NUTRITIONAL RESOURCE USE EFFICIENCY IN RICE PRODUCTION

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"NUTRITIONAL RESOURCE USE EFFICIENCY IN RICE PRODUCTION"** 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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CERTIFICATE

Certified that this thesis, entitled **"NUTRITIONAL RESOURCE USE EFFICIENCY IN RICE PRODUCTION"** is a record of research work done independently by **Mr.S.Vallal Kannan,** 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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INTRODUCTION

Rice is the 'global grain' as almost 515 million tonnes of grain is produced in each year in 89 nations and it is the staple food for more than half of the global population. In 25 years from 1967 to 1992 the world rice harvest doubled but to keep pace with the Asia's still rising population, rice production will have to increase another 60 to 70 per cent by the year 2025 and this production has to come from less land and low inputs (Sanchez *et al.*, 1997). A good percentage of rice is grown in laterite soils. In India it comprises of 107 million hectares mainly in Eastern Madhya Pradesh, Bihar, Orissa, West Bengal, Andhra Pradesh, Karnataka, Kerala and Tamil Nadu. In Kerala laterite constitutes more than 68 per cent of the agricultural soil. Poor productivity and low nutrient use efficiency are the twin issues that characterize the rice production scenario of the laterite soils of the west coast. Intensive weathering, heavy leaching of mineral nutrients and natural water stagnation in the crop growth period have transformed laterite rice tracts of the west coast into a special entity different from conventional rice tracts elsewhere in physico-chemical properties and crop production capabilities. Low cation exchange capacity, low organic matter, high acidity and toxicity due to Fe, Al and Mn, high P fixation and poor nutrient status aggravate the production incapability of laterites.

Stresses due to both deficiencies and toxicities of mineral elements are by and large neglected since they are seldom depressed or symptomatised. Fertility management for productivity improvement is based upon making up the deficiencies of nutrients on one side and ameliorating the ill effects due to toxicity on the other side. Individual studies on productivity improvement of laterites have revealed the failure of even continuous application of 18 t ha^{-1} farm yard manure per season to raise the rice yield level beyond 4 t ha^{-1}. There is also increasing evidence that fertilizer alone cannot sustain yields for long periods. In continuous rice cropping with two to three crops grown annually, the use of fertilizer N was increased with time but the yields often remained stagnant. This reflects a higher fertilizer requirement to produce the same yields, implying a decline in yield response to nutrients, possibly because of an over use of fertilizers.

The continued investigations to uncover the factors responsible for limiting yield expression in laterite soils have resulted in the understanding of direct effect of excess iron absorption (Potty *et al.*, 1992), its metabolic interferences (Bridgit and Potty, 1992), deficiency of some elements manifested as negative effects of some other elements (Mathewkutty, 1994) and narrow N/Fe ratio (Musthafa, 1995) as productivity barriers of laterites. Sreekumaran (1998) elucidated the interrelations among nutrients that decided the yield expression in laterite soils.

Bridgit (1999) observed that rice yield in laterite soil could be increased without any addition of N and P beyond the present recommended level if Fe and Mn absorption could be restricted and cell sap pH maintained at 6.2 and suggested enhancement of K levels and inclusion of S in nutritional management programme to achieve high rice productivity in laterites. Thomas (2001) and Mathew (2002) suggested that the net effect of native and supplied nutrient ions is responsible for deciding productivity and insisted appropriate nutritional and ameliorative management technology for yield improvement.

Soil manipulations under intensive cropping coupled with high temperature and rainfall in the humid tropics cause fast organic matter decline in the laterite rice soils. Estimations to the extent of 10 to 12 t of organic manure addition annually in these soils are available to compensate the organic matter loss per year (Mathew, 2002). Organic carbon content is an index of soil fertility. The interrelations among organic matter, organic carbon and other essential nutrient elements are well established for different soil types. Thus the replenishment of soil organic matter and consequently the organic carbon content is becoming essential to achieve higher productivity. Swaminathan (1987) suggested an integrated nutrient supply system through judicious combination of organic and biological sources along with inorganic fertilizers to improve land and crop productivity and to achieve an ecologically sound sustainable agriculture.

The available cause-cure technologies in order to improve the present productivity level in laterite soils are carefully examined. The present investigation involving an integrated nutrient management system, which may alleviate the stress due to deficiencies and toxicities in soil plant system is taken up with the following objectives.

1. To characterize and quantify the effects of organic sources on nutrient supply, amelioration and inactivation of the deleterious factors in rice culture.
2. To study the supplementary requirements of inputs and their complementary effects on yield improvement.
3. To develop a technology by integrating various inputs and their levels to ensure high resource use efficiency and consequently high productivity.

Review of Literature

2. REVIEW OF LITERATURE

Organic manuring is regaining its importance in crop manurial programmes since people are becoming increasingly aware of the ill effects of chemical fertilizers and also the inability of synthetic fertilizers to supply a range of nutrients to improve the soil fertility. Organic matter addition is essential to maintain or improve the tilth, fertility and productivity of agricultural soil. Organic manuring also improves the physical and microbial conditions of soil and enhances fertilizer use efficiency when applied in conjunction with mineral fertilizers. Thus all the major sources of plant nutrients such as soil, mineral fertilizers, organic manures and biofertilizers should be utilized in an efficient and judicious manner for sustainable crop production in rice cropping system.

Levels of soil organic matter and its enrichment through extraneous additions and or recycling alone as well as supplemented by chemical inputs is generally considered as the panacea for soil and crop productivity.

The review focuses on the organics derived from plant and animal origins, inorganic sources and ameliorants applied in wet land rice system, their effect on reduction of deleterious effect due to any other interactive input use, improvement on soil fertility, nutrient resource use efficiency, amelioration and crop productivity, and also the benefit and possibility of an integrated nutrient management system to solve the soil stresses and to improve the productivity.

2.1 ORGANIC MANURES

The role of manures of both plant and animal origin in improving soil fertility and enhancing production in agriculture has been well recognized and been in practice for many years. In addition to the chemical changes brought about by their soil application, organic manures can also enhance the physical properties of the soil making it more conducive to plant establishment and growth. Organic manures obtained from plants and animals are considered as valuable source of nutrients for plants.

Organic manures including animal manures, crop residues, green manures and composts were traditionally and preferentially used in developing countries until the 1960's when inorganic chemical fertilizers began to gain popularity due to their easy availability less bulk and thus easiness in transport, handling and storage (Dahama, 1996).

2.1.1 Organic manures of plant origin

In sustaining rice production organic manures of plant origin like green and green leaf manures and crop residues or paddy straw are considered to be of immense importance.

2.1.1.1 Green and green leaf manures

Scientific evaluations of green manures were started in the middle of the 20th century and extensive surveys were conducted by Raju (1952) and Vachani and Moorthy (1964) on about 100 leguminous green manure crops in India and recommended several suitable ones for rice culture. Among them, sunhemp *(Crotalaria juncea)* and *Sesbania aculeata* Syn. *Cannabina* were found to be more acceptable to the rice farmers. Sesbania species are well adapted for use as a green manure because of its ability to withstand water logging and flooding, to grow on fine textured soils and to tolerate soil salinity (Evans and Rotar, 1987).

Coarse textured soils low in organic matter and nitrogen showed greater response to green manuring than the highly fertile soils. Tropical soils are mainly low in organic matter, which contributes much to the productivity of soil through mineralisation of nutrients and improvement in soil physical and biological conditions. Increased organic matter status of soil due to incorporation of green manures was observed in crop sequences involving rice and leguminous green manures.

In traditional agriculture, green manures were grown in fallow field and incorporated two to four weeks before sowing of the following crop. But in the present day intensive agriculture, this practice is not feasible, when there is fallow period of only 40-60 days before transplanting of rice. On the basis of yield responses, it was found that a two-week delay between incorporation of green manure and transplanting of rice was not only unnecessary but also disadvantageous in certain situations (Su *et al.*, 1993).

Green leaf manures are preferred when raising green manure crop *in situ* is not possible, especially in areas with limitations such as lack of irrigation and causing loss of a crop growing season. Woody species of genera *Glyricidia, Leuceana* and *Sesbania* are widely used as green leaf manures in the tropics. *Pongamia glabra* a leguminous tree grown in semi arid tropics for green leaf manure, pods and fuel wood (Udayasoorian, 1988) is an excellent green leaf manure which contains 2.78, 0.27 and 0.19 per cent N, P and K,respectively. Balasubramaniyan *et al.* (1993) used leaves of *Pongamia glabra* as a potential source of plant nutrients. Prasanth (2002) identified *Pongamia glabra* as a potential green leaf manure for rice grown in laterite soil.

2.1.1.2 Influence of green and green leaf manure on soil properties

The continuous application of manures can modify, in addition to supply of plant nutrients, the soil physical properties. Incorporation of green manures increased porosity, hydraulic conductivity and water holding capacity and aggregate stability and decreased bulk density (Watanabe and Ventura, 1992). Monnier (1965) stated that easily decomposable materials very low in humus like green manure produce short but intensive effects with regard to soil structural stability.

The ability of green manures to improve soil physical properties and fertility was reported by Biswas *et al.* (1970). Nakaya and Motomura (1984) stated that accumulated organic matter in the soil from long term application of organic materials improved the physical properties of paddy soils, particularly by decreasing the solid ratio, bulk density, specific gravity and crushing strength, increasing the liquid ratio and porosity caused mainly by increase of capillary pores.

Incorporation of green manure increased root density and grain yield and also improved the physical properties of soil under wetland rice (Boparai *et al.*, 1992).

Sadana *et al.* (1995) reported that green manuring under submerged conditions markedly decreased soil solution pH, and pE and increased EC, partial pressure of CO_2 and Fe concentration. Khind *et al.* (1987) reported decrease in soil redox potential (Eh) after addition of *Sesbania* in wet land rice soil.

Green manures have the capability to increase organic matter content and also physical properties of the soil (Singh, 1962). The application of organic manures at 22.5 to 35 t ha^{-1} for five years increased the soil organic matter content by 7.3 per cent to 33.6 per cent compared to control. Also it improved soil organic matter, increased active organic matter content, organic complex formation and total humus content by 17.4 per cent, 52.1 per cent and 6.1 per cent respectively (Chen and Wang, 1987). Kolar *et al.* (1993) could find an increase in the organic carbon content due to green manuring in rice-wheat system. Green manuring benefited the soil by mobilization of plant nutrients absorbed by the green manures and release of the same during subsequent decomposition which increased soil fertility (Paturde and Patankar, 1998).

Agboola (1974) highlighted the ability of green manure to recycle leached plant nutrients. This was accomplished by the absorption of nutrients from the lower depth by roots of legumes and translocation of them to the leaves (Wen, 1984). The effectiveness of green manure was hindered by too early and too late ploughing in before the transplanting of rice. The best time to plough in would be 15 days before transplanting.

Bouldin (1988) showed that green manure contained two fractions; one, which decomposes during the first crop and other, decomposes slowly over the years. He further observed that with most green manure crops first fraction constitutes 50-80 per cent of total N. So the residual effect was relatively small when green manure was applied only once, but the cumulative effects of several applications resulted in long term maintenance of soil properties.

Kundu *et al.* (1990) observed that nitrogen release from *Sesbania* and *Gliricidia* was roughly equal to 21.5 per cent and 32 per cent respectively, of that N from urea, while agronomic efficiency of *Sesbania* and *Glyricidia* was found to be 42 per cent and 66 per cent respectively of that urea N. Green manures that attain peaks of their nitrogen release between fourth and fifth weeks after transplanting rice, were found to be the most productive and useful source of N for transplanted rice. Patiram and Singh (1993) noticed that continuous application of green manure has increased the available P content in soil. Abdul *et al.* (1999) reported that soil available N was greatest with sunhemp followed by daincha. Bharadwaj *et al.* (1981) concluded that green manuring with soil incorporation of sunhemp saved 75 kg N ha^{-1} and daincha 50 kg N ha^{-1} in rice fields. *Sesbania* green manuring enriched soil fertility by increasing organic matter level and P, K and S availability in soil (Pervin *et al.*, 1995). Incorporation of daincha resulted in pronounced increase of soil organic carbon content, available soil N, P and K.

Legume plants have the ability to utilize insoluble phosphates through their well-developed root system and upon mineralization green manures released P in the available form (George, 1989). Balasubramaniyan *et al.* (1993) got increased availability of NPK due to green manuring. Bindra and Thakur (1995) could obtain increased NPK uptake due to green manuring in paddy.

A significant increase in water soluble Ca and Mg with the application of green manures to the flooded soil had been observed by Khind *et al.* (1987). Green manures when incorporated just before transplanting of rice improved the soil environment due to aeration of reducing condition, which helped to increase the availability of Fe, Zn and Mn (Thind and Chahal, 1987 and Sadana and Bajwa, 1987).

Budhar *et al.* (1991) observed that P and K content of soil were higher in plots manured with *Pongamia glabra*, poultry manure and *Sesbania rostrata* and also observed that the post harvest soil N and K contents were the highest after application of *Sesbania* and P content was the highest on application of *Pongamia glabra*.

2.1.1.3 Influence of green and green leaf manures on productivity of rice

A great deal of literature is available on direct effect of green manuring on the grain yield of wetland rice. The major effect is through N contribution but the favourable effects of organic matter addition and availability of other nutrients cannot be overlooked. Several recent experimental evidences showed the positive influence of green manuring in increasing the rice yield to varying magnitudes. Gopalaswamy and Vidhyasekharan (1987) reported that although green manures and urea were equally effective in increasing yields, only green manures increased soil microbial activity indicating higher soil fertility status. In an experiment to find out the effect of farm wastes and green manures in low land rice it was found that plant height was significantly influenced by the basal incorporation of farm wastes and green leaf manure (Budhar *et al.*, 1991).

Mahapatra and Jee (1993) reported green manuring dhaincha alone gave yield of 3.48 tonnes. Gurung and Sherchan (1996) reported a significant 30 to 49 per cent increase in grain yield of rice with green manuring using *Sesbania aculeata,* grown as a sole crop and green manured to rice.

Paturde and Patankar (1998) reported that rice grain yield was significantly increased with green manure compared to no green manure. Dwivedi and Thakur (1999) reported that green manuring with daincha resulted in significantly higher grain yield (4.74 t ha^{-1}). Among the various organic sources tried, *in situ* incorporation of daincha gave remarkably increased grain and straw yields to the extent of 18 and 16 per cent respectively over control (Hemalatha *et al.*, 2000). Highest rice grain yield (3.3 t ha^{-1}) was produced by the application of *S. aculeata* alone while urea alone produced 3.1 t ha^{-1} in the second crop season (Haroon *et al.*, 1992). Mahapatra and Sharma (1996) observed that yield of rice was increased significantly and was on par with highest dose of N (120 kg N ha^{-1}) with application of 5–6 t ha^{-1} of green manure. The yield increase was attributed to significant variations in number of panicles per sq.m, 1000 grain weight and N uptake by the crop.

According to Watanabe and Ventura (1992) grain production per unit weight of absorbed N was lower with green manure than with urea. Musthafa (1995) observed that the yield improvement due to organic manure was by widening of N/Fe ratio in laterite soils. Chakraborty *et al.* (2001) observed that grain and straw yields, N uptake, P recovery and P use efficiency was highest when *S. aculeata* was incorporated followed by fertilizer application @ 30, 15, 15 kg N, P and K ha^{-1} as basal dose. Higher biomass incorporation of green manure increased the yield of rice (Kannan and Wahab, 2002). Sharma (1994) showed that rice yield and P uptake were increased by application of green manure and phosphatic fertilizers.

Gopalaswamy and Vidhyasekharan (1987) reported green manuring with *Pongamia* (12.5 t ha^{-1}) 15 days prior to transplanting produced 6.1 t ha^{-1} grain yield. Maskina *et al.* (1986) evaluated sesbania, sunhemp, cowpea and mungbean as summer green manures for N substitution for the following rice. All the green manures were equally efficient in increasing the grain yield of rice, which was equivalent to that produced by applying 120 kg N ha^{-1} as urea in the fallow plots. The result of these studies indicated the potential of green manuring in increasing rice production and green manuring could be considered as a viable component of integrated nutrient management for rice..

2.1.2 Paddy straw

Another easily available by-product that has the potential for organic manure in the rice farming tracts of the world is rice straw. It is the only organic material available in significant quantities to most rice farmers (Dobermann and Fairhurst, 2002). Though a substantial amount of rice straw produced is used as fodder the possibility of incorporating both fresh straw or composted straw or even ash obtained from straw burning has been explored and the advantages of each have been studied by Ponnamperuma (1984) and Verma and Bhagat (1992). The return of plant nutrients absorbed by crops back to the soil is one of the basic principles in maintaining soil fertility. Eighty per cent of K, Ca and Si, 50 per cent of Mg and 25 per cent N, P and S absorbed by rice plants are accumulated in rice straw (Chatterjee and Maiti, 1981). Hence application of straw returns substantial amount of these nutrients to the soil. Residue incorporation was more beneficial than residue burning which saved the loss of valuable plant nutrients.

2.1.2.1 *Paddy straw on soil properties*

Straw application is known to influence soil properties and crop growth. This is because of the fact that application of the straw and other organic residues affects the soil biological, chemical and physical properties resulting in varied effects on crop growth.

Brandon *et al.* (1997) identified recycling of nutrients, improving reoxidation of top soil layer and increase in water holding capacity as the benefit of straw addition. Muthuvel *et al.* (1981) reported a decrease in the bulk density with increase in organic matter content due to better aggregation. Rath *et al.* (1999) observed a drop in redox potential and Fe^{+2} and suggested that the addition of straw hastened reduction of soil even under non-flooded conditions. Lal *et al.* (2000) reported that incorporation of the wastes significantly increased the pH and nutrient status of acid soils. Verma and Bhagat (1992) extensively explored the possibility of use of rice straw as a nutrient source for rice. Yoshida *et al.* (1996) observed that soil Eh after rice straw application was generally high.

Yonegama and Yoshida (1976) observed that rice straw being low in nitrogen content immobilized soil nitrogen or applied fertilizer nitrogen under both low land and upland conditions. But under lowland conditions, the amount of nitrogen immobilization was small during the first week, which increased subsequently after 2 to 3 weeks under upland conditions. Immobilization of nitrogen was maximum during first week but the extent of immobilization was not as early as under lowland conditions. Ahmed *et al.* (1969) reported that immobilization and mineralization process were related to the C:N ratio of the added materials. Enwezor (1976) reported that nitrogen mineralization decreased with increasing C:N ratio of the organic materials added to soil and no nitrogen was found mineralilzed above a C:N ratio of 16:1. Singh *et al.* (1999) reported that incorporation of rice straw with urea was superior over control in increasing the grain yield but inferior in comparison to other organic materials. This might be due to excessive immobilization and fixation of available soil N by rice straw with wide C:N ratio, causing temporary deficit and severe N starvation of rice plants.

Application of rice straw increased the uptake of Fe and Mn at different stages of growth but pH and Eh values of the soil decreased rapidly with decreasing rice straw addition (Yodkeaw and De Datta, 1989). Hwang and Kim (1977) reported that the use of rice straw markedly increased the organic N, K and silica content in the soil. According to Ponnamperuma (1980) rice straw has a positive effect on soil fertility and its continuous application increased the soil N content. Dhillon and Dev (1983) opined that straw incorporation significantly increased the organic C, total N and hexosamine N and aminoacid N. They also observed that the available N was low and it decreased with continuous cropping where straw was continuously incorporated but total N increased by about 20 per cent after four crops. They further observed an increase in organic carbon level due to straw incorporation. Kurumthottical (1982) reported that organic matter application raised the CEC of the soils in the permanent manurial trial on rice conducted at RARS, Pattambi.

Sharma *et al.* (1988) opined that incorporation of organic wastes improved the N content and increased the available P content by 20 per cent. Luo and Huang (1990) reported that addition of large quantities of rice straw reduced efficiency of applied N. Mukherjee *et al.* (1990) reported that rice straw application increased organic carbon and total nitrogen content of soil. Kosuge and Zulkarnaini (1981) reported that straw application increased uptake of nitrogen, potassium and silicon. Li (1994) suggested the adoption of rice straw manuring to sustain better soil nutrient balance.

Bye (1977) reported that the uptake of K was increased with straw application which was further increased with nitrogen application. Sharma and Sharma (1994) revealed that application of organic materials like wheat straw, farm yard manure, water hyacinth compost @ 5 t ha^{-1} and dual cropping azolla in acid laterite soils increased yield and NPK uptake in rice.

2.1.2.2 Paddy straw on productivity of rice

Ismunadji (1978) noticed that incorporation of paddy straw at 20 t ha^{-1} four weeks prior to transplanting increased grain yield from 2.78 to 3.06 t ha^{-1}. Sidorenko

(1977) noticed in pot trials that application of 5 t ha^{-1} paddy straw decreased growth during early stages but improved the growth in the later stages and increased paddy yields by 55.5 per cent compared to those without straw application.

Ansus and Reyer (1979) noticed that when straw incorporated 30 days before transplanting at 7.5, 15 and 30 kg straw m^{-2} (7.5, 15 and 30 t ha^{-1}), grain yield increased with increasing straw levels from 33 q ha^{-1} in control to 43 q ha^{-1} in the highest dose. Kosuge and Zulkarnaini (1981) reported that number of grains per panicle and per m^2 increases with increasing levels of straw.

Rice straw application in soils with high N levels did not become effective in improving the growth and yield of paddy till the fourth year.Where as, in soils with low N, application of the straw resulted in initial retardation of growth but was restored by the time crop reached panicle initiation stage, however yield obtained was lesser than the soil supplied with chemical fertilizer (Anzai *et al.*, 1989).

Sharma and Mittra (1990) observed that application of 5 t ha^{-1} rice straw 20 to 30 days before transplanting rice gave higher grain yield compared to late transplanting. Jha *et al.* (1992) reported higher paddy yield with the incorporation of fresh rice straw + green manure combined with 60 kg N in three splits.

2.1.3 Organic manures of animal origin

The animal wastes like cowdung and poultry manure are of immense importance to improve the soil fertility and productivity of rice.

2.1.3.1 Cowdung (FYM) on soil properties

Bulk density of soil was decreased by continuous application of farmyard manure under dry farming situations (Havanagi and Mann, 1970). Apart from the favourable influence on bulk density, continuous addition of organic manures brought about improvement in total porosity of soils (Bhatia and Shukla, 1982) which in turn influenced other physical properties. Biswas *et al.* (1971) reported that when the dose of organic manure applied was higher, the bulk density was lowered resulting in the improvement of soil conditions.

The organic manures that are added to the soil undergo microbial decomposition. As a result the soil structure is improved which is reflected in low bulk density and better water conducting properties of soil (Manickam, 1983). Application of farmyard manure and crop residues significantly lowered the bulk density of the soil and penetrometer resistance and increased the cumulative infiltration and water holding capacity of soil (Sharma and Sharma, 1994). Dharwish *et al.* (1995) found that water retention was consistently but slightly improved by organic manure application.

Organic manures work like a slow release nitrogen fertilizers and are considered as efficient nutrient supplementing sources. They improve the physico–chemical properties of the soil and influence the availability and uptake of nutrients. The beneficial effects of farmyard manure incorporation in the field might be due to its richness in almost all nutrients and its slow availability (Nakada, 1980).

Udayasooriyan (1988) reported that continuous application of cowdung increased the organic carbon contents from 0.91 to 1.58 per cent. Chellamuthu *et al.* (1989) observed an increase in the organic carbon, available N and P contents of soil by farmyard manure application. It also resulted in increase in total N content from 0.045 to 0.074 per cent.

Raniperumal and Varadarajan (1967) reported that the organic manure mobilized soil native phosphorus. FYM increased the water-soluble phosphorus and left residual nitrogen in soil while it increased grain yield of rice (Katyal, 1980). Dhargawe *et al.* (1991) reported an increased availability of phosphorus by addition of 10 to 20 tonnes of farmyard manure per hectare. According to Inoko (1984) only about 25-30 per cent N containing in compost and farm yard manure could be absorbed by rice plants during one crop season and the accumulated nutrients from the continuous application of organic matter were gradually mineralized and utilized by successive crops which sustained the productivity.

2.1.3.2 *Cowdung (FYM) on productivity of rice*

Many researchers showed that addition of organic manures increased the yield of rice by enhancing the number of productive tillers, number of panicles per sq.m, filled grains per panicles and 1000 grain weight. The impact of FYM yield attributes of rice is reviewed below.

Long-term application of farm compost to paddy fields promoted the development of lateral roots. Okamura (1989) found that application of organic material alleviated the decline of roots occurring in rice plants with chemical fertilizer application at the later stages of growth. Heavy application of cattle manure increased the plant height, number of tillers and number of grains per panicle but decreased the 1000 grain weight and total yield (Jin *et al.*, 1996).

Song and Zhao (1993) reported that continuous application of manures to paddy fields enhanced root development by reducing tissue lignifications, increasing root diameter, providing nutrients which are lacking in the rhizosphere and forming chelated Fe and Mn.

Sharma (1970) reported that plants with farmyard manure application were taller and produced more tillers and dry matter than those grown with out farmyard manure. Among the organic manures, *sesbania* green manure and farmyard manure exerted almost similar effects in increasing the number of productive tillers. Krishnamoorthy *et al*. (1995) found that organic manures increased the dry matter yield of rice at tillering and flowering stages and farm yard manure treatment was superior to green leaf manure in increasing dry matter yield.

Rathore *et al.* (1995) observed that grains per panicle and 1000 grain weight were significantly higher in BGA and FYM treated plots compared with the unfertilized control. Anilakumar *et al.* (1993) found that continuous application of cattle manure alone in the first crop season was the best, producing 24 per cent more yield than the fertilizer treatment. The treatment supplying half of N through cattle manure also recorded more than 4 t ha^{-1} grain yield of rice.

2.1.3.3 *Poultry manure*

Narahari (1999) estimated that the poultry manure production in India is around 3.8 million tones. Poultry wastes are estimated to supply 0.171 million tones of major plant nutrients and 13.91 thousand tones of micronutrients (Prasad, 1999).

Gaur (1982) noticed that poultry manure contained 3 per cent N and 1.4 per cent K. Prasad *et al.* (1984) reported that the poultry manure contained 1.5 per cent N, 1.0 per cent P_2O_5 and 1.4 per cent K_2O. Devegowda (1997) reported that poultry waste is rich in nitrogen (3.2 to 4 %), phosphorus (2 to 3%), potassium (1.7 to 2.5 %), iron (150 to 451 ppm), calcium (2.4 to 8.8 %), copper (98-150 ppm), manganese (225 to 406 ppm), magnesium (0.44 to 0.67 %), molybdenum and sulphur (0.3 to 0.5 %), zinc (235 to 463 ppm) and sodium (0.54 to 0.94 %). Yadav *et al.* (1989) opined that poultry manure contained 39.2 per cent organic carbon, 0.78 per cent total N, 50.2: 1 C: N ratio, 4.87 per cent protein, 62.71 per cent lignin, 38 per cent hot water soluble poly sacharides and 24.7 per cent ash.

Fertilizer value of poultry manure was three times higher than FYM and this was attributed to combined presence of urinary and faecal excretions in the manure. One tone of built up poultry litter yielded approximately nutrients equivalent to 160 kg ammonium sulphate, 150 kg single super phosphate, 50 kg potassium sulphate, 30 kg calcium, 7 kg magnesium and 7 kg sodium (Devegowda, 1997). The major portion of the phosphorus of poultry manure was inorganic form (74%) with C:P ratio of 32:1 and N:P ratio of 3.4:1 with dry matter content of 62 per cent (Shephered and Whithers, 1999). Poultry manure was rich in plant nutrients and the content of N, P and K was found to be double than that in farm yard manure (Dobermann and Fairhurst, 2000).

2.1.3.4 *Poultry manure on soil properties*

Obi and Ebo (1995) reported that addition of poultry manure @ 10 t ha^{-1} significantly decreased the soil bulk density and increased the organic matter content, total porosity, infiltration rate and hydraulic conductivity. Katyal (1993) recommended the use of poultry manure to build up organic carbon, P content and soil structure. O'Halloran *et al.* (1997) discussed the possibility of using green and animal manure particularly poultry manure as a possible cheaper alternative to liming to correct soil acidity. The results showed that the soil pH increased significantly from 4.92 in control plot to 5.32, six months after application of chicken manure. Rajpur and Goyal (1991) found that poultry manure was an excellent source of organic matter and it can be utilized for field crops.

Katyal and Sharma (1979) reported that the application of FYM and poultry manure improved the availability of macronutrients on the contrary availability of copper was inversely related to organic matter content. Prasad *et al.* (1984) revealed that application of poultry manure along with inorganic fertilizers resulted in higher uptake of zinc and iron by wheat and rice crops. Das *et al.* (1991) found that application of poultry manure @ 5 t ha^{-1} resulted in increased uptake of Ca, Mg, K and Fe and also increased the soil organic carbon, CEC, exchangeable K, Ca and Mg.

Incorporation of poultry manure to soil significantly reduced NH_3 volatilization losses. Crop residue had no effect or slightly reduced NH_3 volatilization losses relative to a bare soil surface, which resulted average loss of 17.5 per cent of total nitrogen through the manure (Schilkle and Sims, 1993). Toor and Bahl (1997) reported an increased efficiency of fertilizer P applied in combination with poultry manure. Phosphorus was maintained in the available form for a longer period.

