Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction

By

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DECLARATION

I, hereby declare that the thesis entitled **“Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction”** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other university or society.

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Certified that the thesis entitled **"Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction"** is a record of research work done independently by **Mr. S.T. Rathish** 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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I. Introduction

Poor productivity and low nutrient use efficiency are the twin issues that characterize the rice production scenario of laterite soils of the west coast of India. Intensive weathering, heavy leaching of mineral nutrients and natural water stagnation during the crop growth period have transformed laterite rice tracts of the west coast into a special entity different form 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 constraints of laterites.

With the steadily declining area and stagnating productivity coupled with high cost of production and changing climatic conditions, the rice cultivation has become more than a challenge in Kerala. At present, area under rice in Kerala is only 2.65 lakh ha with 6.8 lakh tonnes production which meets only 20 per cent of our food grain requirement. At this juncture, it is imperative that all the technologies should be explored and judiciously applied to meet the food security of the burgeoning population.

Kerala occupies a unique place in the study of laterites since it is covering more than half of the geographical area extending over the midland of the state. Rice growth and yield in laterite soils have been reported to be poor due to the absence of response to higher levels of N and P as well as due to the excess amount of soil Fe (Potty *et al*., 1992). Bridgit and Potty (1992) have found that an excess absorption of iron interferes with chlorophyll function and its stability which in turn leads to poor yield. John *et al*. (2005) and Sheela *et al*. (2006) reported sulphur deficiency and its imbalance with nitrogen, affecting yield and quality of rice. It was seen that 70 % of the soil samples collected from different parts of four districts of Kerala *viz.,* Palakkad, Thrissur, Kollam and Thriruvanthapuram, are deficient in sulphur. Nair (1995) also reported that 56 % of the soil samples collected from alluvial soils and 83 % from brown hydromorphic soil in Kerala are sulphur deficient. The progressive increases in the productivity of crops with increasing levels of N is regulated largely by S through its direct and interactive influences with N.

India is the third largest consumer of fertilizers in the world, having a fertilizer consumption of 20.3 million tonnes (Anon, 2007). Use of these chemicals in imbalanced and indiscriminate manner has developed many problems like decline in soil organic matter, increase in salinity and sodicity, deterioration in the quality of crop produce, increase in hazardous pests and diseases, and increase in soil pollutants (Chakarborti and Singh, 2004). Continuous use of inorganic fertilizers has not only brought about loss of vital soil fauna and flora but also resulted in loss of secondary and micro nutrients.

In Kerala rice production is extensively depending on chemical fertilizers for the supply of plant nutrients with little or no application of organic manures. This is mainly due to the non availability and high cost for the application of required quantity of organic manures. Crop residues and farm yard manure are the important sources of soil organic matter vital for the sustainability of agricultural ecosystems. About 25 % of N and P, 50 % of S, and 75 % of K uptake by cereal crops is retained in crop residues, making them valuable nutrient sources (Singh, 2003). Addition of organic matter either as straw, FYM or green manures to the soil can increase soil organic matter content in rice systems.

Sulphur is recognized as the fourth major nutrient after N, P and K and it has direct and indirect roles in enhancing nitrogen use efficiency and crops productivity. Nanawathi *et al*. (1973) reported the content of chlorophyll, water soluble protein and peroxidase in rice were significantly reduced under condictions of sulphur deficiency. Information on significant negative correlation between N:S ratio and yield (Bansal, 1991), significant N × S interaction on rice grain yield (John *et al*., 2004), accumulation of non protein nitrogen in plant and produce (Tisdale *et al*., 1993) etc., necessitates more study on sulphur fertilization in rice.

With large scale shift to mechanized harvest using combine harvesters, it has become a blessing in disguise that the rice straw is inevitably incorporated in to the soil before the next crop, in major rice bowls such as Palakkad, Kole and Kuttanad in Kerala, which can boost the organic matter and nutrient supplementation. Incorporation of rice straw had negative yield effects on rice (Rao and Mikkelsen, 1976 and Verma and Bhagat, 1992) with immobilization, one of the main causes. However, long term incorporation of rice straw can increase readily mineralized organic soil nitrogen, suggesting the potential after several years for reducing fertilizer nitrogen rates for optimal rice yield (Bird *et al*., 2001 and Eagle *et al*., 2001).

