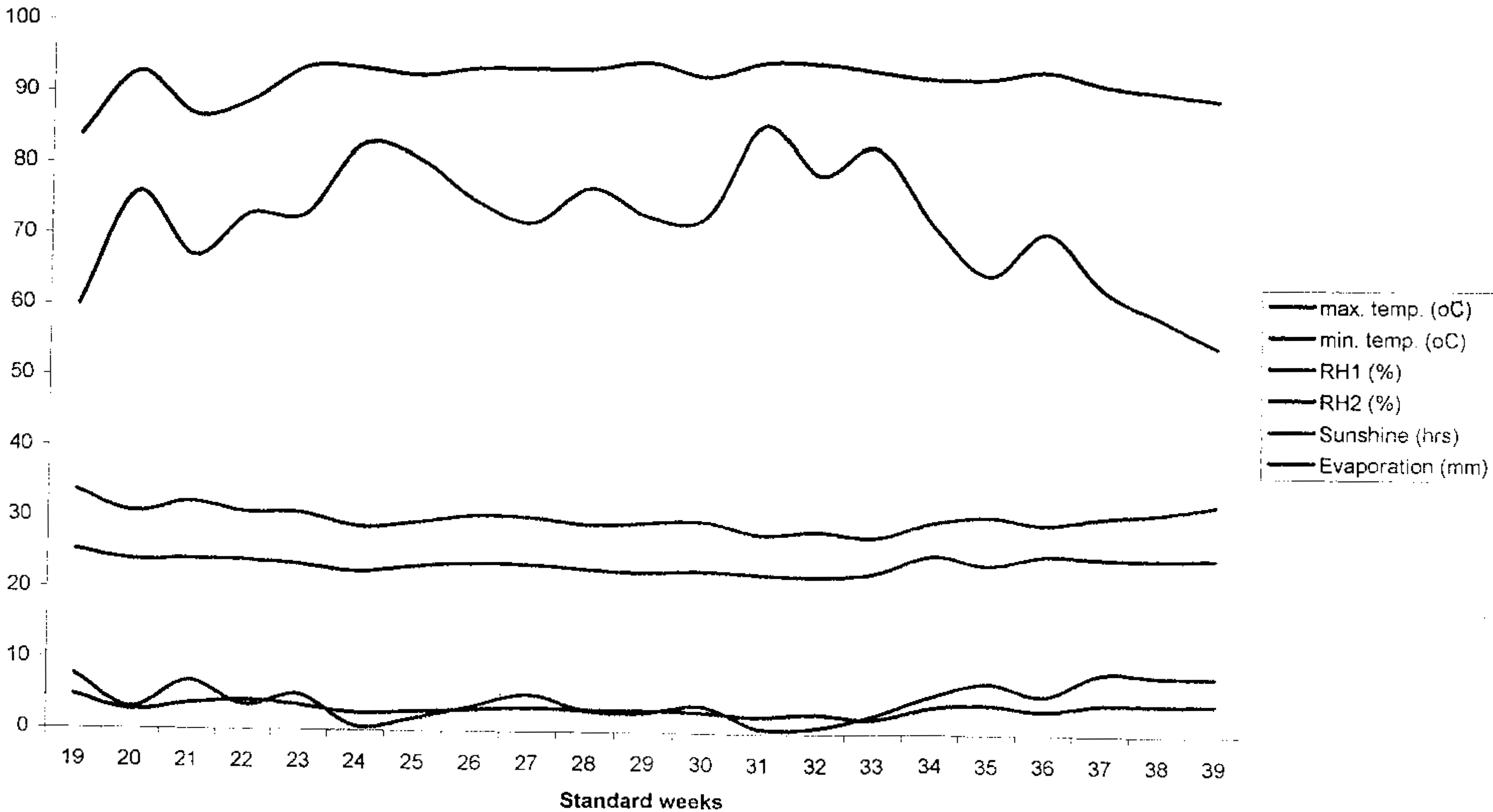
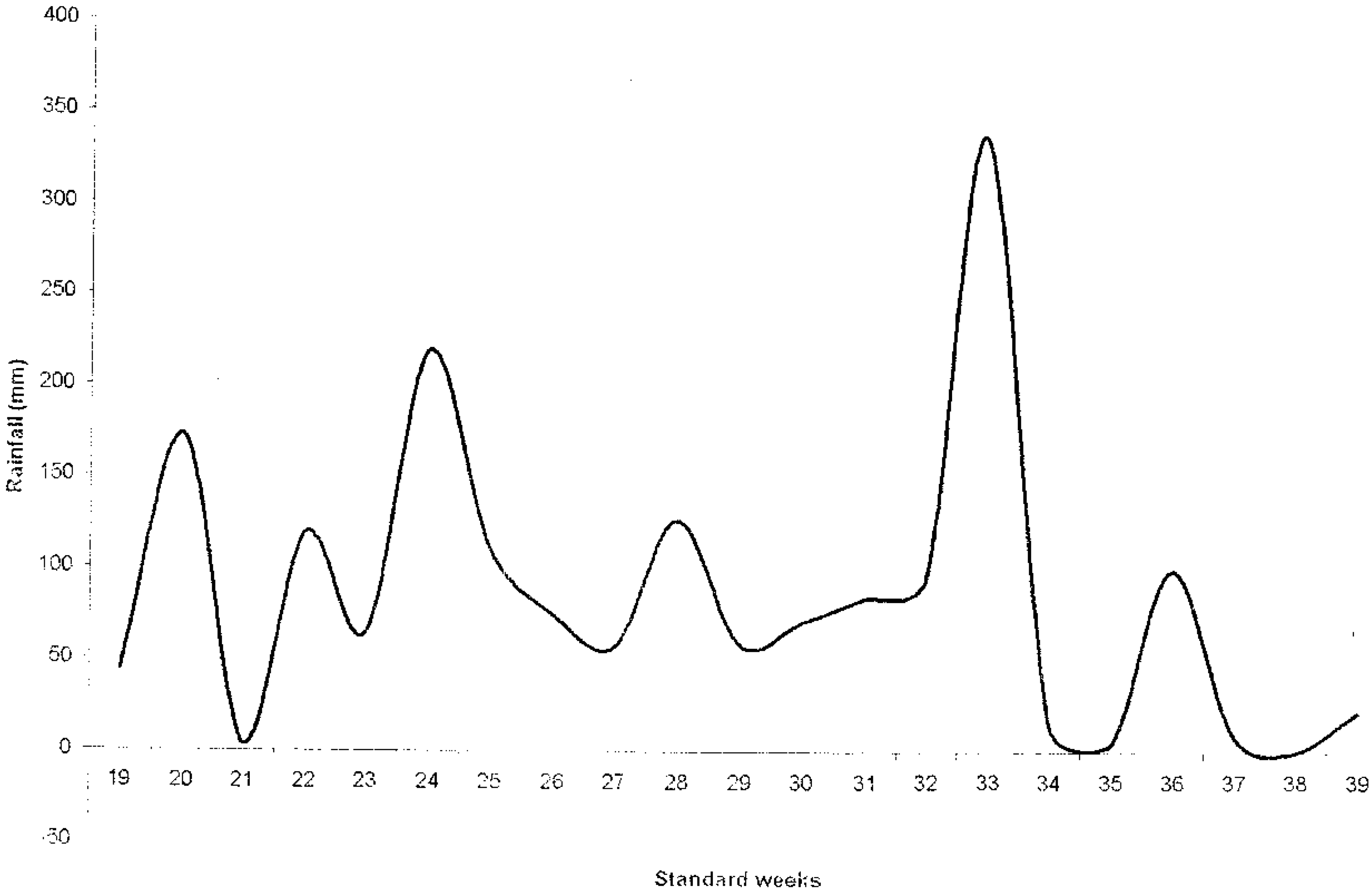


Fig.2. Rainfall data at Vellanikkara during the crop period (5/2002 to 9/2002)



3.1.3. Variety

The rice cultivar, Jyothi, a red kernelled, short duration variety of 110-125 days duration was used for the experiment. This variety is moderately tolerant to BPH and blast disease, susceptible to sheath blight and capable of producing over 8 t ha^{-1} under favourable situations and moderately good yields even under adverse conditions.

3.1.4. Cropping history of the experimental site

The experimental area belonged to a typical single cropped wetland.

The field was under bulk cropping of rice in the previous season.

3.2. Methods

3.2.1. Lay out

The experiment was laid out in randomized block design with three replications and 17 treatments in each replication (Fig.3). The view of the experimental field is presented in Plate I. The individual treatment plot size was 5m x 4 m.

3.2.2. Technical programme

Seeds were sown in the nursery and twenty three days old seedlings were transplanted from the nursery into a well puddled and levelled field at a spacing of 15 cm x 10 cm with 2 seedlings per hill. Date of sowing, transplanting and harvesting are given below.

Particulars	Date
Nursery sowing	23-05-02
Transplanting	26-06-02
Harvesting	28-09-02
Duration	129 days

Plate 1. A view of the experimental field

3.2.2.1. Treatment details

There were 17 treatments including two sources of organic manure and two levels of nutrition.

1. Two sources of organic manure (cow dung and poultry manure) to make up the levels 1:1.25, 1:2.25 and 1:3.5 based on nitrogen equivalents

   In addition to the recommended dose of 5 t ha $^{-1}$ of farm yard manure, 20 kg N was supplied through organic manure either as cow dung or poultry manure out of the recommended 70 kg fertilizer nitrogen (T_1 and T_9). Here the ratio of organic: inorganic was 1:1.25.

   Considering the expected level of crop removal as revealed from the earlier studies, the dose of fertilizer N was increased to 110 kg ha^{-1} of which 20 kg fertilizer N was substituted by organic manure (T_2 and T_{10}). The ratio of organic: inorganic was 1:2.25.

   These two sets were compared with the present recommendation consisting of 5 t ha^{-1} of farmyard manure and 70:35:35 kg NPK ha^{-1}. The ratio between organic to inorganic nitrogen was 1:3.5 (T_{17}).

2. Two levels of nutrition based on the results of the experiments conducted so far.

   phosphorus @ 20 kg ha^{-1} and potassium @ 120 kg ha^{-1} were applied to all the treatments by considering the crop removal as revealed from the earlier studies. The treatments T_1 to T_{16} received P and K based on the crop removal while in T_{17} P and K @ 35 K kg ha^{-1} was given as per the package of practices recommendations.

   Combination of these two were supplemented with lime alone, silica alone and lime + silica.

Treatments

T_1- Cow dung 5t ha $^{-1}$+ 50 kg N (fertilizer)

T_2- Cow dung 5t ha $^{-1}$+ 90 kg N (fertilizer)

T_3 -T_1+Lime @ 150 kg ha^{-1}

T_4 -T_1+Silica @ 500 kg ha^{-1}

T_5 –T_1+Lime @ 150 kg ha^{-1}+ Silica @ 500 kg ha^{-1}

T_6 – T_2+ Lime @ 150 kg ha^{-1}

T_7- T_2+Silica @ 500 kg ha^{-1}

T_8- T_2+Lime @ 150 kg ha^{-1}+ Silica @ 500 kg ha^{-1}

T_9- Poultry manure 1.6t ha^{-1} + 50 kg N (Fertilizer)

T_{10} - Poultry manure 1.6t ha^{-1} + 90 kg N (Fertilizer)

T_{11}- T_9 + Lime @ 150 kg ha^{-1}

T_{12}- T_9+Silica @ 500 kg ha^{-1}

T_{13}- T_9+Lime @ 150 kg ha^{-1}+ Silica @ 500 kg ha^{-1}

T_{14}- T_{10} + Lime @ 150 kg ha^{-1}

T_{15}- T_{10}+Silica @ 500 kg ha^{-1-1}

T_{16}- T_{10}+Lime @ 150 kg ha^{-1}+ Silica @ 500kg ha

T_{17} – Control (Package of practices recommendations, KAU)

(Cow dung 5 t ha^{-1}+70:35:35 NPK kg ha^{-1} + Lime @ 600 kg ha^{-1})

Urea, Ammonium suphate, Rajphos, Muriate of potash, Lime and Sodium silicate were used as the sources of different nutrients. The nutrient content of the sources is presented below.

Fig. 3 Layout plan

N

R3

T_9	T_{17}	T_{10}	T_1	T_{11}	
T_3	T_5	T_{14}	T_8	T_{15}	T_7
T_{13}	T_4	T_6	T_{16}	T_2	T_{12}

R2

T_{16}	T_{15}	T_{14}	T_8	T_{11}	
T_1	T_6	T_5	T_3	T_{10}	T_{12}
T_{13}	T_2	T_{17}	T_9	T_4	T_7

R1

T_{11}	T_{14}	T_2	T_4	T_{12}	
T_9	T_7	T_{16}	T_6	T_1	T_{15}
T_3	T_5	T_{17}	T_8	T_{13}	T_{10}

4m

5 m

T_1- Cow dung 5t ha^{-1}+ 50 kg N (fertilizer)
T_2- Cow dung 5t ha^{-1}+ 90 kg N (fertilizer)
T_3 -T_1+Lime @ 150 kg ha^{-1}
T_4 -T_1+Silica @ 500 kg ha^{-1}
T_5 –T_1+Lime + Silica
T_6 – T_2+ Lime @ 150 kg ha^{-1}
T_7-T_2+Silica @ 500 kg ha^{-1}
T_8- T_2+Lime + Silica
T_9- PM 1.6t ha^{-1} + 50 kg N (Fertilizer)
T_{10}- PM 1.6t ha^{-1} + 90 kg N (Fertilizer)
T_{11}- T_9 + Lime @ 150 kg ha^{-1}
T_{12}- T_9+Silica @ 500 kg ha^{-1}
T_{13}- T_9+Lime + Silica @ 500 kg ha^{-1}
T_{14}- T_{10} + Lime @ 150 kg ha^{-1}
T_{15}- T_{10}+Silica @ 500 kg ha^{-1}
T_{16}- T_{10}+Lime + Silica
T_{17}- Control (Package of Practices Recommendation) (Cow dung 5t ha^{-1}+70:35:35 NPK kg ha^{-1}+lime 600 kg ha^{-1})

Chemical composition of sources of nutrients

Sources of nutrients	Nutrient	Nutrient content %
Urea	Nitrogen (N)	46
Rajphos	Phosphorus (P_2O_5)	18-20
MOP	Potassium (K_2O)	60
Lime	Calcium (Ca)	71.4
Sodium silicate	Silica (SiO_2)	40
Ammonium sulphate	Nitrogen (N)	20

The content of nutrients in the cow dung and poultry manure is also furnished in Appendix V. Plant protection measures were adopted according to necessity. All the cultural operations were carried out as per the Package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

3.2.2.2. Soil and Plant Sampling

Soil samples were taken to evaluate the initial status before starting the experiment and post harvest samples were also drawn from each treatment plot for analysing the nutrient content in the soil.

Regarding plant sampling, 3 stakes were driven randomly and four hills around each stake were maintained for taking observations on growth characters. Six hills were collected randomly as destructive samples from each plot at 35 DAT, 70 DAT, 50 per cent flowering and at harvest for estimating the dry matter production and the nutrient content.

3.2.3. Observations

3.2.3.1. Growth characters

a) Plant height: Height of plants (cm) was measured from the bottom of the plant up to the tip of the longest leaf at 35 DAT, 70 DAT, 50% flowering and at harvest.

b) Number of tillers: The number of tillers was counted at 35 DAT, 70 DAT, 50% flowering and at harvest and expressed as the number of tillers per hill.

c) Dry matter production: The dry weight of the plants at different intervals was taken and used to estimate the total dry matter production (kg ha^{-1}).