More and Chaniskar (1988) reported that application of poultry manure along with single super phosphate to soil resulted in higher phosphorus availability. Poultry manure was superior to FYM and goat manure. Application of 5 tones of poultry manure per hectare plus rock phosphate (21.8 kg P_2O_5 ha^{-1}) and *Bacillus firmus* increased phosphorus uptake of rice crop (Datta and Banik, 1994).

Gupta *et al.* (1996) observed that application of poultry manure has increased the N and P uptake, organic carbon and available P content of soil even after harvest.

2.1.3.5 Poultry manure on productivity of rice

Singh *et al.* (1980) noticed that poultry manure has increased the yield of grain and straw in rice compared to FYM application. Application of poultry manure @ 5 t ha^{-1} resulted in significantly higher yield of wheat (22.89 q ha^{-1}) and rice (33.5 q ha^{-1}) as compared to control (13.5 q ha^{-1} of wheat and 18.7 q ha^{-1} of rice).

In an experiment involving the use of organic manures in rice production, the highest grain yield was obtained by the use of poultry manure at 12.5 t ha^{-1} (Budhar *et al.*, 1991). Maskina *et al.* (1986) observed that rice yields with poultry manure without fertilizer N was two fold when compared with other manures. Dubey and Verma (1999) observed that combined use of 50 per cent NPK + 50 per cent poultry manure significantly increased the grain yield of first rice crop and second rice crop over control. The available N increased to 270 kg ha^{-1} under 50 per cent NPK + 50 per cent poultry manure treatment over initial value of 220 kg ha^{-1}.

Gupta *et al.* (1995) reported that the highest rice yield was obtained with combined application of poultry manure and P. Poultry manure did not perform better than urea in the first year application but by second and third year 120 and 180 kg N as poultry manure produced significantly higher grain yields than the same rates as urea. Yield decreased with the use of urea, but poultry manure sustained the grain yield of rice (Singh *et al.*, 1996).

2.2 INORGANIC FERTILIZERS

Organic manures including animal manures, crop residues, green manures and compost were traditionally and preferentially used in developing countries until the 1960's when inorganic chemical fertilizers began to gain popularity due to their easy availability, less bulk and easiness in transport, handling and storage (Dahama, 1996).

2.2.1 Nitrogen and sulphur use in rice culture

Nitrogen is one of the key element in plant nutrition. The lush green growth with abundant chlorophyll, high number of effective tillers and high dry matter production are all-possible only if N is provided adequately through organic and inorganic fertilizers.

Datta *et al.* (1970) and Lakhdive and Prasad (1970) found that ammonium sulphate and urea were superior to nitrate containing fertilizers in rice. Moorthy and Rao (1971) found that the uptake of ammoniacal N was 5 to 20 times greater than that of nitrate-N, depending on the pH. Pillai and Katyal (1976) reported that the grain yield increased considerably on deep placement of fertilizers as against split application of both urea and ammonium sulphate.

Bhattacharyya *et al.* (1970) reported that the higher yield response of rice to fertilizer application was obtained by applying 44 kg N, 68 kg P_2O_5, 33 kg K_2O per hectare as ammonium sulphate, super phosphate and potassium chloride, respectively. Abichandani and Patnaik (1958) obtained a 40 per cent recovery of applied N in 42 days of submergence from surface applied ammonium sulphate compared with 88 per cent when the fertilizer was incorporated. Takhashi and Yamamura (1995) studied the effects of NH_4, NO_3 and SO_4 on the absorption of P and observed that NH_4 had a decisive role on the absorption of P. Roy (1991) reported that compared to gypsum, ammonium sulphate was found to be a superior source for sulphur to rice.

Application of sulphate containing fertilizers was recommended during final land preparation or before seeding in general (Dev and Sharma, 1988). However, Corpuz and Monuat (1984) opined that in wetland rice soil sulphur containing fertilizers should be broadcast 10 days after transplanting and it should be never be applied at planting and incorporated with the mud or deep placed in the mud. Bouldin and Alimango (1976) found losses of S upto 60 per cent in broadcast ammonium sulphate.

George (1989) observed that both ammonium sulphate and ammonium phosphate sulphate were superior sources of S for rice compared to elemental sulphur. Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970 and Pillai, 1972).

Mac Rey and Ancajas(1970) reported that mixing urea and ammonium sulphate with water-saturated soil reduced losses due to volatilization. Mikkelsen *et al.* (1978) showed that higher concentration of NH_4–N in rice floodwater increased ammonia volatilization losses. Maximum ammonia losses amounted to 18 per cent of urea nitrogen and 15 per cent ammonium sulphate nitrogen when broadcast. Singh and Yadav (1994) reported that soil pH did not change markedly due to continuous use of ammonium sulphate, groundnut cake and FYM in soil, whereas, electrical conductivity decreased over a time more so with basal application of compost or manure.

The effect of sulphur to enhance grain and straw yield of rice was also reported by Biddappa and Sarkunan (1980). Chandrasekaran (1985) found that in ill drained soils addition of sulphate fertilizers prevented injurious effects on rice by the excessive addition of organic manure and restored the rice yields. George (1989) found that S application increased dry matter production and yield contributory factors like number of productive tillers per hill, panicle length, number of panicles and 1000 grain weight.

The highest availability of S in soil was at maximum tillering stage of rice, which was gradually decreased with the advance of crop (Clarson and Ramaswamy, 1992). Singh *et al.* (1993) and Raju *et al.* (1995) reported that application of S up to 60 kg ha^{-1} increased the growth attributes and yield of rice. They observed a significant positive correlation with growth attributes and yield with sulphate.

Ismunadji (1991) reported that ammonium sulphate at levels of 80 kg and 32 kg S ha^{-1} significantly out yielded, the yield produced with the same dose of sulphur by the sources such as gypsum, elemental S, urea-S and S-bentionite. Liu *et al.* (1989) reported that application of S retarded organic matter accumulation in paddy soil and increased available P and S and released K from the clay crystal lattice.

2.2.2 Potassium in rice culture

Application of potassium was not generally done in the past since Indian soils were considered to be rich in K. However, with the introduction of fertilizer responsive high yielding rice varieties and intensive cropping, response to potassium application has been consistently important.

The nutrient ion K^+ is omnipresent in the plant system and is linked with almost all physiological phenomena of the plant. It is possible to attribute a number of functions to K, but hardly possible to endow it with a specific role. It intervenes in the following domains of plant physiology viz., photosynthesis, enzyme activation, metabolism of carbohydrates, organic acids, fats and nitrogenous compounds, protein synthesis, water economy, cell elongation, resistance to drought, frost, lodging, pests, diseases and physiological disorders (Singh and Tripathi, 1979).

2.2.2.1 Effect of potassium on growth and physiological characters

Potassium is indispensable to the growth and grain production of rice. Vijayan and Sreedharan (1972) observed significant increase in plant height with increase in the levels of potassium from 20 to 80 kg ha^{-1} in rice. Similar beneficial effects of potassium to increase the plant height in rice were reported by many workers (Venkatasubbaiah *et al.*, 1982; Xu *et al.*, 1984).

Kulkarni *et al.* (1975) reported that the effect of potassium was significant and positive on tiller production in rice. A positive response of rice to K application was observed by Su (1976). Singh and Singh (1979) and Mishra (1980) obtained increased tillering with application of potassium up to 60 kg K_2O ha^{-1}. Senthilvel and Palaniappan (1985) also reported similar effects of potassium on dry matter production. Increase in leaf area due to potassium application in rice was noticed up to 75 kg K_2O ha^{-1} by Hoang (1974). A positive correlation between potassium application and leaf area index in rice was observed by Mandal and Dasmahapatra (1983).

Tanaka *et al.* (1977) indicated that rice plant was characterized by its high capacity of aborbing as well as exhausting K and there by tended to maintain the K concentration in a plant at a constant level. Hoang (1974) observed increase in chlorophyll content of flag leaf due to potassium application. Potassium checks chlorophyll degradation and promotes the synthesis of both chlorophyll 'a' and 'b'. Ray and Choudhari (1980) after detailed study concluded that the application of potassium increased the retention of chlorophyll in the flag leaf and delayed senescence during the active grain filling stage.

Haeder and Mengel (1974) showed that increasing potassium supply accelerated CO_2 uptake and improved the translocation of carbohydrates to the ear. Mishra (1980) reported that carbohydrate metabolism of rice is affected by varying levels of potassium supply. He found that increasing the levels of potassium helps in building up of starch. Potassium influences many of the processes that are important for the formation of yield in plants such as water economy, the synthesis of carbohydrates and transport of assimilates.

Mitra *et al.* (1990) evaluated effects of higher levels of K on rice in iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increased K application. Dixit and Sharma (1993) observed a significant reduction in the concentration of Al, Fe and acidity of soil by addition of K. Sreemannarayana and Sairam (1995) reported that increasing application of K rate decreased leaf Fe and Mn contents, while it increased leaf Zn content slightly.

Mikkelsen and Patrik (1968) indicated that 75 per cent of total amount of potassium is absorbed prior to the booting stage and no absorption took place from grain forming to grain filling. Lakshmikanthan (2000) found that increasing the levels of K application resulted in increased grain yield.

Muthuswamy *et al.* (1974) reported that higher levels of potassium application increased the uptake of N, P and K by rice. Esakkimuthu *et al.* (1975) observed that nitrogen uptake was more due to potassium application. Mengel *et al.* (1976) reported that N, P and K uptake and their translocation were highest with application of 60 kg K_2O ha^{-1}. Reddy *et al.* (1978) found that N uptake increased with increase in the application of potassium from 50 to 100 kg K_2O ha^{-1}. Steineck and Haeder (1980) propounded that nitrogen utilization by the rice plant was determined by the potassium supply. The total uptake and percentage translocation of N, P and K in rice increased significantly with increasing levels of potassium (Singh and Singh, 1987). Application of K tended to increase grain N content and total N uptake while P content was little affected (Chakravorti, 1989). Jessymol and Mariam (1993) reported that addition of K fertilizers increased water soluble, exchangeable and non-exchangeable K in laterite soils.

Potassium application positively influenced yield attributes in rice. Potassium absorbed at the maximum tillering stage increased the number of panicles, spikelets per panicle and weight of grain (Su, 1976; Mandal and Dasmahapatra, 1983). Similar effects of potassium were also observed by Padmaja (1976); Venkatasubbaiah *et al.* (1982) and Mandal and Dasmahapatra (1983). Singh and Singh (1979) reported that application of 60 kg K_2O ha^{-1} in splits increased panicle length in rice. Similar effects of potassium on panicle length was reported by Xu *et al.* (1984). Vijayan and Sreedharan (1972) reported increase in the number of spikelets per panicle with increase in the level of potassium from 20 to 80 kg K_2O ha^{-1}. Filled grain percentage was more in plants supplied with potassium @ 50 kg K_2O ha^{-1} compared to control (Venkatasubbaiah *et al.* (1982). In potassium deficient soil, K application increased the number of filled grains by 5 to 15 per cent (Linbao, 1985). Singh and Singh (1979) after detailed study on rice, concluded that application of 60 kg K_2O ha^{-1} increased the thousand grain weight compared to control. Sreekumaran (1980) also reported similar results.

Gosh *et al.* (1994) observed greater number of spikelet per panicles, higher grain and straw yield at increased rates of application of potassium. Potassium application was positively correlated to grain weight (Mandal and Dasmahapatra, 1983; Venkatasubbaiah *et al.,* 1982 and Xu *et al.*, 1984). The thousand grain weight was increased by 0.5 to 4 g (Linbao, 1985) with increasing levels of potassium application.

The grain yield of rice increased with increase in level of potassium (Robinson and Rajagopal, 1977) and the effect was linear up to 60 kg K_2O ha^{-1}.

Agarwal (1980) observed significant increase in the rice yield by the application of K_2O ha^{-1} up to 80 kg ha^{-1}. Potassium application increased the rice yield in lateritic soils under submergence and it was even more in soils which were subjected to wetting and drying (Nad and Goswami, 1981). Venkatasubbaiah *et al.* (1982) observed highly significant increases in grain yield due to applied potassium in potassium depleted soil. Gurmani *et al.* (1984) reported a significant increase in grain yield and increase in the level of potassium from 0 to 83 kg K_2O ha^{-1}.

The yield response of rice in most soils was significant at 40 and 60 kg K_2O ha^{-1} (Bharghava *et al.*, 1985). The percentage increase in yield up to maximum of 185 has been obtained by Patiram and Prasad (1987) due to potassium application.

Singh and Prakash (1979) reported an increase in straw yield with increase in level of potassium from 0 to 60 kg K_2O ha^{-1}. Highly significant increase in yields of grain and straw were observed due to applied potassium by Venkatasubbaiah *et al.* (1982). According to them, the effect of potassium application was more on grain yield compared to straw yield.

2.3 INTEGRATED NUTRIENT MANAGEMENT

Considering the very low efficiency of applied N fertilizers and the possibility of only a partial substitution to the rice crop in a system, it has become imperative to integrate the use of organic and inorganic sources of N for higher N use efficiency, more yield and sustained fertility (Swaminathan, 1987). Integrated use of green manures, including grain legumes and incorporating their residues after harvesting pods and inorganic N fertilizer have received attention during recent years for efficient and economic management of N in rice based cropping systems (De Datta, 1981).

Studies revealed that continuous application of inorganic fertilizers alone deteriorated soil health and affected soil productivity. Sinha *et al.* (1983) found that application of organic manure alone or in combination with chemical fertilizer had given higher values of soil organic carbon than with fertilizer alone. Singh and

Nambiar (1986) found that continuous use of fertilizers resulted in the decrease of soil pH. However, NPK in combination with FYM reduced the soil acidity. Liu and Shen (1992) observed that mixed application of inorganic and organic fertilizer compared to no fertilizer or inorganic fertilizers not only increased soil organic matter content but also improved its quality.

In a trial to find out the response of wetland rice to nitrogenous fertilizers in soils amended with organic manure it was found that organic manures exhibited residual effects in terms of available P (Maskina *et al.*, 1986). Liu *et al.* (1990) opined that the elementary use of organic manures with inorganic fertilizer increased the soil organic matter, total N, effectiveness of soil P, population of soil organisms especially some bacteria and the activity of soil enzymes.

Highest available P (105.5 kg ha^{-1}) was recorded when 75 per cent NPK was applied through fertilizers and 25 per cent through gliricidia (Vageesh *et al.*, 1990). Prasad and Rokema (1991) opined that the quantity of N, P and K added through chemical fertilizers, organic manures and biofertilizers were effective to build up N and P but not K in a rice-rice system. Sharma and Mittra (1990) opined that the complementary use of chemical fertilizers and organic manures would augment the efficiency of fertilizers as organic manures affect phosphorus availability in soil through mineralisation of organic P, liberation of Ca bound P through CO_2 formation and complexing of Al and Fe–P through increased microbial activity.

Zia *et al.* (1992) indicated that both organic and inorganic sources increased the total N content of soil. The P content of the soil was not considerably affected by the application of organic N sources and green manure. The maximum increase in P content of soil was due to farmyard manure application.

Balasubramanian *et al.* (1993) opined that green manure in combination with chemical fertilizer resulted in better yield and residual effect for the succeeding crop. Saving to the tune of 25 per cent N was observed when fertilizers were combined with green manuring. Permanent plot experiments in INM in rice sequence in different locations revealed that 15–25 per cent of fertilizer N could be substituted by locally available organic sources of N like FYM, Gliricidia and Paddy straw (Jayakrishnakumar *et al.*, 1994; Hegde, 1996 and Jana and Ghosh, 1996). Mathew and Nair (1997) have found that balanced application of organic manures in combination with chemical fertilizer is important for improving soil organic carbon content and maintaining soil health and productivity.

2.3.1 INM on growth and yield characters of rice

According to Rao *et al.* (1986) application of 120 kg N ha^{-1} in the form of urea alone and 100 kg N ha^{-1} as urea + 2 t paddy straw ha^{-1} gave high rice grain yield and net profit. Green manure plus 50 per cent of the recommended fertilizer N resulted in higher rice yields than when recommended N rates alone were supplied (Mahapatra and Sharma, 1996). The results of experiments conducted in rice-wheat crop sequence revealed the possibility of saving N and P at 20 and 40 kg respectively by applying farm yard manure to paddy crop (Kaushik *et al.*, 1984). Kolar *et al.* (1993) reported that mean rice yields after green manuring with 60 kg fertilizer N ha^{-1} was similar to rice supplied with 120 kg N ha^{-1} without green manuring.

Application of organic material alleviated the decline of roots occurring in rice plants with chemical fertilizer application at later stages of growth. Mandal *et al.* (1990) observed increase in the number of panicles/sq.m, spikelets/panicle, percentage of filled grains and 1000 grain weight with increase in NPK rates and farm yard manure application.

Combined application of inorganic fertilizers along with the organic manures produced highest grain and straw (Subbaiah *et al.*, 1983 and Sharma *et al.*, 1988). Combined application of green manure and urea to supply equal quantities of recommended N dose gave significantly higher yields than when urea alone was applied in three splits (Rabindra *et al.*, 1984). Rajamannar *et al.* (1995) concluded that combined application of organic manure with recommended levels of N increased the grain and straw yield of rice over sole application of organic manure or inorganic fertilizers. Raju *et al.* (1987) found that the combination of green manure with different rates of NPK recorded higher grain and straw yields over crop residues and NPK separately or in combination.

An improvement in organic carbon, available P and K by the addition of cattle manure either alone or in combination with fertilizer have been observed in the permanent manurial trial at Pattambi, Kerala (Johnkutty and Menon, 1986). Similar results have been reported by Prasad and Singh (1981). In soils testing low in N and organic carbon, combined use of green manure with 60 kg N ha^{-1} through mineral fertilizer gave rice yields comparable with 100 kg fertilizer N ha^{-1} (Mahapatra *et al.*, 1997). Khind *et al.* (1987) observed no ammonia volatilization in soil amended with green manures.

Application of green manure at lower level of N (upto 40 kg N ha^{-1}) reduced the volatalization loss, whereas the trend was reverse at higher levels of N (120 kg ha^{-1}) (Chakravarthy, 1989). Chaudhary *et al.* (1981) observed that available phosphorus in the soil has increased significantly with P and FYM application. Paturde and Patankar (1998) reported that yield increased with increasing N rate and was greater with green manures and N.

Vendan and Rajeswari (1999) observed that incorporation of *Sesbania aculeata* at higher seed rate and 100 kg inorganic N ha^{-1} increased post harvest soil total N, available N and P, and organic carbon content but there was a slight decrease in available K content. Chakraborty *et al.* (2001) observed that the agronomic efficiency of P was higher with fertilizer applied @ of 30,15, 30 kg N, P and K ha^{-1} to rice after *S aculeata* incorporation.

2.4 EFFECT OF SOIL AMELIORANTS / AMENDMENTS ON RICE

Padmaja and Verghese (1965) reported that the need for soil amendments for increasing the productivity of laterite and lateritic soils of Kerala has been widely accepted.

2.4.1 Lime (CaO)

In agriculture limestone is the most commonly used material for the purpose of neutralizing soil acidity. Agricultural limestone is usually a mixture of calcite and dolomite that contains silica and other inert materials. The Ca and Mg present in the calcite and dolomite displaced the acidic cations on the soil particles and hydrolyzed products were subsequently neutralized by OH (Caruccio *et al.*, 1988).

He (1992) concluded that lime is not necessary for rice production when soil pH is over 5.6 but when it is below 5.5 lime may be applied in combination with the application of organic manures. The soils with high acidity required liming to obtain significant response from fertilization (Kiome *et al.*, 1998).

The rise in pH due to liming helps to increase base saturation, availability of nutrient and microbial activity, besides reducing the toxicity of aluminium, iron and manganese (Tisdale *et al.,* 1997). The important role of liming was found associated with the reduction of Al and Mn ion concentration from toxic level to tolerance level and as a supplier of plant nutrient.

Mandal and Mandal (1973) in an incubation study have concluded that application of both lime and organic matter lowered significantly the fixation of P as Aluminum phosphate. Application of lime to acid soils have been shown to reduce the soil acidity, improve N, P, K and B availability in the soil and promote symbiotic fixation of nitrogen by legumes (Lasker, 1990). Application of lime increased rice yield by rectifying the ill effects of Fe and Al (Sahu, 1968; Dixit and Sharma, 1993). Marykutty (1986) reported that application of lime significantly decreased available potassium status of the soil from a mean value of 85 ppm to 39.7 ppm.

2.4.2 Ash

Melwas (1995) reported that liming and wood ash application were measures to decrease acidification of forest soils. Vance (1996) opined that ashes from the burning of wood and other plant derived materials have been used as soil amendments for centuries. Although historical interest in land application of ashes declined following the advent of commercial fertilizers and alternative liming materials, additional incentives for the beneficial use have arisen in recent years. He further stated that application of wood ash resulted in neutralization of soil acidity, increased exchangeable nutrient bases decreased extractable micronutrients. Wood ash was in general more effective than lime in increasing dry matter production mainly because of higher P and K uptake (Nkana *et al.*, 1998).

Reuler *et al.* (1996) reported that ash application significantly increased the yields of grain and straw, the uptake of N, P, K and Mg but not of Ca. It was concluded that the response to ash application was mainly a P effect. The recovery fractions of P at about the same application rates were 7.4 per cent and 11.4 per cent with ash and P fertilizer respectively. The CaO equivalent of ash was 44 per cent and $CaCo_3$ equivalent 78 per cent. P use efficiency was higher when P fertilizers were added together with ash.

2.4.2 Ameliorating effects of organics and nutrients

IRRI (1976) reported that addition of organic matter reduces the severity of iron toxicity and that apparently straw could serve as an ameliorant for iron toxic soils. It implied that application of the straw to such soils could improve the early growth of paddy. Bhattacharyya *et al.* (1996) reported that iron toxic soils, application of FYM and K could maintain a balanced uptake of N and P in rice leading to better grain and straw yield.

Gupta and Singh (1989) observed that application of P decreased the toxic level of Fe. Application of N, P and K with Zn and Cu caused drastic reduction in the content of Fe^{2+} in different plant parts by mutual antagonism (Suresh, 1996).

Bridgit (1999) found that yield of rice could be increased without any addition of N and P beyond package of practices recommendations, if Fe and Mn absorption could be restricted and leaf sap pH maintained at around 6.2. She had suggested enhancement of K levels and inclusion of S in nutritional management for high yields and nitrogen use efficiency.

Sahu (1968) reported that high K content of leaf decreased the bronzing in rice plant due to higher Fe content. Application of higher dose of K increased the nutritional status of the crop as well as the yield. Singh and Singh (1979) studied the effect of applied K on Fe toxicity and associated nutritional disorders in wetland rice rich in iron. The result indicated that K content was increased with K application; Fe concentration reduced drastically indicating K-P synergism and K-Fe antagonism. Benckiser *et al.* (1984) observed that Ca and Mg played an important role in alleviating Fe toxicity of rice. The application of Mn and Cu alleviated Fe toxicity by counter balancing higher Fe concentration and reducing sterility.

Materials and Methods

3. MATERIALS AND METHODS

The research project entitled "Nutritional resource use efficiency in rice production," was conducted during 2001-2002 at the Agricultural Research Station, Mannuthy. The details of materials used and methods adopted in the conduct of the experiments as well as evaluation of the results are presented in this chapter.

3.1 LOCATION

The experiment was laid out at the Agricultural Research Station, Mannuthy, Thrissur District, under the Kerala Agricultural University which is located at 10°31'N latitude and 76°13'E longitude and at an altitude of 40.29 M above mean sea level and 6 km East of Trichur town on the right side of Trichur-Palakkad NH-47.

3.2 WEATHER AND CLIMATE

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

The mean maximum temperature experienced was 31.19°C while the mean minimum temperature was 23.58°C with an average mean of 27.39°C.

3.3. SOIL

Laterite sandy clay loam of the Oxisol order is the soil type of the area. The soil is acidic in reaction with a pH 4.95.

The physico-chemical properties of the soil of the experimental field are presented in Table 3.1.

3.4 CROP AND VARIETY

The rice cv. Aiswarya, a red kernelled, short-medium duration variety of 110-125 days duration was used for the experiment. The variety is suitable for direct seeding and transplanting during both first and second crop season, tolerant to BPH

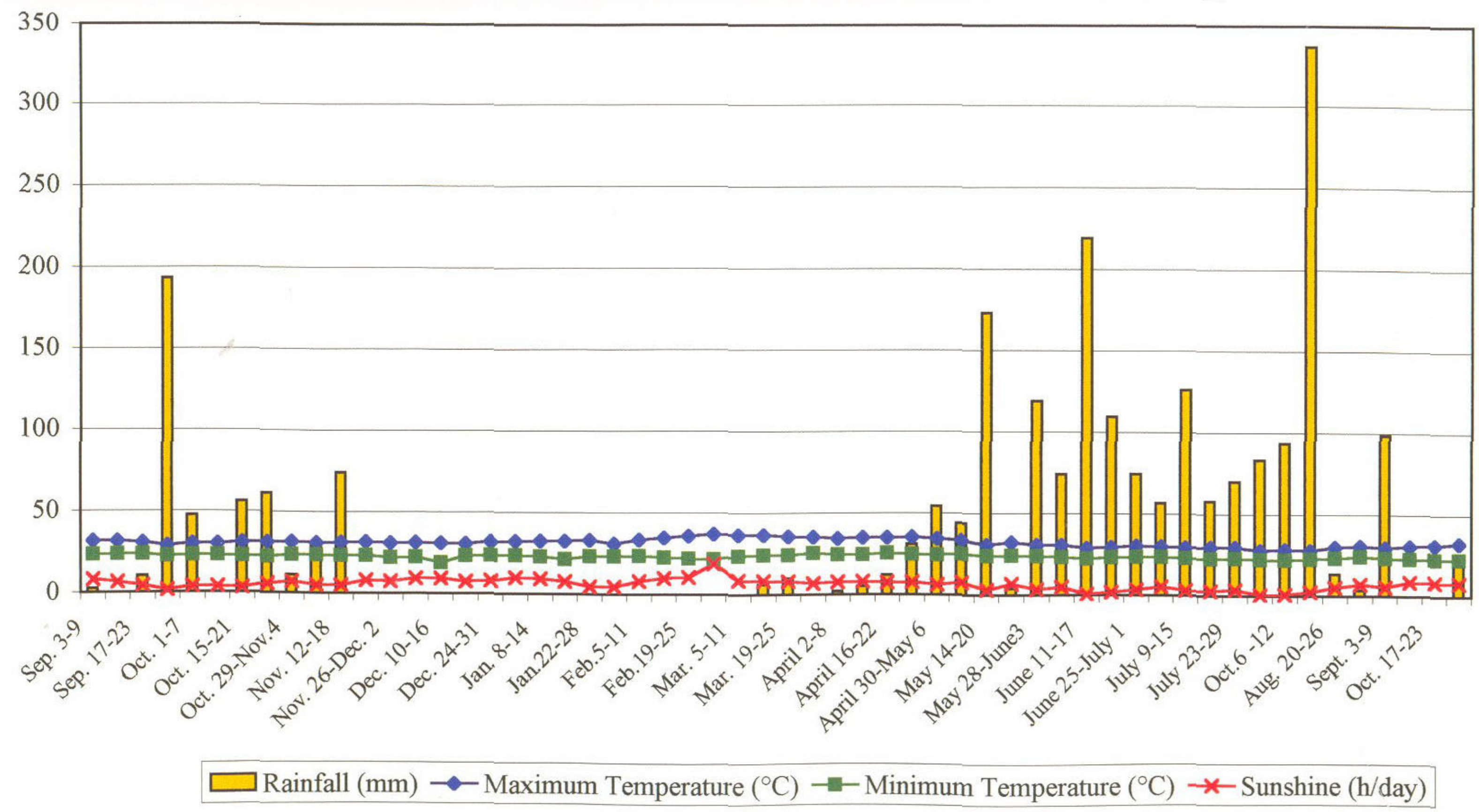

Fig. 1. Weekly weather data during the crop period (*Mundakan* - Summer - *Viruppu*)

Table 3.1. Physico-chemical characteristics of the soil prior to the experiment

(a) Physical properties	Value
Bulk density (g cc^{-1})	1.32
Particle density (g cc^{-1})	2.34
Porosity (%)	49.08
Water holding capacity (%)	49.15
Mechanical composition	
Sand (%)	75.90
Silt (%)	5.30
Clay (%)	18.80
Texture	Sandy clay loam
(b) Chemical properties	
Soil reaction (pH)	4.95
Electrical conductivity (dSm^{-1})	0.12
Organic carbon (%)	0.48
Available nutrients (kg ha^{-1})	
N	256.40
P_2O_5	12.36
K_2O	86.08
Neutral Normal NH_4AC extractable	
Available Ca (kg ha^{-1})	136.28
Available Mg (kg ha^{-1})	165.14
Available S (kg ha^{-1})	23.20
0.1N HCl extractable	
Available Fe (kg ha^{-1})	810.05
Available Mn (kg ha^{-1})	128.29

and rice blast disease, moderately susceptible to sheath blight and capable of producing an yield of over 8 MT under favourble situtions and moderately good yields under adverse conditions.

3.5 CROPPING HISTORY OF THE EXPERIMENTAL SITE

The experimental area was a typical double-cropped wetland. The field was under bulk paddy cultivation during Rabi 2001.