In cognizance of the above facts, the present study involving a nutrient management system with the inclusion of organics, N and S fertilizers to increase the productivity of rice in laterite soils was taken up with the following objectives:

1. to investigate the pattern and factors affecting N:S interaction at varying levels of N application.

2. to evaluate the sulphur supplying capacity of organic matter with different C:N ratios .

3. to the study the of role of graded doses of sulphur and nitrogen in conjunction with different organic manure sources on the growth and yield of rice, and

4. to investigate the role of organics, N and S in regulating the inhibitory effects of Fe and Mn.

Review of Literature

II. Review of literature

The declining productivity with increasing nitrogen levels in almost all crops in several states of India has to be largely related to a relative or absolute deficiency of sulphur due to its governing role in N utilization. Chances are more for Kerala to be sub – optimal in the soil available sulphur status due to its geographical position in the humid tropical tract. The losses due to leaching and erosion are remarkably serious in this high rainfall zone, where two third of the total annual rainfall of 3000 mm is received in the SW monsoon season alone, which extends for hardly three months. The progressive increases in the productivity of crops with increasing levels of N are regulated not only by N but largely by S through its direct and interactive influences with N. It is hoped that the findings of the study will help to assess the soil crop response to sulphur and nitrogen under different organic sources towards enhancing productivity of rice in laterite soil.

2.1 Laterite soils

The term laterite was originally suggested by Buchanan (1807) as a name of highly ferruginous deposits first observed in Malabar in India. Harrassowitz (1926) followed by Martin and Doyne (1927) tried to give chemical definition on the basis of their silica/alumina molar ratio; soils with this value less than 1.33 were designated as laterite soils and those above this value as lateritic soils.

Alexander and Cady (1962) defined laterite is a highly weather material rich in secondary oxides of iron, aluminium or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. According to Venkataraman and Krishnan (1992) the developments of the soil profile and its physical and chemical composition have a significant bearing on crop performance. These were either the result of or were very greatly affected by weather. In soils of high rainfall region, there would be a large accumulation of iron oxide (indicating ferralisation). Since ferralisation and desilicification were associated with laterisation, the overall effect was the formation of a lateritic type of soil characterized by acidic reaction, low base status and presence of plinthitic gravel.

It is either hard or capable of hardening on exposure to wetting and drying. Singh (1995) found manganese toxicity in crops grown on acid and lateritic soils. According to Sehgal *et al*. (1998) red and laterite soils are acidic and have low CEC, low to moderate base saturation. Due to intensive leaching and presence of high amounts of iron and aluminium oxides, the soils show deficiency of nutrients, such as phosphorus, potassium, nitrogen causing nutrient imbalances. These soils are also associated with the toxicity of Fe and Al. Deficiency of N and K was reported in laterite soils of Karnataka (Badrinath *et al*., 1998).

According to Singh (2005) acid and lateritic soils had high available iron content and iron toxicity is common, influencing rice yield during excessive rains. Laterite and lateritic soils are formation peculiar to India and some other tropical countries with intermittently moist climate. In India they cover a total area of about 248000 km^2 (Ray and Choudari, 1980). The high rainfall and temperature conditions of Kerala state are conducive for the laterisation process leading to the development of highly weathered, leached and infertile soils. Laterite soils cover nearly 60 per cent of the total area of the state occupying the mid land and mid upland regions. Laterite and lateritic soils are the weathering products of rock in which several course of weathering and mineral transformations take place. This involved removal of bases and substantial loss of combined silica of primary minerals (Soil Survey, 2007).