3.2.3.2. Yield attributes

a) Number of productive tillers per hill: The number of productive tillers of twelve hills was counted from each individual plot at harvest and the average was worked out.

b) Number of spikelets per panicle: The number of spikelets in each panicle of the twelve observation hills was counted and the average was worked out.

c) Length of panicle: The Length of panicle was measured in cm from the base to the tip of the panicle.

d) Percentage of filled grains: The number of filled grains per panicle was counted and the percentage was worked out.

e) Percentage of chaff: The number of chaffy grains was recorded and expressed on percentage basis.

f) Test weight: Thousand filled grains were collected randomly from samples taken from each plot and the weight was recorded in grams.

g) Grain Yield: All the hills in the net plot area were harvested, threshed and dried to a constant weight. The dry weight was recorded as kg ha^{-1}

h) Straw yield: The straw yield was also recorded on dry weight basis and expressed as kg ha^{-1}

i) Nutrient content: Content of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Si and Na was estimated and expressed as percentage or parts per million (ppm).

j) Nutrient uptake: Uptake of nutrient was calculated from the dry weight of grain and straw and the nutrient content.

3.2.3.3. Other Observations

a. Population of weeds: Number of weeds per square meter in each plot was counted at 20 and 40 DAT. A 0.25 m^2 quadrant was driven randomly at different points and the total number of weeds was worked out.

b. Pest and disease incidence: Scoring for the incidents of pests was done according to the standard procedure (IRRI, 1996). Ten hills in the third row of each plot were rated in accordance with the scale (0- 9) and the percentage was recorded.

3.2.4. Soil analysis

The soil samples were analyzed before and after conducting the experiment.

3.2.5. Chemical analysis

The plant samples were oven dried, ground and subjected to nutrient analysis following the standard procedures (Appendix III). The soil samples in each treatment plot were also analyzed using the standard procedures (Appendix IV).

3.2.6. Statistical analysis

Statistical analysis was done using the analysis of variance technique (Panse and Sukhatme, 1978). MSTATC and MS-Excel Softwares were used for computation and analysis.

RESULTS

4. RESULTS

The results pertaining to the studies on "Integration of nutritional inputs for improving rice productivity in laterite soils" are furnished below:

4.1. Growth characters

4.1.1. Height of plants

The height of plants at different growth stages is furnished in Table 1. It is seen that there was significant difference in height among the treatments at all the stages of growth.

At the maximum tillering stage, T_{13} (Poultry manure +50 Kg N + lime + silica) recorded the maximum height (37 cm), which was on par with other treatments except T_1, T_{15} and T_{17}. The treatment receiving the POP recommendation (T_{17}) has recorded the minimum height of 28.62 cm.

At the PI stage, the treatment receiving cow dung + 90 Kg N + lime + silica (T_8) showed the highest value (65.61 cm) followed by T_{16} (Poultry manure +90 Kg N+ lime + silica) and were on par with T_5, T_7, T_{10}, T11, T_{12}, T_{13}, T_{14} and T_{15}. The control plot recorded the minimum of 56.02 cm.

The same trend was noticed at 50 per cent flowering where T_8 had the maximum height of 86.51 cm, which was on par with T_7, T10, T13, T15 and T_{16}. The minimum of 74.49 cm was seen in the control plants.

At the time of harvest, T_{15} receiving poultry manure 1.6 t +90 Kg N + silica recorded the maximum height of 96.57 cm and it was 20 per cent more than in the control plot.

Table 1. Height of plants at different stages of growth of rice as influenced by the treatments

Treatments	Height (cm)			
	Maximum tillering	Panicle initiation	50% flowering	Harvest
T_1-Cd + 50 kg N	33.24	56.00	75.29	85.75
T_2-Cd + 90 kg N	34.95	58.44	78.79	88.41
T_3-Cd + 50 kg N + Lime	34.00	58.30	76.62	82.78
T_4-Cd + 50 kg N + Silica	34.24	60.38	81.04	86.41
T_5-Cd + 50 kg N + lime + silica	33.58	60.80	79.16	88.99
T_6-Cd + 90 kg N + Lime	34.50	60.38	79.12	89.30
T_7-Cd + 90 kg N + silica	34.12	61.30	83.70	89.49
T_8-Cd + 90 kg N+ lime + silica	34.58	65.61	86.51	91.14
T_9-PM + 50 kg N	35.83	59.88	77.87	86.42
T_{10}-PM + 90 kg N	36.20	61.66	84.25	88.62
T_{11}-PM + 50 kg N + lime	34.45	63.24	80.33	89.34
T_{12}-PM + 50 kg N + silica	34.08	62.36	81.70	88.61
T_{13}-PM + 50 kg N + lime + silica	37.00	61.72	85.05	92.63
T_{14}-PM + 90 kg N + lime	33.70	61.33	80.41	89.43
T_{15}-PM + 90 kg N + silica	33.08	62.69	82.54	96.57
T_{16}-PM + 90 kg N + lime + silica	34.75	65.21	85.24	91.29
T_{17}- control (package of practices)	28.62	56.02	74.49	80.71
SEm ±	1.281	1.752	1.573	0.237
CD (0.05)	3.678	5.020	4.150	0.68

Cd-cow dung @5 t ha^{-1} **PM**- poultry manure @1.6 t ha^{-1} **Lime**-@150 kg ha^{-1} **Silica**-@500 kg ha^{-1} **POP**-Cd@ 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime @600 kg ha^{-1}

The observation on height revealed that the addition of PM and silica is beneficial for increasing the height of rice plant. Rice plants responded well to the higher dose of nitrogen.

4.1.2. Number of tillers

The number of tillers per hill at different growth stages is recorded in Table 2. It shows that there was significant difference in the number of tillers among the treatments, at all the stages of growth.

At the maximum tillering stage, T_{16} recorded the maximum number of tillers (6.24) and was on par with other treatments except T_1, T_7, T_{11} and T_{17}. The treatment receiving T_1 recorded the minimum number of tillers (4.87).

Similarly at the panicle initiation stage, the treatment T_{14} recorded the highest number of tillers (9.23), which was on par with T_6, T_8, T_9, T_{11}, T_{12}, T_{15}, T_{16} and T_{17}. The treatment T_{10} recorded the lowest number of tillers (7.15).

At the time of 50 per cent flowering, T_{14} showed the maximum number of tillers per hill (7.74) while T_1 recorded the lowest number (5.87). T_{14} was on par with all other treatments except T_1, T_5, T7 and T_{17}.

During the harvesting stage, the tiller number ranged from 6.41 in T_3 to 8.18 in T_{14}. T_{14} was also on par with T_8 and T_{15}.

The observations on the number of tillers revealed that substitution of N by organic manures along with increased dose of N, lime and silica enhanced the tillering capacity of rice plants.

4.1.3. Dry matter production

The dry matter production at different growth stages of rice is furnished in Table 3. It shows that there was significant difference among all the treatments the all stages except the panicle initiation stage.

Table 2. Number of tillers at different stages of growth of rice as influenced by the treatments

Treatments	Number of tillers (no. hill $^{-1}$)			
	Maximum tillering	Panicle initiation	50% flowering	Harvest
T_1-Cd + 50 kg N	4.87	7.35	5.87	7.09
T_2-Cd + 90 kg N	5.29	7.99	6.58	7.39
T_3-Cd + 50 kg N + Lime	5.62	8.02	7.39	6.41
T_4-Cd + 50 kg N + Silica	5.74	7.73	7.16	6.45
T_5-Cd + 50 kg N + lime + silica	5.33	7.67	6.54	6.43
T_6-Cd + 90 kg N + Lime	5.50	8.62	6.66	7.35
T_7-Cd + 90 kg N + silica	4.87	7.29	6.12	6.85
T_8-Cd + 90 kg N+ lime + silica	5.33	8.6	7.66	8.06
T_9-PM + 50 kg N	5.83	8.16	7.03	6.87
T_{10}-PM + 90 kg N	5.49	7.15	6.73	6.82
T_{11}-PM + 50 kg N + lime	5.09	8.25	6.7	7.46
T_{12}-PM + 50 kg N + silica	6.08	8.88	7.54	6.55
T_{13}-PM + 50 kg N + lime + silica	6.12	7.79	6.74	7.35
T_{14}-PM + 90 kg N + lime	5.98	9.23	7.74	8.18
T_{15}-PM + 90 kg N + silica	5.5	8.33	6.7	7.98
T_{16}-PM + 90 kg N + lime + silica	6.24	8.08	7.29	7.25
T_{17}- control (package of practices)	4.99	8.85	6.21	6.98
SE m ±	0.350	0.401	0.406	0.150
CD (0.05)	1.004	1.15	1.16	0.43

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

Table 3. Dry matter production at different stages growth of rice as influenced by the treatments

Treatments	Maximum tillering (kg ha^{-1})	Panicle initiation (kg ha^{-1})	50% flowering (kg ha^{-1})	Harvest (kg ha^{-1})
T_1-Cd + 50 kg N	1331	3498	4730	11264
T_2-Cd + 90 kg N	2255	4798	8263	12980
T_3-Cd + 50 kg N + Lime	2398	4345	6437	13288
T_4-Cd + 50 kg N + Silica	2490	4349	8017	13112
T_5-Cd + 50 kg N + lime + silica	2129	4453	7766	12760
T_6-Cd + 90 kg N + Lime	2171	3969	8252	11748
T_7-Cd + 90 kg N + silica	3348	4393	9396	14784
T_8-Cd + 90 kg N+ lime + silica	3289	5232	8683	15576
T_9-PM + 50 kg N	2528	4004	7916	13068
T_{10}-PM + 90 kg N	2735	4363	7513	12760
T_{11}-PM + 50 kg N + lime	2059	4105	8617	11308
T_{12}-PM + 50 kg N + silica	3588	3617	9115	12100
T_{13}-PM + 50 kg N + lime + silica	2578	4809	7128	12056
T_{14}-PM + 90 kg N + lime	2222	4697	7401	12628
T_{15}-PM + 90 kg N + silica	2974	4121	8994	11572
T_{16}-PM + 90 kg N + lime + silica	2952	4532	8961	14124
T_{17}- control (package of practices)	1901	3577	6871	12452
SE m ±	244.8	372.7	715.3	791.7
CD (0.05)	702	NS	2052.7	2272

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 600 kg ha^{-1}

At maximum tillering stage, the dry matter production was highest for T_{12} (3588 kg ha^{-1}), which was on par with T_7, T_8, T_{15} and T_{16} while the least was in T_1 (1331 kg ha^{-1}).

The dry matter production at the panicle initiation stage was the maximum for T_8 (5232 kg ha^{-1}) and the minimum in T_1 (3498 kg ha^{-1}).

At 50 per cent flowering stage, the highest dry matter production was observed in T_7 (9396 kg ha^{-1}), which was on par with all other treatments except T_1,T_3,T_{13} and T_{17}.T_1 had the minimum value of 4730 kg ha^{-1}.

During the harvesting stage, maximum dry matter production was noticed in T_8 (15576 kg ha^{-1}) and was on par with T_7 and T_{16}.T_1 recorded the lowest value of 11264 kg ha^{-1}.

4.2. Nutrient content in plants

4.2.1. Nutrient content at the maximum tillering stage

The details of major, secondary and micronutrient content in rice plants is presented in Table 4. The values were significantly different except for P and Ca.

The N concentration in rice plants was highest in T_7 (3.81%) and was on par with T_3, T_9, T_{12}, T_{15} and T_{16}. It was the least in T_1 (2.07%). In the case of P content, the highest value was recorded in T_1 (1.006%) while the least value was 0.240 per cent in T_{17} though not significant. Potassium content was significantly higher in T_{16} (3.36%), which was on par with T_1, T_4 and T_{15} while the least was in T_2 (2.28%).

The highest content of Ca (0.48%) was observed in T_{17}. For Mg, the highest value was obtained in the case of T_3 (0.366%), which was on par with T_{16} and the least was observed in T_4 (0.096%). Regarding sulphur, the highest value was obtained in T_9 (2833 ppm) and was on par with T_7, T_{11} and T_{14}. The lowest value was in T_{17} (1371 ppm).

Table 4. Effects of treatments on nutrient content of rice plant at maximum tillering stage

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (%)	SiO_2 (%)
T_1-Cd + 50 kg N	2.07	1.006	3.23	0.360	0.168	2573	2520	453.3	30.00	80.0	0.150	2.62
T_2-Cd + 90 kg N	2.76	0.279	2.28	0.360	0.288	2509	1700	546.6	30.00	33.33	0.050	2.69
T_3-Cd + 50 kg N + Lime	3.54	0.316	2.58	0.440	0.366	2625	2487	533.3	33.33	46.66	0.100	2.78
T_4-Cd + 50 kg N + Silica	2.33	0.307	3.23	0.360	0.096	2645	1247	460.0	43.33	46.66	0.250	2.79
T_5-Cd + 50 kg N + lime + silica	2.52	0.315	2.81	0.400	0.120	1714	1087	366.6	36.66	66.66	0.400	2.79
T_6-Cd + 90 kg N + Lime	2.82	0.374	3.03	0.440	0.192	1575	1877	663.3	43.33	30.00	0.150	2.77
T_7-Cd + 90 kg N + silica	3.81	0.342	2.91	0.360	0.192	2740	1060	596.6	40.00	30.00	0.467	2.92
T_8-Cd + 90 kg N+ lime + silica	2.93	0.398	2.83	0.440	0.216	2493	1683	420.0	66.66	120.00	0.400	3.00
T_9-PM + 50 kg N	3.64	0.257	2.61	0.440	0.216	2833	1310	550.0	66.66	23.33	0.050	2.83
T_{10}-PM + 90 kg N	3.23	0.375	3.08	0.360	0.200	2557	1443	576.6	30.00	40.00	0.200	2.85
T_{11}-PM + 50 kg N + lime	2.89	0.375	3.15	0.440	0.288	2659	1540	400.0	73.33	60.0	0.050	2.84
T_{12}-PM + 50 kg N + silica	3.55	0.371	2.88	0.440	0.144	2623	1523	523.3	33.33	86.66	0.267	2.88
T_{13}-PM + 50 kg N + lime + silica	2.93	0.367	3.16	0.400	0.264	2829	1590	593.3	60.00	46.66	0.417	2.08
T_{14}-PM + 90 kg N + lime	2.89	0.350	2.80	0.400	0.144	2652	2867	683.3	53.33	56.66	0.050	2.84
T_{15}-PM + 90 kg N + silica	3.51	0.377	3.20	0.360	0.200	1612	977	476.6	30.00	43.33	0.367	2.93
T_{16}-PM + 90 kg N + lime + silica	3.71	0.410	3.36	0.400	0.328	1532	1830	480.0	40.00	86.66	0.583	3.05
T_{17}- control (package of practices)	2.37	0.240	2.70	0.480	0.168	1371	1830	443.3	33.33	36.66	0.200	2.56
SE m ±	0.106	0.180	0.054	0.00	0.021	64.05	59.43	39.35	3.34	6.28	0.013	0.037
CD (0.05)	0.30	NS	0.16	NS	0.06	183.8	170.5	112.9	9.6	18.02	0.038	0.108

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

Regarding the micronutrients, T_{14} had the maximum Fe content of 2867 ppm while T_{15} recorded the minimum of 976.6 ppm. Mn content was also higher in T_{14} (683.3 ppm), which was on par with T_6, T_7, T_{10} and T_{13}. Content of Zn was highest in T_{11} (73.33ppm) while the minimum value of 30 ppm was recorded in T_1, T_2, T_{10} and T_{15}.