3.6 EXPERIMENTAL METHODS

The cropping was conducted during mundakan, summer and virippu season of 2001-2002. The experimental design was split plot design with three replications. The plot size was 5.0 x 4.0 m and the spacing adopted was 15 x 10 cm. The net plot size was 4.4 x 3.6 m. Treatments of the experiment consisted of different sources of organic manure and fallow as main plot treatment and two sources of nitrogen and two quantity of potassium along with ameliorants (CaO and ash), replicated thrice. The management practices other than the treatments was uniformly followed as per package of practices recommendations. Urea, Ammonium sulphate, Mussorie rock phosphate and Muriate of potash were used as the sources of different nutrients. Treatment details are provided in Table 3.2. Layout of the experiment is depicted in Fig. 2. The physico-chemical characters of organic sources are given in the Table 3.3. The nutrient concentrations of other sources of nutrients are given in Table 3.4.

Table 3.4 Sources of nutrients and its content

Nutrient	Source	Nutrient content (%)
Nitrogen	Urea	46
Nitrogen	Ammonium Sulphate	20.5
Phosphorous (P_2O_5)	Mussorie rock phosphate	20-22
Potassium (K_2O)	Muriate of potash	60
Calcium	Lime	75 (100*)
Sulphur	Ammonium sulphate	24
Ash		43*

* Neutralising value

Table 3.2. Treatment details

Mundakan (September-January)	Summer (March-May)	Sub-plot treatments (*virippu* - June to September)
Rice	*OS_1 - Green manuring (*Sesbania aculeata)*	**F_1 - Full N as urea : Half P : Full K
Rice	*OS_2 - Green manuring + CaO 300 kg	F_2 - Full N as urea : Half P : Double K
Rice	*OS_3 - Green manuring + CaO 300 kg + 300 kg Ash	F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K
Rice	OS_4 - Fallow	F_4 - Full N as NH_4SO_4 : Half P + CaO 300 kg + 300 kg Ash : Double K
Rice	OS_5 - Fallow followed by incorporation of green leaf manure (*Pongamia glabra*) @ 5 t of dry matter ha^{-1} at 15 days before *virippu* crop	
Rice	OS_6 - Fallow followed by the incorporation of paddy straw @ 5 t ha^{-1} at 15 days before *virippu* crop	
Rice	OS_7 - Fallow followed by incorporation of cowdung @ 5 t ha^{-1} at 15 days before *virippu* crop	
Rice	OS_8 - Fallow followed by incorporation of poultry manure @ 5 t ha^{-1} at 15 days before *virippu* crop	

* The mean weight of green manure incorporated into soil was 16.4 t ha^{-1}

** The normal recommended nutrient dose as per KAU Package of Practices is 90:45:45 NPK kg ha^{-1}

N ↑

Fig. 2. Layout of the experimental field during *virippu* season

4m; 5m

RI				RII				RIII			
OS5F3	OS5F$_2$	OS5F$_4$	OS5F$_1$	OS3F$_2$	OS3F$_3$	OS3F$_1$	OS3F$_4$	OS6F$_4$	OS6F$_2$	OS6F$_3$	OS6F$_1$
OS3F$_2$	OS3F$_3$	OS3F$_1$	-OS3F$_4$	OS8F$_3$	OS8F$_1$	OS8F$_4$	OS8F$_2$	OS4F$_1$	OS4F$_3$	OS4F$_2$	OS4F$_4$
OS8F$_4$	OS8F$_2$	OS8F$_3$	OS8F$_1$	OS2F$_2$	OS2F$_4$	OS2F$_1$	OS2F$_3$	OS8F$_2$	OS8F$_4$	OS8F$_1$	OS8F$_3$
OS4F$_3$	OS4F$_1$	OS4F$_4$	OS4F$_2$	OS6F$_1$	OS6F$_3$	OS6F$_2$	OS6F$_4$	OS2F$_3$	OS2F$_1$	OS2F$_4$	OS2F$_2$
OS1F$_1$	OS1F$_3$	OS1F$_2$	OS1F$_4$	OS4F$_3$	OS4F$_1$	OS4F$_4$	OS4F$_2$	OS7F$_1$	OS7F$_3$	OS7F$_2$	OS7F$_4$
OS6F$_2$	OS6F$_4$	OS6F$_1$	OS6F$_3$	OS1F$_2$	OS1F$_4$	OS1F$_1$	OS1F$_3$	OS5F$_2$	OS5F$_4$	OS5F$_1$	OS5F$_3$
OS2F$_4$	OS2F$_2$	OS2F$_3$	OS2F$_1$	OS7F$_1$	OS7F$_3$	OS7F$_2$	OS7F$_4$	OS3F$_3$	OS3F$_1$	OS3F$_4$	OS3F$_2$
OS7F$_3$	OS7F$_1$	OS7F$_4$	OS7F$_2$	OS5F$_4$	OS5F$_2$	OS5F$_3$	OS5F$_1$	OS1F$_2$	OS1F$_3$	OS1F$_1$	OS1F$_4$

Table 3.3. Characters of organic manure and their mean nutrient content

Sl.. No.	Particulars	Organic carbon content (%)	Lignin content (%)	Fibre (%) (NDF)	C:N ratio	Major nutrients (%)					Minor nutrients (ppm)			
						N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
1	Green manure	48.5	8.93	22.5	14:1	3.43	0.287	1.92	1.716	0.263	200	9.58	9.69	0.21
2	Green leaf manure	49.3	10.07	22.1	16:1	3.12	0.436	1.39	3.964	0.271	310	10.21	9.12	0.32
3	Paddy straw	36.9	18.75	40.7	54:1	0.69	0.356	1.91	2.082	0.277	540	75.33	8.71	0.51
4	Cowdung	22.1	5.71	13.3	37:1	0.60	0.340	0.44	2.921	0.504	180	104.26	4.37	0.17
5	Poultry manure	33.9	2.08	8.7	15:1	2.32	1.380	1.85	0.975	0.191	170	386.00	2.92	0.13
6	Ash	-	-	-	-	0.17	0.480	2.31	17.2	0.890	970	410.00	3.12	0.27

Table 3.5. Sowing and harvesting dates of crops in the experiment

Date of sowing in nursery	Date of transplanting	Date of harvesting	Duration (days)
23-05-2002	12-06-2002	23-09-2002	121

3.7 CROP CULTURE

General principles of low land rice culture were followed in the management of the experiments. The experimental area was ploughed twice during summer season. The layout was laid as per the design of the individual experiments with strong bunds and sowing of green manure seeds was taken in the respective allotted fields as per the treatments and at 15 days before transplanting green manures (45 days of maturity), green leaf manures and organic manures and ameliorants were applied, puddled and levelled and strengthened the bunds.

Seeds of the rice cv. Aiswarya were obtained from the Regional Agricultural Research Station, Pattambi. Seedlings of 21 days old were transplanted in a well puddled and levelled field at a spacing of 15 cm x 10 cm @ 2-3 seedlings/hill. Date of nursery sowing, transplanting and harvesting are given in Table 3.5.

A basal dose of organic manures and fertilizers, lime and ash was applied in all the experimental plots as per the treatments. The full quantity of phosphorus and half quantity of K were applied as basal and half N and remaining K were applied as top dressing at panicle initiation stage (KAU, 1996).

Experimental plots were harvested when matured. Plants in two border rows on all sides of each plot were harvested and removed first. The remaining was harvested and the yield was recorded as net plot yield. Threshing was done on the same day and wet yields were recorded. Moisture percentage of grain and straw were estimated. Dry weight of grain and straw were worked out and recorded at 12 per cent moisture content.

3.8 OBSERVATIONS

3.8.1 Analysis of organics

Samples of all the green manures, green leaf manures and other organic manures used in the experiment were taken and analysed for organic carbon content, lignin and crude fibre, macro and micro nutrients. Lignin content was estimated by spectro photometric method using acetyl bromide (Hatfield, 2001) and fibre was estimated following the method described by Maynard (1970). Organic carbon content of the organic manures were estimated using the method suggested by el Wakeel and Riley (1956). The C:N ratio was also worked out.

3.8.1.1 Efficiency of organics

The efficiency of organics was calculated by using following indices with the consideration of fallow as a control field.

1) Agronomic efficiency (kg/kg)

$$= \frac{\text{Grain yield of fertilized crop (kg) - Grain yield of unfertilized crop (kg)}}{\text{Quantity of fertilizer applied (kg)}}$$

2) Physiological efficiency (kg/kg)

$$= \frac{\text{Total dry matter yield of fertilized crop (kg) - Total dry matter yield of unfertilized crop (kg)}}{\text{Nutrient uptake of fertilized crop (kg) - Nutrient uptake by unfertilized crop (kg)}}$$

3) Uptake efficiency (%)

$$= \frac{\text{Nutrient uptake by fertilized crop - Nutrient uptake of unfertilized crop}}{\text{Quantity of fertilizer applied}} \times 100$$

3.8.2 Plant analysis

Ten hills per plot selected at random were used as observational plants for recording biometric observations and chemical analysis. Five other hills were separately selected and used for estimation of chlorophyll 'a' and 'b' and leaf cell sap pH.

3.8.2.1 Biometric observations

i) Height of plants (cm)	: At active tillering, panicle initiation and 50 per cent flowering
ii) Tiller count (Nos./hill)	: At active tillering, panicle initiation and 50 per cent flowering
iii) Dry matter production (kg/ha)	: At active tillering, panicle initiation and 50 per cent flowering
iv) Productive tillers (No./hill)	: At harvest
v) Number of spikelets per panicle	: At harvest
vi) Number of filled grains per panicle	: At harvest
vii) Number of unfilled grains per panicle	: At harvest
viii) Percentage of filled grains	: At harvest
ix) Grain yield (kg/ha)	: At harvest
x) Straw yield (kg/ha)	: At harvest

3.8.2.2 Physiological observations

1)	Chlorophyll content	: Chlorophyll content of index leaves was estimated colorimetrically in a Spectronic-20 Spectro-photometer (Yoshida *et al.*, 1972) at maximum tillering, panicle initiation and at 50 per cent flowering stage.
2)	Plant sap pH	: Plant sap pH was estimated at maximum tillering, panicle initiation and 50 per cent flowering using a pH meter. A 1:2.5 leaf sample : water suspension was utilized (Jackson, 1958).

3.8.2.3 Chemical observations

For chemical analysis of plant six hills were selected at randomly from the destructive sampling area of each plot. Plant samples were collected at different stages (maximum tillering, panicle initiation, 50% flowering and at harvest) and dried in a hot air oven for 72 hours at 60°C ± 5°C. They were powdered well by hand crushing and analysed for nutrient contents by methods given in Table 3.6.

Table 3.6. Methods used for plant chemical analysis

Sl.No.	Nutrient	Method	Reference
1	Nitrogen	Microkjeldhal digestion and distillation method	Jackson, 1958
2	Phosphorus	Diacid extract estimated colorimetrically in a Spectronic-20 Spectrophotometer by Vanadomolybdophosphoric yellow colour method	Jackson, 1958
3	Potassium	Diacid extract method using a Flame photometer	Jackson, 1958
4	Calcium	Diacid extract method using Atomic Absorption Spectrophotometer	Jackson, 1958
5	Magnesium	Diacid extract method using Atomic Absorption Spectrophotometer	Jackson, 1958
6	Iron	Diacid extract method using Atomic Absorption Spectrophotometer	Jackson, 1958
7	Manganese	Diacid extract method using Atomic Absorption Spectrophotometer	Jackson, 1958
8	Sulphur	Turbidimetric method using Spectronic-20 Spectrophotometer	Hart, 1961

3.8.2.4 Yield

Yield of grain and straw were estimated on per hectare basis and expressed as t ha^{-1}.

3.8.3 Soil

3.8.3.1 Physico-chemical characteristics

Soil samples collected from the experimental plots before *mundakan*, after *mundakan*, before *virippu*, middle of the cropping (*virippu*) and after the harvest of the crop were dried, crushed the clods and passed through 2 mm sieve for analyzing physico-chemical characteristics of the soil. The methods used for various analyses are given in Table 3.7. The values of before *mundakan*, after *mundakan* and before *virippu* are presented in Table 3.8. The soil samples were analysed for pH and Ec using portable pH and EC meters during *virippu* and after harvest of the crop. The bulk density of the soil was collected by using core sampler during the above periods.

3.9 STATISTICAL ANALYSIS

Statistical analysis of data was done as per the methods suggested by Panse and Sukhatme (1978) Micro soft Excel 2000 and MSTAT packages were used for computations.

3.10 ECONOMICS

The benefit cost ratio was worked out for different combinations of treatments by subtracting the cost of cultivation from gross return.

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

Table 3.7. Methods used for soil physical and chemical analysis

(a) Physical analysis

Sl. No.	Character	Method	Reference
1	Particle density	Keen-Raezkowski brass cup method	Piper, 1942
2	Bulk density	,,	
3	Pore space	,,	
4	Water holding capacity	,,	
5	Mechanical composition of soil	International pipette method	Piper, 1942

(b) Chemical analysis

Sl. No.	Character	Method	Reference
1	Soil reaction (pH)	Soil water suspension of 1:2.5 and read in a pH meter	Hesse, 1971
2	Electrical conductivity (dSm^{-1})	,,	Jackson, 1958
3	Organic carbon (%)	Walkley-Black method	Jackson, 1958
4	Available N (kg/ha)	Alkaline permanganate method	Subbiah and Asija, 1956
5	Available P_2O_5 (kg/ha)	Ascorbic acid reduced molybdophosphoric blue color method	Watanabe and Olsen, 1965
6	Available K_2O (kg/ha)	Neutral Normal NH_4AC extract method using Flame photometer	Jackson, 1958
7	Exchangeable Ca (kg/ha)	Neutral Normal NH_4AC extract using Atomic Absorption spectro photometry	Jackson, 1958
8	Exchangeable Mg (kg/ha)	Neutral Normal NH_4AC extract using Atomic Absorption spectro photometry	Jackson, 1958
9	Available S (kg/ha)	Turbidimetric method	Hesse, 1971
10	Available Fe (kg/ha)	0.1N HCl extract method using Atomic Absorption Spectrometry	Jackson, 1958
11	Available Mn (kg/ha)	0.1N HCl extract method using Atomic Absorption Spectrometry	Jackson, 1958

Table 3.8. Soil physico-chemical characters of experimental plot

Particulars	pH	EC (dSm^{-1})	Bulk density ($g\ cc^{-1}$)	OC (%)	Available N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	Available K ($kg\ ha^{-1}$)	Available Ca ($kg\ ha^{-1}$)	Available Mg ($kg\ ha^{-1}$)	Available S ($kg\ ha^{-1}$)	Available Fe ($kg\ ha^{-1}$)	Available Mn ($kg\ ha^{-1}$)	Available SiO_2 ($kg\ ha^{-1}$)
Before *Mundakan*	4.90	0.166	1.31	0.58	294.60	8.38	94.72	134.70	180.30	23.9	802.2	125.10	188.16
After *Mundakan*	4.96	0.136	1.33	0.54	296.16	8.34	92.12	121.60	166.20	22.5	723.4	118.40	152.32
Before *Virippu*	4.10	0.165	1.34	0.52	274.20	8.33	89.64	118.40	184.30	19.8	743.4	129.40	116.48

Results

4. RESULTS

4.1 CROP GROWTH CHARACTERS

Crop growth characters such as height of plant, number of tillers and plant dry matter production were determined at active tillering, panicle initiation and at 50 per cent flowering.

4.1.1 Height of plants

The height of plants as influenced by various organic and inorganic treatments are given in Table 4.1. Different organic treatments have significant influence on height of the plant at different stages of the crop. At active tillering stage the height of the plant was the highest (37.40 cm) in green manure alone applied treatment. The treatment of fallow-green leaf manure was next best followed by the previous fallow and fallow-cowdung treatment. Green manure + CaO, fallow-poultry manure and green manure + CaO + ash were on par. Fallow-paddy straw treatment showed the lowest (32.54 cm) plant height. Among the different sources and quantities of inorganic fertilizers applied, F_1 (N as urea, half P and full recommended K) produced the highest plant height of 36.90 cm. It was followed by F_2 (N as urea, half P and double dose of recommended K) and F_4 (N as NH_4So_4, half P + CaO + ash and double dose of recommended K). F_3 (N as urea, half P, CaO + ash + double dose of recommended K) resulted in the lowest height of 32.74 cm.

At panicle initiation, the height of plant was the highest (67.46 cm) in green manure + CaO + ash. The treatment of green manure + CaO was close to it followed by fallow-green leaf manure, fallow-poultry manure and green manure which were on par. Fallow-cowdung and fallow-paddy straw treatment resulted in relatively lower height, however the plant height was the lowest (60.12 cm) in the previous fallow.

At 50 per cent flowering, green manure + CaO + ash treatment recorded the highest plant height of 87.27 cm followed by green manure + CaO fallow-green

Table 4.1. Effect of treatments on plant height (cm) at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	39.12	38.14	35.17	37.14	37.40	62.26	64.76	66.23	69.79	65.79	80.21	83.71	84.41	87.54	83.97
GM + CaO	36.52	34.73	32.64	33.64	34.38	62.72	65.22	68.74	70.53	66.80	82.79	84.22	86.85	91.65	86.38
GM + CaO + Ash	35.41	35.02	30.64	33.61	33.67	63.35	65.75	69.11	71.62	67.46	83.11	86.11	88.21	91.65	87.27
Fallow	38.40	36.41	33.24	35.19	35.81	56.22	58.70	60.75	64.81	60.12	74.58	78.58	79.24	83.45	78.96
Fallow - GLM	39.85	37.35	33.63	36.45	36.82	62.16	64.33	67.21	70.35	66.01	80.64	83.85	85.41	91.22	85.28
Fallow - Ps	33.12	33.14	31.72	32.17	32.54	60.82	63.72	64.35	67.21	64.04	74.46	77.16	79.24	85.00	78.96
Fallow - Cd	37.61	36.63	32.42	34.59	35.31	61.83	64.72	65.69	67.61	64.96	74.27	77.75	79.50	85.82	79.33
Fallow - Pm	35.16	35.23	32.49	33.40	34.07	63.76	64.30	66.69	68.72	65.87	81.39	82.66	83.47	85.09	83.40
Mean	36.90	35.84	32.74	34.53		61.64	63.95	66.10	68.83		78.93	81.75	83.29	87.80	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.18	0.15	0.41			0.18	0.13	0.36			0.03	0.02	0.06	
CD (p=0.05)		0.55	0.41	1.16			0.55	0.36	1.01			0.10	0.06	0.18	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

leaf manure, green manure alone, fallow-poultry manure, fallow-cowdung treatments which were on par. Fallow-paddy straw and the previous fallow were having the lowest plant height of 78.96 cm.

Inorganic treatments significantly influenced the plant height at panicle initiation and at 50 per cent flowering. F_4 treatment recorded the highest plant height with 68.83 and 87.80 cm at panicle initiation and 50 per cent flowering, respectively. The treatments of F_3 and F_2 were the next best. F_1 treatment recorded the lowest plant height of 61.64 cm and 78.93 cm at panicle initiation and 50 per cent flowering stage, respectively.

Significant interaction was found between different organic and inorganic treatments with regard to plant height. At active tillering stage, the combination of fallow-green leaf manure x F_1 recorded the highest plant height of 39.85 cm where as it failed to produce the same response with F_3. The highest plant height of 71.62 cm was recorded in the combination treatments of green manure + CaO + ash x F_4 at panicle initiation. The lowest height of 56.22 cm was resulted in the treatment of the previous fallow x F_1.

At 50 per cent flowering, the combination of green manure + CaO + ash x F_4 and green manure + CaO x F_4 recorded the maximum height of 91.65 cm, however the same main plot treatment differed significantly in combination with F_2.

4.1.2 Number of tillers

Significant influence of the main plot and sub plot treatments on tiller production was observed and presented in Table 4.2.

At active tillering stage, green manure + CaO + ash treatment recorded the highest number of 8.18 tillers per hill. It was comparable with the treatment of green manure + CaO followed by fallow-poultry manure, green manure, fallow-green leaf manure, fallow-cowdung and fallow-paddy straw. Fallow-poultry manure and green manure alone were recorded on par. The lowest tiller number of 6.61 per hill was recorded in previous fallow treatment.

Table 4.2. Effect of treatments on number of tillers per hill at **different** stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering					% of tiller decline
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments					
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	
GM	8.65	7.38	7.54	7.13	7.68	11.54	10.23	10.95	9.23	10.49	8.71	7.93	8.28	7.35	8.07	23.10
GM + CaO	8.66	7.43	8.18	7.35	7.91	12.29	11.23	11.85	9.61	11.24	8.44	8.06	8.34	7.52	8.09	28.10
GM + CaO + Ash	8.83	7.83	8.23	7.83	8.12	12.46	11.83	12.31	10.17	11.69	8.86	8.12	8.63	7.83	8.39	28.20
Fallow	7.56	6.29	6.42	6.17	6.61	9.27	7.78	8.65	7.54	8.31	6.68	6.21	6.38	6.18	6.36	23.50
Fallow - GLM	8.27	6.81	7.81	6.66	7.39	11.16	9.61	8.67	8.63	9.52	7.83	6.58	6.92	6.65	7.00	26.50
Fallow - Ps	7.74	6.66	6.83	6.35	6.90	10.14	8.53	9.63	8.24	9.14	7.16	6.28	6.31	6.48	6.56	28.20
Fallow - Cd	8.65	6.75	7.44	6.40	7.16	10.53	9.13	10.22	8.54	9.60	7.36	6.42	6.83	6.60	6.80	29.10
Fallow - Pm	8.53	7.17	8.14	7.04	7.72	11.41	10.26	10.56	8.93	10.29	7.94	6.84	6.09	6.78	7.16	34.30
Mean	8.29	7.04	7.56	6.87		11.10	9.83	10.35	8.86		7.87	7.06	7.35	6.93		
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treat ments	Sub-plot treat ments	Interaction		
S.E		0.03	0.02	0.05			0.09	0.06	0.18			0.03	0.02	0.06		
CD (p=0.05)		0.10	0.06	0.16			0.27	0.09	0.50			0.08	0.06	0.16		

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Different inorganic treatments had significant influence on tiller numbers. F_1 treatment recorded the highest tiller number of 8.29 per hill. F_3 treatment was next best followed by F_2. While F_4 treatment recorded the lowest tiller number of 6.87 per hill.

At panicle initiation stage, green manure + CaO + ash treatment recorded the highest tiller number (11.69) per hill. The treatments of green manure + CaO, green manure alone and fallow-poultry manure were next best treatments and were on par. Fallow-cowdung and fallow-paddy straw treatments resulted in similar tiller production. Previous fallow treatment recorded the lowest tiller (8.31) number per hill.

Among inorganic treatments F_1 recorded the highest tiller numbers (11.10) per hill. F_3 and F_2 were next best treatments, while F_4 treatment recorded the lowest tiller number (8.86) per hill.

At 50 per cent flowering green manure + CaO + ash treatment recorded the highest tiller (8.39) per hill. Green manure + CaO and green manure alone were next best treatments and were on par. Previous fallow treatment recorded the lowest tiller (6.36) number per hill.

Among inorganic treatments F_1 treatment produced the highest tiller number (7.87) per hill. While F_4 treatment resulted in the lowest tiller number (6.93) per hill.

Significant interaction between organic and inorganic treatments were obtained. The combination treatment of green manure + CaO + ash x F_1 was found to produce the highest tiller number (8.83, 12.46 and 8.86) per hill and previous fallow x F_4 treatment recorded the lowest tiller number (6.17, 8.31 and 7.54) per hill at maximum tillering, panicle initiation and 50 per cent flowering, respectively.

4.1.3 Total dry matter production

The effect of different nutrient sources on total dry matter production is presented in Table 4.3.

At active tillering stage, maximum plant dry matter was observed in green manure treatment (2.89 t ha^{-1}) closely followed by fallow-green leaf manure which was on par. Fallow-cowdung and previous fallow treatments were the next best treatments. The lowest dry matter production (2.47 t ha^{-1}) was recorded in the fallow-paddy straw treatment.

Among inorganic treatments F_1 resulted in the highest dry matter production of 3.03 t ha^{-1}. F_2 and F_4 were next in order while the lowest dry matter production (2.37 t ha^{-1}) was observed in F_3 treatment.

At panicle initiation stage, green manure + CaO + ash treatment resulted in the highest dry matter production of 4.96 t ha^{-1}. Dry matter production in the green manure and green manure + CaO treatments were at par. The treatments fallow-green manure, fallow-poultry manure, fallow-cowdung closely following. However they were on par with fallow-paddy straw treatment. Previous fallow recorded the lowest dry matter production of 3.97 t ha^{-1}.

Among the inorganic treatments, F_4 resulted in the highest dry matter production of 4.81 t ha^{-1}. The F_3 and F_2 were the next best treatments. The lowest dry matter production (4.27 t ha^{-1}) was resulted by the F_1 treatment.

At 50 per cent flowering, green manure + CaO + ash treatment recorded the highest dry matter production of 6.17 t ha^{-1}, followed by fallow-green leaf manure and green manure + CaO. The lowest dry matter production of 5.41 t ha^{-1} was recorded in fallow-paddy straw treatment.

Significant interaction effect between organic and inorganic treatments was observed. At active tillering organic treatment x F_1 combination resulted in higher dry matter production but at panicle initiation and 50 per cent flowering progressive increase in dry matter production was brought about by F_2, F_3 and F_4 treatments. The dry matter production of 2.34 t ha^{-1} was produced by green manure alone x F_1 at active tillering, however at panicle initiation and 50 per cent flowering, higher dry matter production was produced by green manure + CaO x F_2 (5.42 t ha^{-1}) and green manure

Table 4.3. Effect of treatments on total dry matter production (t ha^{-1}) at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	3.28	2.92	2.42	2.91	2.89	**4.37**	4.56	4.97	5.01	4.73	5.56	5.89	5.95	7.28	5.92
GM + CaO	3.02	2.61	2.36	2.39	2.64	**4.39**	4.58	4.88	5.05	4.73	5.77	5.27	6.18	6.62	7.96
GM ± CaO + Ash	2.92	2.59	2.21	2.47	2.55	**4.45**	5.42	4.88	5.08	4.96	5.79	6.04	6.29	6.56	6.17
Fallow	2.93	2.81	2.42	2.73	2.72	**3.86**	4.06	4.25	3.71	3.97	5.13	5.51	5.58	5.95	5.54
Fallow - GLM	3.34	2.85	2.46	2.85	2.88	**4.32**	4.51	4.75	5.04	4.65	5.61	5.91	6.06	6.51	6.02
Fallow - Ps	2.69	2.45	2.29	2.46	2.47	**4.22**	4.45	4.54	4.79	4.50	4.49	5.39	5.59	6.08	5.41
Fallow - Cd	3.13	2.78	2.35	2.68	2.74	**4.29**	4.53	4.64	4.83	4.57	5.13	5.43	5.61	6.15	5.58
Fallow - Pm	2.89	2.56	2.48	2.56	2.63	**4.29**	4.50	4.71	4.92	4.61	5.67	5.82	5.92	6.17	5.89
Mean	3.03	2.70	2.37	2.66		**4.27**	4.58	4.70	4.81		5.40	5.66	5.90	6.29	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.08	0.02			0.05	0.03	0.09			0.06	0.04	0.11	
CD (p=0.05)		0.34	0.22	0.63			0.14	0.09	0.26			0.17	0.18	0.33	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

+ CaO x F_4 (6.62 t ha^{-1}). The lowest dry matter production (2.21 t ha^{-1}) was produced by green manure + CaO + ash x F_2, previous fallow x F_4 (3.71 t ha^{-1}) and fallow-paddy straw x F_1 treatments at maximum tillering, panicle initiation and 50 per cent flowering, respectively.

The treatments of green manure + CaO + ash x F_4, green manure + CaO x F_4, fallow-green leaf manure x F_4, green manure x F_4, green manure x F_3, fallow-poultry manure x F_4, green manure + CaO x F_4, green manure + CaO + ash x F_3, fallow-cowdung x F_4, fallow-paddy straw x F_4 were on par at panicle initiation stage.

Green manure + CaO + ash x F_4, fallow-green leaf manure x F_4, green manure + CaO + ash x F_3, fallow x F_4 and green manure + CaO x F_4 treatments were on par at 50 per cent flowering.

4.2 PHYSIOLOGICAL CHARACTERS

4.2.1 Chlorophyll content

Chlorophyll content was recorded at maximum tillering, panicle initiation and 50 per cent flowering and presented in Tables 4.4a and 4.4b.

At active tillering stage the highest chlorophyll 'a' content of 2.44 $\mu g\ g^{-1}$ was observed in the fallow-green leaf manure treatment. The fallow-poultry manure, fallow-paddy straw and green manure + CaO + ash treatments were on par. Previous fallow recorded the lowest content of 1.71 $\mu g\ g^{-1}$.

The inorganic treatments showed increasing chlorophyll content from F1 to F_4. The F_4 treatment recorded the highest content of 2.38 $\mu g\ g^{-1}$ while the F_1 treatment recorded the lowest content of 1.85 $\mu g\ g^{-1}$. A similar pattern was observed with chlorophyll 'b' also. The fallow-green leaf manure recorded the highest chlorophyll 'b' value (1.27 $\mu g\ g^{-1}$) while the lowest chlorophyll 'b' value (0.99 $\mu g\ g^{-1}$) was recorded in the previous fallow treatment. Fallow-poultry manure, fallow-cowdung, green manure + CaO + ash, green manure + CaO, fallow-cowdung and green manure alone treatments were next in the order.