2.1.1 Rice production in laterite soils

Laterite soils of the state, often referred to as middle valley laterites, occupy 235000 km^2 of the land area of the state. It accounts for more than 60 per cent of the rice soils in Kerala. The productivity of rice in laterite soils is seriously affected because of several limiting factors associated with these soils, including nutrient toxicities. The soils are inherently acidic and infertile with high phosphate fixation. Due to high rainfall during monsoons the recovery of applied N and K is very less, with a fertilizer use efficiency of 30 – 35 per cent for N and 50 – 60 per cent for K. According to Patnaik (1971), low productivity of laterite and allied soils could generally be attributed low pH, low base saturation, low available P and high P fixing capacity and toxicity of Fe and Al. Due to the lateritic nature of the soils, phosphorus and potassium nutrition of rice was adversely affected leading to the non responsiveness to P and K. Washing off cations and toxicity of soluble iron and aluminium in low lying areas added to the soil problems. Iron and Mn chlorosis in paddy due to excess available forms of iron and Mn was reported by Karim and Mohsin (1964). Santos (1966) was of the opinion that the low yields of rice in acid soils were not due to Ca deficiency; but due to decreased availability of P and toxic levels of Al and Fe. Kanwar and Grewal (1960) noticed that when soluble phosphoric acid was applied to laterite and acid soils, it becomes fixed in the soil largely as basic iron phosphates. The free sesquioxodes were responsible for 72 per cent of the P fixed in acid soils.

Bridgit and Potty (1992) reported that individually all the elements in the plant system were higher than what is required to produce a yield above 7000 kg ha^{-1} when rice was grown in laterite soils. The low yield in laterite soils therefore had been not due to deficiency of major elements, but due to excess of native elements like Fe, Mn and Zn getting absorbed into the plant and inhibiting the expression of yield. These elements were far higher than the critical level proposed by Tandon (1991). They have further found that Fe content in the root was as high as 98000 ppm and has been higher in the plant through the progressive phases. While Fe decreased steadily form culm to boot leaf, Mn level increased from culm to boot leaf. John *et al*. (2001) also has reported that toxicities of Fe, Al and Mn are limiting the crop production in laterites and that these nutrient imbalances are to be rectified for sustaining crop production.

Ota (1968) found that poor development of lateral roots and root hairs and the development of lion tail roots were often observed in plants grown under iron toxic conditions. He also noticed that bronzing of paddy was due to high Al content and Ca deficiency. IRRI (1972) reported that excess iron led to bronzing in latertie soils of India, Ceylon, Thailand, Malaysia and Combodia.

Anilakumar *et al*. (1992) noticed accumulation of an extraordinary high level of iron in rice in early stages but the content declined as growth advanced. The sluggish growth rate observed in early stages as well as incomplete metabolism of N might be partly due to this excess Fe. Fe toxicity caused fewer panicles and filled grains, delayed crop maturity and yield reduction of 1.0 to 2.0 t ha^{-1}. Musthafa and Potty (1996) have reported that high nitrogen absorption and resultant narrow N/Fe ratio lead to low productivity of rice. Response of K in laterite soil is in part by limiting the uptake of cations like Fe, Mn, Cu etc. which in turn implied that a relatively high content of K will be required.

Rice growth and yield in laterite soils have been reported to be poor due to the absence of response of higher levels of N and P as well as due to the excess amount of soil Fe (Potty *et al*., 1992). Bridgit and Potty (1992) have found that an excess absorption of iron interferes with chlorophyll function and its solubility which in turn leads to poor yield of rice crop. In laterite soils it was observed that Ca application could effectively check iron content, which is the main yield limiting factor, but it could not contain the adverse effects of Mn and Zn which directly interfered with N metabolism (John *et al*., 2004).

2.2 Submerged soils and rice nutrition

When an aerobic soil is submerged, Eh decreases during the first few days and reaches minium, then it increases, attains a maximum and decreases asymptotically to value characteristic of the soil, after 8 – 12 weeks of submergence (Ponnamperuma, 1965). The mineralization of organic nitrogen in submerged soils stops at the ammonia stage because of the lack of nitrogen to carry the process via nitrite to nitrate (Ponnamperuma, 1972). Williams *et al*. (1968) observed an increase in the yield of rice on flooded fields when nitrogen content of the straw that was plowed in exceeded 0.6%, and a decrease in yield when the nitrogen content was below 0.5%.

Thus inspite of the lower nitrogen factor in flooded soils, materials with wide C: N ratios such as straw and weeds, instead of supplying nitrogen may depress its availability to rice, especially in soils low in organic matter (IRRI, 1976).