In the case of Cu, the highest value was in T_8 (120 ppm) and the least value of 30 ppm was in T_6 and T_7. For Na, the highest value was obtained for T_{16} with 0.583 per cent and T_2, T_9, T_{11} and T_{14} recorded the lowest content of 0.050 per cent. Silica content was significantly higher in T_{16} and T_8 with values of 3.05 and 3.00 respectively. T_{13} recorded the minimum value of 2.08.

4.2.2. Nutrient content at the panicle initiation stage

Table. 5 represent the content of nutrients at the panicle initiation stage. There was significant difference among the treatments for all the nutrients except Mg and Cu.

The concentration of N in the rice plant was highest in T_8 and T_{10} with a value of 2.13 per cent and was on par with T_6. The least value was noted in T_{15} (1.66%). In the case of P content, the highest value was recorded in T_7 (0.433%), which was on par with T_8 (0.413%), while the minimum was noticed in T_{17} (0.277%). Potassium content was the highest in T_8 (3.53%), which was on par with T_7 (3.36%) and the lowest in T_{17} (2.58%).

Calcium content was significantly superior in T_{17} (0.493%) and the least value (0.333 %) was in T_7. Magnesium content was highest for T_5 (0.272%) though not significant and the least was recorded for T_1 (0.168 %). Control plots (T_{17}) contained the maximum of sulphur (6233 ppm) but were on par with T_4 whereas T_6 had the minimum of 641.4ppm.

In the case of Fe, the highest value was obtained for T_{15} (1500 ppm) and on par with other treatments except T_5, T_6, T_8 and T_{14}. The least was obtained in T_8 (616.6 ppm). For Mn, the highest value was noticed in T_7 (643.3 ppm), which

Table 5. Effect of treatments on nutrient content of rice plant at panicle initiation stage

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (%)	SiO_2 (%)
T_1-Cd + 50 kg N	1.86	0.298	3.18	0.413	0.168	891	1103	606.7	33.33	30.0	0.100	2.25
T_2-Cd + 90 kg N	2.01	0.371	3.10	0.387	0.216	2709	1333	500.0	40.00	23.38	0.05	2.30
T_3-Cd + 50 kg N + Lime	1.91	0.365	3.20	0.427	0.192	1643	1093	456.7	36.66	33.33	0.350	2.23
T_4-Cd + 50 kg N + Silica	1.95	0.372	2.90	0.387	0.200	5009	1267	516.7	33.33	16.66	0.05	2.39
T_5-Cd + 50 kg N + lime + silica	1.89	0.350	3.05	0.373	0.272	1816	880	556.7	26.66	30.00	0.100	2.35
T_6-Cd + 90 kg N + Lime	2.04	0.367	2.70	0.387	0.192	641	940	456.7	46.66	46.66	0.433	2.29
T_7-Cd + 90 kg N + silica	1.99	0.433	3.36	0.333	0.232	943	1260	643.3	40.00	40.00	0.400	2.42
T_8-Cd + 90 kg N+ lime + silica	2.13	0.413	3.53	0.413	0.264	1172	617	503.3	40.00	26.66	0.100	2.42
T_9-PM + 50 kg N	1.99	0.347	2.98	0.440	0.224	1172	1363	623.3	43.33	23.33	0.100	2.38
T_{10}-PM + 90 kg N	2.13	0.353	3.15	0.387	0.216	1219	1233	633.3	36.66	36.66	0.100	2.32
T_{11}-PM + 50 kg N + lime	1.79	0.370	2.90	0.413	0.184	1077	1353	520.0	30.00	23.33	0.200	2.30
T_{12}-PM + 50 kg N + silica	1.96	0.335	3.23	0.387	0.192	950	1180	530.0	36.66	23.33	0.417	2.26
T_{13}-PM + 50 kg N + lime + silica	1.82	0.385	2.93	0.347	0.232	859	1117	426.7	36.66	26.66	0.150	2.48
T_{14}-PM + 90 kg N + lime	1.90	0.363	3.15	0.427	0.208	1544	723	536.7	26.66	26.66	0.150	2.34
T_{15}-PM + 90 kg N + silica	1.66	0.398	3.08	0.360	0.232	886	1500	506.7	26.66	23.33	0.150	2.39
T_{16}-PM + 90 kg N + lime + silica	1.78	0.399	3.31	0.413	0.200	1020	1273	483.3	36.66	20.00	0.383	2.51
T_{17}- control (package of practices)	1.75	0.277	2.58	0.493	0.224	6233	1383	613.3	36.66	36.66	0.05	3.55
SE m ±	0.038	0.011	0.065	0.017	0.026	557.8	151.3	40.92	3.87	8.46	0.006	0.025
CD (0.05)	0.11	0.032	0.18	0.049	NS	1601	434.0	117.4	11.11	NS	0.019	0.07

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 600 kg ha^{-1}

was on par with T_1, T_5, T_9, T_{10}, T_{12}, T_{14} and T_{17}. While the lowest value was recorded in T_{13} (426.7ppm).

The treatment receiving T_6 had the maximum Zn content of 46.66 ppm, which was on par with all other treatments except T_1, T_4, T_5, T_{11}, T_{14} and T_{15}. The treatments T_5,T_{14} and T_{15} had the lowest value being 26.66 ppm. Similarly content of Cu was also highest in T_6 (46.66 ppm) and lowest in T_4 (16.66ppm) though not significant. Sodium content was highest in T_6 (0.433%), which was on par with T_{12} while the least was obtained in T_2, T_4 and T_{17} with a value of 0.050 per cent. Similarly in the case of silica content, the highest value was obtained in T_{17} (3.55%) and the least was noticed in T_3 (2.23%).

4.2.3. Nutrient content at flowering stage

Nutrient content in the plant at 50 per cent flowering stage is presented in Table 6.

Among the major nutrients, the maximum N concentration was noticed in T_2 (1.76%) and was on par with T_3, T_6, T_{11}, T_{14} and T_{16} while the least was recorded in T_{13} (1.2%). The treatment receiving T_8 recorded the highest value of P, being 0.321 per cent, which was on par with T_3, T_7, T_{11}, T_{13}, T_{14} and T_{15} and the minimum was recorded by T_5 (0.189%). Potassium had its maximum content in T_{10} (2.68%), which was on par with T_1, T_3, T_7, T_{14}, T_{15} and T_{16} whereas T_{17} had the minimum of 2.1 per cent.

Calcium content was highest in T_2 (0.437%), which was on par with all other treatments except T_6, T_7, T_{11} and T_{13}. The least value was noticed in T_7 (0.293%). Magnesium content was highest in T_5 (0.232%) and the minimum T_{11} (0.160 %) though not significant. Similarly in the case of S, the highest value was obtained in T_2 (2505 ppm) while the least was in T_6 (670.9 ppm) but not significant.

In the case of Fe, the highest concentration was observed in T_{17} (1253 ppm) while the lowest was in T_3 (733.3 ppm) though not significant. The Mn

Table 6. Effects of treatments on nutrient content of rice plant at 50% flowering stage

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (%)	SiO_2 (%)
T_1-Cd + 50 kg N	1.31	0.254	2.51	0.400	0.192	945	1143	630.0	40.0	33.33	0.100	5.08
T_2-Cd + 90 kg N	1.76	0.240	2.13	0.437	0.200	2505	1007	486.6	33.33	23.33	0.050	5.12
T_3-Cd + 50 kg N + Lime	1.62	0.277	2.65	0.397	0.224	1149	733	513.3	33.33	40.00	0.05	5.10
T_4-Cd + 50 kg N + Silica	1.50	0.0266	2.42	0.397	0.176	941	1107	523.3	33.33	20.00	0.417	5.22
T_5-Cd + 50 kg N + lime + silica	1.36	0.189	2.48	0.373	0.232	1104	1327	326.6	30.00	30.00	0.150	5.28
T_6-Cd + 90 kg N + Lime	1.59	0.260	2.26	0.333	0.168	671	837	616.6	33.33	53.33	0.05	5.10
T_7-Cd + 90 kg N + silica	1.53	0.289	2.55	0.293	0.176	1047	1187	516.6	40.00	23.33	0.217	5.27
T_8-Cd + 90 kg N+ lime + silica	1.41	0.321	2.33	0360	0.184	746	1113	406.6	36.66	46.66	0.283	5.27
T_9-PM + 50 kg N	1.44	0.261	2.45	0.373	0.176	1011	933	550.0	33.33	23.33	0.100	5.11
T_{10}-PM + 90 kg N	1.53	0.269	2.68	0.360	0.168	911	993	603.3	36.66	23.33	0.05	5.17
T_{11}-PM + 50 kg N + lime	1.72	0.284	2.26	0.347	0.160	1235	1240	426.6	30.00	20.00	0.433	5.11
T_{12}-PM + 50 kg N + silica	1.46	0.198	2.38	0.360	0.192	1009	1420	520.0	30.00	23.33	0.100	5.27
T_{13}-PM $\pm$ 50 kg N + lime + silica	1.20	0.302	2.43	0.333	0.208	959	767	523.3	36.66	13.33	0.233	5.33
T_{14}-PM + 90 kg N + lime	1.61	0.310	2.65	0.400	0.192	1970	1063	410.0	36.66	43.33	0.250	5.27
T_{15}-PM + 90 kg N + silica	1.55	0.294	2.55	0.360	0.168	925	1070	610.0	36.66	26.66	0.100	5.24
T_{16}-PM + 90 kg N + lime + silica	1.57	0.271	2.66	0.387	0.184	784	863	503.3	33.33	23.33	0.217	5.29
T_{17}- control (package of practices)	1.38	0.207	2.10	0.400	0.184	719	1253	383.3	36.66	93.33	0.183	5.01
SE m ±	0.070	0.016	0.063	0.030	0.034	543.0	201.7	52.76	4.34	10.22	0.041	0.034
CD (0.05)	0.20	0.046	0.19	0.08	NS	NS	NS	151.4	NS	29.3	0.118	0.10

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

content was highest in T_6 (616.6 ppm), which was on par with all the treatments except T5, T8, T11, T14, and T_{17} while the lowest was in T_5 (326.7 ppm). In the case of Zn, the highest value was noticed in T_1 and T_7 (40 ppm), while the lowest was observed in T_5, T_{11} and T_{12} (30 ppm). The concentration of Cu was highest for T_{17} and the minimum of 13.33 ppm in T_{13}. In the case of Na, the highest value was noticed in T_{11} (0.433%) and on par with T_4 while the least was observed in T_2, T_3, T_6 and T_{10} (0.05%). Silica had its maximum value in T_{16} (5.29%), which was on par with T_4, T_5, T_7, T_8, T_{12}, T_{13}, T_{14} and T_{15}. The control plot recorded the minimum of 5.01 per cent.

4.2.4. Nutrient content in the grain at harvest

The nutrient content in the grain is presented in Table 7. It shows that there is no significant difference in the content of the element except that for N, S, Fe and Zn.

The concentration of N was highest in the case of T_{16} with 1.36 per cent but on par with T_7 and T_8, while the least content was noticed in T_{17} (0.95%). In the case of P, the highest concentration was for T_{17} (0.15%) and the least in T_1 (0.128%) and the difference was not significant. K content was the maximum in T_{16} (0.830%) and the minimum in T_{17} (0.490%).

Regarding the secondary nutrients, the maximum content of Ca and Mg was noticed in T_{16} with 0.034 per cent and 0.099 per cent, respectively, while the lowest values were recorded in T_{17} with 0.023 per cent and 0.087 per cent respectively. Sulphur content was significantly superior in T_{16} (1003 ppm) and the lowest value was noted in T_{17} (875 ppm). Content of Fe was highest in T_{17} (300 ppm) while the lowest value was in T_{16} with 100 ppm. Mn content was highest in T_2 and T_{16} (73.33 ppm) and the lowest in T_{17} (30 ppm) though not significant. The treatment receiving T_4, T_5, T_{10}, T_{15} and T_{16} recorded 30 ppm Zn that was on par with T_1 and T_{11}. The minimum value of 20 ppm was recorded in T_{12} and T_{17}. Cu content was 10 ppm in all the treatments. The content of Na was highest in T_4 and T_{16} with 0.049 per cent while the minimum was recorded in T_9

Table 7. Effect of treatments on nutrient content of grain at harvest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (%)	SiO_2 (%)
T_1-Cd + 50 kg N	0.98	0.128	0.690	0.026	0.091	943	163.3	63.33	26.67	10	0.048	2.32
T_2-Cd + 90 kg N	1.15	0.131	0.720	0.026	0.093	986	136.7	73.33	23.33	10	0.046	2.34
T_3-Cd + 50 kg N + Lime	1.05	0.133	0.720	0.028	0.093	947	156.7	56.66	20.00	10	0.047	2.33
T_4-Cd + 50 kg N + Silica	1.21	0.145	0.730	0.026	0.092	950	173.3	63.33	30.00	10	0.049	2.56
T_5-Cd + 50 kg N + lime + silica	1.25	0.143	0.750	0.028	0.095	954	220.0	50.00	30.00	10	0.048	2.59
T_6-Cd + 90 kg N + Lime	1.20	0.138	0.750	0.028	0.094	990	243.3	70.00	23.33	10	0.047	2.58
T_7-Cd + 90 kg N + silica	1.32	0.143	0.760	0.027	0.095	995	150.0	36.67	23.33	10	0.048	2.53
T_8-Cd + 90 kg N+ lime + silica	1.34	0.149	0.790	0.030	0.098	1000	116.7	33.33	20.00	10	0.048	2.54
T_9-PM + 50 kg N	1.04	0.133	0.750	0.028	0.094	948	236.7	50.00	20.00	10	0.045	2.36
T_{10}-PM + 90 kg N	1.18	0.139	0.780	0.029	0.067	991	180.0	63.33	30.00	10	0.046	2.38
T_{11}-PM + 50 kg N + lime	1.09	0.138	0.790	0.030	0.096	953	196.7	50.00	26.67	10	0.046	2.37
T_{12}-PM + 50 kg N + silica	1.12	0.140	0.780	0.029	0.097	959	210.0	46.67	20.00	10	0.046	2.58
T_{13}-PM + 50 kg N + lime + silica	1.23	0.145	0.810	0.032	0.098	964	200.0	50.00	23.33	10	0.048	2.59
T_{14}-PM + 90 kg N + lime	1.18	0.142	0.790	0.031	0.098	995	163.3	46.67	23.33	10	0.048	2.40
T_{15}-PM + 90 kg N + silica	1.29	0.143	0.800	0.032	0.097	1002	210.0	50.00	30.00	10	0.047	2.55
T_{16}-PM + 90 kg N + lime + silica	1.36	0.148	0.830	0.034	0.099	1003	100.0	73.33	30.00	10	0.049	2.62
T_{17}- control (package of practices)	0.95	0.150	0.490	0.023	0.087	875	300.0	30.00	20.00	10	0.047	2.31
SE m ±	0.019	0.00	0.00	0.00	0.007	0.357	17.97	10.13	2.09	0.000	0.000	0.000
CD (0.05)	0.05	NS	NS	NS	NS	1.03	51.5	NS	5.99	NS	NS	NS

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

(0.045%) though not significant. Regarding silica, the maximum value was in T_{16} with 2.62 per cent, whereas the minimum was in T_{17} (2.31%).