Table 4.4(a). Effect of treatments on chlorophyll 'a' content ($\mu g\ g^{-1}$) at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	1.67	1.94	2.16	2.35	2.03	1.84	2.06	2.34	2.44	2.17	0.91	0.68	1.16	1.18	0.98
GM + CaO	1.70	2.20	2.44	2.53	2.22	1.91	2.42	2.62	2.68	2.41	0.95	1.18	1.29	1.31	1.18
GM + CaO + Ash	1.85	2.30	2.53	2.29	2.32	2.14	2.36	2.59	2.73	2.46	1.05	1.18	1.16	1.27	1.16
Fallow	1.62	1.69	1.74	1.80	1.71	1.83	1.84	1.93	1.97	1.89	0.90	0.94	0.94	0.96	0.94
Fallow - GLM	2.03	2.34	2.57	2.81	2.44	2.21	2.37	2.59	2.82	2.50	1.07	1.17	1.28	1.39	1.22
Fallow - Ps	2.01	2.18	2.45	2.64	2.32	2.10	2.30	2.51	2.64	2.39	1.02	1.13	1.23	1.30	1.17
Fallow - Cd	1.83	1.87	1.97	2.11	1.95	1.94	2.07	2.19	2.25	2.11	0.96	1.02	1.07	1.11	1.04
Fallow - Pm	2.07	2.26	2.46	2.53	2.33	2.20	2.33	2.51	2.58	2.41	1.10	1.14	1.29	1.27	1.18
Mean	1.85	2.10	2.29	2.47		2.02	2.22	2.41	2.51		1.00	1.05	1.17	1.22	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.02			0.01	0.01	0.01			0.03	0.02	0.05	
CD (p=0.05)		0.03	0.02	0.05			0.01	0.01	0.01			0.09	0.06	0.16	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.4(b). Effect of treatments on chlorophyll 'b' content ($\mu g\ g^{-1}$) at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	0.89	0.96	1.04	1.14	1.01	1.03	1.15	1.21	1.27	1.16	0.56	0.61	0.65	0.68	0.63
GM + CaO	0.92	1.03	1.17	1.21	1.08	1.08	1.17	1.22	1.30	1.19	0.60	0.64	0.67	0.70	0.65
GM + CaO + Ash	1.02	1.10	1.20	1.28	1.15	1.15	1.23	1.31	1.34	1.26	0.61	0.67	0.70	0.73	0.68
Fallow	0.81	0.88	0.95	0.98	0.90	0.98	1.09	1.13	1.20	1.10	0.78	0.58	0.60	0.65	0.65
Fallow - GLM	1.18	1.23	1.31	1.35	1.27	1.28	1.36	1.43	1.47	1.39	0.69	0.74	0.78	0.80	0.75
Fallow - Ps	1.04	1.15	1.20	1.30	1.17	1.10	1.22	1.30	1.34	1.24	0.60	0.65	0.70	0.73	0.67
Fallow - Cd	0.96	1.05	1.12	1.21	1.08	1.05	1.18	1.22	1.29	1.18	0.57	0.64	0.66	0.70	0.64
Fallow - Pm	1.08	1. 13	1.21	1.28	1.18	1.12	1.22	1.31	1.34	1.25	0.60	0.65	0.77	0.73	0.67
Mean	0.99	1.07	1.15	1.27		1.10	1.20	1.27	1.32		0.62	0.65	0.68	0.71	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01			0.01	0.01	0.01			0.01	0.01	0.02	
CD (p=0.05)		0.01	0.01	0.01			0.01	0.01	0.01			0.03	0.02	0.05	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

At panicle initiation stage also the highest chlorophyll 'a' content (2.50 μg g^{-1}) was recorded in the fallow-green leaf manure treatment. Green manure + CaO + ash was the next best treatment. Fallow-poultry manure and green manure + CaO were on par in chlorophyll 'a' content.

Among the inorganic treatments, the highest chlorophyll 'a' content of 2.51 μg g^{-1} was recorded in the F_4 treatment. The treatments of F_3 and F_2 were the next best and the lowest content of 2.02 μg g^{-1} was recorded in the F_1 treatment.

The highest chlorophyll 'b' content (1.39 μg g^{-1}) was recorded in the fallow-green leaf manure treatment. The lowest chlorophyll 'b' content (1.10 μg g^{-1}) was recorded in previous fallow treatment.

The chlorophyll contents were relatively lower at 50 per cent flowering stage compared to other stages and the influence of various treatments were not remarkable. However the lowest chlorophyll 'a' content was observed in the previous fallow treatment.

Among inorganic treatments F_1 and F_3 treatments were on par and F_1 treatment recorded the lowest content of 1.00 μg g^{-1}. Chlorophyll 'b' content was highest in the fallow-green leaf manure treatment (0.75 μg g^{-1}) and other sources were on par. The F_4 treatment recorded the highest chlorophyll 'b' content of 0.71 μg g^{-1} and the lowest of 0.62 μg g^{-1} was observed in F_1 treatment.

The combination of fallow-green leaf manure x F_4 recorded the highest content of 2.81 μg g^{-1} and 1.35 μg g^{-1} of chlorophyll 'a' and 'b', respectively whereas the lowest content of 1.62 μg g^{-1} and 0.81 μg g^{-1} of chlorophyll 'a' and 'b' contents were recorded in the previous fallow x F_1 treatment at active tillering.

Similar highest and lowest contents of chlorophyll 'a' and 'b' were observed in the above treatments at panicle initiation and 50 per cent flowering also.

4.2.2 Cell sap pH

The variation in cell sap pH is presented in Tables 4.5. The analysis done at active tillering showed the highest value of 6.32 in green manure + CaO + ash

Table 4.5. Effect of treatments on plant cell sap pH at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	5.29	5.61	5.84	5.92	5.66	4.84	5.01	5.33	5.53	5.20	5.31	5.75	5.73	5.85	5.66
GM + CaO	5.56	5.82	5.93	6.13	5.86	5.13	5.22	5.39	5.52	5.32	5.44	5.84	6.04	6.03	5.89
GM + CaO + Ash	6.12	6.22	6.43	6.53	6.32	5.73	5.81	6.01	6.21	5.94	5.85	6.02	6.13	6.16	6.04
Fallow	4.91	5.13	5.33	5.42	5.20	4.64	4.87	4.92	5.11	4.89	5.16	5.36	5.61	5.82	5.39
Fallow - GLM	5.72	5.82	6.15	5.24	5.98	5.81	5.12	5.31	5.65	5.35	5.36	5.51	5.73	5.95	5.64
Fallow - Ps	5.42	5.62	5.68	5.91	5.66	5.01	5.26	5.45	5.58	5.32	5.22	5.63	5.82	5.95	5.66
Fallow - Cd	5.43	5.63	5.69	6.14	5.72	5.72	5.21	5.82	5.95	5.38	5.23	5.53	5.91	6.05	5.68
Fallow - Pm	5.27	5.41	6.31	6.39	5.85	5.02	5.25	5.75	6.12	5.24	5.68	5.83	6.05	6.13	5.92
Mean	5.47	5.66	5.92	6.08		5.15	5.23	5.32	5.71		5.45	5.85	6.04	5.89	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01			0.06	0.04	0.12			0.01	0.01	0.01	
CD (p=0.05)		0.03	0.02	0.01			0.17	0.02	0.33			0.01	0.02	0.0[illegible]	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

treatment. The fallow-green leaf manure, fallow-poultry manure, fallow-cowdung, green manure alone, and fallow-paddy straw were the next best in order. The lowest value of 5.20 was recorded in the previous fallow treatment.

Among inorganic treatments, F_4 recorded the highest cell sap pH of 6.08 whereas the lowest value of cell sap pH was recorded in the F_1 treatment.

At panicle initiation stage, the highest value of 5.94 was recorded in the green manure + CaO + ash treatments. The treatments of fallow-cowdung and fallow-poultry manure were next best. The treatments of fallow-green leaf manure, green manure + CaO, fallow-paddy straw and green manure alone were on par, whereas the lowest value of 4.89 was recorded in the previous fallow treatment.

Among the inorganic treatments F_4 and F_1 recorded the highest (5.69) and lowest (5.15) cell sap pH, respectively.

The analysis on the combined effect of organic and inorganic treatments on cell sap pH showed that the highest value of 6.53, 6.21 and 6.16 was produced by green manure + CaO + ash x F_4 treatment where as the lowest values of 4.91, 4.64 and 5.16 were recorded by fallow x F_1 treatments at active tillering, panicle initiation and 50 per cent flowering, respectively.

4.3 YIELD AND YIELD ATTRIBUTES

The yield attributes such as productive tillers, spikelets per panicle, filled grain per cent and 1000 grain weight as well as the grain and straw yields were given in Tables 4.6, 4.7, 4.8 and 4.9.

Number of productive tillers per hill was maximum (6.48) in the treatment of green manure + CaO + ash. Green manure + CaO, green manure alone, fallow-green leaf manure, fallow-poultry manure treatments were in next in order. The treatments of fallow-cowdung and fallow-paddy straw treatments were on par. The lowest number of 4.61 was recorded in the previous fallow treatment.

Table 4.6. Effect of treatments on yield attributes at different stages of rice

Treatment	Productive tillers (No./hill)	Spikelet/ panicle (Numbers)	Filled grains (%)	1000 grain weight (g)
GM	5.93	67.30	73.37	26.65
GM + CaO	6.32	74.58	75.27	26.97
GM + CaO + Ash	6.48	76.46	72.38	27.12
Fallow	4.61	54.75	75.29	26.25
Fallow - GLM	5.65	70.10	78.50	26.88
Fallow - Ps	5.15	56.07	74.08	26.96
Fallow - Cd	5.17	62.41	75.16	26.56
Fallow - Pm	5.20	62.99	74.40	26.49
CD (0.05)	0.03	1.95	4.48	0.03
F_1	5.31	60.52	73.44	26.50
F_2	5.46	63.92	75.68	26.68
F_3	5.74	66.73	74.96	26.81
F_4	5.75	77.17	75.15	26.95
CD (0.05)	0.01	1.44	NS	0.02
Treatment combination	S	NS	NS	S

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Among the inorganic treatments the highest number of productive tillers (5.75) was recorded in F_4 treatment, which was at par with F_3. The lowest value (5.31) was recorded in F_1 treatment at harvest.

The analysis of the combined effect of organic and inorganic treatments showed that the highest number of productive tillers were produced in the green manure + CaO x F_4 treatment. The combination of green manure + CaO x F_3 and green manure + CaO x F_2 were on par. The lowest productive tiller count of 4.32 was recorded by fallow x F_1 treatment.

The number of spikelets per panicle was the highest (76.46) in green manure + CaO + ash which was on par with green manure + CaO. The lowest spikelet numbers (54.75) was observed in previous fallow, which was on par with fallow-paddy straw treatment. Among the inorganic treatments the highest number of 71.17 was recorded in the F_4 treatment, whereas lowest number of 60.52 was recorded in F_1 treatment.

Among the combined treatments of organic and inorganic treatments on number of spikelets per panicle, the highest spikelet number was observed in green manure + CaO + ash x F_4 treatment. Green manure + CaO + ash x F_3, green manure + CaO x F_3, green manure + CaO + ash x F_2 and fallow-green leaf manure x F_4 treatments were on par. The lowest spikelet number was observed in fallow-paddy straw x F_1 treatment.

The percentage of filled grain was the highest (78.50%) in fallow - green leaf manure treatments. The previous fallow, green manure + CaO, fallow-cowdung, fallow-poultry manure and fallow-paddy straw treatments were on par with green leaf manure treatment. The lowest percentage of 72.38 was recorded in green manure + CaO + ash treatment and green manure alone which were on par. Among different inorganic treatments no significant difference was observed. No significant interaction was observed between the organic and inorganic treatments with regard to the percentage of filled grains.

Table 4.7. Effect of treatments on number of productive tillers and test weight [1000 grain (g)] at harvest

Main plot treatments	Productive tillers per hill					Test weight [1000 grain (g)]				
	Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	5.50	5.86	6.15	6.22	5.93	26.34	26.54	26.73	26.97	26.65
GM + CaO	6.08	6.08	6.41	6.51	6.32	26.74	26.84	27.11	27.18	26.97
GM + CaO + Ash	6.35	6.41	6.52	6.65	6.48	26.85	27.10	27.18	27.34	27.12
Fallow	4.32	4.53	4.63	4.95	4.61	26.10	26.25	26.27	26.39	26.25
Fallow - GLM	5.28	5.28	6.55	5.58	5.65	26.66	26.85	26.93	27.08	26.88
Fallow - Ps	4.95	5.04	5.23	5.37	5.15	26.73	26.93	27.03	27.13	26.96
Fallow - Cd	5.07	5.14	5.18	5.31	5.17	26.38	26.50	26.61	26.76	26.56
Fallow - Pm	5.04	5.17	5.21	5.39	5.20	26.22	26.42	26.59	26.73	26.49
Mean	5.31	5.46	5.74	5.75		26.50	26.68	26.81	26.95	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01			0.01	0.01	0.02	
CD (p=0.05)		0.03	0.01	0.01			0.03	0.02	0.05	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

The 1000 grain weight was the highest (27.12 g) in green manure + CaO + ash treatment. Green manure + CaO and fallow-paddy straw treatments were on par. The lowest 1000-grain weight (26.25 g) was recorded in the previous fallow treatment.

Among the inorganic treatments, the highest 1000 grain weight of 26.95 g was recorded in F_4 and the lowest 1000 grain weight of 26.50 g was recorded in F_1. The combination of green manure + CaO + ash x F_4 recorded the highest (27.34 g) 1000 grain weight.

Among the different organic sources, the grain yield obtained (5.88 t ha^{-1}) in the green manure + CaO + ash treatment was significantly high. Green manure + CaO treatment produced the next higher yield of 5.40 t ha^{-1}. Green manure alone and fallow-green leaf manure treatments were next in order and were on par. Fallow-poultry manure, fallow-cowdung and fallow-paddy straw treatments were at par. The lowest grain yield of 2.79 t ha^{-1} was recorded in the previous fallow treatment.

Among the inorganic treatments, the F_4 treatment recorded the highest grain yield of 4.77 t ha^{-1} and the lowest yield of 3.50 t ha^{-1} was recorded in the F_1 treatment.

The treatment combination of green manure + CaO + ash x F_4 recorded the highest grain yield (6.64 t ha^{-1}), whereas the lowest grain yield of 2.35 t ha^{-1} was recorded in the treatment combination of previous fallow x F_1.

The influence of treatments on the straw yield also followed a similar pattern. Straw yield was the highest (6.13 t ha^{-1}) in the green manure + CaO + ash treatment. Green manure + CaO produced 5.45 t ha^{-1}, however significantly difference with the best and other treatments. The treatments of green manure alone and fallow-green manure were on par. The lowest straw yield of 2.99 t ha^{-1} was observed in the previous fallow treatment.

Among the inorganic treatments, F_4 and F_1 recorded the highest (4.95 t ha^{-1}) and the lowest (3.85 t ha^{-1}) straw yield, respectively. The treatment combination of green manure + CaO + ash x F_4 recorded the highest straw yield (6.75 t ha^{-1}). The treatment

Table 4.8. Effect of treatments on grain and straw yield of rice (t ha^{-1})

Treatment	Grain	Straw	Grain : straw ratio	Harvest index
GM	4.34	4.73	0.92	0.48
GM + CaO	5.40	5.45	0.99	0.49
GM + CaO + Ash	5.88	6.13	0.96	0.49
Fallow	2.79	2.99	0.93	0.48
Fallow - GLM	4.58	4.70	0.97	0.49
Fallow - Ps	3.12	3.60	0.87	0.46
Fallow - Cd	3.32	3.76	0.88	0.47
Fallow - Pm	3.56	3.83	0.93	0.48
CD (0.05)	0.23	0.36	0.06	0.04
F_1	3.50	3.85	0.91	0.48
F_2	3.92	4.26	0.92	0.48
F_3	4.32	4.50	0.96	0.49
F_4	4.77	4.95	0.96	0.49
CD (0.05)	0.11	0.24	0.10	0.03
Treatment combination	S	S	NS	NS

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.9. Effect of treatments on grain and straw yield (t ha^{-1})

Main plot treatments	Grain					Straw				
	Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	3.47	4.15	4.63	5.14	4.34	4.24	4.47	4.93	5.27	4.73
GM + CaO	4.67	5.21	5.70	6.02	5.40	4.79	5.69	5.85	6.07	5.45
GM + CaO + Ash	5.15	5.69	6.03	6.64	5.88	5.61	6.01	6.14	6.75	6.13
Fallow	2.35	2.62	3.04	3.14	2.79	2.65	2.74	3.26	3.32	2.99
Fallow - GLM	3.66	4.15	5.04	5.48	4.58	3.78	4.27	4.14	5.63	4.70
Fallow - Ps	2.76	2.95	3.22	3.58	3.12	3.47	3.53	3.69	3.97	3.60
Fallow - Cd	2.78	3.14	3.23	4.13	3.32	3.35	3.60	3.56	4.51	3.76
Fallow - Pm	3.15	3.43	3.65	4.03	3.56	3.52	3.83	3.84	4.12	3.83
Mean	3.50	3.92	4.32	4.77		3.85	4.26	4.50	4.95	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.08	0.04	0.12			0.11	0.09	0.21	
CD (p=0.05)		0.23	0.11	0.31			0.36	0.24	0.67	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

combinations of green manure + CaO + ash x F_2, green manure + CaO x F_4, green manure + CaO x F_3, green manure + CaO x F_2, fallow-green leaf manure x F_4 and green manure + CaO + ash x F_1 were on par. Fallow x F_1 treatment recorded the lowest straw yield of 2.65 t ha^{-1}.

4.4 ELEMENTAL COMPOSITION OF RICE PLANT

4.4.1 Nitrogen

Nitrogen content at maximum tillering, panicle initiation and 50 per cent flowering stages of plant is presented in Table 4.10.

At active tillering stage, N concentration varied from 1.82 per cent in the previous fallow treatment to 2.63 per cent in the green manure + CaO + ash treatment. Green manure + CaO and fallow-green leaf manure treatments were on par. Fallow-poultry manure and green manure alone recorded lower N content but significantly higher than the previous fallow which recorded the lowest N content of 1.82 per cent.

Among inorganic treatments, F_4 treatment was observed to have the highest N concentration of 2.57 per cent. The F_1 treatment resulted in the lowest N content of 2.02 per cent. The treatments of F_3 and F_2 have intermediate content of N.

Combination of green manure + CaO + ash x F_4 treatment produced with highest N content of 2.87 per cent. N content of plants in the fallow-poultry manure x F_4 treatment was on par. The lowest N content of 1.61 per cent was observed in the previous fallow x F_1 treatment.

Rice plants analysed at panicle initiation stage showed nitrogen concentration of 1.50 per cent in the green manure + CaO + ash. Fallow-paddy straw treatment recorded the lowest value of 1.12 per cent. The inorganic treatments influenced the N content of plants significantly and it varied from 1.51 per cent in F_4 to 1.16 per cent in F_1. F_3 and F_2 treatments showed intermediate concentrations of 1.37 and 1.31 per cent respectively.

Table 4.10. Effect of treatments on nitrogen (%) content of plant at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	1.83	2.47	2.52	2.63	2.36	1.21	1.33	1.41	1.53	1.37	0.96	0.99	1.06	1.31	1.08
GM + CaO	2.39	2.45	2.58	2.73	2.54	1.41	1.44	1.47	1.55	1.46	0.99	1.17	1.21	1.36	1.18
GM + CaO + Ash	2.26	2.67	2.74	2.87	2.63	1.41	1.45	1.52	1.61	1.50	1.06	1.16	1.24	1.37	1.21
Fallow	1.61	1.84	1.86	1.96	1.82	1.00	1.14	1.21	1.39	1.19	0.79	0.82	0.93	1.03	0.89
Fallow - GLM	2.10	2.52	2.62	2.74	2.51	1.23	1.36	1.39	1.55	1.38	1.00	1.07	1.14	1.23	1.12
Fallow - Ps	1.84	2.07	2.34	2.45	2.18	0.91	1.06	1.12	1.39	1.12	0.83	0.98	1.18	1.28	1.07
Fallow - Cd	2.02	2.16	2.26	2.34	2.20	0.96	1.19	1.23	1.32	1.17	0.85	1.02	1.07	1.13	1.02
Fallow - Pm	2.06	2.36	2.45	2.85	2.43	1.13	1.52	1.57	1.75	1.49	0.96	1.12	1.19	1.31	1.14
Mean	2.02	2.32	2.43	2.57		1.16	1.31	1.37	1.51		0.93	1.04	1.13	1.25	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.02			0.01	0.01	0.01			0.01	0.02	0.01	
CD (p=0.05)		0.03	0.02	0.05			0.01	0.01	0.02			0.01	0.06	0.01	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Combination of fallow-poultry manure x F_4 treatment resulted in the highest nitrogen concentration of 1.75 per cent. The lowest N content of 0.91 per cent was observed in the fallow-paddy straw x F_1 treatment combinations.

At 50 per cent flowering, green manure + CaO + ash treatment resulted in the N concentration of 1.21 per cent followed by green manure + CaO, fallow-poultry manure, fallow-green leaf manure, green manure alone, fallow-paddy straw and fallow-cowdung. The lowest nitrogen concentration of 0.89 per cent was observed in the previous fallow treatment. Rice plants showed the highest (1.25%) and the lowest (0.93%) plant N contents in F_4 and F_1 treatments, respectively. Whereas F_3 and F_2 were of intermediate nitrogen concentrations.

Green manure + CaO + ash x F_4 treatment combination resulted in the highest nitrogen concentration of 1.37 per cent. The lowest value of 0.79 per cent was recorded in fallow x F_1 treatment combination. The combination treatments of green manure + CaO x F_4, green manure x F_4, fallow-poultry manure x F_4 were on par.

4.4.2 Phosphorus

Plant P content at various stages is presented in Table 4.11.

At active tillering, no remarkable variation in the concentrations of P have been noticed except in the treatment fallow-poultry manure, which had the highest phosphorus concentrations of 0.31 per cent. Green manure treatment recorded the lowest P content of 0.23 per cent. The combination treatments also showed no remarkable variation in the P concentrations.

At panicle initiation stage, application of green manure + CaO + ash resulted in the highest P concentration of 0.47 per cent however green manure treatment recorded similar P concentration. The lowest P concentration of 0.33 per cent was recorded in the treatment of fallow-cowdung. Among inorganic treatment, the highest and lowest P concentrations were observed in F_4 and F_1 treatments, respectively whereas F_3 and F_2 were intermediate in P content.

Table 4.11. Effect of treatments on phosphorous (%) content of plant at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	0.31	0.33	0.33	0.36	0.33	0.45	0.46	0.47	0.49	0.47	0.36	0.39	0.39	0.44	0.39
GM + CaO	0.36	0.36	0.37	0.38	0.37	0.42	0.42	0.48	0.45	0.45	0.36	0.38	0.39	0.39	0.36
GM + CaO + Ash	0.36	0.32	0.33	0.36	0.34	0.45	0.46	0.47	0.49	0.47	0.39	0.40	0.41	0.42	0.41
Fallow	0.35	0.36	0.38	0.39	0.37	0.31	0.33	0.38	0.39	0.35	0.25	0.28	0.29	0.31	0.28
Fallow - GLM	0.37	0.37	0.38	0.31	0.36	0.40	0.41	0.45	0.48	0.43	0.36	0.40	0.44	0.46	0.42
Fallow - Ps	0.31	0.35	0.37	0.39	0.36	0.29	0.35	0.39	0.42	0.36	0.21	0.25	0.26	0.27	0.25
Fallow - Cd	0.31	0.36	0.36	0.40	0.36	0.29	0.30	0.36	0.37	0.33	0.22	0.22	0.23	0.28	0.24
Fallow - Pm	0.30	0.33	0.32	0.33	0.32	0.33	0.34	0.36	0.38	0.35	0.28	0.31	0.34	0.35	0.32
Mean	0.33	0.35	0.36	0.37		0.37	0.38	0.42	0.44		0.30	.33	0.34	0.36	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.02	0.01	0.01			0.01	0.01	0.01			0.01	0.01	0.01	
CD (p=0.05)		0.05	0.05	0.05			0.01	0.01	0.02			0.01	0.01	0.02	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Wide variation in the phosphorus concentration was observed in combination treatments. The highest content of 0.49 per cent was recorded in green manure + CaO + ash + F_4 whereas lowest content of 0.29 per cent was observed in treatment combinations of fallow-cowdung x F_1 and fallow - paddy straw x F_1 at panicle initiation stage.

At 50 per cent flowering stage, the highest phosphorus concentration was noticed in the treatment of fallow-green leaf manure, whereas the lowest was recorded in fallow-cowdung treatment. In combination treatments fallow-green leaf manure x F_4 recorded the highest P content of 0.46 per cent and fallow-paddy straw x F_1 recorded lowest value of 0.21 per cent.

4.4.3 Potassium

The potassium content at different stages of plant is summarized in Table 4.12.

K concentration at all the stages varied significantly due to the effect of organic treatment, inorganic treatment and their combinations. At active tillering, among the organic treatments green manure + CaO + ash recorded the highest K content of 3.3 per cent, whereas the lowest content of 2.74 per cent in the previous fallow. Among inorganic treatments, F_4 recorded the highest of 3.23 per cent. The lowest content of 2.8 per cent was recorded in the F_1 treatment.

Among the treatment combinations, green manure + CaO + ash x F_4 recorded the highest content of 3.47 per cent however green manure + CaO x F_4 was at par. The lowest content of 2.54 per cent was observed in the previous fallow x F_1 treatment combination.

4.4.4 Primary nutrients of grain and straw

The analytical results of primary nutrients of grain and straw were presented in Tables 4.13 and 4.14.

4.4.4.1 Nitrogen

The grain N content was the highest in the green manure + CaO + ash treatment with 1.22 per cent. The lowest N content of 0.92 per cent was recorded in

Table 4.12. Effect of treatments on potassium (%) content of plant at different stages

Main plot treatments	Active tillering					Panicle initiation					50% flowering				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	3.15	3.14	3.21	3.28	3.19	2.53	2.73	2.78	2.83	2.72	1.86	2.08	2.16	2.37	2.12
GM + CaO	2.94	3.26	3.35	3.43	3.25	2.65	2.82	2.88	2.95	2.82	2.65	2.15	2.31	2.44	2.38
GM + CaO + Ash	3.10	3.32	3.41	3.47	3.32	2.73	2.85	2.91	3.05	2.89	2.24	2.37	2.41	2.58	2.40
Fallow	2.54	2.75	2.75	2.93	2.74	2.36	2.47	2.55	2.65	2.51	1.83	1.94	2.05	2.15	1.99
Fallow - GLM	2.69	2.89	3.03	3.15	2.94	2.51	2.60	2.60	2.80	2.64	2.05	2.15	2.15	2.26	2.17
Fallow - Ps	2.62	2.96	3.14	3.23	3.01	2.42	2.61	2.73	2.84	2.65	2.05	2.18	2.25	2.36	2.21
Fallow - Cd	2.58	2.78	2.85	3.02	2.81	2.45	2.63	2.69	2.77	2.64	1.82	1.94	2.04	2.18	2.00
Fallow - Pm	2.78	2.94	3.10	3.22	3.01	2.51	2.58	2.69	2.88	2.66	2.13	2.23	2.31	2.37	2.26
Mean	2.80	3.01	3.10	3.23		2.52	2.66	2.74	2.85		2.08	2.13	2.22	2.34	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.02			0.01	0.01	0.01			0.01	0.01	0.01	
CD (p=0.05)		0.03	0.02	0.05			0.03	0.01	0.05			0.03	0.01	0.01	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

the previous fallow treatment. The highest straw N content of 0.98 per cent was in the fallow-green leaf manure and the lowest (0.74%) was recorded in the previous fallow treatment.

Similar to the plant N content at different stages, the inorganic treatment F_4 recorded the highest N content of 1.22 per cent and 0.96 per cent in grain and straw, respectively. The lowest values of 0.98 per cent and 0.75 per cent, respectively for grain and straw were produced by F_1 treatment. The F_3 and F_2 were in intermediate concentration of N in grain and straw.

Treatment combination of green manure + CaO + ash x F_4 recorded the highest value of 1.35 per cent in straw and 1.07 per cent in grain. The content of 0.85 per cent and 0.64 per cent in grain and straw were produced by the combination of fallow x F_1.

4.4.4.2 Phosphorus

The grain P content did not vary significantly among organic and inorganic treatments. However, the highest grain P content of 0.12 was observed in the green manure alone, green manure + CaO, green manure + CaO + ash and previous fallow. Whereas, the lowest value was observed in fallow-poultry manure treatment.

Among the combination treatment no significant P content was observed. The highest content of 0.152 per cent was obtained in the treatment combination of green manure x F_4 whereas the lowest content was observed in fallow-poultry manure x F_1.

A very similar trend was observed in the straw P content also. There was no significant difference between the organic or inorganic treatments but among treatment combinations, P concentration in straw significantly differed due to their treatment effects.