Transformations of N in wet land rice soil included changes in both aerobic and anaerobic microsystems. Ammonia volatilization, nitrification, leaching and run – off were reported to be the pathways through which N is lost from the rice soil (Patrick and Mahapatra, 1968; Savant and De Datta, 1982). Ammonia volatilization losses from rice fields range from 7 to 48% of the quantity of fertilizer N applied, depending upon the dose of N, its method of application, and soil characteristics (Freney *et al*., 1990). According to Prasad and Power (1997) N losses by denitrification vary from 3 to 62% of applied N in arable soils. Losses were greatest from rice paddies. Aulakh *et al*. (2000) found that in flooded soils commonly used for rice farming, submergence of soils results in the depletion of O_2, creating conditions congenial for denitrification. Soils that remain submerged for prolonged periods of time are common in traditional rice cultivation. They also reported that substantial amounts of fertilizer N are lost via denitrification in semiarid subtropical soils under nearly saturated and flooded conditions that are prevalent in wet land rice growing areas. Because of the anaerobic environment in which rice is grown, the use of NH_4^+ - forming fertilizers is necessary due to rapid denitrification of NO_3^- in the soil after the permanent flood is applied (De Datta and Patrick, 1986). Norman *et al*. (2003) reported that in the oxidized zone, urea – N is in more intimate contact with the soil exchange complex, where it is able to attract an H^+ ion and is converted to the stable NH_4^+ salt. In this state, the N is less susceptible to gaseous losses via NH_3 voltalization as well as the nitrification – denitrification loss process and remains available to the developing rice plant.

Saleque and Kirk (1995) showed that rice plants growing in flooded soil were able to solubilize P and there by increase their P uptake by inducing an acidification in the rhizosphere. Under highly reduced conditions, in submerged soils, sulfate was reduced to sulfide (Takai and Kamura, 1966). Sulfide inhibited the respiration and oxidizing power of rice roots, thus retarded the uptake of various nutrients and hence caused poor growth (Mitsui *et al*., 1951).

The concentration of Fe in soil solution for rice varied greatly. At one extreme, 45 ppm (Baba, 1958) or 50 ppm Fe (Ishizuka *et al*., 1961) produced Fe toxicity in the plant. At the other extreme rice growth was not affected when the Fe concentration was as high as 1680 ppm (De Datta and Mandal, 1957). The concentration of Fe that produces Fe toxicity symptoms appears to vary with pH of the solution. The concentration of Fe in soil solutions within common pH levels ranges from 30 to 550 µg L^{-1}, whereas in very acid soil it can exceed 2000 µg L^{-1} (Pendias and Pendias, 2001).

Pendias and Pendias (2001) found when soils are waterlogged, the reduction of Fe^{3+} to Fe^{2+} takes place and is reflected in an increase in Fe solubility. This process of Fe reduction is strongly related to metabolism of bacteria and can result in a high Fe^{2+} concentration in some submerged soils (e.g., paddy soils). The toxicity of iron is associated with reduced soil condition of submerged or flooded soils, which increases concentration and uptake of iron. Suresh (2005) found that iron toxicity symptoms of rice are characterized by a reddish brown mottling (bronzing) or in some cultivars, oranging and yellowing spreading downwards from the tips of the older leaves followed by the drying of the leaves, roots are scanty, coarse and often dark brown due to the coating of ferric oxide. Higher concentration of iron in the rhizosphere also has antagonistic effects on the uptake of many essential nutrients and consequently yield reduction (Fageria *et al*., 2008).

Cheng and Quellette (1971) reported that Mn concentration in the soil solution increased after flooding. Mn toxicity in wet land rice was uncommon since roots have a high degree of Mn excluding power and rice has high degree of tolerance for high Mn contents in tissues. Apart from its role as a plant nutrient, Mn plays an important part in redox equilibria. Toxicity of Mn to some field crops might be expected on acid soils of pH around 5.5 or lower and with a high Mn level. However, the critical Mn content and unfavourable soil pH range depends upon several other environmental factors. Mn toxicity is also known to occur at higher pH levels in poorly drained (poorly aerated) soils. However, if acid soils are very low in total Mn, plants are not subjected to Mn toxicity. As Beckwith *et al*. (1975) reported, flooding did not always increase Mn uptake by rice shoots, since flooding may also increase soil pH and therefore decrease Mn uptake.