The soil ameliorants could not make any significant change in the content of nutrients in the grain except that of N, S, Fe and Zn.

4.2.5. Nutrient content of straw

The content of nutrient in the straw at harvest is presented in Table 8. The concentration of N in the straw was highest in case of T_{15} (0.859%) and the least in T_9 (0.607%). Phosphorus content was highest in T_{14} (0.16%), which was on par with T_{11}, T_{12}, T_{13} and T_{15} whereas T_{17} had the minimum of 0.067 per cent. For K, the highest value was recorded in T_{10} (2.98%) while the least was obtained for T_{17} (2.26%).

In case of secondary nutrients, the Ca content was highest in T_{17} (0.56%), which was on par with T_3, T_6, T_8, T_9, T_{10}, T_{11}, T_{14} and T_{16}. The lowest value was in T_2 (0.333%). The Mg content was highest for T_{14} (0.280%) and the minimum in T_{17} (0.160%). The treatment T_{12} contained the maximum sulphur (1083 ppm) while the least was in T_{17} (532.6 ppm).

Fe content was highest in the case of T_9 (1723 ppm) and on par with T_2, T_3, T_{11}, T_{14}, T_{15} and T_{16} while the least concentration was obtained in T_5 (883.3 ppm). Mn had the highest value of 870 ppm, which was on par with T_3, T_7, T_{11}, T_{12}, T_{14} and T_{15}. The least value was noticed in T_{13} (536.7 ppm). Zinc content was the highest in T_7 (70 ppm) and the least in T8 (36.66 ppm). The copper content was highest in T_{16} (46.66 ppm) and the lowest was in T_3 (10 ppm). In the case of Na, the maximum value of 0.3 per cent was noticed in T_8 and T_{16} while the least was recorded in T_1, T_9, T_{10}, T_{11} and T_{14} with 0.05 per cent. Silica content had the maximum value for T_4 and T_8 (5.62%) and was on par with T_7 and T_{16}. The least value was recorded in T_{17} (5.14%).

Table 8. Effects of treatments on nutrient content in straw at harvest

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (ppm)	Fe ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (%)	SiO_2 (%)
T_1-Cd + 50 kg N	0.625	0.088	2.73	0.360	0.200	934	1143	697	53.33	30.00	0.050	5.29
T_2-Cd + 90 kg N	0.747	0.125	2.75	0.333	0.224	580	1470	637	56.66	40.00	0.150	5.30
T_3-Cd + 50 kg N + Lime	0.672	0.098	2.31	0.427	0.208	644	1707	760	60.00	10.00	0.100	5.35
T_4-Cd + 50 kg N + Silica	0.728	0.109	2.56	0.360	0.200	850	1250	680	46.66	26.66	0.150	5.62
T_5-Cd + 50 kg N + lime + silica	0.663	0.123	2.56	0.347	0.216	934	883	617	60.00	20.00	0.283	5.44
T_6-Cd + 90 kg N + Lime	0.803	0.137	2.45	0.413	0.224	963	1173	630	46.66	30.00	0.150	5.38
T_7-Cd + 90 kg N + silica	0.672	0.114	2.45	0.387	0.192	680	933	837	70.00	43.33	0.150	5.51
T_8-Cd + 90 kg N+ lime + silica	0.765	0.117	2.71	0.427	0.240	561	973	620	36.66	23.33	0.300	5.62
T_9-PM + 50 kg N	0.607	0.125	2.70	0.493	0.224	603	1723	687	56.66	40.00	0.050	5.40
T_{10}-PM + 90 kg N	0.831	0.117	2.98	0.493	0.200	580	1167	870	66.66	26.66	0.050	5.30
T_{11}-PM + 50 kg N + lime	0.709	0.144	2.61	0.440	0.200	827	1280	790	63.33	20.00	0.050	5.33
T_{12}-PM + 50 kg N + silica	0.681	0.141	2.68	0.400	0.192	1083	970	743	46.66	40.00	0.150	5.43
T_{13}-PM + 50 kg N + lime + silica	0.700	0.155	2.55	0.347	0.192	623	920	537	50.00	40.00	0.200	5.47
T_{14}-PM + 90 kg N + lime	0.672	0.161	2.73	0.427	0.280	675	1523	730	53.33	23.33	0.050	5.30
T_{15}-PM + 90 kg N + silica	0.859	0.152	2.33	0.400	0.184	691	1303	747	53.33	23.33	0.150	5.47
T_{16}-PM + 90 kg N + lime + silica	0.635	0.120	2.68	0.453	0.192	696	1367	663	66.66	46.66	0.300	5.55
T_{17}- control (package of practices)	0.709	0.067	2.26	0.560	0.160	533	890	573	50.00	13.33	0.233	5.14
SE m ±	0.063	0.007	0.058	0.034	0.019	23.30	162.3	51.75	5.91	58.7	0.005	0.047
CD (0.05)	NS	0.02	0.169	0.97	NS	66.89	465.8	148.52	16.97	13.8	0.015	0.137

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

4.3. Uptake of nutrients

The total uptake of nutrients at harvest is presented in Table 9. It reveals that there is significant difference between the treatments.

The highest N uptake 0f 143.1 kg ha^{-1} was recorded in T_{15}, which was significantly higher than all the treatments while the least value was recorded in T_{17} with 86.4 kg ha^{-1}. Phosphorus uptake was highest in T_1 (21.83 kg ha^{-1}) and was significantly superior with all treatments while the minimum was in T_{17} (11.37 kg ha^{-1}). In the case of K, the uptake was highest in T_{10} (228.3 kg ha^{-1}) and was on par with T_8. The least value was noticed in T_{17} (138.9 kg ha^{-1}).

Regarding the uptake of secondary nutrients, the highest Ca uptake was for T_{10} with 30.89 kg ha^{-1} and was on par with T_8, T_9 and T_{16} and T_{17} while the least value was recorded in T_1 (19.31 kg ha^{-1}). In the case of Mg, the highest uptake was in T_{14} (23.54 kg ha^{-1}), which was on par with T_8 while the lowest was 11.50 kg ha^{-1} in T_{17}. With regard to the S, the value was highest for T_{12} (12.80 kg ha^{-1}) though it was on par with T_5 and T_6. The lowest value was noted in the control plots (6.85 kg ha^{-1}).

In the case of micronutrients, the uptake of Fe was highest for T_3 (11.08 kg ha^{-1}), which was on par with T_2, T_9 and T_{14} while the least uptake was noticed in T_{17} with 5.79 kg ha^{-1}. Mn uptake was highest in T_{10} (5.54 kg ha^{-1}) and was on par with T_7 whereas T_{17} had the lowest uptake of 2.90 kg ha^{-1}. In the case of Zn, the highest uptake was noticed in T_{10} and T_{16} (0.60 kg ha^{-1}) and was on par with T_5, T_7, T_{11} and T_{15} whereas the least value was recorded T_{17} with 0.32 kg ha^{-1}. Regarding copper, the uptake was highest in T_{16} (0.34 kg ha^{-1}) and was on par with T_2, T_7 and T_{12}. The least value was recorded in T_{17} (0.15 kg ha^{-1}). The uptake of sodium was highest in T_8 (21.99 kg $ha^{-1)}$, which was on par with T_{16} while the least was recorded in T_9 (5.49 kg ha^{-1}). Silica uptake had the maximum value of 520.7 kg ha^{-1} in T_8 though it was on par with T_7. The lowest value of 379.7 kg ha^{-1} in T_{17}.

Table 9. Effects of treatments on nutrient uptake in the plant at harvest (kg ha^{-1})

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Na	SiO_2
T_1-Cd + 50 kg N	91.2	21.83	181.90	19.31	15.92	10.34	6.88	3.94	0.483	0.183	5.22	419.5
T_2-Cd + 90 kg N	122.8	16.34	211.40	21.41	19.58	10.18	9.60	4.26	0.490	0.300	11.99	472.7
T_3-Cd + 50 kg N + Lime	116.1	14.29	191.26	26.88	18.48	10.11	11.08	4.95	0.477	0.157	8.83	491.0
T_4-Cd + 50 kg N + Silica	124.8	16.22	198.90	22.76	17.92	11.42	8.47	4.40	0.480	0.220	12.08	501.8
T_5-Cd + 50 kg N + lime + silica	123.5	16.89	200.46	22.27	19.11	11.94	6.68	3.96	0.560	0.190	19.87	494.6
T_6-Cd + 90 kg N + Lime	123.1	16.61	183.90	24.51	18.49	11.81	8.04	3.92	0.410	0.230	11.33	465.2
T_7-Cd + 90 kg N + silica	130.2	15.80	203.26	24.73	16.64	10.67	6.52	5.19	0.533	0.310	12.29	520.0
T_8-Cd + 90 kg N+ lime + silica	136.8	17.21	222.30	28.76	21.54	10.15	6.88	4.11	0.360	0.210	21.99	520.7
T_9-PM + 50 kg N	103.7	15.92	207.03	28.41	18.48	8.91	10.10	4.12	0.430	0.277	5.49	473.0
T_{10}-PM + 90 kg N	129.8	16.41	226.30	30.89	16.33	10.21	8.08	5.54	0.600	0.230	6.09	474.2
T_{11}-PM + 50 kg N + lime	111.5	17.07	194.70	25.92	17.30	10.88	8.27	4.63	0.520	0.180	5.80	448.3
T_{12}-PM + 50 kg N + silica	115.4	17.69	209.00	25.28	17.75	12.80	7.07	4.65	0.410	0.300	11.86	491.0
T_{13}-PM + 50 kg N + lime + silica	124.1	17.00	203.90	22.30	16.38	9.18	5.52	3.26	0.390	0.277	14.46	505.3
T_{14}-PM + 90 kg N + lime	118.1	19.12	218.80	26.65	23.54	10.63	10.40	4.78	0.480	0.210	6.19	481.1
T_{15}-PM + 90 kg N + silica	143.1	19.34	196.76	26.79	18.09	11.26	9.47	4.93	0.540	0.210	12.50	514.2
T_{16}-PM + 90 kg N + lime + silica	128.3	16.99	214.70	29.22	18.01	10.81	8.80	4.43	0.600	0.340	21.11	504.5
T_{17}- control (package of practices)	86.4	11.37	138.86	28.50	11.50	6.85	5.79	2.90	0.327	0.150	14.01	379.7
SE m ±	1.089	0.890	3.074	0.982	0.829	0.398	0.552	0.134	0.029	0.017	0.321	1.528
CD (0.05)	3.127	2.55	8.822	2.82	2.38	1.14	1.58	0.385	0.083	0.049	0.92	4.38

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 600 kg ha^{-1}

4.4. Yield attributing characters

The yield attributes such as number of productive tillers, length of panicle, number of spikelets per panicle, and percentage of filled grains are given in Table 10.

4.4.1. Number of productive tillers

The number of productive tillers per hill was highest in T_{15} (7.58), which was on par with T_8 (7.10); while the lowest number was recorded in the control plots (4.95).

4.4.2. Length of panicle

The length of panicle was on par in all the treatments except in T_{14} and T_{17} though T_{15} recorded the highest value of 20.74 cm. The control plots recorded the minimum value of 18.30cm.

4.4.3. Numbers of spikelets per panicle

The number of spikelets per panicle was highest in T_5 (107), which was on par with T_2, T_7, T_{15} and T_{16} while the least was recorded in T_1 (86.8).

4.4.4. Percentage of filled grains

The percentage of filled grains was highest for the treatment T_6 (87.18%), which was on par with T_1, T_2, T_9, and T_{11} while the least value was noticed in T_{17} (79.81%).

Poultry manure application has improved the yield attributes in general.

4.5. Yield characters

Table 11 shows the influence of treatments on yield characters. All the characters except grain: straw ratio was found to be significant.

Table 10. Effect of treatments on yield attributes

Treatments	Number of productive tillers/hill	Length of panicle (cm)	Number of spikelets per panicle	% Of filled grains
T_1-Cd + 50 kg N	5.40	19.33	86.80	86.05
T_2-Cd + 90 kg N	6.42	20.73	102.30	86.34
T_3-Cd + 50 kg N + Lime	6.07	19.45	87.30	83.68
T_4-Cd + 50 kg N + Silica	6.17	20.46	100.06	82.76
T_5-Cd + 50 kg N + lime + silica	5.38	19.46	107.00	85.04
T_6-Cd + 90 kg N + Lime	5.95	20.96	96.36	87.18
T_7-Cd + 90 kg N + silica	6.83	21.36	102.19	83.63
T_8-Cd + 90 kg N+ lime + silica	7.10	20.26	97.66	81.98
T_9-PM + 50 kg N	5.05	20.16	88.16	86.83
T_{10}-PM + 90 kg N	6.54	20.71	100.33	84.13
T_{11}-PM + 50 kg N + lime	6.30	19.76	90.40	86.43
T_{12}-PM + 50 kg N + silica	5.79	19.7	93.33	84.76
T_{13}-PM + 50 kg N + lime + silica	6.50	20.16	97.06	83.10
T_{14}-PM + 90 kg N + lime	5.83	19.01	97.80	84.79
T_{15}-PM + 90 kg N + silica	7.58	20.74	105.03	83.41
T_{16}-PM + 90 kg N + lime + silica	6.36	19.70	104.40	85.01
T_{17}- control (package of practices)	4.95	18.30	88.96	79.81
SE m ±	0.171	0.499	1.907	0.653
CD (0.05)	0.49	1.43	5.47	1.87

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

Table 11. Effect of treatments on yield characters

Treatments	1000 grain wt. (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain : straw ratio
T_1-Cd + 50 kg N	24.76	6104	5314	1.14
T_2-Cd + 90 kg N	32.33	6851	5895	1.18
T_3-Cd + 50 kg N + Lime	33.24	6807	6247	1.06
T_4-Cd + 50 kg N + Silica	33.26	6807	5830	1.15
T_5-Cd + 50 kg N + lime + silica	31.18	6763	5873	1.15
T_6-Cd + 90 kg N + Lime	33.32	6587	5489	1.19
T_7-Cd + 90 kg N + silica	32.49	6872	6225	1.08
T_8-Cd + 90 kg N+ lime + silica	33.11	6631	6269	1.06
T_9-PM + 50 kg N	33.24	6719	5865	1.13
T_{10}-PM + 90 kg N	32.67	6872	5862	1.17
T_{11}-PM + 50 kg N + lime	32.35	6697	5434	1.18
T_{12}-PM + 50 kg N + silica	33.06	6763	5830	1.16
T_{13}-PM + 50 kg N + lime + silica	33.45	6741	6082	1.10
T_{14}-PM + 90 kg N + lime	33.60	6521	6126	1.06
T_{15}-PM + 90 kg N + silica	34.88	7004	6137	1.13
T_{16}-PM + 90 kg N + lime + silica	34.36	6653	5950	1.11
T_{17}- control (package of practices)	26.05	5325	5050	1.05
SE m ±	0.487	166.9	231.5	0.076
CD (0.05)	1.39	479	664	NS

Cd-cow dung 5 t ha^{-1} **PM-** poultry manure 1.6 t ha^{-1} **Lime-**150 kg ha^{-1} **Silica-**500 kg ha^{-1} **POP-**Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

4.5.1. Thousand grain weight

The thousand-grain weight was highest for T_{15} (34.88 g) and was on par with T_{14} and T16 while the lowest value was recorded in T_{17} (26.05 g).