4.4.4.3 Potassium

In grain and straw, the highest K concentration (0.67 and 2.65%) were recorded in the treatment green manure + CaO + ash. Whereas, the lowest

Table 4.13. Effect of treatments on primary nutrient content (%) of grain

Main plot treatments	Sub plot treatments														
	F1			F2			F3			F4			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
GM	0.97	0.106	0.46	1.07	0.109	0.56	1.16	0.129	0.63	1.26	0.152	0.67	1.12	0.12	0.58
GM + CaO	1.07	0.115	0.56	1.12	0.121	0.62	1.19	0.122	0.63	1.31	0.136	0.69	1.17	0.12	0.62
GM +CaO + Ash	1.10	0.099	0.61	1.18	0.106	0.66	1.25	0.120	0.69	1.35	0.140	0.72	1.22	0.12	0.67
Fallow	0.84	0.088	0.43	0.87	0.101	0.48	0.93	0.132	0.50	1.06	0.136	0.53	0.93	0.12	0.49
Fallow - GLM	1.09	0.084	0.51	1.16	0.098	0.55	1.21	0.113	0.59	1.30	0.120	0.63	1.19	0.11	0.57
Fallow - Ps	0.94	0.104	0.57	1.02	0.107	0.60	1.07	0.113	0.62	1.18	0.122	0.67	1.05	0.10	0.62
Fallow - Cd	0.91	0.105	0.49	0.94	0.077	0.54	1.02	0.116	0.59	1.12	0.124	0.61	1.00	0.11	0.56
Fallow - Pm	1.06	0.103	0.53	1.09	0.109	0.57	1.13	0.112	0.61	1.21	0.118	0.64	1.12	0.11	0.59
Mean	1.00	0.101	0.52	1.06	0.104	0.57	1.12	0.120	0.61	1.22	0.131	0.65			
		Main plot treatments				Sub-plot treatments				Interaction					
		N	P	K		N	P	K		N	P	K			
S.E		0.01	0.01	0.01		0.01	0.01	0.01		0.01	0.01	0.01			
CD (p=0.05)		0.01	0.01	0.01		0.01	0.01	0.01		0.02	0.01	0.05			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.14. Effect of treatments on primary nutrient content (%) of straw

Main plot treatments	Sub plot treatments														
	F1			F2			F3			F4			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
GM	0.71	0.106	2.14	0.75	0.109	2.32	0.79	0.129	2.41	0.84	0.152	2.66	0.77	0.205	2.38
GM + CaO	0.72	0.115	2.30	0.79	0.121	1.74	0.83	0.122	2.50	0.97	0.136	2.70	0.83	0.208	2.31
GM+CaO + Ash	0.80	0.099	2.54	0.85	0.106	2.61	0.99	0.120	2.67	1.02	0.140	2.78	0.92	0.189	2.65
Fallow	0.64	0.088	1.93	0.74	0.101	2.18	0.76	0.132	2.23	0.81	0.136	2.38	0.74	0.201	2.18
Fallow - GLM	0.85	0.084	2.24	0.98	0.098	2.34	1.01	0.113	2.43	1.07	0.120	2.48	0.98	0.161	2.37
Fallow - Ps	0.76	0.104	2.23	0.86	0.107	2.35	0.94	0.113	2.45	1.01	0.122	2.71	0.89	0.183	2.43
Fallow - Cd	0.78	0.105	2.10	0.83	0.077	2.17	0.93	0.116	2.23	0.97	0.124	2.23	0.88	0.190	2.20
Fallow - Pm	0.76	0.103	2.32	0.87	0.109	2.45	0.92	0.112	2.53	0.96	0.118	2.59	0.89	0.171	2.48
Mean	0.75	0.170	2.23	0.83	0.182	2.27	0.90	0.196	2.43	0.96	0.205	2.58			
		Main Plot treatments	Sub-plot treatments	Interaction		Main plot treatments	Sub-Plot treatments	Interaction		Main plot treatments	Sub-plot treatments	Interaction			
S.E		0.01	0.01	0.01		0.01	0.01	0.01		0.06	0.04	0.12			
CD (p=0.05)		0.01	0.01	0.02		0.01	0.01	0.01		0.18	0.12	0.34			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

concentrations (0.49% and 2.18%) were recorded in the previous fallow treatment. F_4 treatment recorded the highest K content of 0.65 per cent and 2.58 per cent in grain and straw respectively.

The treatment combination of green manure + CaO + ash x F_4 recorded the highest K concentration of 0.72 per cent and 2.78 per cent in grain and straw, respectively. The lowest K concentration in grain was recorded in the treatment combination of previous fallow x F_1. Similar straw K content was observed in green manure + CaO x F_2, previous fallow x F_1 and green manure + CaO x F_2.

4.4.5 Calcium

Calcium (%) content at panicle initiation, grain and straw are presented in Tables 4.15.

At panicle initiation the highest Ca concentrations of 0.186 per cent was observed in the fallow-green leaf manure and the lowest of 0.108 per cent in fallow-paddy straw treatment. Fallow-poultry manure and green manure + CaO were in next best resulted in higher Ca content, next to fallow-green leaf manure and the previous fallow treatment resulted in similar Ca concentration.

F_4 and F_2 treatments recorded highest and lowest value of Ca concentrations of 0.18 per cent and 0.11 per cent, respectively.

The treatment combination of fallow-green leaf manure x F_4 treatment resulted in the highest value of 0.256 per cent and lowest concentration of 0.09 per cent in fallow-paddy straw x F_2 treatment.

The grain Ca content was highest (0.056%) in the green manure treatment. The treatment fallow-paddy straw was on par. Fallow-green leaf manure treatment recorded the lowest Ca concentrations of 0.028 per cent.

Among the inorganic treatments, the F_4 recorded the highest concentration of 0.066 and 0.32 per cent in grain and straw respectively. A concentration of 0.023 and 0.23 per cent, which was the lowest in the grain and straw was resulted by the F_2 treatment.

Table 4.15. Effect of treatments on calcium content (%) of plant at panicle initiation, grain and straw

Main plot treatments	Panicle initiation					Grain					Straw				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	0.12	0.10	0.17	0.17	0.14	0.058	0.025	0.066	0.073	0.056	0.32	0.23	0.34	0.39	0.32
GM + CaO	0.14	0.13	0.15	0.18	0.15	0.042	0.037	0.046	0.077	0.051	0.36	0.32	0.37	0.40	0.37
GM + CaO + Ash	0.12	0.10	0.13	0.15	0.12	0.040	0.027	0.044	0.062	0.043	0.27	0.27	0.30	0.32	0.29
Fallow	0.13	0.12	0.14	0.16	0.14	0.037	0.022	0.038	0.050	0.037	0.21	0.20	0.25	0.27	0.23
Fallow - GLM	0.16	0.12	0.21	0.26	0.19	0.028	0.013	0.032	0.036	0.027	0.23	0.22	0.26	0.28	0.25
Fallow - Ps	0.10	0.09	0.12	0.13	0.11	0.039	0.036	0.054	0.086	0.054	0.21	0.21	0.27	0.27	0.24
Fallow - Cd	0.12	0.11	0.14	0.20	0.14	0.013	0.011	0.040	0.089	0.038	0.21	0.20	0.29	0.29	0.25
Fallow - Pm	0.13	0.09	0.19	0.21	0.16	0.033	0.013	0.049	0.059	0.037	0.22	0.22	0.27	0.31	0.26
Mean	0.13	0.11	0.16	0.18		0.036	0.023	0.046	0.066		0.25	0.23	0.30	0.32	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01			0.001	0.001	0.002			0.01	0.01	0.01	
CD (p=0.05)		0.01	0.01	0.01			0.003	0.002	0.006			0.01	0.01	0.01	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Grain Ca concentration of 0.089 per cent, which was the highest recorded in fallow-cowdung x F_4 treatment combination. The lowest content of 0.11 per cent was recorded in fallow-paddy straw x F_4.

The Ca content in straw was the highest in the green manure + CaO (0.37%) whereas, the previous fallow treatment had the lowest concentration of Ca (0.23%). The treatment combination of green manure + CaO x F_4 recorded the highest concentration. Green manure x F_4 treatment was the next in order. Fallow x F_2 treatment combination showed the lowest concentration of 0.20 per cent.

4.4.6 Magnesium

Magnesium (%) content at panicle initiation, grain and straw are presented in Tables 4.16 and 4.17. Among the organic treatments, the highest Mg content of 0.27 per cent was recorded in fallow-poultry manure treatment. Whereas the lowest Mg content of 0.24 per cent was recorded in the treatments of green manure and fallow followed by the application of green leaf manure.

Among inorganic treatments, the highest Mg content of 0.27 per cent was observed in F_1 treatment. The treatments of F_2 and F_3 recorded intermediate value of Mg concentration, whereas the lowest Mg content of 0.23 was recorded in the F_4 treatment.

Among the treatment combinations, fallow-green leaf manure x F_1, fallow-paddy straw x F_1, fallow-cowdung x F_1 and fallow-poultry manure recorded the highest Mg content of 0.28 per cent, whereas the lowest value of 0.25 per cent was recorded in the fallow-cowdung x F_4 and green manure + CaO + ash x F_4 treatments. There was no significant difference in the Magnesium content of grain and straw in the main plot, sub plot or their combinations.

4.4.7 Sulphur

Sulphur content of grain and straw are presented in Table 4.18. The grain S content was the highest in green manure treatment with 0.114 per cent. The lowest S

Table 4.16. Effect of treatments on magnesium content (%) at panicle initiation stage, grain and straw of rice

Treatment	Panicle initiation stage	Grain	Straw
GM	0.24	0.12	0.27
GM + CaO	0.26	0.12	0.27
GM + CaO + Ash	0.26	0.13	0.27
Fallow	0.26	0.12	0.26
Fallow - GLM	0.24	0.13	0.25
Fallow - Ps	0.26	0.12	0.24
Fallow - Cd	0.26	0.12	0.24
Fallow - Pm	0.27	0.13	0.26
CD (0.05)	0.01	0.01	0.01
F_1	0.27	0.13	0.27
F_2	0.26	0.13	0.26
F_3	0.26	0.12	0.26
F_4	0.23	0.12	0.25
CD (0.05)	0.01	0.01	0.01
Treatment combination	S	NS	NS

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.17. Effect of treatments on magnesium content (%) at panicle initiation stage

Main plot treatments	Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean
GM	0.27	0.26	0.26	0.16	0.24
GM + CaO	0.27	0.26	0.26	0.26	0.26
GM + CaO + Ash	0.27	0.26	0.25	0.26	0.26
Fallow	0.27	0.26	0.26	0.26	0.24
Fallow - GLM	0.27	0.26	0.26	0.26	0.26
Fallow - Ps	0.28	0.26	0.26	0.16	0.26
Fallow - Cd	0.28	0.26	0.26	0.25	0.26
Fallow - Pm	0.25	0.27	0.27	0.26	0.27
Mean	0.27	0.26	0.26	0.23	
		Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01	
CD (p=0.05)		0.01	0.01	0.01	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.18. Effect of treatments on sulphur content (%) of grain and straw

Main plot treatments	Grain					Straw				
	Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	0.113	0.106	0.101	0.136	0.114	0.199	0.145	0.137	0.320	0.201
GM + CaO	0.115	0.105	0.096	0.137	0.113	0.317	0.212	0.186	0.336	0.263
GM + CaO + Ash	0.104	0.103	0.075	0.122	0.101	0.338	0.332	0.301	0.366	0.334
Fallow	0.092	0.082	0.074	0.097	0.036	0.239	0.223	0.189	0.373	0.256
Fallow - GLM	0.112	0.092	0.062	0.128	0.098	0.283	0.261	0.177	0.267	0.247
Fallow - Ps	0.086	0.073	0.064	0.086	0.077	0.234	0.159	0.132	0.237	0.191
Fallow - Cd	0.067	0.065	0.062	0.071	0.066	0.315	0.262	0.231	0.331	0.285
Fallow - Pm	0.082	0.067	0.062	0.098	0.077	0.211	0.201	0.192	0.219	0.206
Mean	0.096	0.087	0.074	0.109		0.267	0.224	0.193	0.306	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.001	0.001	0.001			0.001	0.001	0.004	
CD (p=0.05)		0.001	0.006	0.002			0.009	0.006	0.017	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

content of 0.066 per cent was recorded in fallow-cowdung treatment. Green manure + CaO treatment recorded similar S content of the treatment green manuring alone.

Among the inorganic treatments, the highest S content of 0.109 per cent was observed in the F_4 treatment, whereas F_1, F_2, F_3 treatments were next in the order. The treatment combination of green manure + CaO x F_4 recorded the highest S content of 0.137 per cent. The treatment combinations of green manure x F_4 was on par, whereas the treatment combinations of fallow-poultry manure x F_3 recorded the lowest S content (0.062%).

In straw, green manure + CaO + ash resulted in the highest S content of 0.334 per cent, whereas the lowest content (0.191%) was recorded in the fallow-paddy straw treatment. F_4 treatment observed the highest S content of 0.306 per cent. The treatments of F_1, F_2 and F_3 were next in order. Among the treatment combinations, fallow x F_4 and fallow x F_2 recorded the highest S content, whereas fallow-paddy straw x F_3 recorded the lowest S concentration.

4.4.8 Fe

Fe (%) content at panicle initiation, grain and straw are presented in Table 4.19. At panicle initiation, the highest Fe content of 0.272 per cent was observed in fallow-poultry manure treatment, whereas fallow-cowdung recorded the lowest Fe content of 0.168 per cent. Among the inorganic treatments, the highest Fe concentration was recorded in F_1 treatment, whereas F_2, F_3, F_4 contained relatively lower Fe concentration.

The treatment combinations of fallow-green leaf manure x F1, green manure + CaO + ash x F_1 and green manure x F_1 recorded highest Fe concentration at panicle initiation, grain and straw, respectively.

4.5 NUTRIENT UPTAKE

Nutrient uptake at panicle initiation, grain and straw were estimated and presented in Tables 4.20, 4.21, 4.22, 4.23, 4.24 and 4.25.

Table 4.19. Effect of treatments on iron content (%) at panicle initiation stage, grain and straw

Main plot treatments	Panicle initiation					Grain					Straw				
	Sub-plot treatments					Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	0.382	0.272	0.218	0.214	0.272	0.025	0.018	0.010	0.009	0.016	0.245	0.208	0.166	0.132	0.188
GM + CaO	0.358	0.245	0.167	0.121	0.223	0.024	0.012	0.011	0.010	0.014	0.212	0.168	0.141	0.118	0.160
GM + CaO + Ash	0.292	0.260	0.215	0.138	0.226	0.036	0.028	0.014	0.011	0.022	0.141	0.126	0.102	0.091	0.115
Fallow	0.339	0.196	0.184	0.164	0.221	0.014	0.010	0.007	0.006	0.010	0.135	0.107	0.108	0.091	0.115
Fallow - GLM	0.531	0.421	0.162	0.178	0.323	0.020	0.012	0.011	0.009	0.013	0.136	0.131	0.111	0.055	0.108
Fallow - Ps	0.367	0.305	0.302	0.296	0.318	0.016	0.015	0.013	0.012	0.014	0.164	0.161	0.124	0.126	0.144
Fallow - Cd	0.233	0.157	0.145	0.138	0.168	0.029	0.023	0.021	0.015	0.022	0.231	0.218	0.120	0.109	0.170
Fallow - Pm	0.521	0.424	0.363	0.168	0.369	0.014	0.014	0.010	0.007	0.011	0.086	0.078	0.074	0.072	0.077
Mean	0.378	0.285	0.220	0.117		0.022	0.017	0.013	0.010		0.169	0.150	0.118	0.100	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.001	0.001	0.01			0.001	0.001	0.001			0.001	0.001	0.001	
CD (p=0.05)		0.021	0.014	0.039			0.002	0.001	0.001			0.001	0.008	0.002	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

At panicle initiation stage, the highest uptake of the nutrients *viz.*, N, P, K, Mg and Mn recorded in green leaf manure + CaO + ash treatment. The Ca uptake was the highest value in fallow-green leaf manure treatment. The uptake of Fe was highest in fallow-poultry manure treatment.

The lowest uptake of N, P, Fe and Mn were observed in the previous fallow treatment, whereas K, Ca and Mg uptake was lowest in fallow-cowdung, fallow-paddy straw and fallow-green leaf manure treatment respectively.

Among the inorganic treatments, F_4 recorded the highest uptake values of N, P, K, Ca, Mg and Mn. F_1 resulted the lowest uptake values of the treatments. The trend in the Fe uptake just reverse, where F_1 treatment recorded the highest uptake. The highest N uptake of 160.94 was recorded in the treatment combination of green manure + CaO + ash x F_3 and lowest with 62.19 kg ha^{-1} in fallow x F_1.

With regard to P uptake, the highest of 24.95 was in green manure + CaO + ash x F_2 and the lowest of 11.98 in fallow x F_1.

The K uptake was the highest (155.06 kg ha^{-1}) in the treatment combination of green manure + CaO + ash x F_4 and the lowest of 76.26 kg ha^{-1} in fallow x F_4.

The highest Mg uptake was observed in green manure + CaO + ash x F_2 and the lowest in green manure x F_4. The highest Mn uptake was obtained in fallow-poultry manure x F_4 and lowest in fallow x F_4.

In grain, highest uptake of N, P, K, Mg, Fe and Ca was recorded in green manure + CaO + ash treatment and the lowest uptake values of this nutrient was observed in previous fallow treatment. The highest Ca uptake was recorded in green manure + CaO treatment.

Among inorganic treatments, F_4 recorded the highest uptake value of N, P, K, Mg and S whereas, the F_1 recorded the lowest values. With regard to Fe uptake this was just reverse.

Table 4.20. Effect of treatments on uptake of nutrients at panicle initiation stage (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	Fe	Mn
GM	111.58	22.22	128.60	6.57	11.21	12.86	6.47
GM + CaO	120.06	22.21	133.30	7.09	12.43	10.54	6.94
GM + CaO + Ash	130.39	23.30	143.29	6.09	12.98	11.20	7.43
Fallow	72.29	14.10	99.70	5.52	10.40	8.78	4.72
Fallow - GLM	116.81	20.01	122.87	8.61	11.12	15.03	6.42
Fallow - Ps	98.12	16.20	119.44	4.86	11.79	14.31	7.28
Fallow - Cd	100.54	15.08	93.29	6.44	11.92	7.67	5.35
Fallow - Pm	111.92	16.12	122.52	7.13	12.39	16.99	6.86
CD (0.05)	4.2	1.4	4.2	1.4	1.4	2.94	1.23
F_1	86.33	15.81	107.71	5.38	11.62	16.15	4.96
F_2	106.20	17.39	121.77	6.03	12.04	13.04	5.99
F_3	114.23	19.74	128.81	7.05	12.22	10.34	6.44
F_4	123.46	21.14	136.91	8.64	13.46	5.62	7.24
CD (0.05)	1.45	0.90	1.60	0.60	0.90	1.26	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.21. Effect of treatments on uptake of nutrients at panicle initiation stage (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	Fe	Mn
GM + F_1	79.93	19.65	112.69	5.32	11.70	16.68	5.28
GM + F_2	112.68	20.98	124.54	4.42	11.99	12.40	6.07
GM + F_3	125.26	23.36	138.19	8.25	12.97	10.58	7.01
GM + F_4	131.76	24.45	141.78	8.57	7.82	10.72	7.67
GM + CaO + F_1	104.92	18.43	116.34	6.18	11.67	15.71	6.19
GM + CaO + F_2	112.16	19.22	129.10	5.81	12.08	11.21	6.59
GM + CaO + F_3	137.97	23.44	140.66	7.52	12.85	6.11	7.11
GM + CaO + F_4	100.59	24.25	149.09	894	13.19	13.35	7.13
GM + CaO + Ash + F_1	144.82	20.03	121.51	5.25	11.82	11.57	6.27
GM + CaO + Ash + F_2	133.54	24.95	154.58	5.58	14.15	13.81	7.86
GM + CaO + Ash + F_3	145.91	22.94	141.83	6.14	12.67	6.72	7.84
GM + CaO + Ash + F_4	160.94	24.89	155.06	7.42	13.12	17.20	5.08
Fallow + F_1	62.19	11.98	91.17	5.06	10.28	7.57	4.41
Fallow + F_2	93.19	13.41	100.41	4.79	10.73	7.47	4.92
Fallow + F_3	79.01	16.14	108.32	6.07	11.02	6.96	5.91
Fallow + F_4	72.73	13.30	76.26	6.05	12.75	19.66	3.01
Fallow - GLM + F_1	111.67	18.51	108.38	6.69	12.01	18.18	5.87
Fallow - GLM + F_2	113.75	18.50	117.36	5.55	11.87	7.31	6.27
Fallow - GLM + F_3	127.19	21.36	125.29	9.73	12.19	8.43	7.36
Fallow - GLM + F_4	137.98	14.18	141.08	12.94	8.06	18.48	7.81
Fallow - paddy straw + F_1	77.70	12.25	102.20	4.14	11.71	12.88	6.54
Fallow - paddy straw + F_2	92.19	15.58	116.25	3.92	11.62	13.45	4.01
Fallow - paddy straw + F_3	106.16	17.69	123.86	5.54	11.70	13.42	4.81
Fallow - paddy straw + F_3	117.35	20.12	136.03	5.98	12.16	11.16	8.04
Fallow - cowdung + F_1	86.61	12.44	105.06	4.93	11.58	9.99	4.12
Fallow - cowdung + F_2	97.74	13.58	119.01	5.11	11.67	7.10	5.56
Fallow - cowdung + F_3	104.81	16.67	124.76	6.45	11.78	6.35	5.71
Fallow - cowdung + F_4	113.02	17.87	133.79	9.51	12.21	6.66	6.38
Fallow - poultry manure + F_1	88.39	14.16	107.71	5.54	11.80	22.31	4.84
Fallow - poultry manure + F_2	129.87	15.31	112.58	3.60	12.29	19.09	6.84
Fallow - poultry manure + F_3	115.44	16.96	126.75	8.95	12.67	17.10	7.39
Fallow - poultry manure + F_4	140.13	18.68	141.61	10.07	12.68	8.26	8.61
CD (0.05)	5.2	3.8	13.00	2.60	1.80	1.01	1.45

Table 4.22. Effect of treatments on uptake of nutrients by grain (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	S	Fe
GM	48.65	5.38	24.20	2.43	5.21	4.95	6.51
GM + CaO	63.13	6.69	33.68	2.69	6.58	6.15	7.55
GM + CaO + Ash	71.68	6.82	39.47	2.52	7.52	5.93	12.92
Fallow	25.92	3.41	13.52	1.03	3.42	2.39	2.68
Fallow - GLM	54.50	4.76	26.11	1.23	5.72	4.48	6.64
Fallow - Ps	32.79	3.50	19.28	1.68	3.84	2.41	4.37
Fallow - Cd	33.20	3.48	18.59	1.26	4.01	2.19	7.30
Fallow - Pm	51.10	3.95	21.02	1.32	4.49	2.74	4.63
CD (0.05)	2.3	NS	2.80	0.70	NS	0.23	0.46
F_1	34.95	3.49	18.17	1.26	4.43	3.36	7.69
F_2	41.51	4.07	22.32	0.90	4.89	3.39	6.65
F_3	48.35	6.23	26.33	1.98	5.31	3.19	6.91
F_4	58.15	6.24	30.98	3.14	5.63	5.24	4.29
CD (0.05)	1.1	NS	1.10	0.20	NS	0.66	0.11

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.23. Effect of treatments on uptake of nutrients by grain (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	S	Fe
GM + F_1	33.61	3.67	15.94	2.01	4.27	3.91	8.66
GM + F_2	44.40	4.52	23.24	1.04	5.02	4.39	7.47
GM + F_3	53.65	5.97	29.14	3.05	5.50	4.67	4.16
GM + F_4	64.70	7.81	34.41	3.74	6.06	6.98	4.62
GM + CaO + F_1	49.90	5.36	26.12	1.95	5.69	5.36	10.72
GM + CaO + F_2	58.36	6.31	32.31	1.92	6.36	5.47	6.25
GM + CaO + F_3	67.77	6.95	35.88	2.62	6.94	5.46	6.26
GM + CaO + F_4	78.80	8.18	41.51	4.63	7.21	8.24	5.41
GM + CaO + Ash + F_1	56.61	5.09	31.57	2.06	6.84	5.35	10.52
GM + CaO + Ash + F_2	67.13	6.03	37.55	1.54	7.56	6.88	15.92
GM + CaO + Ash + F_3	74.77	7.24	41.63	2.65	7.42	4.52	8.44
GM + CaO + Ash + F_4	89.58	9.29	47.78	4.12	8.16	8.09	7.30
Fallow + F_1	28.12	2.06	16.91	0.87	2.96	2.16	3.29
Fallow + F_2	22.80	2.34	12.58	0.57	3.28	2.15	2.36
Fallow + F_3	37.59	4.02	15.22	1.16	3.74	2.25	2.13
Fallow + F_4	33.26	4.28	16.63	1.57	3.73	3.04	1.88
Fallow - GLM + F_1	38.94	3.07	18.64	1.02	4.64	4.09	9.31
Fallow - GLM + F_2	48.13	4.08	21.16	0.54	5.19	3.82	4.97
Fallow - GLM + F_3	60.94	5.69	24.48	1.61	6.24	3.12	5.54
Fallow - GLM + F_4	71.21	6.57	34.51	1.97	6.74	7.01	4.38
Fallow - paddy straw + F_1	25.93	2.87	15.73	1.08	3.47	1.37	4.41
Fallow - paddy straw + F_2	30.04	3.15	17.67	1.06	3.68	2.14	4.41
Fallow - paddy straw + F_3	34.44	3.63	19.95	1.73	3.92	2.05	4.18
Fallow - paddy straw + F_3	42.17	4.36	23.95	3.07	4.32	3.07	4.28
Fallow - cowdung + F_1	25.24	2.91	13.32	0.36	3.68	1.86	8.04
Fallow - cowdung + F_2	29.52	2.42	16.95	0.34	3.98	2.04	7.22
Fallow - cowdung + F_3	32.99	3.75	19.08	1.29	4.04	2.01	6.79
Fallow - cowdung + F_4	46.27	5.12	25.20	3.68	4.08	3.02	6.19
Fallow - poultry manure + F_1	33.36	3.24	16.55	2.04	5.35	2.58	4.41
Fallow - poultry manure + F_2	37.32	3.73	19.52	0.44	4.35	2.29	4.79
Fallow - poultry manure + F_3	41.25	4.09	22.26	1.79	4.56	2.26	3.28
Fallow - poultry manure + F_4	48.79	4.76	25.81	2.13	4.96	3.95	2.42
CD (0.05)	6.20	3.1	1.55	1.86	NS	1.86	0.31

Table 4.24. Effect of treatments on nutrient uptake in straw (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	S	Fe
GM	36.41	9.69	112.53	15.08	12.91	9.46	8.94
GM + CaO	45.19	11.33	125.23	19.87	14.92	14.16	8.71
GM + CaO + Ash	56.38	11.03	162.39	17.77	17.96	20.47	7.04
Fallow	22.14	6.01	65.23	7.01	7.50	7.66	3.32
Fallow - GLM	46.67	7.56	111.41	11.66	11.84	11.61	5.12
Fallow - Ps	32.57	6.69	88.94	8.71	8.82	6.99	9.51
Fallow - Cd	33.05	7.14	82.63	9.24	9.16	10.70	6.35
Fallow - Pm	34.06	6.54	94.72	9.84	9.95	7.88	2.95
CD (0.05)							
F_1	28.88	6.55	85.86	9.74	10.28	10.28	6.50
F_2	35.37	7.76	96.72	9.89	11.12	11.78	6.39
F_3	41.05	8.94	110.79	13.45	11.72	8.80	5.38
F_4	47.47	10.13	127.33	15.73	12.36	15.13	4.95
CD (0.05)	2.40	2.10	2.88	2.26	2.35	1.44	1.92

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.25. Effect of treatments on nutrient uptake in straw (kg ha^{-1})

Treatment	N	P	K	Ca	Mg	S	Fe
GM + F_1	30.12	8.29	90.78	11.45	11.92	8.44	10.35
GM + F_2	33.53	8.99	103.73	10.06	12.34	6.48	9.34
GM + F_3	38.99	10.30	118.39	16.92	13.57	6.75	8.14
GM + F_4	52.65	11.27	140.29	20.18	13.80	16.91	6.95
GM + CaO + F_1	30.16	7.71	96.35	15.16	11.85	13.28	8.92
GM + CaO + F_2	44.52	11.21	96.31	18.14	15.55	11.95	9.47
GM + CaO + F_3	46.85	11.97	148.62	21.11	15.30	10.50	7.96
GM + CaO + F_4	58.30	14.12	162.27	24.28	16.11	20.19	7.09
GM + CaO + Ash + F_1	44.91	9.26	140.35	14.93	15.94	18.98	7.92
GM + CaO + Ash + F_2	51.14	10.35	157.20	16.18	15.88	19.97	7.58
GM + CaO + Ash + F_3	60.74	12.52	165.65	18.47	16.07	18.47	6.26
GM + CaO + Ash + F_4	68.82	14.51	188.94	21.86	17.48	24.69	6.14
Fallow + F_1	16.92	5.08	51.05	5.63	6.93	6.32	3.57
Fallow + F_2	20.31	5.32	59.74	5.41	7.11	6.36	2.93
Fallow + F_3	24.78	6.75	72.70	8.28	8.35	6.16	3.52
Fallow + F_4	26.87	6.99	78.95	9.06	8.39	12.37	3.12
Fallow - GLM + F_1	32.08	4.64	84.54	8.53	9.70	10.68	5.28
Fallow - GLM + F_2	41.85	6.75	99.92	9.52	10.93	11.14	5.59
Fallow - GLM + F_3	51.86	9.64	124.78	13.51	12.94	9.09	5.70
Fallow - GLM + F_4	60.18	10.46	139.47	15.92	13.72	15.01	3.09
Fallow - paddy straw + F_1	26.34	5.68	77.29	7.38	8.73	8.10	5.68
Fallow - paddy straw + F_2	30.32	6.31	82.49	7.23	8.60	5.60	5.67
Fallow - paddy straw + F_3	34.59	7.10	92.00	9.83	8.91	4.86	4.56
Fallow - paddy straw + F_3	40.08	7.82	107.42	10.67	8.93	9.41	5.00
Fallow - cowdung + F_1	26.14	6.03	70.37	6.87	8.34	10.56	7.74
Fallow - cowdung + F_2	29.89	6.66	78.15	7.17	8.93	9.43	7.85
Fallow - cowdung + F_3	33.09	6.80	81.83	10.28	8.57	8.22	4.27
Fallow - cowdung + F_4	43.77	9.12	103.77	13.18	10.74	14.93	6.01
Fallow - poultry manure + F_1	26.77	5.39	81.71	7.85	9.51	7.43	3.03
Fallow - poultry manure + F_2	33.29	6.43	93.74	8.42	10.02	7.69	2.94
Fallow - poultry manure + F_3	35.37	6.88	97.25	10.38	9.99	7.38	2.84
Fallow - poultry manure + F_4	39.51	7.53	106.60	12.88	10.17	9.01	2.97
CD (0.05)	1.34	0.68	22.80	0.70	NS	1.13	1.34

The treatment combination of green manure + CaO + ash x F_4 recorded the highest N, P, K uptake values. Ca and S uptakes were the highest in green manure + CaO x F_4 whereas, Mg and Fe uptake were highest in green manure + CaO x F_2. In straw, the highest uptake of N, P, K, Ca, Mg, S were highest in green manure + CaO + ash, the lowest uptakes were recorded in fallow treatment.