2.3 Soil organic matter and rice

Soil organic matter consists of decomposing plant and animal residues. In addition to these materials, soil organic matter contains living and dead microbial cells, microbially synthesized compounds and a number of derivatives produced as a result of microbial activity. It is the store house of all essential plant nutrients. It protects soils against erosion and helps to form good soil structure. It provides good aeration and better water movement by loosening the soil. For achieving maximum benefit, organic matter must be decomposed and continuously replenished with the addition of fresh organic materials to the soil. Soil fertility and nutrient supplying capacity of a soil can be maintained on a long term basis only by replenishing, by addition through external inputs, nutrients removed by cropping and those lost through physical, chemical and biological processes. Soils with moderate to high content of organic matter or added organic matter can help adjust soil pH to the near neutral range (6.5 – 7.5), which is of benefit to the rice crop, because this pH range appears to favour nutrient uptake by wetland rice (Sahrawat, 2005).

Rice plant requires an adequate supply of nutrients from various sources for optimal growth. These nutrients can be supplied by organic matters such as green manures, green leaf manures, oil cakes, compost, crop residues and farmyard manure should be used in combination with manure fertilizers to satisfy part of the rice crops requirement for nutrients and to sustain soil quality in the long run (Dobermann and Fairhurst, 2000).

Green manuring is an old practice. In the present context of integrated nutrient supply system, it needs adequate attention since it is a renewable source of input for building of soil fertility and supplementing plant nutrients, especially N. This practice is more appropriate for irrigated agriculture, due to easy mineralization of nutrients from the turned over plants in the soil. Green manures may be either leguminous crops grown *in situ* (*Sesbania* spp, *Crotalaria juncea*), or leguminous/non – leguminous plants/trees, grown on bunds or waste lands, for utilizing vegetative parts for green manuring of soils.

Fageria *et al*. (2007) found that maximum rice grain yield was obtained with the application of green manure + $N_{45}P_{120}K_{100}$ (application of P and K at sowing and N top dressing) and these results showed that green manure can reduce chemical fertilizer application and the cost of production. Incorporation of red gram stalks and ratooned green manure biomass to rice crop contributed 16 – 55 kg N /ha (Kalpana *et al*., 2001). Garg *et al*. (2007) reported that the green manuring could save 80 kg N and 38 kg P_2O_5/ha in comparison to farmer practice of a rice crop. Joseph *et al*. (2008) reported that rice intercropped with dhaincha and in situ incorporation at 35 DAS + 100 % N application recorded higher growth rate of 19.80g/m^2/day during 50 – 65 DAS and 16.34 g/m^2/day during 65 DAS to harvest. Patro *et al*. (2009) concluded that application of 180 kg N ha^{-1} with either *Sesbania* or *Crotalaria* green manured rice registered significantly greater soil microbial biomass nitrogen at all the stages of rice growth. Vallalkannan *et al*. (2005) found that raising of green manure with the application of lime and ash @ 300 kg each per hectare has proved very good in laterite soil to give good rice growth and yield.

Oil cakes of non edible types like castor, neem and pungam are widely used as organic manures. The non – edible cakes contain high amount of plant nutrients. Most of the oil cakes are valued much of their alkaloid contents, which inhibit the nitrification process of N transformation in soils. Neem cake contains alkaloids, nimbin and nimbitidin, which effectively inhibit the nitrification process. Oil cakes have a much higher nutrient content, particularly of N and P, than do normal crop residues, such as cereal straw or bulky organic manures. Owing to their low C:N ratio, these decompose at a faster rate in the soil to furnish available nutrients (Roy *et al*., 2007).

Use of compost can be beneficial to improve organic matter status in soil because compost is rich source of nutrients with high organic matter content. Depletion of nutrients and poor organic matter contents of soils can only be replenished by applying compost to these soils (Sarwar, 2005). Compost prepared from crop residues, leaves, grass clippings, plant stalks, vines, weeds, twigs and branches are very good alternative which proved useful in many countries of the world. Use of compost has not only been adopted to enhance soil organic matter but also to control the environmental pollution from debris. According to Sarwar (2005), the grain yield and yield components (plant height, number of fertile tillers and 1000 grain weight) of rice and wheat increased significantly with the application of different organic materials but compost proved the most superior in this regard. The combination of compost with chemical fertilizer further enhanced the biomass and grain yield of both crops (Sarwar *et al*., 2007; Sarwar *et al*., 2008).