4.5.2. Grain yield

The grain yield was significantly higher for T_{15} (7004 kg ha^{-1}), which was on par with the treatments except T_1, T14 and T_{17}. The lowest yield was recorded in T_{17} (5325 kg ha^{-1}). The influence of treatments on the grain yield has been depicted in Fig.4.

4.5.3. Straw yield

The quantity of straw obtained was highest in case of the treatment receiving T_8 (6269 kg ha^{-1}) and was significantly superior to T_1, T_6, T_{11} and T_{17}. The lowest weight was noticed in T_{17} (5050 kg ha^{-1}). The variation in the straw yield as influenced by the treatments is shown in Fig.5.

4.5.4. Grain: straw ratio

The grain: straw ratio was highest for the treatment T_6 (1.19) even though there was no significant difference.

The results indicate that addition of more organic manures along with fertilizer N, lime and silica contributed more biomass than the present POP recommendation.

4.6. Correlation of nutrient content with the grain yield

Correlation analysis was worked out between the nutrient content at different stages of growth and yield (Table 12). It was found that the content of N at the maximum tillering stage, P at the panicle initiation stage, and silica at 50 per cent flowering stage were positively correlated with the grain yield. There was negative correlation between the Cu content at 50 per cent flowering and the

Table 12. Correlation coefficients of nutrient content in different stages and grain yield.

Stages	N %	P %	K %	Ca %	Mg %	S %	Fe ppm	Mn ppm	Zn ppm	Cu ppm	Na %	Si %	Grain yield kg ha^{-1}
Maximum Tillering	0.53299	-0.2123	0.07371	-0.4722	0.20119	0.37445	-0.4003	0.19146	0.09743	-0.0538	0.16719	0.29921	6630
Panicle Initiation	0.28311	0.7312	0.4589	-0.7302	0.13985	-0.5719	0.0023	-0.3037	-0.0431	-0.2720	0.2509	-0.8033	6630
50% flowering	0.34092	0.08217	0.42242	0.00031	0.00598	0.21954	-0.234	0.26357	-0.2713	-0.8223	-0.0319	0.54428	6630
Grain	0.58817	-0.1812	0.83341	0.52067	0.12091	0.72169	-0.4653	0.33453	0.30629	0.000	-0.0826	0.42185	6630
Straw	0.23585	-0.2802	0.26549	-0.5022	0.26335	0.10902	0.27841	0.41274	0.24808	0.32908	-0.1214	0.58080	6630

Fig.4. Influence of treatments on grain yield of rice

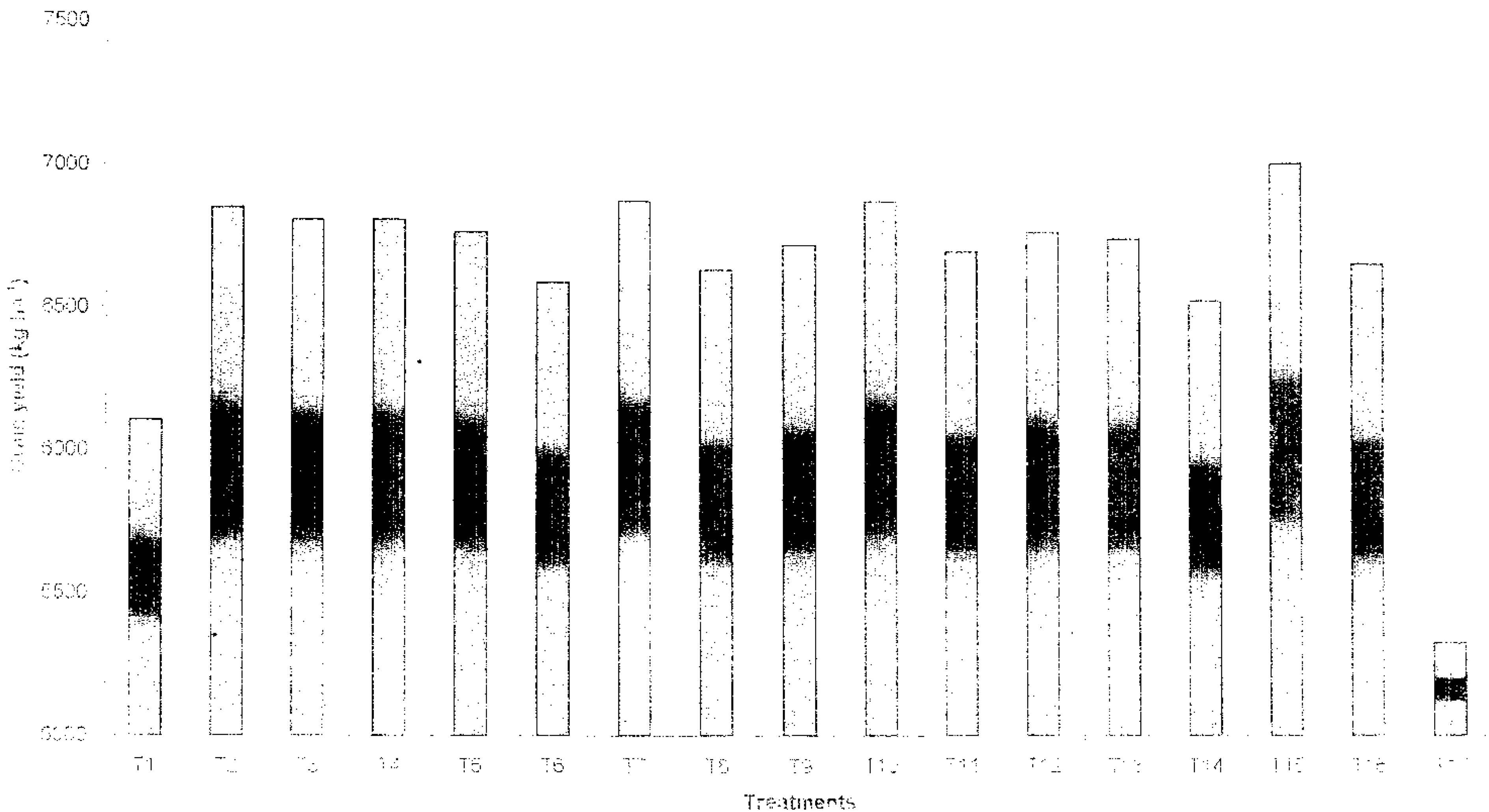
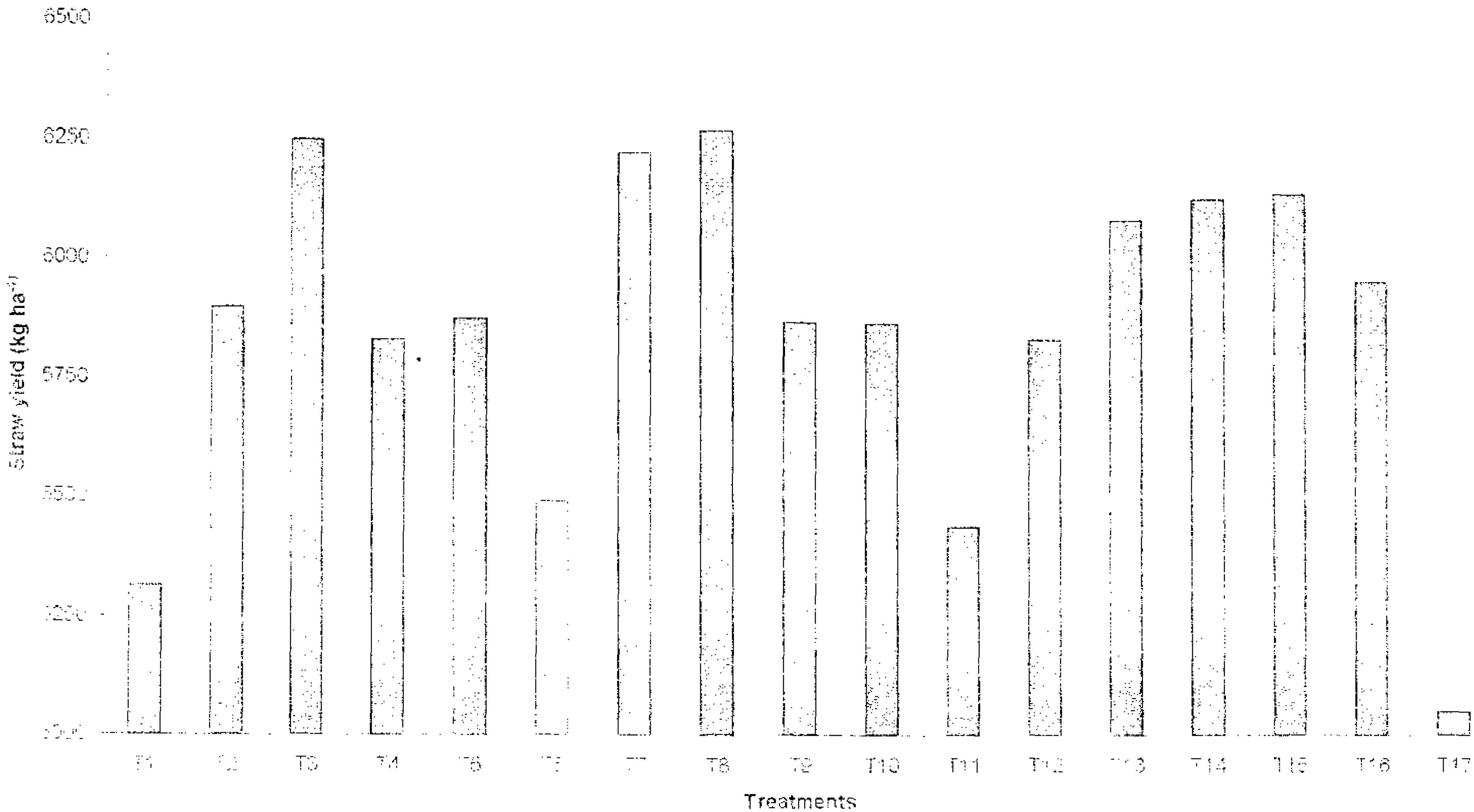


Fig.5. Influence of treatments on straw yield of rice



grain yield. At the time of harvest N, K, Ca and S content in the grain were positively correlated with grain yield. Silica content in the straw was also positively correlated with the grain where as the Ca content had the negative influence.

4.7. Pest and disease incidence

Pest and disease incidence at the panicle initiation stage is presented in Table 13.

In the case of pests, the attack of leaf roller and stem borer was highest in the treatment receiving POP (T_{17}) with values of 63.7 per cent and 0.72 per cent respectively, while the lowest incidence was noticed in T_{15}, with 22.3 per cent and 0.23 per cent, respectively. Gall midge incidence was also higher in T_{17} (0.72%) while the least incidence was in T_4 (0.36%).

Compared to the control and the treatments significantly reduced the incidence of leaf roller, stem borer and gall ridge. In general soil ameliorants, especially silica, imparted resistance to major pests in rice.

4.8. Occurrence of weeds

Effect of treatments on weed population on 20 DAP and 40 DAP is shown in Table 14. Compared to the control plots, treatments reduced the weed population both at 20 and 40 days after transplanting.

Weed population was 68.3 per square meter in T_{17}, which was significantly higher than all other treatments, and the least number was noticed in T_7 (30.3). Also, at 40 days after transplanting, maximum weed population was noticed in T_{17} (53.3), while the least number was recorded in T_{12} (14.3).

In general, silica application reduced the occurrence of weeds.

Table 13 . Effect of treatments on insect and pests at panicle initiation stage

Treatments	Leaf roller (%)	Stem borer (%)	Gall midge (%)
T_1-Cd + 50 kg N	37.3	0.28	0.53
T_2-Cd + 90 kg N	38.8	0.25	0.59
T_3-Cd + 50 kg N + Lime	34.0	0.24	0.44
T_4-Cd + 50 kg N + Silica	22.6	0.24	0.36
T_5-Cd + 50 kg N + lime + silica	23.0	0.26	0.43
T_6-Cd + 90 kg N + Lime	31.4	0.26	0.43
T_7-Cd + 90 kg N + silica	22.9	0.24	0.40
T_8-Cd + 90 kg N+ lime + silica	23.0	0.25	0.47
T_9-PM + 50 kg N	23.6	0.26	0.54
T_{10}-PM + 90 kg N	36.6	0.25	0.55
T_{11}-PM + 50 kg N + lime	38.1	0.25	0.46
T_{12}-PM + 50 kg N + silica	33.4	0.25	0.44
T_{13}-PM + 50 kg N + lime + silica	22.6	0.25	0.44
T_{14}-PM + 90 kg N + lime	23.6	0.25	0.44
T_{15}-PM + 90 kg N + silica	22.3	0.23	0.42
T_{16}-PM + 90 kg N + lime + silica	23.4	0.25	0.44
T_{17}- control (package of practices)	63.7	0.72	0.72
SE m ±	0.737	0.175	0.011
CD (0.05)	2.11	0.50	0.03

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 600 kg ha^{-1}

Table 14. Effect of treatments on weed population

Treatments	20 days after transplanting (no. m^{-2})	40 days after transplanting (no. m^{-2})
T_1-Cd + 50 kg N	42.66	35.00
T_2-Cd + 90 kg N	51.67	36.00
T_3-Cd + 50 kg N + Lime	49.67	45.67
T_4-Cd + 50 kg N + Silica	30.66	20.67
T_5-Cd + 50 kg N + lime + silica	35.00	25.00
T_6-Cd + 90 kg N + Lime	50.00	40.00
T_7-Cd + 90 kg N + silica	30.33	19.67
T_8-Cd + 90 kg N+ lime + silica	33.67	22.33
T_9-PM + 50 kg N	45.00	37.67
T_{10}-PM + 90 kg N	52.00	36.66
T_{11}-PM + 50 kg N + lime	52.33	37.00
T_{12}-PM + 50 kg N + silica	37.67	14.33
T_{13}-PM + 50 kg N + lime + silica	35.00	19.33
T_{14}-PM + 90 kg N + lime	48.00	41.00
T_{15}-PM + 90 kg N + silica	33.67	19.67
T_{16}-PM + 90 kg N + lime + silica	35.67	15.67
T_{17}- control (package of practices)	68.33	53.33
SE m ±	2.387	2.097
CD (0.05)	6.85	6.02

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 600 kg ha^{-1}

4.9. Nutrient status of the soil at harvest

The effect of treatments on post harvest status of available nutrients in the soil is presented in Table 15. It revealed that the treatment effect was significant except for organic carbon and Mg. The status of the available nutrient was improved considerably except in the case of some elements and treatments.

The organic carbon content of the soil was higher in T_{16} (0.67%) than the control plots (T_{17}). In all the treatment plots the value has been considerably increased than in the control.

Nitrogen content in the soil was also considerably increased by soil amelioration. T_7 and T_{11} had the maximum content of 407.7 kg ha^{-1} while the least was in T_4 (353.3 kg ha^{-1}). Phosphorus was highest in T_4 (20.12 kg ha^{-1}) and the lowest in T_3 (10.47 kg ha^{-1}). T_7 had the highest K content of 98.43 kg ha^{-1} while in the control plots K status remained almost the same as the initial value of 92.6 kg ha^{-1}.