The highest uptake of Fe in straw was in the green manure alone treatment.

Highest nutrient accumulation of N, P, K, Mg and S in the straw were in treatment combinations of green manure + CaO + ash x F_4, whereas the lowest was observed in fallow x F_1 except sulphur. The highest value of Ca and Fe uptake were recorded in combination treatment of green manure + CaO + ash x F_2.

4.6 SOIL CHARACTERS

4.6.1 Soil pH and EC

The values of pH and EC are furnished in Tables 4.26 and 4.27.

During the virippu season, the pH values varied between 4.78 in the previous fallow to 5.92 in green manure + CaO + ash. Among inorganic treatments F_4 resulted in the highest (5.76) and F_1 lowest (5.15) values, respectively.

The combination treatment of green manure + CaO + ash x F_4 recorded the highest (6.21) and fallow x F_1 recorded the lowest (4.61) pH values.

After harvest of the crop, the highest pH value of 5.73 was recorded in green manure + CaO + ash treatment, pH of green manure + CaO treatment was on par. The previous fallow recorded the lowest pH value of 4.68. The treatment combination of green manure + CaO x F_4 and green manure + CaO + ash x F_4 recorded the highest but same pH of 6.11. Fallow x F_1 recorded the lowest pH of 4.54. No significant variation was observed in EC values during cropping and after harvest of the crop both in organic, inorganic treatment and their combinations.

Table 4.26. Effect of treatments on soil pH at cropping and after harvest of the crop

Main plot treatments	During Cropping					After harvest of the crop				
	Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	5.20	5.52	5.83	5.88	5.61	5.08	5.29	5.50	5.56	5.36
GM + CaO	5.54	5.71	6.10	6.14	5.87	5.23	5.56	5.92	6.11	5.70
GM + CaO + Ash	5.62	5.79	6.10	6.21	5.93	5.32	5.57	5.90	6.11	5.73
Fallow	4.61	4.68	4.82	5.02	4.78	4.54	4.58	4.78	4.82	4.68
Fallow - GLM	5.07	5.21	5.63	5.93	5.46	4.99	5.27	5.47	5.63	5.34
Fallow - Ps	5.16	5.22	5.54	5.81	5.43	5.09	5.19	5.42	5.53	5.31
Fallow - Cd	5.06	5.16	5.41	5.51	5.28	4.92	4.97	5.27	5.32	5.12
Fallow - Pm	4.92	5.11	5.31	5.57	5.23	4.90	4.96	5.10	5.35	5.08
Mean	5.15	5.30	5.59	5.76		5.01	5.18	5.42	5.55	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01			0.01	0.01	0.01	
CD (p=0.05)		0.01	0.03	0.05			0.03	0.02	0.01	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.27. Effect of treatments on soil Ec at cropping and after harvest of the crop

Treatment	Ec (dSm^{-1})	
	During cropping season	After harvest of the crop
GM	0.139	0.098
GM + CaO	0.261	0.098
GM + CaO + Ash	0.150	0.099
Fallow	0.119	0.099
Fallow - GLM	0.136	0.100
Fallow - Ps	0.146	0.101
Fallow - Cd	0.144	0.090
Fallow - Pm	0.153	0.112
CD (0.05)	0.127	0.147
F_1	0.131	0.130
F_2	0.138	0.123
F_3	0.144	0.110
F_4	0.217	0.105
CD (0.05)	0.08	0.055
Treatment combination	NS	NS

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

4.6.2 Organic carbon content in soils

Organic carbon content of soil at cropping and after harvest of the crop is presented in Table 4.28. During rice cropping the highest value (0.93%) of organic carbon was observed in the fallow-poultry manure treatment. Green manure alone and fallow-paddy straw treatments were on par. The lowest organic carbon content of 0.50 per cent was observed in the previous fallow. Among sub plot treatment F_4 recorded highest (0.81%) and F_1 recorded lowest (0.64%) values. The combination of fallow-poultry manure x F_4 recorded highest (1.04%) organic carbon content whereas the lowest (0.46%) was recorded in fallow x F_4 treatment.

At after harvest of the crop, the highest soil organic carbon of 0.96 per cent was recorded in the green manure + CaO + ash treatment. Fallow-poultry manure, green manure + CaO and green manure alone treatments were on par. The lowest organic carbon content of 0.54 per cent was recorded in the previous fallow.

Among inorganic treatments, F_4 treatment recorded the highest value of 0.85 per cent and F_1 recorded the lowest value of 0.65 per cent. Among treatment combinations, green manure + CaO + ash x F_4 recorded the highest organic carbon content of 1.09 per cent. Fallow-green leaf manure x F_4 and green manure + CaO + ash x F_3 were observed to be on par. The lowest organic carbon content of 0.48 per cent was recorded in fallow x F_1 treatment.

4.6.3 Available nutrient content of soil

4.6.3.1 Available N

The values of available N, P and K content of the soil at cropping and after harvest of the crop are given in Tables 4.29 and 4.30.

The highest value of 534.0 kg ha^{-1} of available N content was recorded in fallow-green leaf manure treatment, whereas the lowest value of 439.0 kg ha^{-1} was recorded in the previous fallow.

Table 4.28. Effect of treatments on the soil organic carbon (%) at cropping and after harvest of the crop

Main plot treatments	At cropping					After harvest of the crop				
	Sub-plot treatments					Sub-plot treatments				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
GM	0.64	0.68	0.71	0.73	0.69	0.69	0.72	0.84	0.91	0.79
GM + CaO	0.64	0.75	0.78	0.82	0.75	0.72	0.78	0.83	0.87	0.81
GM + CaO + Ash	0.73	0.83	0.92	0.95	0.86	0.86	0.91	1.01	1.10	0.97
Fallow	0.46	0.48	0.51	0.53	0.47	0.48	0.52	0.56	0.62	0.54
Fallow - GLM	0.54	0.66	0.74	0.75	0.50	0.57	0.64	0.71	1.04	0.74
Fallow - Ps	0.62	0.69	0.71	0.74	0.69	0.63	0.66	0.69	0.72	0.67
Fallow - Cd	0.56	0.68	0.86	0.91	0.75	0.51	0.52	0.63	0.74	0.60
Fallow - Pm	0.90	0.94	0.97	1.04	0.96	0.77	0.79	0.86	0.83	0.81
Mean	0.64	0.71	0.78	0.81		0.65	0.69	0.77	0.85	
		Main plot treatments	Sub-plot treatments	Interaction			Main plot treatments	Sub-plot treatments	Interaction	
S.E		0.01	0.01	0.01			0.03	0.01	0.05	
CD (p=0.05)		0.01	0.01	0.01			0.01	0.01	0.01	

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Among sub plot treatments, the highest available N content of 550.0 kg ha^{-1} was obtained in F_4 and the lowest content of 431.0 kg ha^{-1} was found at F_1.

Among the treatment combinations, fallow-green leaf manure x F_4 recorded highest (624.0 kg ha^{-1}) available N content however fallow-poultry manure x F_4 treatment was on par. Fallow-cowdung x F_1 treatment recorded the lowest available N content.

After harvest of the crop, the highest value was recorded in fallow-poultry manure treatment and lowest available N recorded in the fallow-paddy straw treatment. F_4 treatment recorded the highest value of 446 kg ha^{-1} and F_1 recorded the lowest content of 328 kg ha^{-1}. The combination treatment of green manure x F_4, fallow-cowdung x F_4 and green manure + CaO + ash x F_4 were on par. The lowest available N content was recorded in green manure x F_1 treatment.

4.6.3.2 Available P

At cropping, the highest available P content of 10.47 kg ha^{-1} was observed in fallow-poultry manure treatment. Fallow-cowdung, fallow-green leaf manure treatments were on par. The lowest (7.65 kg ha^{-1}) was observed in fallow. The treatment combination of fallow-poultry manure x F_4 recorded the highest (12.24 kg ha^{-1}). The P content in the fallow-poultry manure x F_3 and fallow-green leaf manure x F_4 were on par. The treatment fallow x F_1 recorded the lowest available phosphorus content.

After harvest of crop, the highest (8.70 kg ha^{-1}) value of available soil P was observed in fallow-poultry manure treatment. The lowest value of 6.06 kg ha^{-1} was recorded in fallow-green leaf manure treatment. Fallow-poultry manure x F_4 treatment combinations recorded the highest value of 9.81 kg ha^{-1} available P and the lowest value of 5.3 kg ha^{-1} was recorded in green leaf manure x F_3 combination treatments.

4.6.3.3 Available K

Among the organic sources, the available K was the highest with 169.7 kg ha^{-1} in fallow-paddy straw treatment and it was lowest with 133.9 kg ha^{-1} in green

Table 4.29. Effect of treatments on the available primary nutrient (kg ha^{-1}) of soil at cropping

Main plot treatments	Sub plot treatments														
	F1			F2			F3			F4			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
GM	454	7.84	132.3	477	8.55	165.8	492	8.65	121.7	537	8.77	116.5	490	8.45	134.1
GM + CaO	436	7.53	138.2	483	7.63	158.4	498	8.26	126.1	514	9.33	114.7	483	8.19	134.4
GM + CaO + Ash	467	7.81	156.8	491	7.81	156.8	498	8.77	123.8	530	9.51	109.4	497	8.09	133.9
Fallow	410	5.93	169.2	424	7.83	179.4	470	8.44	156.8	461	8.38	112.4	439	7.65	154.4
Fallow - GLM	482	7.77	156.7	514	8.03	168..5	515	9.14	142.3	624	10.64	121.4	534	8.89	147.2
Fallow - Ps	420	7.93	184.4	498	8.40	191.5	498	8.57	168.4	608	9.28	134.3	506	8.54	169.7
Fallow - Cd	373	8.21	168.4	415	8.64	184.6	483	9.20	156.8	514	9.84	145.7	444	8.97	163.9
Fallow - Pm	404	8.23	156.9	467	9.51	179.3	592	10.89	145.6	624	12.24	132.7	522	10.47	153.6
Mean	431	9.67	156.9	470	8.30	173	506	9.00	142.7	550	9.82	123.4			
		Main Plot treatments	Sub-plot treatments	Interaction		Main plot treatments	Sub-Plot treatments	Interaction		Main plot treatments	Sub-plot treatments	Interaction			
S.E		3.47	2.05	5.8		0.05	0.05	0.15		0.6	0.4	1.2			
CD (p=0.05)		11.00	6.00	17.0		0.14	0.42	0.15		1.8	1.2	3.5			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.30. Effect of treatments on available primary nutrient of soil after harvest of the crop (kg ha^{-1})

Main plot treatments	Sub plot treatments														
	F1			F2			F3			F4			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
GM	294	6.70	103.6	311	7.60	148.6	389	6.59	98.6	473	5.95	87.5	367	6.71	109.5
GM + CaO	325	6.94	123.6	366	7.22	133.4	373	6.57	112.5	436	6.27	121.5	373	6.75	122.7
GM + CaO + Ash	357	6.18	106.9	390	7.32	112.4	451	7.15	104.8	467	6.84	89.6	416	6.87	103.4
Fallow	316	5.74	110.7	358	6.82	134.5	373	5.84	108.6	411	6.60	102.7	364	6.25	114.1
Fallow - GLM	319	6.66	112.3	373	6.23	123.4	389	5.30	96.6	414	6.04	88.6	369	6.06	105.2
Fallow - Ps	294	7.29	151.7	351	6.94	180.4	373	6.68	112.3	389	6.83	101.7	349	6.93	136.6
Fallow - Cd	357	7.94	133.4	364	8.16	160.8	389	8.62	125.3	471	9.44	110.0	395	8.54	132.4
Fallow - Pm	372	7.79	112.4	420	8.10	123.4	432	9.10	114.5	514	9.80	108.8	435	8.70	114.8
Mean	328	6.90	119.3	364	7.3	139.6	396	6.98	109.2	446	7.22	101.3			
		Main Plot treatments	Sub-plot treatments	Interaction		Main plot treatments	Sub-Plot treatments	Interaction		Main plot treatments	Sub-plot treatments	Interaction			
S.E		1.8	1.34	3.8		0.01	0.01	0.03		2.1	1.6	4.7			
CD (p=0.05)		6.0	3.8	11		0.04	0.03	0.07		6.53	4.7	13.3			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

manure + CaO + ash treatment during the cropping seasons. The content were found to be reduced after the crop harvest to 136.6 and 103.4 kg ha^{-1} respectively in the above treatments.

Among the inorganic treatments, F_2 treatment recorded the highest value of 173.0 kg ha^{-1} and F_4 recorded the lowest value of 123.4 kg ha^{-1}. After harvest of the crop the K content was reduced to 139.6 and 101.3 kg ha^{-1} respectively in F_2 and F_4.

Among the treatment combinations, fallow-paddy straw x F_2 recorded the highest content and green manure + CaO + ash x F_4 recorded the lowest during the cropping season. But after harvest the lowest K content was observed in green manure + CaO x F_4.

4.6.4 Available secondary and micronutrients

The contents of calcium (Ca), magnesium (Mg) and sulphur (S), iron (Fe) and Manganese (Mn) in soil during the virippu and after harvest of the crop are presented in Tables 4.31, 4.32, 4.33 and 4.34.

The results showed that fallow-cowdung treatment recorded the highest calcium concentration of 142.80 kg ha^{-1} and lowest content of 98.00 kg ha^{-1} was observed in fallow-paddy straw treatment. After harvest of the crop, the highest of 80.22 kg ha^{-1} and lowest of 48.01 kg ha^{-1} contents were recorded in fallow-paddy straw and previous fallow treatment.

Among the combination treatment fallow-poultry manure x F_4 and fallow-poultry manure x F_1 recorded the highest of 162.5 kg ha^{-1} and the lowest content of 69.43 kg ha^{-1} in soils during cropping. After harvest of the crop fallow-paddy straw x F_4 and green manure x F_1 treatments showed the highest and the lowest available Ca concentration.

Among inorganic treatments, F_4 and F_1 recorded the highest and lowest concentration of Ca, S, whereas F_4 and F_1 treatments recorded the lowest and highest concentration of Mg, Fe and Mn in soil during cropping and after harvest of the crop.

Table 4.31. Effect of treatments on available secondary nutrient in soil at cropping (kg ha^{-1})

Main plot treatments	Sub plot treatments														
	F1			F2			F3			F4			Mean		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
GM	85.13	11.32	20.1	95.25	10.83	20.6	117.4	9.77	21.4	148.50	9.38	22.6	116.6	10.33	21.2
GM + CaO	196.54	11.31	19.9	115.30	10.31	20.8	124.6	9.56	22.5	153.30	9.31	22.7	122.4	10.12	21.5
GM + CaO + Ash	82.65	12.23	20.2	93.49	11.65	21.8	128.4	11.37	21.9	156.50	8.51	23.4	115.3	10.94	21.7
Fallow	76.08	11.52	17.3	88.66	11.12	18.9	104.7	10.42	19.2	138.60	7.77	20.5	102.2	10.21	18.9
Fallow - GLM	114.60	12.81	17.5	134.30	11.77	19.1	146.4	10.72	19.9	160.70	10.61	20.7	139.0	11.48	19.3
Fallow - Ps	75.64	10.51	17.6	97.64	9.78	18.8	98.2	8.82	19.3	120.50	8.74	20.9	98.0	9.46	19.2
Fallow - Cd	113.50	11.92	18.1	146.50	11.75	18.6	152.7	11.57	19.2	158.4	8.71	21.3	142.80	10.85	19.4
Fallow - Pm	64.65	10.45	19.1	66.59	8.48	19.9	101.3	8.24	19.4	165.50	8.16	23.0	98.77	8.83	20.7
Mean	83.67	11.51	18.7	104.8	10.71	19.8	121.7	10.06	20.7	149.9	8.83	21.9			
		Main Plot treatments	Sub-plot treatments	Interaction		Main plot treatments	Sub-Plot treatments	Interaction		Main plot treatments	Sub-plot treatments	Interaction			
S.E		0.12	0.07	0.20		0.04	0.03	0.08		0.6	0.3	0.8			
CD (p=0.05)		0.37	0.20	0.56		0.13	0.08	0.22		1.80	0.77	2.18			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.32. Effect of treatments on available secondary **nutrient** of soil after harvest of the crop (kg ha^{-1})

Main plot treatments	Sub plot treatments														
	F1			F2			F3			F4			Mean		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
GM	42.19	10.81	18.9	50.97	6.79	19.6	65.38	6.33	21.4	76.26	6.31	22.2	58.70	7.56	20.5
GM + CaO	75.40	7.11	19.4	71.65	6.95	20.4	69.63	6.89	21.8	61.43	5.63	22.9	69.53	5.56	21.1
GM + CaO + Ash	67.41	8.88	19.6	68.67	8.56	20.8	71.41	7.54	21.6	74.43	6.07	23.2	70.48	7.77	21.3
Fallow	34.44	7.07	16.5	49.66	6.73	18.2	50.51	6.28	18.6	57.45	5.65	19.4	48.01	6.43	18.2
Fallow - GLM	58.23	9.33	16.8	66.38	9.23	18.6	77.50	7.93	19.6	86.38	6.96	20.5	72.12	8.36	18.8
Fallow - Ps	58.45	8.55	17.0	80.38	8.33	18.5	89.45	7.43	19.1	92.60	7.29	20.3	80.22	7.91	18.7
Fallow - Cd	53.41	9.71	17.8	65.32	9.15	18.2	90.66	8.15	19.3	91.77	7.95	20.7	75.29	8.74	19.0
Fallow - Pm	53.50	9.44	18.8	59.58	8.34	19.6	64.00	7.88	20.4	84.62	6.06	22.8	69.54	7.93	20.4
Mean	55.38	8.87	18.1	64.08	8.01	19.2	72.37	7.30	20.3	78.12	6.49	21.6			
		Main Plot treatments	Sub-plot treatments	Interaction		Main plot treatments	Sub-Plot treatments	Interaction		Main plot treatments	Sub-plot treatments	Interaction			
S.E		0.08	0.06	0.18		0.01	0.01	0.02		0.20	0.12	0.36			
CD (p=0.05)		0.26	0.18	0.52		0.03	0.02	0.05		0.60	0.36	1.01			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

The combination treatment of fallow-green leaf manure x F_1 and green manure x F_1 recorded the highest Mg content. Fallow x F_4 and green manure + CaO x F_4 recorded the lowest value of Mg concentration in soils at cropping and after harvest of the crop.

Available S concentration was recorded the highest in green manure + CaO + ash treatment and it was lowest in previous fallow both during cropping and after harvest of the crop. The highest value of available S concentration was recorded in the treatment combination of green manure + CaO + ash x F_4 whereas the lowest was observed in the previous fallow x F_1 treatment both during cropping and after harvest of the crop.

Available Fe in soil in the organic treatments was highest in the fallow-paddy straw and lowest in the previous fallow. Among the treatment combinations, green manure x F_1, previous fallow x F_4 recorded the highest and lowest Fe concentration respectively, during cropping. After harvest of the crop, the highest value of Fe was recorded in green manure + CaO + ash treatment and lowest value in fallow-cowdung treatment. Among the combinations, green manure + CaO + ash x F_1 recorded the highest Fe concentration whereas previous fallow x F_1 recorded the lowest.

Available soil Mn concentration was the highest in fallow-green leaf manure treatments both during and after harvest of the crop. Fallow-cowdung treatment showed lowest values of soil Mn at cropping whereas green manure + CaO recorded the lowest soil Mn content after harvest of the crop.

Combination treatment of fallow-green leaf manure x F_1 recorded the highest soil available Mn content both during cropping and after harvest of the crop whereas green manure + CaO + ash x F_4 resulted in the lowest at cropping and green manure + CaO x F_4 after harvest of the crop.

4.7 EFFICIENCY OF ORGANICS

The efficiency of various organics is presented in Table 4.35. The highest agronomic efficiency of 17.76 was recorded in cowdung treatment, however, the uptake efficiency was only 33.36. The green manuring resulted in the highest

Table 4.33. Effect of treatments on available micronutrient of soil at cropping (kg ha^{-1})

Main plot treatments	Sub plot treatments									
	F1		F2		F3		F4		Mean	
	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn
GM	407.0	130.1	339.1	129.1	315.8	123.8	281.3	120.5	335.8	125.9
GM + CaO	591.6	141.5	467.1	132.7	272.6	120.3	256.7	119.7	397.1	131.1
GM + CaO + Ash	357.1	133.1	357.0	133.5	295.1	123.4	283.6	114.9	321.6	126.2
Fallow	353.0	136.6	316.6	129.6	310.1	129.4	216.1	117.8	299.1	128.4
Fallow - GLM	392.4	163.5	349.6	148.7	328.6	147.5	269.1	146.2	334.8	141.5
Fallow - Ps	434.8	154.4	419.5	152.5	415.1	146.4	403.4	133.5	418.2	146.5
Fallow - Cd	364.7	131.3	352.7	130.6	324.2	127.5	277.7	135.6	329.8	128.0
Fallow - Pm	419.5	135.6	381.7	136.3	371.2	134.9	333.1	133.3	376.5	134.8
Mean	415.1	142.0	372.1	136.5	329.1	131.7	290.1	136.1		

	Main-plot treatment		Sub-plot treatment		Interaction	
	Fe	Mn	Fe	Mn	Fe	Mn
S.E	2.1	0.25	1.3	0.17	6.4	0.5
CD (p=0.05)	6.54	7.6	4.2	5.0	12.0	1.14

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

Table 4.34. Effect of treatments on available micronutrient of soil after harvest of the crop (kg ha^{-1})

Main plot treatments	Sub plot treatments									
	F1		F2		F3		F4		Mean	
	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn
GM	610.8	120.8	479.8	121.3	444.4	120.4	407.1	111.5	485.6	118.8
GM + CaO	446.6	124.47	444.4	123.3	305.3	114.6	299.5	111.3	377.9	118.41
GM + CaO + Ash	872.5	126.9	492.2	125.5	386.0	118.4	388.1	113.4	534.7	121.0
Fallow	690.4	124.7	396.7	120.7	297.1	116.5	262.0	112.3	411.7	118.8
Fallow - GLM	505.8	132.6	318.8	128.7	312.9	122.4	310.2	118.3	362.0	125.5
Fallow - Ps	370.2	131.4	328.2	128.8	278.4	133.5	267.9	118.3	311.4	125.4
Fallow - Cd	337.8	125.6	301.6	124.5	297.1	123.5	291.1	115.1	307.1	122.2
Fallow - Pm	440.2	127.3	435.3	120.7	411.1	118.5	427.8	116.6	403.0	120.7
Mean	536.9	126.8	399.2	124.2	341.6	119.7	319.4	114.62		
		Main-plot treatment		Sub-plot treatment		Interaction				
		Fe	Mn	Fe	Mn	Fe	Mn			
S.E		0.81	0.05	0.06	0.04	0.6	0.1			
CD (p=0.05)		2.05	1.14	1.5	1.11	3.8	1.31			

F_1 - Full N as urea : Half P : Full K of normal recommended dose

F_2 - Full N as urea : Half P : Double K of normal recommended dose

F_3 - Full N as urea : Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

F_4 - Full N as NH_4SO_4: Half P + CaO 300 kg + 300 kg Ash : Double K of normal recommended dose

physiological efficiency of 89.02 and uptake efficiency of 57.30 ' of the N derived from it and consequently resulted in a reasonably higher agronomic efficiency of 14.09.

Table 4.35. Use Efficiencies of various organic manures

Organic manures	Agronomic efficiency	Physiological efficiency	Uptake efficiency(%)
Green manure	14.09	89.02	57.30
Green leaf manure	11.49	66.69	50.14
Paddy straw	9.73	58.03	21.57
Cowdung	17.76	75.44	33.66
Poultry manure	10.84	43.42	31.98

4.8 ECONOMICS

The economics of various treatments are presented in Table 4.36. The highest net return was observed for the treatment green manure + CaO + ash x F_4 where the net income was Rs. 31812 per hectare with a benefit cost ratio of 2.25. The lowest benefit cost ratio of 1.13 was observed for fallow x F_1 with the net income of only Rs. 2437 per hectare.

4.9 CORRELATION STUDIES

4.9.1 Correlation of yield attributes

Data on correlation of yield attributes are presented in Table 4.37. A scrutiny of the data on correlation with yield revealed that it was the productive tillers, number of spikelets/panicle and test weight that had high positive relation with yield. The contribution of filled grains was less and there was negative correlation with other attributes.

4.9.2 Correlation of nutrients with yield at panicle initiation

Table 4.38 depicts correlation of nutrients with yield at panicle initiation stage with yield of the crop. N, P, K, Ca, S were favourably correlated with productive tillers, grain and straw yield and Mg and Fe were negatively correlated.

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Table 4.36. Benefit cost analysis of different treatments

Treatment	Cost (Rs. ha^{-1})	Income (Rs. ha^{-1})			Net income	B:C ratio
		Grain	Straw	Total		
GM + F_1	20900	26025	5300	31325	10425	1.49
GM + F_2	21500	31125	5587	36712	15212	1.71
GM + F_3	23750	34725	6162	40887	17137	1.72
GM + F_4	25635	38550	6587	45137	19502	1.77
GM + CaO + F_1	21265	35025	5987	41012	19747	1.93
GM + CaO + F_2	21865	39075	7000	46075	24210	2.11
GM + CaO + F_3	24115	32750	7312	50062	25947	2.07
GM + CaO + F_4	26000	45150	7587	52727	26727	2.03
GM + CaO + Ash + F_1	21690	38625	7012	45637	23947	2.10
GM + CaO + Ash + F_2	21290	42675	7512	50187	28897	2.20
GM + CaO + Ash + F_3	24450	45225	7675	52900	28450	2.16
GM + CaO + Ash + F_4	26425	49800	8437	58237	31812	2.25
Fallow + F_1	18500	17625	3312	20937	2437	1.13
Fallow + F_2	19100	19650	3425	23075	3975	1.21
Fallow + F_3	21350	22800	4075	26875	5525	1.26
Fallow + F_4	23235	23550	4150	27700	4465	1.20
Fallow - GLM + F_1	21235	27450	4724	32175	10940	1.52
Fallow - GLM + F_2	21835	31125	5537	36662	14827	1.68
Fallow - GLM + F_3	24085	37800	6425	44225	20140	1.84
Fallow - GLM + F_4	25970	41100	7037	48137	22167	1.85
Fallow - paddy straw + F_1	21000	20700	4337	25037	4037	1.19
Fallow - paddy straw + F_2	21600	22125	4412	26537	4937	1.23
Fallow - paddy straw + F_3	23850	24150	4612	28762	4912	1.21
Fallow - paddy straw + F_3	25734	26850	4962	31812	6078	1.24
Fallow - cowdung + F_1	20750	20850	4187	25037	4287	1.21
Fallow - cowdung + F_2	21350	23550	4500	28050	6700	1.32
Fallow - cowdung + F_3	23590	24225	4450	58675	35085	1.22
Fallow - cowdung + F_4	25485	30975	5637	36612	11127	1.44
Fallow - poultry manure + F_1	21000	23625	4400	28025	7025	1.33
Fallow - poultry manure + F_2	21600	25725	4387	30012	8412	1.39
Fallow - poultry manure + F_3	23850	27375	4562	31937	8087	1.34
Fallow - poultry manure + F_4	25735	30225	5037	35262	9527	1.37

4.9.3 Correlation of nutrient with grain yield at harvest stage

Table 4.39 is a record of correlation of various nutrients in straw with grain yield. N, P, K, Ca, Mg and S were positively correlated with yield and Fe was negatively correlated.