Calcium content was also increased irrespective of the application of lime. In T_1 and T_{17} the value was decreased than the initial value of 119.2 kg ha^{-1}. Mg content in all the plots was 35.8 kg ha^{-1} though the initial status was 30.3 kg ha^{-1}. The sulphur content was increased by 30 per cent in T_{12} (381.6 kg ha^{-1}), which was reduced to 186.6 kg ha^{-1} in T_{14}.

There was considerable reduction in the status of Fe due to the treatment effects while the control plot showed almost similar value as that of the initial value. T_{13} recorded the lowest content of 427.3 kg ha^{-1}. Poultry manure or FYM in combination with lime and silica could considerably reduce the Fe content in the soil.

Mn content was also reduced even upto 32.11 kg ha^{-1} in T_5 from 88.3 kg ha^{-1}. Zn content did not vary much among the treatments though it was reduced to one third of the initial status of 1.28 kg ha^{-1}. Except in T_7, T_9, T_{10} and T_{16}, the copper content was reduced from 3.58 kg ha^{-1} and was 1.64 kg ha^{-1} in T_5 and T_{15}. The status of sodium was also reduced due to the treatment effects. T_{10} had the lowest value of 28 kg ha^{-1} but it was as high as 90 kg ha^{-1} in T_{12} though the initial value was 99 kg ha^{-1}.

Table 15. Effect of treatments on post harvest status of available nutrients of soil (kg ha^{-1})

Treatments	OC%	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Na
T_1-Cd + 50 kg N	0.60	376.3	14.15	95.53	99.3	35.83	264.4	447.9	34.34	0.448	2.24	77.33
T_2-Cd + 90 kg N	0.63	395.1	16.24	97.71	278.8	35.83	292.4	456.4	39.57	0.448	2.99	36.00
T_3-Cd + 50 kg N + Lime	0.64	395.1	10.47	94.84	238.4	35.83	367.1	432.5	33.60	0.448	2.24	82.67
T_4-Cd + 50 kg N + Silica	0.65	353.3	20.12	97.85	178.8	35.83	353.6	432.9	33.60	0.448	2.09	64.00
T_5-Cd + 50 kg N + lime + silica	0.65	363.8	15.37	96.22	298.0	35.83	232.3	430.7	32.11	0.448	1.64	88.00
T_6-Cd + 90 kg N + Lime	0.58	395.1	10.88	95.98	178.8	35.83	231.3	449.2	41.81	0.448	3.44	30.00
T_7-Cd + 90 kg N + silica	0.60	407.7	12.47	98.43	178.8	35.83	327.7	462.4	33.60	0.448	3.58	50.67
T_8-Cd + 90 kg N+ lime + silica	0.63	376.3	13.44	97.41	238.4	35.83	267.6	462.9	47.04	0.448	2.98	50.00
T_9-PM + 50 kg N	0.64	382.6	12.62	97.07	238.4	35.83	235.4	463.9	58.24	0.448	4.33	75.33
T_{10}-PM + 90 kg N	0.65	382.6	15.63	97.52	238.4	35.83	267.5	449.5	49.28	0.448	3.73	28.00
T_{11}-PM + 50 kg N + lime	0.65	407.7	18.84	95.97	298.0	35.83	348.4	481.2	49.28	0.448	3.28	70.00
T_{12}-PM + 50 kg N + silica	0.66	401.4	13.79	97.07	238.4	35.83	381.6	440.1	61.97	0.747	2.98	90.00
T_{13}-PM + 50 kg N + lime + silica	0.65	374.2	15.43	96.19	238.4	35.83	366.1	427.3	45.55	0.448	2.69	58.00
T_{14}-PM + 90 kg N + lime	0.65	382.6	13.79	95.74	178.8	35.83	186.6	440.8	38.03	0.448	3.44	72.00
T_{15}-PM + 90 kg N + silica	0.66	382.6	14.05	97.92	178.8	35.83	210.5	432.5	38.83	0.448	1.64	68.00
T_{16}-PM + 90 kg N + lime + silica	0.67	370.0	13.13	97.06	178.8	35.83	352.6	495.5	48.30	0.448	4.33	72.67
T_{17}- control (package of practices)	0.53	374.2	14.13	92.08	117.2	35.83	265.5	585.9	35.09	0.448	2.84	68.67
SE m ±	0.000	5.334	0.178	0.557	19.60	0.000	4.367	5.706	1.514	0.036	0.109	1.475
CD (0.05)	NS	15.3	0.512	1.60	56.3	NS	12.5	16.4	4.34	0.104	0.32	4.23

Cd-cow dung 5 t ha^{-1} **PM**- poultry manure 1.6 t ha^{-1} **Lime**-150 kg ha^{-1} **Silica**-500 kg ha^{-1} **POP**-Cd 5 t ha^{-1}+ 70:35:35 NPK kg ha^{-1}+Lime 6oo kg ha^{-1}

DISCUSSION

5. DISCUSSION

The experiment entitled "Integration of nutritional inputs for improving rice productivity in laterite soils" was conducted during the Virippu season of 2002 at the Agricultural Research Station, Mannuthy. The experiment consisted of 17 treatments including two sources of organic manure and two levels of nutrition with combinations of lime and silica to develop a cost effective, high yield and sustainable production technology for rice by identifying the components of good management. The results pertaining to the study have been discussed below.

The results revealed that the overall treatment effects have enhanced the production over the package of practices recommendation. It is also revealed that substitution of fertilizer nitrogen by organic manures is advantageous than the present recommendation. Poultry manure and silica could significantly increase the height of rice plants. Also, substitution of N by organic manures along with increased dose of N, lime and silica could enhance the tillering capacity of the plants. Soil ameliorants, especially silica could impart resistance to major pests in rice. The silica application has also reduced the occurrence of weeds.

5.1. Organic and inorganic nitrogen

The data showed that the highest grain yield of 7004 kg ha^{-1} was recorded by T_{15} (Poultry manure+ 90 kg ha^{-1} N+ 500 kg ha^{-1} silica), which was significantly superior to the package of practices recommendations (Table 11). An increase of 1680 kg ha^{-1} grain and 1087 kg ha^{-1}straw in T_{15} would appear to be due to the application of silica, substitution of cow dung by poultry manure and increased dose of N with an organic: inorganic ratio of 1:2.25, increased dose of K and reduced dose of P. Positive and significant influence of inclusion of silica and enhancing the level of K in the laterite soils has been already reported Bridgit (1999) and Lakshmikanthan (2000). Substantial yield improvement and nutrient use efficiency of rice have also been reported Musthafa (1995) and Sindhu (2002).

A perusal of the data shows that the significant and profound influence on yield by the treatments over the package of practices has come from the increased number of productive fillers, spikelet production and grain weight (Table. 10). Grain filling and grain weight are the functions of translocation to the ear head whereas spikelet numbers is a function of preinhibited metabolic efficiency. In the light of the above, the results indicate that plants in the control plots had been subjected to early metabolic inhibitions and later translocation inhibitions. Metabolic inhibition can only be due to metabolic or physiological unavailability in spite of absorption or failure to absorb itself. Data on tiller count and N content at the panicle initiation stage showed that there was not any reduction in the N content of the plant. As such, the low spikelet number indicated the metabolic shortage. Bridgit (1999) have reported 0.9 per cent N in the leaf at the panicle initiation stage for a 6 tonnes of grain yield per ha as against 1.75 per cent in the present study. Sreekumar (1998) has reported that the situations of metabolic deficiency in spite of content or chemical sufficiency in pepper.

Another significant finding has emanated from a comparison of T_1 (cow dung 5 t ha^{-1}+ 50 kg ha^{-1} N) and T_9 (poultry manure 1.6 t ha^{-1}+ 50 kg ha^{-1} N). The treatments were identical in terms of quantity of N but differed only in the sources of organic nitrogen. The former received organic matter through cow dung where as the latter through poultry manure. The treatments differed between them mainly in early stage vigorous growth, tiller decline in the early flowering and non-productive tiller formation and thousand grain weight. T_9 had given a test weight of 33.24 as against 24.76 in T_1, that is, a 34 per cent variation that has resulted in a yield improvement of 615 kg ha^{-1} grain. This is an ample proof to the view that while organics in general is capable of mitigating the ill effects of fertilizers; they also vary in their efficiency in doing so. Poultry manure 1.6 kg ha^{-1} + 50 kg ha^{-1} N gave a grain yield of 6719 kg ha^{-1} which was 1395 kg ha^{-1} over the package of practices recommendations.

Superiority of poultry manure over cow dung in the nutritional management system probably is related to its content of nutrients other than NPK. Cow dung has been found to contain Fe, Zn and Cu in levels toxic to rice plants (Yoshida, 1981). Poultry manure on the other hand had the content of these elements in far less quantities. Poultry manure had a three fold higher Ca content than cow dung (Appendix V). This Ca might have been useful in reducing the uptake of unfavourable elements by the rice plants, which contributed to the physiological inhibition. Cow dung, on the other hand, was in effect worsening the situations through incidental application of some elements in toxic levels. A comparison of elemental compositions of these two sources as well as their production capabilities would confirm that it is not merely the source that is important, but the source and content jointly decide the efficiency. This result would further suggest that generalised use of organic farming might be misleading. Objective management should always be based not only on the content of the main elements like N, but the other elements as well.

The significant superiority of poultry manure over cow dung under scores the truth that crop response in terms of productivity is a multi-element function and explaining it on a single element basis is wrong and misleading. One advantage of organic farming is that the system of multi-element based analysis is brought down on a unitary scale. However it should not be misconstrued that it is a source dependent management.

The package of practices recommendations had actually an organic: inorganic ratio of 1:3.5 whereas T_1 (cow dung 5 t ha^{-1}+ 50 kg ha^{-1} N) had a ratio of 1:1.25. The difference in yield can therefore be attributed to the difference in the ratio of integration of organic and inorganic sources. The difference of 780 kg of grain ha^{-1} under 1:1.25 ratio would mean that the efficiency of N in effecting the yield is influenced by the ratio. So the failure of rice to respond beyond 50 kg ha^{-1} N appears to be basically, not because of the inability of the plant but because of the unfavourable ratio. It is probably that a ratio of 1:1.25 may be required to nullify the unfavourable chemical effects of fertiliser N.

Data on rice productivity in the poultry manure treatment at Karamana during 1977 - 1992 (KAU, 1997) have shown that the exclusive dependence on fertilisers as well as marginal integration with organics have led to decline in productivity over time. Decline in the nutrient use efficiency during the last quarter of the century has remained a national problem without eluding the cause. The results of the present study have indicated that in all probability it may have unfavourable balance in inorganic–organic interaction. However, further investigations are required to confirm the results.

A comparison of T_1 (cow dung 5 t ha^{-1}+ 50 kg ha^{-1} N) and T_9 (poultry manure 1.6 t ha^{-1}+ 50 kg ha^{-1} N) have shown that in spite of the same ratio of integration and quantity of N, there was a significant difference in productivity to the tune of 615 kg ha^{-1} grain and 551 kg ha^{-1} straw. The causes of this difference can only the attributed to the variations in the organic source (Fig.6). This significant difference confirmed that a source dependent input application might not be advisable.

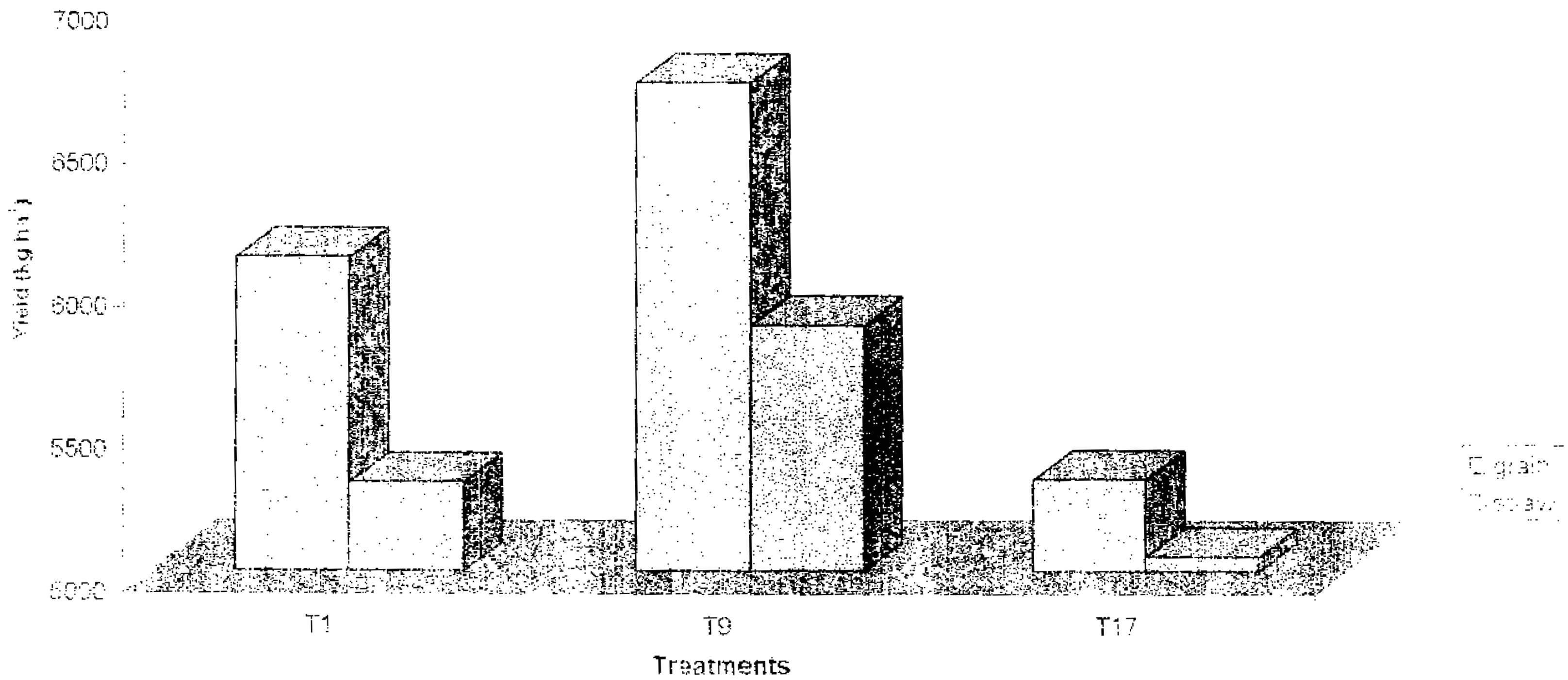
Failure of cow dung to cope up with poultry manure evidently had been due to its composition unsuitable to laterite soils. This further underlines the importance of contents. These results lead to the conclusion that yields are a net effect of environment and not of any one, two or three elements. These results also possibly indicate that microelement management, especially their excess levels, holds the key to improved productivity and use efficiency of major nutrients. Similar results have also been reported Bridgit (1999) and Musthafa (1995).

Translocation inhibition may be due to insufficient vascular development or due to the obstructions or diversions (De Datta, 1981).

5.2. Fertilizer nitrogen and potassium

A comparison of T_1 and T_{17} showed that cow dung 5 t ha^{-1} with 50 kg N (T_1) has recorded 780 kg ha^{-1} grain and 264 kg ha^{-1} straw more than the control. This received 120 kg K instead of 35 kg and 20 kg P instead of 35 kg than the

Fig.6. Grain and straw yield as influenced by the source of organic manure



T1 - Cowdung 5 t + 50:20:120 kg NPK ha^{-1}

T9 - Poultry manure 1.6 t + 50:20:120 kg NPK ha^{-1}

T17 - Control (POP recommendations) - Cowdung 5 t +70:35:35 kg NPK ha^{-1} + 600 kg lime ha^{-1}

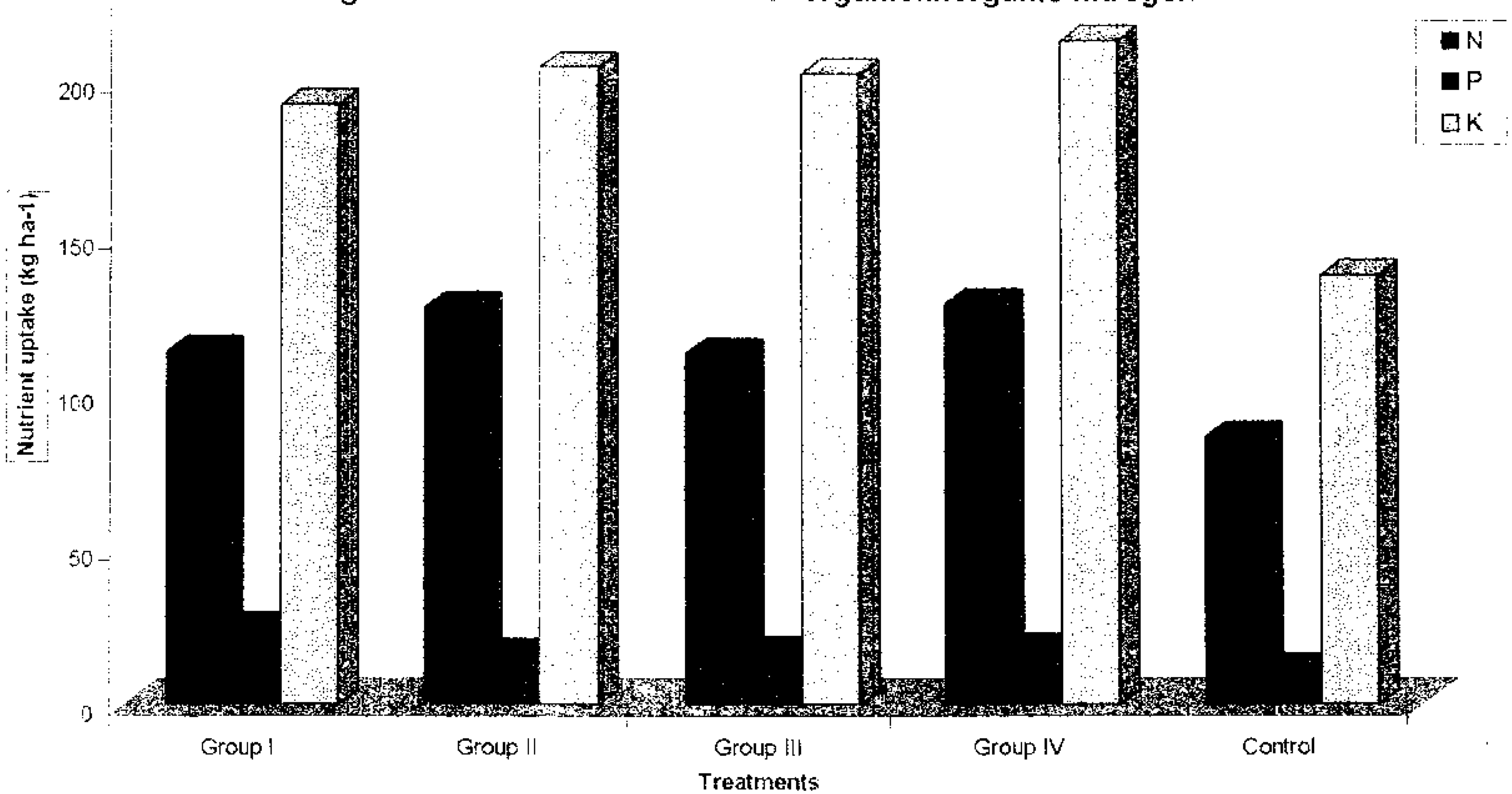
package of practices. The uptake studies showed that the plants absorb around 20 kg P and more than 120 kg potassium (Fig.7). When P is applied in excess, this might have lead to the unavailability of essential nutrients especially micronutrients due to the maximum bonding strength (Tinker, 1964). Also, P combines with Zn and makes it unavailable. When K is applied only @ 35 kg ha^{-1}, the native resources have to be tapped by the plants from the clay minerals like biotite, bendonite etc. which may lead to soil degradation. This suggests that the uptake linked management technique has to be evolved to preserve the productive capacity of the soil. In other words, the present system might have been responsible for progressively decreasing the nutrient use efficiency.

The data also suggests that the fertilizer N, at least at higher levels of applications, has some unfavourable effects capable to nullify its important source value itself. Integration of organic and inorganic sources suppresses the unfavourable effects. The unfavourable effect, probably is its chemical effect, as biologically it is the most important nutrient. Increased yield due to integrated management have also been reported Anilakumar *et al.* (1993) and Reddy and Shivaraj (1999b).

5.3. Silica and Lime

Application of lime with cow dung has increased the yield of grain and straw significantly. Also, both the lime and silica have significantly increased the yield at 50 kg N with cow dung. But there was no apparent effect when they were applied together (Fig.8). It is possible that when elements are applied as chemical sources, there might have been interactions in which both of them might have neutralised. This may be due to the chemical interaction, which are invariable when chemical sources are applied. The advantage of organic sources may be one that it excludes the possibility of ionic interaction among elements because of their organically bound nature.

Fig.7. Uptake of major nutrients as influenced by the source of organic manures and the ratio of organic:inorganic nitrogen



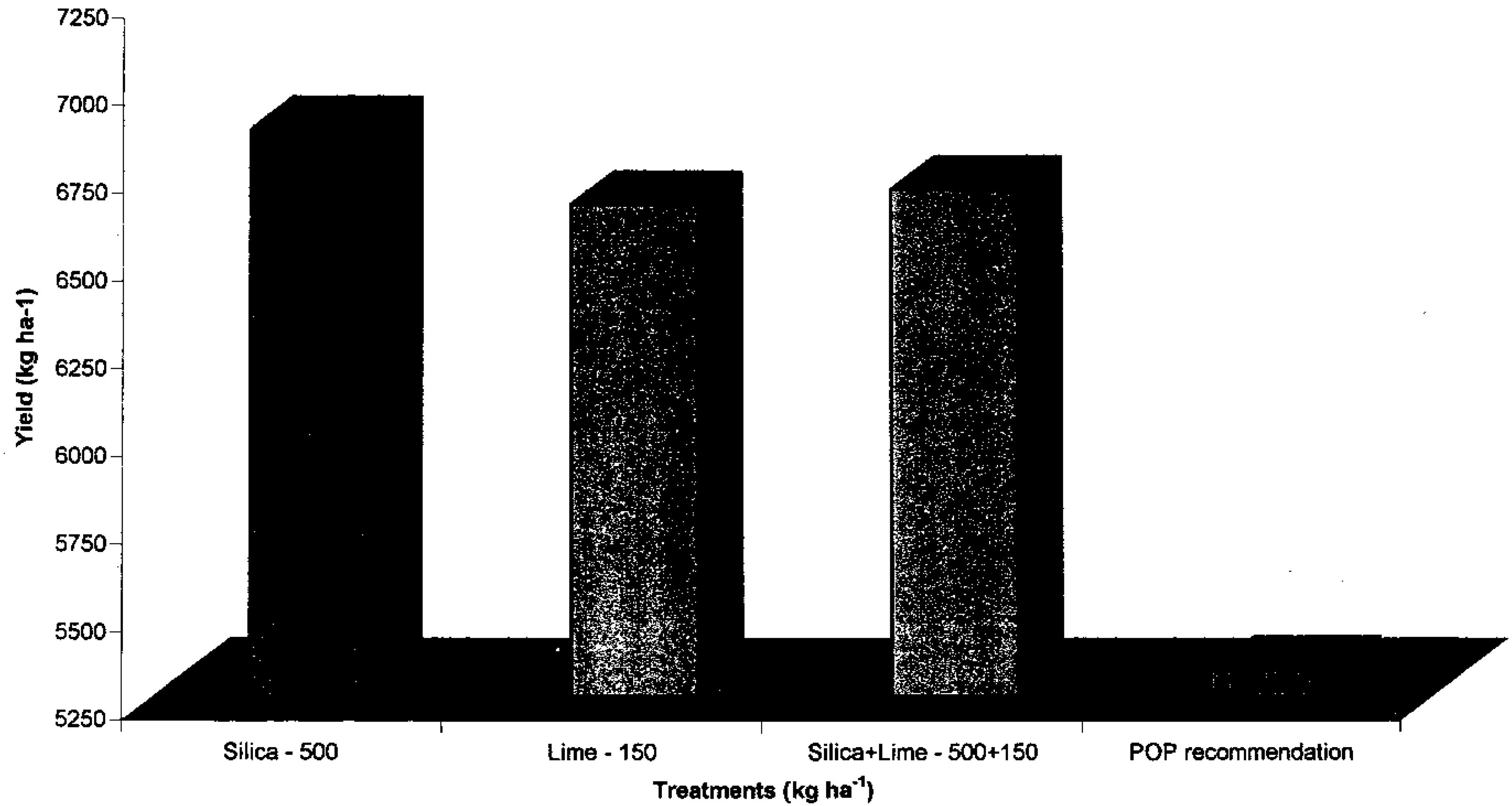
Group I - Mean of the treatments T[illegible], T[illegible], T[illegible] and T[illegible]

Group II - Mean of the treatments T[illegible], T[illegible], T[illegible] and T[illegible]

Group III - Mean of the treatments T[illegible], T[illegible], T[illegible] and T[illegible]

Group IV - Mean of the treatments T[illegible], T[illegible], T[illegible] and T[illegible]

Fig.8. Influence of soil ameliorants on grain and straw yield of rice



5.4. Elemental composition and yield expression

A critical evaluation of the data on individual elemental status of the plant showed that the plant absorbed the elements those were applied but other elements as well. Nutritionally the suppressive effects would appear to be due to the excess content of micronutrients especially Fe, Mn and Zn. Yoshida (1981) had reported that the ultimate critical limits of Fe, Zn and Cu were 300, 20 and 300 mg/kg respectively. He had also reported that the silica deficiency is to be expected when the content falls below 6 per cent. The significant negative influence of Fe on productivity may be due to its continued absorption in the later stages to levels beyond critical values. Absorption of excess levels of Fe, Zn, Ca and Mg are the limiting factors of productivity (Table 6 and 7). Enhancement of K level restricts the uptake of these elements.

The correlation analysis revealed that the yield and N content at maximum tillering, P content at panicle initiation stage and silica content in the plant at 50% flowering are positively correlated with grain yield. But Ca, S and Si content at panicle initiation stage and Cu contented at 50% flowering are negatively correlated with grain yield. N, K, Ca and S content in the grain and Si content in the straw had a positive effect while Ca content in the straw had a negative effect with grain yield (Table 12). This also confirms that N, K, Ca, S and silica have contributed to express the maximum yield potential of rice.

Top dressing of S can help in increasing the productivity as reported by Bridgit (1999). Reducing the application of P can minimize the negative influence of Zn and Mg (Sindhu, 2002). Increasing the dose of N, K and application of lime and silica have nullified the negative effects. Top dressing of N as ammonium sulphate also was favourable in enhancing the yield.

5.5. Effect of treatments on soil characteristics

The comparison of the nutrient status of the soil before and after the experiment has revealed that there was considerable improvement in the nutrient status of soil in the case of treatment plots than in the control. There was considerable reduction in the status of Fe and Mn, which suggests that poultry manure or cow dung in combination with lime, and silica would be responsible for this (Fig.9).

5.6. Pest and disease resistance

The lesser susceptibility of the plant to the attack of major pest and diseases in the treatment plots confirmed the beneficial effect of the application of 500 kg ha^{-1}silica and potassium 120 kg ha^{-1} (Table 13). Physical resistance imparted by the silica and potassium has been reported Takahashi (1997). It is believed that the formation of a silicate epidermal layer prevents the physical penetration by insects and makes the plants cells less susceptible to enzymatic degradation by fungal pathogens. Physiologically, the resistance is achieved by the accelerated synthesis of phenols, which may be related to the sulphur content. The reduction in stem borer incidence by improving silica concentration has also been reported by many (Sawant *et al.*, 1994, IRRI, 1991). Application of 500 kg ha^{-1} of silica reduced the incidence of stem borer and leaf folder (Lakshmikanthan, 2000).

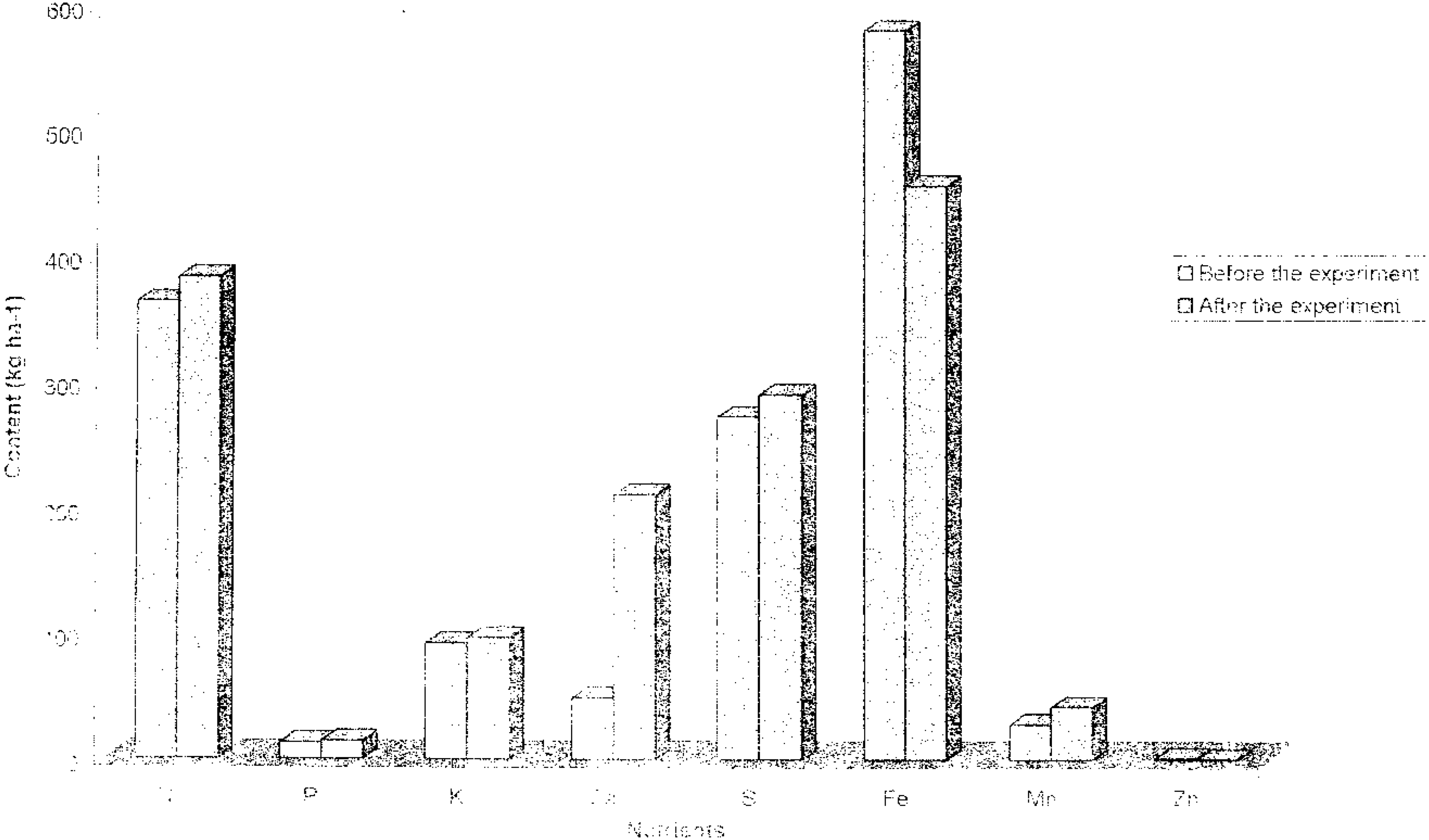
5.7. Occurrence of weeds

The table 14 showed that the significant reduction in weed population in the treatments plots was an added advantage. All the treatment plots, especially, the silica receiving plots, reduced the weed population, which in turn contributed to the higher productivity.