4.9.4 Nutrient ratios of plant at PI stage

The nutrient ratios in plant is an important parameters which decide the productivity of the crop. The ratio of Fe with other nutrients was found to have important role on the productivity of laterite soil.

Table 40 shows the effect of treatments on nutrient ratios of plant at panicle initiation stage. The lowest level of N/Fe ratio was observed in fallow-poultry manure treatment and fallow-paddy straw treatments which were on par. The highest level of N/Fe ratio was observed in green manure + CaO + ash treatment, which was resulted in the highest grain yield.

Among inorganic treatments, the lowest N/Fe ratio was recorded in F_1 treatment. The F_2, F_3 and F_4 treatment recorded a stepwise increase in the N/Fe ratio. It is to be mentioned that the yield also followed an increasing trend with the increasing N/Fe ratio.

The highest P/Fe and K/Fe ratio was recorded in green manure + CaO + ash treatment. The lowest was recorded in fallow-poultry manure treatment. Among inorganic treatments, the lowest and highest P/Fe and K/Fe ratios were observed in F_1 and F_4 treatments, respectively, whereas F_2 and F_3 treatments were of intermediate ratios. No noticeable variations were observed in the ratios of N/K, N/Mg, P/N, P/K, P/Mg, K/N, K/Mg and Ca + Mg/K.

Table 4.37. Correlation of yield attributes with yield

Characters	Productive tillers	No. of spikelets/ panicle	% of filled grains	Test weight	Yield
Productive tillers	1.000				
No. of spikelets/ panicle	0.842**	1.000			
% of filled grains	-0.074	0.020	1.000		
Test weight	0.742**	0.699**	0.036*	1.0000	
Yield	0.931*	0.923*	0.010	0.784*	1.000

* Significant at 5% level
** Significant at 1% level

Table 4.38. Correlation co-efficient of plant nutrients (%) at panicle initiation stage with tillers, productive tillers and yield

Nutrient content (%)	Tillers	Productive tillers	Grain yield	Straw yield
N	0.108	0.633**	0.738**	0.644**
P	0.275**	0.832**	0.863**	0.805**
K	0.117	0.758**	0.825**	0.784**
Ca	-0.274**	0.195	0.351**	0.265**
Mg	0.306**	-0.189	-0.324**	-0.289**
Fe	0.351**	-0.312**	-0.364**	-0.339**
S	0.060	0.246*	0.363**	0.308**

Table 4.39. Correlation co-efficient between content of different nutrients in straw as well as with grain yield

	N	P	K	Ca	Mg	Fe	S	Yield
N	1.000							
P	0.088	1.000						
K	0.513**	0.178	1.000					
Ca	0.211*	0.611**	0.330**	1.000				
Mg	-0.556**	0.043	-0.106	0.326**	1.000			
Fe	-0.560**	0.005	-0.382**	0.051	0.331**	1.000		
S	0.161	0.086	0.216*	0.228*	0.009	-0.098	1.000	
Grain yield	0.475**	0.494**	0.456**	0.694**	0.333**	-0.191	0.363**	1.000
Straw yield	0.439**	0.319**	0.410**	0.624**	0.310**	-0.219	0.308**	1.000

* Significant at 5% level
** Significant at 1% level

Table 4.40. Effect of treatments on the nutrient ratios of rice plant at PI stage

Treatment	N/P	N/K	N/Ca	N/ Mg	N/Fe	P/N	P/K	P/Ca	P/Mg	P/Fe	K/N	K/P	K/Ca	K/ Mg	K/Fe	Ca+ Mg/K
GM	2.91	0.50	9.79	5.71	5.04	0.34	0.17	3.36	1.96	1.73	1.99	5.79	19.4	11.3	10.0	0.14
GM + CaO	3.24	0.52	9.73	5.62	6.55	0.30	0.16	3.00	1.69	2.02	1.93	6.27	18.8	10.8	12.6	0.15
GM + CaO + Ash	3.19	0.52	12.50	5.77	6.64	0.31	0.16	3.92	1.77	2.08	1.93	6.15	24.1	11.1	12.8	0.13
Fallow	3.40	0.47	8.50	4.58	5.38	0.29	0.14	2.50	1.35	1.58	2.11	7.17	18.0	9.7	11.4	0.16
Fallow - GLM	3.21	0.52	7.26	5.75	6.24	0.31	0.16	2.26	1.79	1.33	1.91	6.14	13.9	11.0	8.2	0.16
Fallow - Ps	3.11	0.42	10.18	4.31	4.27	0.32	0.14	3.27	1.38	1.13	2.37	7.36	24.1	10.2	8.3	0.14
Fallow - Cd	3.55	0.44	8.36	4.50	6.96	0.28	0.13	2.36	1.27	1.96	2.26	8.00	18.9	10.2	15.7	0.15
Fallow - Pm	4.26	0.56	9.31	5.52	4.04	0.23	0.13	2.19	1.30	0.95	1.79	7.60	16.6	9.9	7.2	0.16
CD (0.05)	1.00	0.33 (NS)	1.00	1.00 (NS)	0.48	1.00 (NS)	0.33 (NS)	1.00	1.00 (NS)	0.48	3.00 (NS)	1.00	3.00	3.00 (NS)	1.4	0.67 (NS)
F_1	3.14	0.46	8.92	4.30	3.07	0.32	0.15	2.85	1.37	0.99	2.17	6.81	18.4	9.3	6.6	0.16
F_2	3.45	0.49	11.91	5.04	4.60	0.29	0.14	3.45	1.46	1.33	2.03	7.00	24.2	10.2	9.3	0.14
F_3	3.26	0.50	8.56	5.27	6.23	0.16	0.15	2.63	1.62	1.91	2.00	6.52	17.1	10.5	12.5	0.15
F_4	3.43	0.53	8.39	6.57	12.90	0.29	0.15	2.44	1.91	3.76	1.89	6.79	15.8	12.4	24.4	0.14
CD (0.05)	1.00 (NS)	1.00 (NS)	1.00	1.00	0.71	1.00 (NS)	1.00 (NS)	1.00	1.00 (NS)	0.71	1.00	1.00	1.00	1.00	0.70	2.00 (NS)

Discussion

5. DISCUSSION

Yield expression can be defined as the net product of interaction between the environment and the plant. Since nutrient availability is a major factor controlling biomass productivity, understanding the processes contributing to nutrient exchanges in the soil and arriving at an optimum integration of organic and inorganic nutrient sources become necessary in improving growth and yield of rice. Balanced application of organic manures in combination with chemical fertilizers is important for improving soil organic carbon and nutrient contents and maintaining soil health and productivity which are prerequisites for better plant growth. This approach could be realized to a great extent by manipulating the amount of one or more nutrients added and increasing the efficiency of fertilizer applied by more efficient management and precise application. Practices like application of organic manures of plant and animal origin and proper crop rotation with nutrient fixing crops may result in achieving higher crop productivity.

Long term experiments have shown that neither organic source nor mineral fertilizers alone can achieve sustainability in crop production. Productivity can be definitely raised through an integrated use of both organic and inorganic sources of nutrients which would be perhaps due to correction of stresses on one side and creating favourable physical and chemical conditions of the soil on the other. Appropriate amelioration becomes very much important in nutrient management system of rice culture. Laterite soils with its inherent negative influences on availability, dynamics and metabolism of nutrient elements in the rhizosphere and within the plant demands preventive and curative measures to result in better rice growth and yield.

The present study has specific objectives to characterise and quantify the effects of organic sources on nutrient supply, amelioration and inactivation of the deleterious factors in rice culture, to study the supplementary requirements of inputs and its complementary effects on yield improvement and also intended to develop a technology by integrating various inputs and their levels to ensure higher resource use efficiency and consequently higher productivity. The results of the study have been discussed in the context of plant growth and physiological characters, yield attributes and yield, elemental composition of plants and their uptake, and soil nutrient characters to facilitate formation of integrated production technology in rice culture.

5.1 PLANT GROWTH AND PHYSIOLOGICAL CHARACTERS

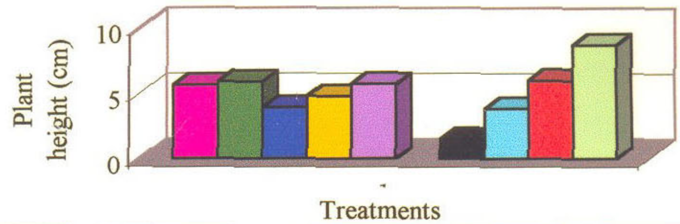
Increase in plant height is a direct expression of plant growth, which is highly related to the nutrient availability in soil, particularly during initial plant growth nutrient taken up by the plant. Though the difference in plant height at active tillering stage was less, the same at panicle initiation and 50 per cent flowering was spectacular. The height of the crop that followed a previous fallow was significantly lower than the treatment that followed a green manure crop. The adding of ameliorants such as CaO and ash further improved the growth in terms of plant height. The treatments, previous fallow followed by various organic manures also have resulted in higher plant height than non addition of organic manures. Fallow-paddy straw treatments also resulted in a similar lower height as that of previous fallow treatment.

Analysis of the influence of various inorganic treatments F_1 to F_4 (Fig. 3) shows a stepwise increased in response by the crop to each added component such as doubling of K application, further addition of CaO and ash, and the change of N source to NH_4SO_4 *i.e.* the addition of sulfur component. The highest plant height was resulted by the treatment *viz.* application of NH_4SO_4 + half P + CaO + ash. Another observation to be noted that the kind of height difference was observed at later stages *viz.* panicle initiation or 50 per cent flowering and not during the initial stage where the plant height was relatively less in F_3 and F_4 than F_1.

Tiller production and total dry matter production were the other growth parameters (Table 4.2 and 4.3) observed to understand the response of the treatments. A very similar trend of response of treatments as in the case of plant height was observed for these parameters also (Fig. 4 & 5). However the tiller decline from the one observed at panicle initiation stage to that of 50 per cent flowering was highest with 34.3 per cent for the fallow-poultry manure treatment.

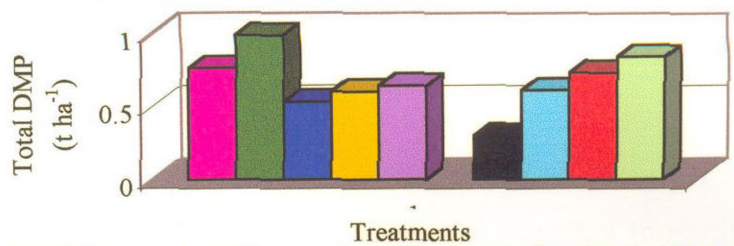
A detailed analysis of the data brings out the point that keeping the land idle as a fallow between the *mundakan* and *virippu* season is detrimental for a good paddy crop in laterite soil. However, under such situation incorporation of adequate green leaf manure or organic manure may improve the situation. Raising of green manure with application of CaO and ash at 300 kg each per hectare was proved very good in laterite soil to give good rice growth. Low growth and productivity of rice in fallow-rice system was attributed to very low ammonium content in soil by John (1987). During fallow period there can be natural oxidation of Fe, Mn and Al and the excess presence, availability and absorption of these elements result in inhibited metabolism within the plant and affect growth and development. Incorporation of paddy straw before *virippu* crop also has resulted in reduced growth of plants. Though paddy straw incorporation is a widely recommended practice, the above observation caution the use of paddy straw in laterites chracterised by low organic matter and nutrient status particularly N. Though the crop can benefit by silicon, K availability etc., straw incorporation without addition of adequate N can result in considerable immobilization of available N and other nutrients which may reduce the initial rice growth as observed in this experiment. Singh (1992) reported that incorporation of 5 t paddy straw has resulted in reduced growth of rice. However, Mathew (2002) has observed kharif straw incorporation at 5 t ha^{-1} together with 20 kg N ha^{-1} has increased the growth and yield of rice in laterite soil.

The supply of ameliorants such as lime and ash both during green manure crop and rice might have benefited the external nutritional environment and the plant. Ash with its high content of Si and K and CaO with its capability for correcting soil acidity which is the predominant barrier for yield were able to improve the growth of plants.



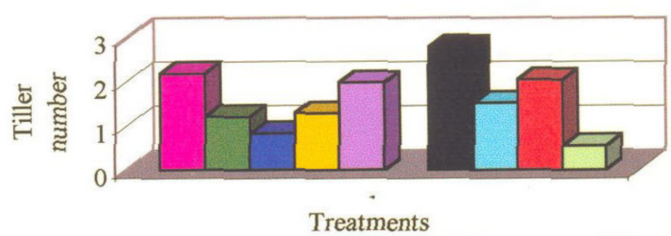
GM	Fallow - GLM
Fallow - paddy straw	Fallow - cowdung
Fallow - poultry manure	
F1	F2
F3	F4

Fig. 3. Increase in plant height in the organic and inorganic treatments over fallow at panicle initiation



GM	Fallow - GLM
Fallow - paddy straw	Fallow - cowdung
Fallow - poultry manure	
F1	F2
F3	F4

Fig. 4. Increase in total DMP in the organic and inorganic treatments over fallow at panicle initiation



GM	Fallow - GLM
Fallow - paddy straw	Fallow - cowdung
Fallow - poultry manure	
F1	F2
F3	F4

Fig. 5. Increase in tiller number in the organic and inorganic treatments over fallow at panicle initiation

The production of more vegetative tillers need not be complementary to enhance the rice yields. The availability and absorption of nutrients particularly N is known to favour tiller production (Tisdale *et al.*, 1997). However an unbalanced accumulation of these elements in plants may result in increased tiller decline and consequently lower number of panicle bearing tillers and reduced yields. The higher rate of tiller decline have been reported to be to exclude excess Fe in the plant, though the plant is forced to shed N, P and K in this process (Mustafa, 1995). Increased application of potassium has also found to increase tiller production reported by Mishra (1980). The dry matter production at different growth stages also has been found higher in the treatment combinations of green manure + CaO + ash x N as NH_4 SO_4, Half P, CaO + ash and double dose of K. This is quite expected since the plant height and tiller production was highest in this treatment.

Various physiological observations such as cell sap pH and chlorophyll content of the leaves were most favourable in this treatment to result in the highest yield. The higher chlorophyll content in the leaves need not result in higher yield but the vegetative growth. Grain yield is a product of post flowering photosynthate accumulation supplemented by translocation in earlier growth which is not a chlorophyll function, most important is the balanced availability and metabolism of the elements within the plant.

The change in the chlorophyll content from panicle initiation to 50 per cent flowering showed a general tendency towards decline in chlorophyll 'a' and increase in chlorophyll 'b' as well as total chlorophyll in those treatments which resulted in higher vegetative growth. As chlorophyll 'a' is a precurser of chlorophyll 'b', the decline in the conversion of chlorophyll 'a' to chlorophyll 'b' in those treatments that resulted in relatively lesser plant growth is indicative of instability of chlorophyll 'a' which is probably due to the stress created by nutrient excesses or deficiency. Comparatively low interrelation of chlorophyll 'a', the actual photosynthetic pigment with the plant dry matter production would seem to be due to a stress effect. In this experiment a favourable chlorophyll 'a' and 'b' contents at all the stages of observation were recorded in the treatment where there was green leaf manure component together with addition of sulphur, CaO, ash and doubling of K which means that an ideal nutritional environment was created by this particular treatment. Higher chlorophyll content, higher number of effective tillers and high dry matter production were possible only under this combination.

Leaf cell sap pH is considered as a physiological index of crop productivity. Marykutty *et al.* (1999) observed that a pH of 6.21 was optimum for maximum productivity. A cell sap pH near to this was observed only in those treatments where lime, the common ameliorant for acid soils was received. The addition of green manure component was found to make the cell sap pH further favourable. The treatments with a previous fallow without the ameliorants were found to result the cell sap pH between 4 and 5.2 and consequently the plant growth was poor. A cell sap pH of 6.21 at panicle initiation stage was observed in the treatment of green manure + CaO + ash x N as NH_4 SO_4, Half P, CaO + ash + double dose of K, (Table 4.5) which resulted in the best growth and yield of rice.

5.2 YIELD ATTRIBUTES AND YIELD

The rice grain yield is a product of number of panicle per m^2, number of grains per panicle, percentage of filled grains and 1000 grain weight, each of these characters can be influenced by various processes consequently resulting in the yield variations.

Absence of integration among the yield components would appear to be the cause of low realized productivity. A higher productive tiller count and spikelet number is suggestive of a favourable nutritional environment, particularly during panicle initiation stage. De Datta (1981) has reported that any nutritional stress at this stage can influence these yield components and reduce the yield mainly by way of reduction in the spikelet number. The highest number of productive tillers (6.48) and spikelet number (76.48) obtained in green manure + CaO + ash treatment as against 4.61 and 54.75, respectively in the previous fallow treatment clearly shows the merit of this treatment over previous fallow (Fig. 6). In general the number of productive tillers has been found to be low even with the application of various ameliorants in order to change the nutritional environment. It is to be assumed that an expected improvement in the number of productive tillers is not achieved with the various treatments tried and this still remains as a constraint for higher productivity in laterite soil.

The correlation studies as reported in Table 4.39 shows significant positive correlation for spikelets per panicle, productive tillers and test weight with yield. However, near independence of the yield component from one another can only be the result of lack of co-ordination in the yield process. The percentage filled grains did not show the positive influence on the yield and is indicative of some suppressing influence at the later stages, which is suggestive of reduced photosynthesis and translocation in later stages. Progressive decline in chlorophyll and unfavourable cell sap pH appeared to be the prime cause for this.

5.2.1 Yield improvement over the previous season

The yield of the *mundakan* crop raised with the package of practices recommendation was 2.36 t ha^{-1}. Noticeable variations were caused by the various treatments imposed during the *virippu* season as seen from Table 5.1 and Fig. 7. A reduction in the yield level was seen with the fallow x F_1 and F_2 and fallow- paddy straw x F_1 and F_2. The yield level was just maintained or slightly improved in the fallow x F_3 and F_4 and fallow-paddy straw x F_3 and F_4. The treatments F_3 and F_4 differed with F_1 and F_2 in case of the addition of lime and ash and sulphur. Hence, it is to be assumed that these additions have improved the yield considerably. A close analysis will show that the doubling of K dose also has increased the yield irrespective of the main plot treatment.

Among the main plot treatments, inclusion of green manure component has increased the yield considerably, but with the addition of lime and ash during green manuring also has resulted in considerable yield increase. Green manuring with lime and ash has resulted in 3.5 t ha^{-1} yield increase when both these treatments were

Table 5.1. Yield improvement of virippu rice compared to mundakan rice (t ha^{-1})

Treatments	Grain	Straw
GM+F_1	0.51	0.77
GM+F_2	1.19	1.00
GM+F_3	2.03	1.46
GM+F_4	2.18	1.80
GM + CaO+F_1	1.71	1.32
GM + CaO+F_2	2.25	2.22
GM + CaO+F_3	2.74	2.38
GM + CaO+F_4	3.06	2.60
GM + CaO + Ash+F_1	2.19	2.14
GM + CaO + Ash+F_2	2.73	2.54
GM + CaO + Ash+F_3	3.07	2.67
GM + CaO + Ash+F_4	3.68	3.28
Fallow+F_1	-0.61	-0.82
Fallow+F_2	-0.34	-073
Fallow+F_3	0.08	-0.21
Fallow+F_4	0.18	-0.15
Fallow - GLM+F_1	0.70	0.31
Fallow - GLM+F_2	1.19	0.80
Fallow - GLM+F_3	2.08	1.67
Fallow - GLM+F_4	2.52	2.16
Fallow - paddy straw+F_1	-0.20	0.00
Fallow - paddy straw+F_2	-0.01	0.06
Fallow - paddy straw+F_3	0.26	0.22
Fallow - paddy straw+F_4	0.62	0.50
Fallow - cowdung+F_1	-0.18	-0.12
Fallow - cowdung+F_2	0.18	0.13
Fallow - cowdung+F_3	0.27	0.09
Fallow - cowdung+F_4	1.17	1.04
Fallow - poultry manure+F_1	0.19	0.05
Fallow - poultry manure+F_2	0.47	0.36
Fallow - poultry manure+F_3	0.69	0.18
Fallow - poultry manure+F_4	1.07	0.56

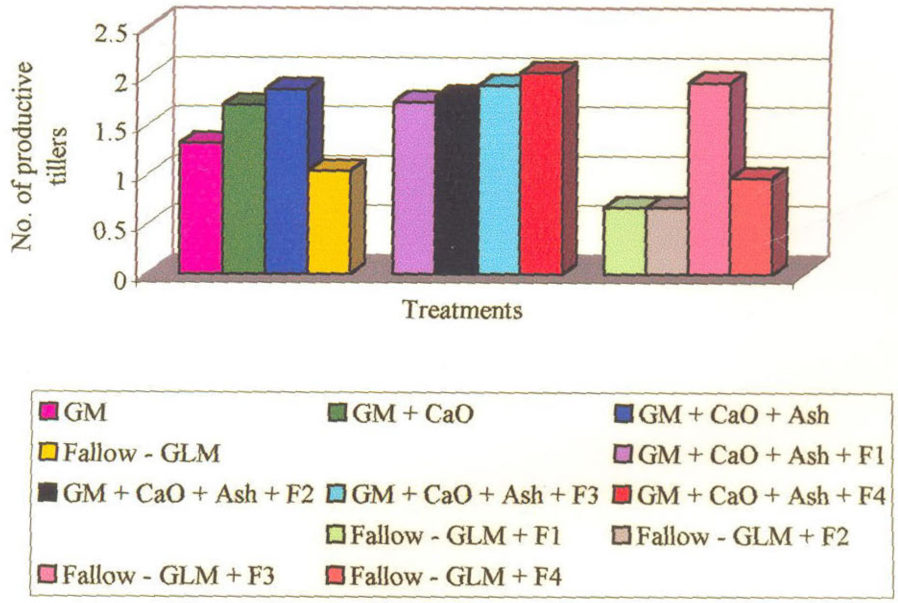


Fig. 6. Increase in productive tillers in the organic treatments and their combinations with ameliorants over fallow

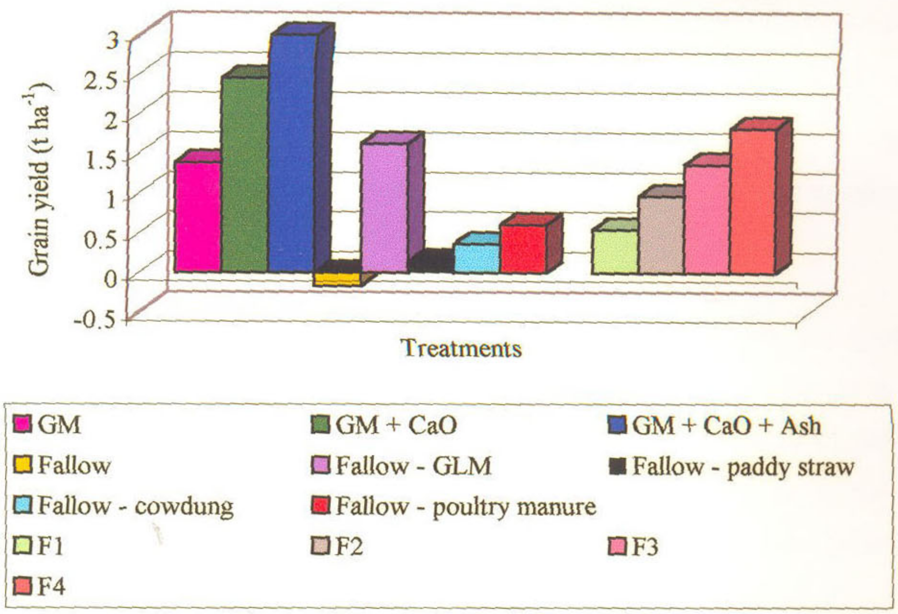


Fig. 7. Influence of nutrient sources on improvement of grain yield compared with *Mundakan*

applied in combination with F_4. This shows that a two time application of lime and ash both during green manuring and during rice crop has definite advantage over a previous fallow in laterite soil. The nutritional advantages of the inclusion of these components will be discussed in the coming sections. Fallow followed by paddy straw has not favoured the nutritional environment and consequently resulted in lesser yield. The cowdung or poultry manure application in the previous fallow plot also were not comparable with the yield advantage obtained when green leaf manure was incorporated in the rice crop preceded by a fallow season.

5.3 PLANT ELEMENTAL COMPOSITION AND UPTAKE

The elemental composition of plant is indicative of the amount of available nutrient in soil and the ability of the plant to absorb nutrients, however the absorption may be influenced by the presence of other native or applied elements in the soil due to their excesses or deficiencies.

The yield improvement realised from any nutrient need not be necessarily due to increased content but the product of the changed interaction among the elements. Any nutritional input brings about variation in the content of all the elements in plant systems, which suggested that the plant content of element is a product of interaction. Fertility management therefore would mean not merely making up the deficiency of any element through its addition but should ensure combination of elements.

Nitrogen is the premier element, which is responsible for growth and development of the plant. The N content of the plant is consistently lower at different stages than the critical limits reported for optimum growth and yield in the previous fallow treatment or in the previous fallow-paddy straw treatment or in the previous fallow-cowdung treatment. The wider C:N ratio and consequent low mineralisation and immobilization of the available N might have resulted in lower available mineral N and consequently low N content. The green manure component was successful in maintaining optimum plant N content. The stepwise addition of lime, ash and sulphur has resulted in the increase of N content consequently due to the increased root and shoot growth and greater absorption of N.

The higher N content associated with less yield in certain treatment implied that the plant has failed metabolically to utilize the higher quantity of N absorbed by them. Ameliorative management can ensure the balanced availability of other nutrients. Musthafa and Potty (1996) has reported enhancement of application of K in laterite soil has increased grain N content. Reuler *et al.* (1996) reported that ash application significantly increased uptake of N probably due to higher K content in ash.

Though P is not included as a treatment in this experiment based on the previous studies the dose has been reduced to half of the normal recommended dose, which amounts to 22.5 kg ha^{-1}. A six tonne crop does not require more than 20 kg P ha^{-1} based on the P uptake value. Increasing P level in the plant also tilts Fe and Mn balance unfavourably. Laterite soil with inherent capacity for heavy P fixation is having available P only in the less than optimum quantity. However adding organic components has resulted in enhanced P mineralization and the P content was more than the critical limits, however the content was lower in the previous fallow, or fallow-paddy straw or fallow-cowdung due to less mineralization. The production of organic acid during the decomposition can enhance the mineralisation and soil P and improve the availability and uptake of P.

Enhancing K level was found to facilitate a better nutritional environment by reducing Fe and Mn content in the plant and consequently generated a favourable N/Fe, N/Mn and K/Fe balance in the plant. Relatively wider N/Fe ratios are observed (Table 4.40) for the treatment which resulted in higher growth and productivity. The F_4 treatment has resulted in a 12.90 N/Fe ratio against a 3.07 in F_1 treatment which shows the importance of addition of ameliorants and nutrient supplying inputs like lime and ash and including the sulphur component in the fertilization programme. De Datta(1981) has stressed the importance for maintenance of favourable nitrogen-potassium balance in order to reduce the ill effects of Fe in acid soils.

Doubling of K from the F_2, F_3 and F_4 treatments has helped in the availability of potassium in the soil and enhanced the K content. Just like N the concentration of K in rice plants was significantly less in previous fallow with the combination of F_1 treatment both at PI and 50 per cent flowering. All other treatments have contributed sufficient quantity of K into soil solution either directly or by mineralization.

Mathew (2002) has reported that K content in plant decreased with straw incorporation and attributed the reason to the formation of potassium silicate in plant as reported by Islam and Saha (1969). Though there was the possibility for such a mechanism in the case of the treatment where ash or paddy straw, which have the capacity to release large quantity of silica, has been incorporated a reduced K content in plant parts were not observed in this experiment.

A perusal of the data in 4.15 about calcium content in plant and the correlation of Ca to the growth parameters and yield and with various nutrient content shows that the lime application was not responsible for improving its content in plants but modifying the rhizosphere environment and influencing the availability and uptake of other nutrients. Thus calcium application has positively influenced the uptake of N, P, K, Mg and sulphur and ultimately the grain yield. Similar observations were reported by Aulakh and Dev (1978) and Bridgit (1999).

The Fe content was considerably reduced in the treatments where lime was applied. When K application was doubled then also similar effect was observed (Fig. 8 & 9). The ameliorating effect of lime has improved the soil pH and EC (Table 4.26 & 4.27 and Fig. 10 & 11) and resulted in lesser solubility of ferrous iron and consequently lower uptake of Fe.