Conclusion

The present study revealed that addition of poultry manure with fertilizer N in the ratio of 1:2.25 along with silica could improve the productivity of rice in laterite soils. The treatments could significantly increase the height, number of productive tillers, number of spikelets per panicles and thousand grains weight which influenced the yield process to contribute the maximum grain production. Application of Silica could considerably reduce the occurrence of weeds and incidence of pests. Hence it is clear that the uptake linked management technique has to be evolved to preserve the productive capacity of the soil and enhance the crop productivity.

Fig.9. Status of nutrients in the soil before and after the experiment



SUMMARY

SUMMARY

The experiment entitled "Integration of nutritional inputs for improving rice productivity in laterite soils" was conducted during the virippu season of 2002 at the Agricultural Research Station, Mannuthy. The experiment consisted of 17 treatments including two sources of organic manure and two levels of nutrition with combinations of lime and silica to develop a cost effective, high yield and sustainable production technology for rice by identifying the components of good management. The experiment was taken up using Jyothi as the test variety. The summary of the results obtained from the study is presented below.

(1) The treatment receiving poultry manure with 90 kg ha^{-1} of fertilizer N and 500 kg ha^{-1} of silica recorded the maximum grain yield of 7004 kg ha^{-1}.

(2) The Straw yield was highest in the treatment receiving cow dung, 90 kg ha^{-1} N of fertilizer, 150 kg ha^{-1} lime and 500 kg ha^{-1} silica.

(3) An increase in 1680 kg ha^{-1} grain and 1087 kg ha^{-1} in T_{15} (poultry manure with 90 kg ha^{-1} of fertilizer N, 500 kg ha^{-1} of silica and in addition of 85 kg K) than the package of practices recommendations (POP) appear to be due to the application of silica, substitution of cow dung by poultry manure and increased dose of N with an organic: inorganic ratio of 1:2.25, increased dose of K and reduced dose of P.

(4) The treatment receiving poultry manure with 90 kg ha^{-1} of fertilizer N , 500 kg ha^{-1} of silica (T_{15}) recorded the maximum height, productive tillers, number of spikelets / panicle and thousand grain weight. Increased number of florets and grain weight which influences the yield process have contributed to the maximum grain production.

(5) Height of plants increased in the poultry manure treated plots when compared to cow dung treated plots and control plot.

(6) Substitution of N by the organic manures along with increased dose of N, lime, silica and K enhanced the tillering capacity of the rice plants and contributed more biomass than the present package of practices recommendations.

(7) Poultry manure application has improved the number of productive tillers per hill, length of panicle, and number of spikelets per panicle and percentage of filled grains.

(8) The superiority of T_9 (poultry manure 1.6 t ha^{-1} +50: 20: 120 kg NPK ha^{-1}) over T_1 (cow dung 5 t+ 50: 20: 120 kg NPK ha^{-1}) revealed that the poultry manure is better than the cow dung for rice. While organics in general are capable of mitigating the ill effects of the fertilizers, they also vary in their efficiency in doing so. So, the content and source jointly decide the efficiency of the organics.

(9) Cow dung has been found to contain Fe, Zn and Cu in toxic levels to rice plants but has lesser content of Ca. Poultry manure on the other hand had the content of elements in far less quantities but had a three fold higher Ca content. This has been useful in reducing the uptake of unfavourable elements by the rice plant.

(10) Positive correlation was found between the content of N at the maximum tillering stage, P at the panicle initiation stage, silica at 50 per cent flowering stage and the grain yield. There were negative correlations between the Cu content at 50 per cent flowering stage and the grain yield. N, K, Ca and S content in the grain were also positively correlated with grain yield. The silica content in the straw was positive correlated where as the Ca content had the negative influence on the grain yield.

(11) Increase in the level of K @ 120 kg ha^{-1} has recorded 1387 kg ha^{-1} more grain than that @ 35 kg ha^{-1} of K as in the package of practices. The uptakes of K by the plants are seen far above the applied levels. Hence,

the study suggests that the present recommendation of 35 kg ha^{-1} K has to be enhanced up to 120 kg ha^{-1} to prevent the soil degradation.

(12) The results of the present study have indicated that in all probability, it may have unfavourable balance in organic – inorganic interactions in the present package of practices recommendation. The difference in yield between T_1 (cow dung +50 kg N) and T_{17} (package of practices recommendation) has been attributed to the difference in the ratio of integration of organic and inorganic. The package of practices (T_{17}) had a ratio of 1:3.5 where as T_1 had that of 1:1.25. The difference of 826 kg ha^{-1} of grain yield under 1:1.25 ratio would mean that the efficiency of N in affecting the yield is influenced by the ratio.

(13) There was no apparent effect when lime and silica were applied together but individually they could improve the yield. It may be due to the chemical interactions, which are invariable, when the elements are applied as chemical resources.

(14) It is also seen that the rice plants absorb only around 20 kg P and hence, the P recommendation can be reduced from 35 kg to 20 kg ha^{-1}. Excess application of P may lead to the unavailability of other nutrients, especially the micronutrients.

(15) In general, silica applied plots had lesser number of weeds.

(16) The attack of pests, especially that of leaf roller, stem borer and gall midge were less in the treatment plots than in the package of practices. Soil ameliorants, especially silica imparted resistance in rice plants. Accumulation of non-metabolic N in the plants receiving the package of practices recommendations might have invited the pests.

(17) The study revealed that the present system of soil management is responsible for the progressively decline in the nutrient use efficiency.

The uptake linked management technique has to be evolved to preserve the productive capacity of the soil.

(18) The results indicate that the plants receiving the package of practices recommendation (T_{17}) had been subjected to early metabolic inhibitions and later translocation inhibitions.

CONCLUSION

The study on "Integration of nutritional inputs for improving rice productivity in laterite soils" revealed that poultry manure is better than cow dung for rice in laterite soils. Increasing the dose of N and K along with the substitution of N by the organic manures and reduced dose of P could considerably increase the rice productivity than the existing package of Practices recommendation of Kerala Agricultural University. Soil ameliorants viz. lime and silica could improve the yield and the silica application imparted resistance to pests and diseases. Considering the economics, it is also found that the application of poultry manure not only reduces the cost of cultivation but also increases the net profit by improving the productivity.

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APPENDICES

APPENDIX-I

Weekly weather data at Vellanikkara (5/2002 TO 9/2002)

Std.week no	Temperature ^{0}C Max.	min.	mean	Relative humidity% Morning	evening	Sunshine hrday^{-1}	Evaporation mmweek^{-1}	Rainfall mm
19	33.7	25.3	29.5	84	60	7.7	4.8	44.2
20	30.8	24.0	27.4	93	76	3.1	2.7	173.2
21	32.2	24.2	28.2	87	67	6.9	3.7	4.0
22	30.8	24.0	27.4	89	73	3.5	4.2	119.0
23	30.7	23.4	27.1	94	73	5.0	3.5	64.2
24	28.9	22.5	25.7	94	83	0.6	2.5	219.1
25	29.5	23.3	26.4	93	81	1.8	2.8	109.8
26	30.5	23.7	27.1	94	75	3.5	3.1	74.6
27	30.3	23.6	26.9	94	72	5.2	3.4	57.0
28	29.4	23.1	26.3	94	77	3.0	3.1	126.0
29	29.7	22.7	26.2	95	73	2.7	3.1	58.0
30	29.9	22.9	26.4	93	73	3.8	2.9	70.4
31	28.1	22.5	25.3	95	86	0.7	2.4	83.6
32	28.6	22.2	25.4	95	79	0.9	2.8	94.0
33	27.9	22.8	25.4	94	83	2.6	2.1	337.0
34	30.1	25.4	27.8	93	72	5.4	3.8	13.8
35	30.9	24.1	27.5	93	65	7.3	4.3	3.8
36	29.8	25.4	26.5	94	71	5.5	3.4	98.7
37	30.7	25.0	26.8	92	63	8.7	4.4	8.0
38	31.3	24.8	27.1	91	59	8.3	4.3	0.0
39	32.5	25.0	27.6	90	55	8.2	4.4	21.5

Appendix -II

Physico-chemical characteristics of the soil of the experimental site

PH	5.30
Electrical conductivity (ds m^{-1})	0.12
Bulk density (g cm^{-3})	1.33
Particle density (g cm^{-3})	2.30
Porosity (%)	49.00
Water holding capacity (%)	49.15
Mechanical composition	
Sand %	76.25
Silt %	4.44
Clay %	18.35
Available nutrients	
Organic carbon (%)	0.53
N (kg ha^{-1})	363.76 (medium)
P (kg ha^{-1})	12.87 (medium)
K (kg ha^{-1})	92.60 (low)
Ca (kg ha^{-1})	49.20
Mg (kg ha^{-1})	30.30
S (kg ha^{-1})	273.70
Na (kg ha^{-1})	99.00
Fe (kg ha^{-1})	582.20
Mn (kg ha^{-1})	28.20
Zn (kg ha^{-1})	1.28
Cu (kg ha^{-1})	3.58

Appendix IV

Methods used for soil chemical analysis

Character	Method	Reference
Soil reaction(pH)	Soil water suspension of 1:2.5 and read in a pH meter	Jackson, 1958
Electrical conductivity	Soil water suspension of 1:2.5 and read in a pH meter	Jackson, 1958
Organic carbon	Walkely and Black method	Walkely and Black, 1934
Available Nitrogen	Alkaline permanganate method	Subbaiah and Asija, 1956
Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue colour method	Watanable and Olsen, 1965
Available K_2O	NH_4 Acetate extract using Flame Photometer	Jackson, 1958
Exchangeable Ca	Neutral normal ammonium acetate extract using EDTA Titration method	Jackson, 1958
Exchangeable Mg	Neutral normal ammonium acetate extract using EDTA Titration method	Jackson, 1958
Available S	$CaCl_2$ extract-turbidimetry method	Chesnin and Yien, 1951
Available Fe	DTPA extract method using Atomic Absorption Spectrophotometer	Lindsay and Norvell, 1978
Available Mn	DTPA extract method using Atomic Absorption Spectrophotometer	Lindsay and Norvell, 1978
Available Zn	DTPA extract method using Atomic Absorption Spectrophotometer	Lindsay and Norvell, 1978
Available Cu	DTPA extract method using Atomic Absorption Spectrophotometer	Lindsay and Norvell, 1978

Appendix III.

Methods used for plant nutrient analysis

Nutrient	Method	Reference
N	Microkjeldahl digestion and distillation method	Jackson, 1958
P	Vanadomolybdo phosphoric yellow colour method using Spectronic 20	Jackson, 1958
K	Diacid extract using Flame Photometer	Cheng and Bray, 1951
Ca	Neutral normal NH_4OAC using EDTA titration method	Jackson, 1958
Mg	Neutral normal NH_4OAC using EDTA titration method	Jackson, 1958
S	Turbidimetric method using Spectronic 20	Williams and Stein bergs, 1959
Fe	Diacid extract using Atomic Absorption Spectra Photometer	Jackson, 1958
Mn	Diacid extract using Atomic Absorption Spectro Photometer	Jackson, 1958
Zn	Diacid extract using Atomic Absorption Spectro Photometer	Jackson, 1958
Cu	Diacid extract using Atomic Absorption Spectro Photometer	Jackson, 1958
Si	Rapid micro determination of silicon	Nayar *et al.*, 1975
Na	Diacid Extract using Flame Photometer	Cheng and Bray, 1951

APPENDIX -V

Nutrient status of cow dung and poultry manure

Nutrients	Cow dung	Poultry manure
N%	0.4	1.2
P%	0.31	1.4
K%	0.42	0.81
Ca(mg/g)	2.8	9.1
Mg(mg/g)	5.01	1.93
Cu (μg/g)	4.4	2.8
Zn (μg/g)	36.0	14.5
Fe (μg/g)	0.14	0.1

INTEGRATION OF NUTRITIONAL INPUTS FOR IMPROVING RICE PRODUCTIVITY IN LATERITE SOILS

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ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

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2003

ABSTRACT

A study on "Integration of nutritional inputs for improving rice productivity in laterite soils" was taken up during 2001-2003 at the College of Horticulture, Vellanikkara. The experiment consisted of 17 treatments including two sources of organic manure and two levels of nutrition with combinations of lime and silica to develop a cost effective, high yield and sustainable production technology for rice by identifying the components of good management.

The treatment receiving poultry manure with 90 kg ha^{-1} of fertilizer N and 500 kg ha^{-1} of silica recorded the maximum height productive tillers, number of spikelets per panicle and thousand grain weight which contributed to the maximum grain yield of 7004 kg ha^{-1}. An increase in 1680 kg grain yield and 1087 kg straw yield than the package of practices recommendation of Kerala Agricultural University appear to be due to the application of Silica, substitution of cow dung by the poultry manure and increased dose of N with an organic : inorganic ratio of 1:2.25, increased dose of K and reduced dose of P.

Cow dung contains Fe, Zn and Cu in toxic levels to rice. Poultry manure has the content of these elements in far less quantities but has higher Ca content which helps in reducing the uptake of unfavourable elements by the rice plants.

Increase in the level of K application @120 kg ha^{-1} has recorded 1387 kg ha^{-1} more grain than the present recommendation of 35 kg ha^{-1} and the uptake of K by the plants are far above the applied levels. This suggests that the present recommendation of 35 kg ha^{-1} of K has to be enhanced up to 120 kg ha^{-1} to prevent the soil degradation. It is also seen that the rice plants absorb only around 20 kg P and hence the P recommendation can be reduced from 35 kg to 20 kg ha^{-1}.

There was no apparent effect when lime and silica were applied together but individually they could improve the yield. The number of weeds and the incidence of pests and disease were less in the treatment plots, which revealed the influence of soil ameliorants in imparting resistance in the rice pants.

The results of the present study indicate that the failure of rice plants to respond to higher doses of fertilizer N, appears to be because of the unfavourable organic: inorganic ratio. A ratio of 1:2.25 was found to be beneficial to nullify the unfavourable chemical effects of fertilizer N.