The antagonistic effect of Fe and K was evident from the observations of reduction in the elemental plant Fe content when the K levels were increased. Singh and Singh (1979) has made a similar observation that the ferrous iron concentration has drastically reduced by increased K application due to K-Fe antagonism. Chang and Houng (1981) has reported about the antagonistic action between potassium and iron. The excessive concentration of ferrous iron in the soil solution will under certain

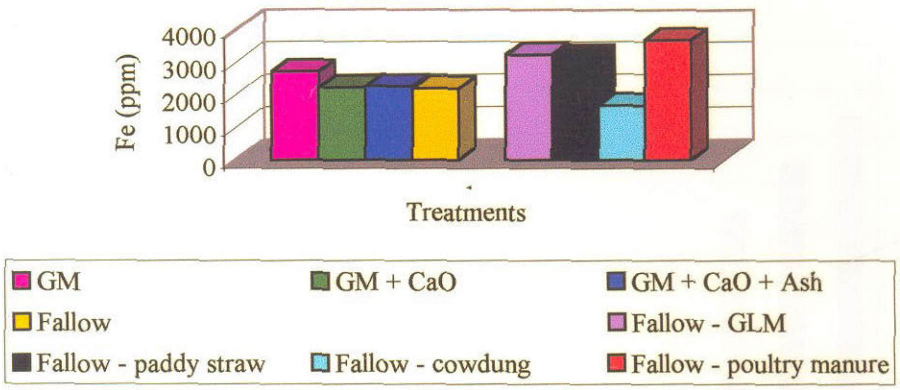


Fig. 8. Influence of nutrient sources on Fe at panicle initiation stage

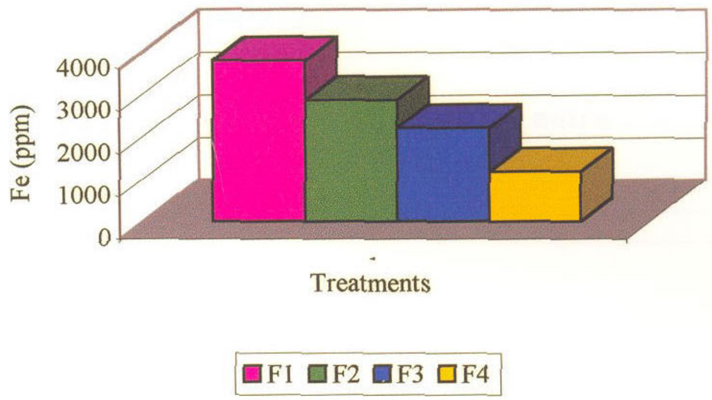


Fig. 9. Influence of inorganic sources on Fe at panicle initiation stage

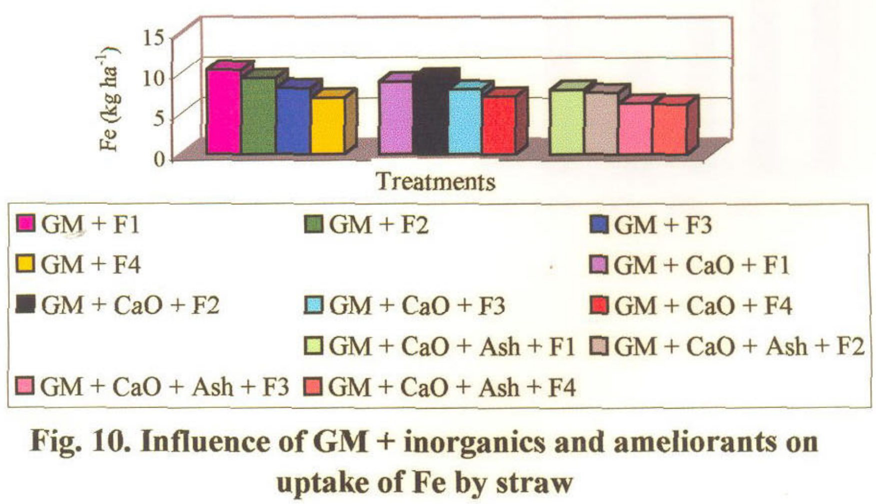
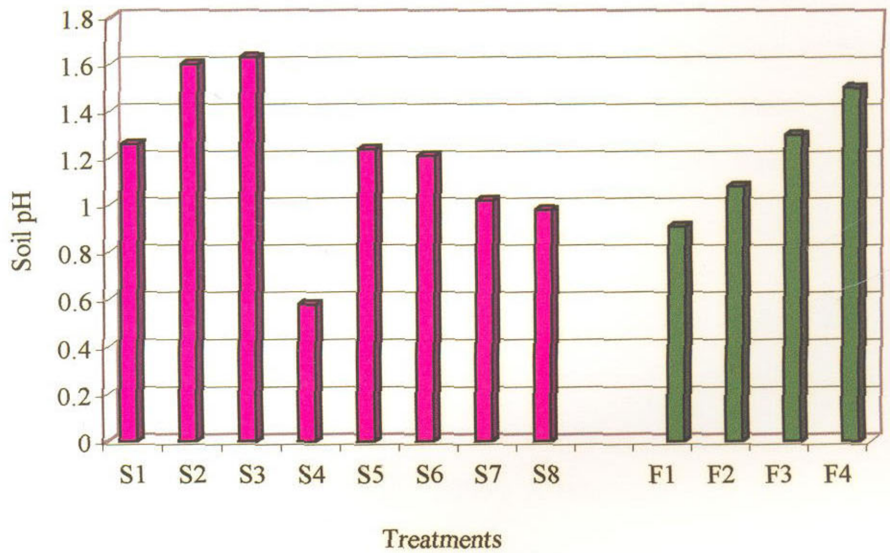
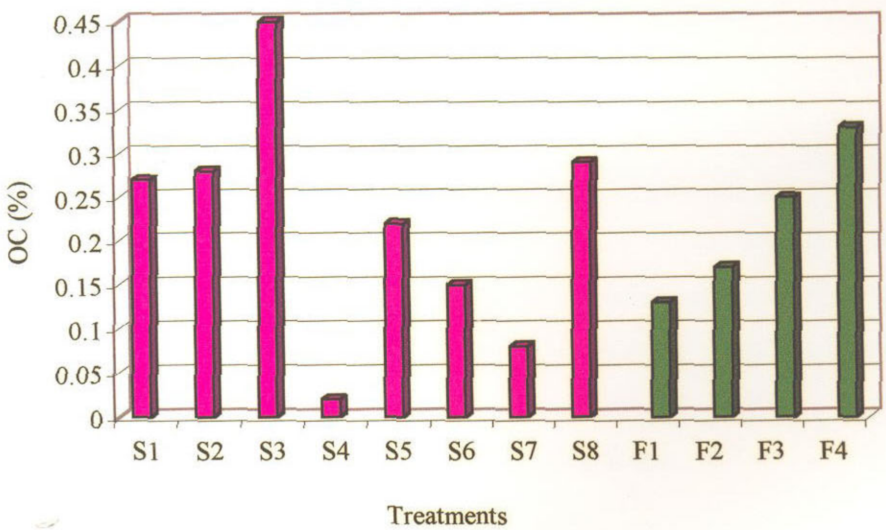


Fig. 10. Influence of GM + inorganics and ameliorants on uptake of Fe by straw



Initial value 4.1

Fig. 11. Changes of soil pH influenced by nutrient sources



Initial value 0.52

Fig. 12. Changes of soil organic carbon influenced by nutrient sources

conditions combine with the potassium salts in the soil to form sparingly soluble double salts containing K_2SO_4 and $FeSO_4$ in various proportion and thus decrease the availability of K. In laterite, when iron concentration is higher the same mechanism can be operated and the amount of K as well as iron can be decreased. Additional quantities of K application thus become a necessity in laterite soil to reduce the iron uptake and increased K uptake.

Addition of ash twice during the green manuring as well as during rice crop might have released considerable quantity of K and silica to the soil solution. Laterite soils by its definition are deficient in silica and physical unavailability of this element is a major factor for low yield (Bridgit, 1999). A rice crop with about 10 t dry matter production at harvest may remove approximately one tonne of silica. (De Dattta, 1981). Plants not deficient in silica remains free of pest and diseases and imparts resistance to the plant and hence silica performs a protective function and reduce the gap between realized and realizable yield.

5.5 SOIL PROPERTIES

A perusal of the data on soil pH shows that the pH during cropping in the previous fallow treatment was quite unfavourable. A pH higher than 5 was observed only with the previous fallow x F_4 combination. However in the treatment Green manure + ash + CaO x F_4, the pH was more or less optimum for good rice growth. De Datta (1981) has reported that a slightly acidic to neutral soil is the best with regard to the availability of plant nutrients and hence an increased growth, development and productivity of the crop. The neutralizing behaviour of lime, supplementation of bases by ash and influence of K on the lowering of available Fe might have benefited the crop during the process of maintaining an optimum soil pH.

The Eh is an important chemical property which regulates available P and Fe in the soil. Ponnamperuma (1980) has reported that an Eh around 150 mv is optimum for flooded rice. Available plant Fe usually increase with a decrease in Eh. In the Table 4.27 it is seen that in the previous fallow plot, the Eh was 119 mv which is the lowest among all the treatments and this treatment resulted in low growth rate, low dry matter accumulation at vegetative stage and lowest straw and grain yield. The narrow N/Fe ratio at panicle initiation stage compared to the green manuring or green manuring + ameliorant treatment throws light to the reasons for low yield level.

Soil organic matter is the key to soil fertility and productivity. The organic carbon content of the soil is the best index of soil fertility. In the previous fallow treatment, the organic carbon content was as low as 0.46 per cent which was increased by addition of organic manures. The improvement in the organic carbon content subsequently improved the yield level which indicates the relationship between organic carbon content of the soil and crop productivity.

5.6 EFFICIENCY OF ORGANICS

The effectiveness of particular input can be evaluated by measuring the ratio of grain yield to the N accumulation in the material. The use efficiency of N in the various organic manures is estimated in terms of agronomic, physiological and uptake efficiency. Though the use efficiency observed for the cowdung was highest it did not result in higher productivity. The green manure with the agronomic efficiency of 14.09 resulted in the highest yield and was characterized by the highest physiological efficiency and uptake efficiency (Fig. 13). Physiological efficiency is the ratio of grain yield to the N absorbed and it is a function of distribution of N in the plant at harvest and per cent N in grain. The ratio of N absorbed to the N applied is termed as uptake efficiency and is a function of proportion of root surface area, and distribution and uptake per unit area. These factors are dependent upon soil physical and chemical status, and health and growth characteristics of the plant (Mikkelson, 1987). Hence, it is to be assumed that a very favourable soil nutritional environment was available with the incorporation of green manure where both physiological efficiency and uptake efficiency were greater resulting in a reasonably higher agronomic efficiency.

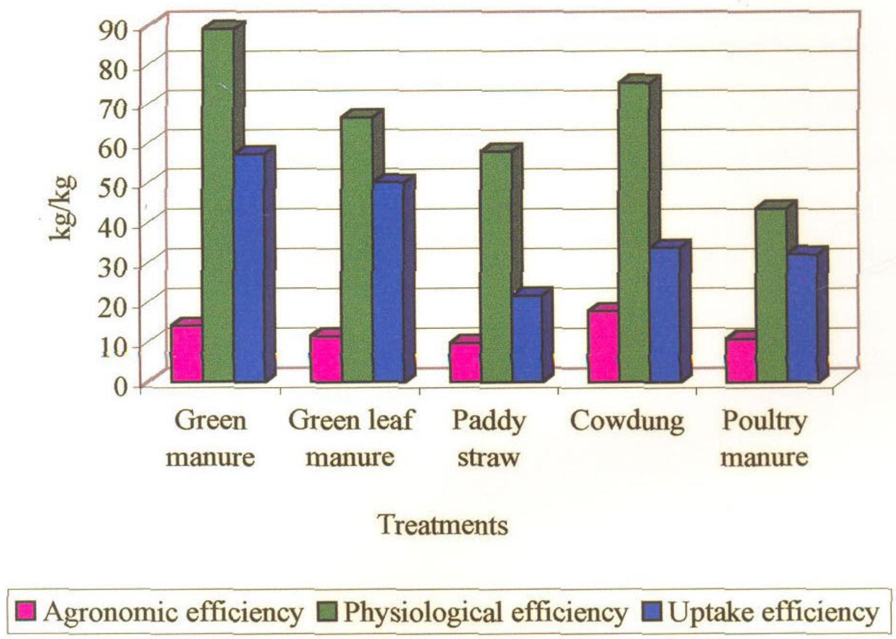


Fig. 13. Use efficiencies of various organic manures

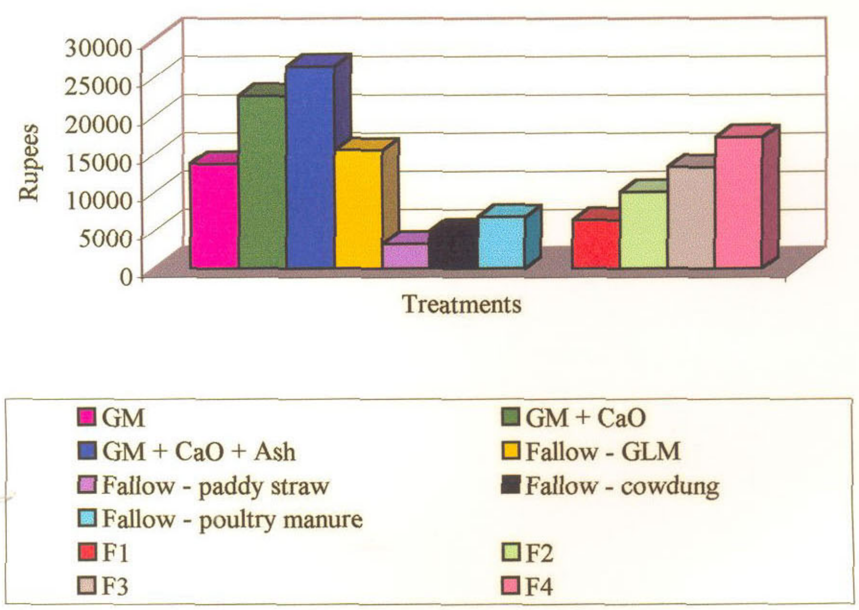


Fig. 14. Increase in income from different treatments over fallow

5.7 BENEFIT COST ANALYSIS

When compared to the treatment fallow-rice, significant increase in the net income was observed with the rice crop, which were given various organic or inorganic treatments. A change in the N source from urea to ammonium sulfate resulted in the supplementation of sulfur, which resulted in considerable yield income and consequently higher net income. Similarly enhancement of N:R ratio and addition of ameliorants also enhanced the yield and consequently the BC ratio.

Summary and Conclusion

6. SUMMARY AND CONCLUSION

A field experiment was conducted at Agricultural Research Station, Mannuthy during 2001-2002, to characterize and quantify the effect of organic sources on nutrient supply, amelioration and inactivation of the deleterious factors in rice culture and to study the supplementary requirements of inputs and complementary effects on yield improvement. It was also intended to develop a technology by integrating various inputs and their levels to ensure high resources use efficiency and consequently high productivity.

The experiment was laid out in split plot design with three replications. Different sources of organic manure *viz.*, green manure, green leaf manure, paddy straw, cowdung and poultry manure, and fallow constituted the main plot treatments. Two sources of nitrogen *viz.*, urea and ammonium sulphate and two levels of potash *viz.*, 45 and 90 kg K_2O ha^{-1} along with ameliorants of lime and ash constituted the sub plot treatment. A medium duration high yielding Aiswarya was the test variety.

Analysis of the biometric observations revealed that the plant height at active tillering stage was the highest in the green manure alone treatment compared to green manure with ameliorants *viz.*, lime alone or lime and ash. This difference in plant height was leveled off towards panicle initiation. At 50 per cent flowering, the effect of ameliorants was evident and the highest plant height was observed for the treatment green manure + lime + ash. Previous fallow plot recorded the lowest plant height at all the stages. Among the organic manures added to the previous fallow treatment, poultry manure recorded the highest plant height at 50 per cent flowering.

With regard to the tiller production, the treatment green manure + lime + ash recorded the highest number of tillers at active tillering, panicle initiation and 50 per cent flowering. The poultry manure added to the previous fallow treatment resulted in the highest tiller decline of 34.3 per cent, the same was lowest in green manuring treatment. The total dry matter production was the highest in the green

A favourable soil pH and EC reported for higher crop growth and yield was maintained in the treatment combination of green manure + lime + ash x F_4 and this positively influenced the nutrient absorption by the plant as indicated by the plant elemental composition. In the rice crop which followed a previous fallow, these parameters were quite unfavourable for attaining the higher productivity.

The highest soil organic carbon content was recorded in green manure + lime and ash x N as NH_4SO_4+ half P+ lime+ ash + double K treatment both during and after harvest of the crop.

The available N after the harvest was highest in the treatment of green manure + lime + ash indicating a sustained fertility of soil. However, the P and K levels were moderate indicating a higher uptake of P and K corresponding with the higher crop productivity and enhanced uptake in this treatment.

A higher residual K was observed in the treatment fallow – paddy straw and fallow – cowdung probably due to the lower removal of this element by the crop during crop growth and consequent less dry matter production. The available soil S, Fe and Mn recorded the highest content in the fallow – green leaf manure with N as NH_4SO_4, half P, lime, ash and double dose of K both during and after harvest of the crop.

The physiological and uptake efficiency of the N derived from green manuring was higher compared to other organic sources and consequently resulted in better agronomic efficiency.

The treatment combination of green manure + lime + ash x F_4 recorded the highest benefit cost ratio of 2.25. The lowest benefit cost ratio was observed in the previous fallow x F_1 treatment combination.

The following conclusions were drawn from the results of the experiment.

In the *mundakan – summer – virippu* rice cropping system in laterite soil leaving the land fallow during *summer* may considerably reduce the yield during *virippu* if not supplemented with adequate organic manure and ameliorants like lime and ash.

If the summer season is kept fallow, green leaf manuring could be a better substitute for addition of organic matter to the laterite soil.

Paddy straw incorporation at 15 days before *virippu* crop in laterite soil was found to reduce the yield of *virippu* rice probably due to high rate of immobilization of N.

The increase in acidity and consequent higher solubilization and uptake of Fe in *virippu* crop was evidently due to summer fallow which favour natural oxidation of Fe and Mn.

Ameliorants like lime and ash added both during summer green manuring and *virippu* rice crop enhanced the rice growth and yield through modification of pH, supplementation of potash and silica.

Enhancement of N:K ratio to 1:1 was found to enhance rice productivity in laterite soil. Addition of K application did not increase the K content in the plant but reduced Fe uptake.

Changing the N source to ammonium sulphate and thereby sulphur fertilization was found to increase growth and yield of rice. Ammonium sulphate treatment helped mainly to increase plant height but not tiller production. Among yield attributes, spikelet production was very much influenced by sulphur fertilization.

The physiological and uptake efficiency of the N derived from green manuring was higher compared to other organic sources and consequently resulted in better agronomic efficiency. This indicates the need for a green manure - rice system in laterite soil to enhance soil and crop productivity.

The green manured rice with ameliorants such as lime and ash, and ammonium sulphate as N and S source resulted in the highest net return and B:C ratio of 2.25.

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*Originals not seen

Appendix

APPENDIX-I

Weather data (weekly from 01-09-2001 to 30-9-2002)

Standard week	Temperature (°C)			RH (%)		Rainfall (mm)	Sunshine (h/day)	Wind velocity (km/hr)	Evaporation mm/day
	Maximum	Minimum	Mean	Morning	Evening				
Sep. 3-9 36	31.8	23.2	27.5	97	59	2.5	8.2	3.2	4.7
Sep. 10-16 37	31.7	23.5	27.6	96	61	-	6.6	3.0	4.1
Sep. 17-23 38	30.8	23.5	27.15	88	69	10.2	4.5	3.4	4.3
Sep. 24-30 39	28.8	22.3	25.55	94	80	193.4	1.6	3.5	2.3
Oct. 1-7 40	30.1	23.1	26.60	93	72	47.6	3.6	2.9	3.3
Oct. 8-14 41	30.1	23.0	26.55	91	74	-	3.6	3.1	3.3
Oct. 15-21 42	31.0	22.8	26.90	90	70	56.2	3.2	3.2	3.1
Oct. 22-28 43	31.5	22.3	26.90	91	69	61.5	5.6	3.4	3.6
Oct. 29-Nov.4 44	31.8	23.5	27.65	90	62	11.3	7.0	2.8	3.8
Nov. 5-11 45	31.2	23.6	27.40	92	68	30.6	5.0	3.2	3.2
Nov. 12-18 46	31.4	23.2	27.30	91	67	74.3	5.0	4.1	3.3
Nov. 19-25 47	31.7	23.3	27.50	73	53	-	8.1	7.6	5.4
Nov. 26-Dec. 2 48	31.2	22.1	26.65	72	52	-	7.6	6.3	4.7
Dec. 3-9 49	31.5	22.3	26.90	72	48	-	9.4	8.8	5.5

Contd.

Appendix-I. Continued

Standard week	Temperature (°C)			RH (%)		Rainfall (mm)	Sunshine (h/day)	Wind velocity (km/hr)	Evaporation mm/day
	Maximum	Minimum	Mean	Morning	Evening				
Dec. 10-16 50	31.1	18.9	25.00	67	37	-	9.2	7.0	5.6
Dec. 17-23 51	30.9	23.2	27.05	74	53	-	7.4	12.8	6.2
Dec. 24-31 52	32.1	23.7	27.90	76	51	-	8.1	11.8	6.6
Jan.1 to 7 1	32.4	23.7	28.05	70	44	-	9.8	12.7	7.4
Jan. 8-14 2	32.5	23.0	27.75	81	44	-	9.3	11.0	6.8
Jan. 15-21 3	32.5	21.3	26.90	76	42	-	7.8	5.0	5.3
Jan.22-28 4	33.4	23.4	28.10	88	50	-	4.7	3.6	3.8
Jan. 29-Feb. 4 5	31.1	23.4	27.25	69	50	-	4.6	10.6	5.4
Feb.5-11 6	33.6	23.7	28.66	72	47	-	8.0	6.8	6.4
Feb. 12-18 7	34.8	22.8	28.80	66	32	-	9.9	7.8	6.7
Feb.19-25 8	36.1	22.2	29.15	77	28	-	10.6	7.0	7.4
Feb. 26-Mar. 4 9	37.3	21.8	29.55	76	25	-	19.1	5.0	7.0
Mar. 5-11 10	36.6	23.6	30.10	84	38	-	8.7	5.3	6.4
Mar. 12-18 11	36.6	24.2	30.40	84	36	6.2	8.4	5.4	6.0

Contd.

Appendix-I. Continued

Standard week	Temperature (°C)			RH (%)		Rainfall (mm)	Sunshine (h/day)	**Wind velocity (km/hr)**	Evaporation mm/day
	Maximum	Minimum	Mean	Morning	Evening				
Mar. 19-25 12	35.6	24.4	30.00	85	41	10.1	8.0	**5.0**	6.3
Mar. 26-April 1 13	35.4	25.6	30.50	87	49	-	6.9	**3.8**	5.4
April 2-8 14	34.6	24.6	29.60	86	53	2.2	7.9	**4.1**	4.8
April 9-15 15	35.1	24.5	29.80	85	53	5.4	8.0	**4.3**	5.3
April 16-22 16	35.2	25.4	30.30	86	57	12.2	7.6	**3.7**	4.2
April 23-29 17	35.3	24.9	30.10	85	56	31.0	7.7	**4.4**	5.4
April 30-May 6 18	34.6	24.5	29.55	85	60	54.4	6.2	**4.7**	5.0
May 7-13 19	33.7	25.3	29.50	84	60	44.2	7.7	**4.9**	4.8
May 14-20 20	30.8	24.0	27.40	93	76	173.2	3.1	**3.3**	2.7
May 21-27 21	32.2	24.2	28.20	87	67	4.0	6.9	**3.6**	3.7
May 28-June3 22	30.8	24.0	27.40	89	73	119.0	3.5	**4.2**	4.2
June 4-10 23	30.7	23.4	27.05	94	73	74.2	5.0	**4.0**	3.5
June 11-17 24	28.9	22.5	25.70	94	83	219.1	0.6	**3.7**	2.5
June 18-24 25	29.5	23.3	26.40	93	81	109.8	1.8	**4.5**	2.8

Contd.

Appendix-I. Continued

Standard week	Temperature (°C)			RH (%)		Rainfall (mm)	Sunshine (h/day)	Wind velocity (km/hr)	Evaporation mm/day
	Maximum	Minimum	Mean	Morning	Evening				
June 25-July 1 26	30.5	23.7	27.10	94	75	74.6	3.5	3.7	3.1
July 2-8 27	30.3	23.6	26.95	94	72	57.0	5.2	3.7	3.4
July 9-15 28	29.4	23.1	26.25	94	77	126.1	3.0	4.0	3.1
July 16-22 29	29.7	22.7	26.20	95	73	58.0	2.7	3.8	3.1
July 23-29 30	29.9	22.9	26.40	93	73	70.4	3.8	3.7	2.9
July 30-Aug. 5 31	28.1	22.5	25.30	95	86	83.6	0.73	4.0	2.4
Oct.6 -12 32	28.6	22.2	25.40	35	79	94.0	0.9	3.8	2.8
Aug. 13-19 33	27.9	22.8	25.35	94	83	337.0	2.6	3.7	2.1
Aug. 20-26 34	30.1	23.4	26.78	93	72	13.8	5.4	3.7	3.8
Aug. 27-Sept. 2 35	30.9	24.1	27.50	93	65	3.8	7.3	3.8	4.3
Sept. 3-9 36	29.8	23.2	26.50	94	71	98.7	5.5	3.7	3.4
Sept. 10-16 37	30.7	22.9	26.80	92	63	-	8.7	3.7	4.4
Oct. 17-23 38	31.3	22.8	27.05	91	59	-	8.3	3.6	4.3
Oct. 24-30 39	32.5	22.7	27.60	90	55	21.5	8.2	3.6	4.4

NUTRITIONAL RESOURCE USE EFFICIENCY IN RICE PRODUCTION

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ABSTRACT OF THE THESIS

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ABSTRACT

The chemical constraints for higher yields in laterite soils are identified as low cation exchange capacity and organic matter content, high acidity, iron and aluminium toxicity, high phosphorous fixation and poor nutrient status. Investigations carried out to identify the limiting factors and their mode of action in laterite soil revealed direct effect of excess iron absorption, their metabolic interference, unfavourable Ca + Mg / K ratio, and deficiency of certain elements manifested as negative effects of some others.

Management of organic manuring modified by amelioration with suitable amendments was reported to be an ideal remedial measure for reducing the above chemical constraints. An experiment was conducted at Agricultural Research Station, Mannuthy during 2001-2002, to characterize and quantify the effect of organic sources on nutrient supply, amelioration and inactivation of the deleterious factors in rice culture and to study the supplementary requirements of inputs and complementary effects on yield improvement. It was also intended to develop a technology by integrating various inputs and their levels to ensure high resource use efficiency and consequently higher productivity.

The plant height and tiller production was highest in the treatment green manure + lime + ash at active tillering, panicle initiation and 50 per cent flowering. The total dry matter production was highest in the green manuring + lime and green manuring + lime + ash treatment. All the growth parameters such as plant height, tiller count and total dry matter production showed a stepwise improvement with doubling of K, doubling of K along with addition of lime and ash, and doubling of K with addition of lime, ash and sulphur over the treatment where K was given at normal rate and without any ameliorants.

The highest chlorophyll content both 'a' and 'b' was found as resulted in the fallow – green leaf manure treatment, however, this was not reflected in the

process of yield formation since the highest yield was observed for the treatment, green manure + lime + ash. The favourable cell sap pH around 6.21 was observed in the treatment green manure + lime + ash which resulted in the highest grain and straw yield.

The highest grain and straw yield of 6.64 and 6.75 t ha^{-1}, respectively was observed in the treatment combination green manure + lime + ash x N as NH_4SO_4 + half P + lime + ash + double dose of K which indicate the importance of addition of lime, ash and sulphur as ammonium sulphate in the fertilizer package of rice in laterite soil.

The following conclusions are drawn from the results of the experiment.

In the *mundakan – summer – virippu* rice cropping system in laterite soil leaving the land fallow during *summer* may considerably reduce the yield during *virippu* if not supplemented with adequate organic manure and ameliorants like lime and ash. If the summer season is kept fallow, green leaf manuring could be a better substitute for addition of organic matter to the laterite soil.

Paddy straw incorporation at 15 days before the *virippu* cropping in laterite soil was found to reduce the yield of *virippu* rice probably due to high rate of immobilization of N.

The increase in acidity and consequent higher solubilization and uptake of Fe in *virippu* crop was evidently due to summer fallow which favour natural oxidation of Fe and Mn.

Ameliorants like lime and ash added both during summer green manuring and *virippu* rice crop enhanced the rice growth and yield through modification of pH, supplementation of potash and calcium.

Enhancement of N:K ratio to 1:1 was found to enhance rice productivity in laterite soil. Addition of K application did not increase the K content in the plant but reduced Fe uptake.

Changing the N source to ammonium sulphate and thereby sulphur fertilization was found to increase growth and yield of rice. Ammonium sulphate treatment helped mainly to increase plant height but not tiller production. Among yield attributes spikelet production was very much influenced by sulphur fertilization.

The physiological and uptake efficiency of the N derived from green manuring was higher compared to other organic sources and consequently resulted in better agronomic efficiency. This indicates the need for a green manure - rice system in laterite soil to enhance soil and crop productivity.

The green manured rice with ameliorants such as lime and ash, and ammonium sulphate as N and S source resulted in the highest net return and B:C ratio of 2.25.