In India, about 100 mt of crop residues are available for recycling in agriculture annually (Dobermann and Fairhurst, 2002). Verma and Bhagat (1992) reported increase in soil organic matter and improvement of rice and wheat yield following incorporation of residues. Plant residues are an important source of C in soil and nutrients for crops in agricultural systems. In tropical agricultural systems, the decomposition of crop residues and green manures is often too fast to sustain soil organic mater at acceptable level (Whitbread *et al*., 1999). Burning of crop residues not only results in loss of organic matter and plant nutrients, but also causes environmental pollution, fire hazards and destruction of natural fauna and flora in the soil (Katyal, 2002). Singh (2003) reported that about 25 % of N and P, 50 % of S and 75 % of K taken up by cereal crops are retained in the crop residue, making viable nutrient sources. Crop residues are a larger reservoir of plant nutrients (approximately supplementing 0.5, 0.36 and 0.5 mt of NPK respectively), improve physical and biological properties, and protect the soil from wind and water erosion.

Recycling of crop residues reduces soil erosion, nutrient loss and improves the physico – chemical and biological properties of the soil, playing an important role in energy flow and nutrient recycling (Singh and Ganguly, 2005). According to Kaur and Benipal (2006) residues return carbon to the soil, which improves soil structure, the ability of the soil to hold nutrients, and water holding capacity. Residues provide potassium as well as other nutrients that may not be available in inorganic fertilizers. Singh *et al*. (2007) reported that crop residues not only replenish soil organic matter, a key determinant of soil quality, but also supply essential plant nutrients (N,P,K,S and micro nutrients) when mineralized. Kumar *et al*. (2008) reported that the continuous recycling of crop residue with organic amendments restores the organic matter content and also supplements the nutrients pool of the soil.

Land application of animal manure increases soil organic matter and improves a number of soil properties including soil tilth, water holding capacity, oxygen content, and soil fertility (Cassman *et al*., 1995). Manure application will also reduce soil erosion, restore eroded cropland, improve solar heat absorption, increase water infiltration rates, reduce nutrient leaching, and increase crop yields (Freeze *et al*. 1993). In addition, animal manure provides more trace elements than commercial fertilizer (Haynes, 1984). Nambiar (1994) studied that the application of 15 tones FYM/ha/annum for 16 years either build up or maintained the available Zn status. Native organics like farmyard manure, poultry manure, crop residues etc. that could maintain efficiency of macronutrient fertilizers by preventing occurrence of micronutrient deficiencies in soils and crops (Sakal *et al*., 1996).

The chief sources of micronutrients used by farmers level are organic matters available in farmhouses. These include FYM, compost, dungs of various animals, poultry manure, green manure and crop residues in farm fields. According to Saha and Samant (2006) FYM contains approximately 1788 mg/kg Fe, 34 mg/kg Zn, 137 mg/kg Mn, 2.5 mg/kg Cu, 4.6 mg/kg B, 2.1 mg/kg Mo and rice straw contains approximately 225 mg/kg Fe, 30 mg/kg Zn, 700 mg/kg Mn, 4.5 mg/kg Cu, 8.0 mg/kg B, 0.1 mg/kg Mo. A rice farmer applying compost @ 10t/ha will provide 3.6 kg Fe, 0.85 kg Zn, 2.0 kg Mn, 0.14 kg Cu, 1.0 kg B and 0.02 kg Mo/ha, which is equivalent to 19 kg Ferrous sulphate, 4.25 kg Zinc sulphate, 6.7 kg Manganese sulphate, 4.2 kg Copper sulphate, 0.9 kg Borax and 0.0385 kg Ammonium molybdate, respectively. Singh (2000) studied that the regular application of farm yard manure (FYM) at 10-15 tonnes/ha, helps in mitigating deficiencies of all the micronutrients in long run. Organic manures 12 t ha^{-1} FYM, 5 t ha^{-1} poultry manure and 2.5 t ha^{-1} of piggery manure were as efficient as 11.2 kg Zn ha^{-1} in meeting the Zn requirements. According to Araji *et al*. (2001) nitrogen, phosphorus and potassium are the elements that are most frequently needed for crops in relatively large quantities. Phosphorus in manure is equally available to plants as inorganic fertilizers. Roy *et al*. (2007) found that the well rotted FYM contains 0.5 – 1.0 per cent N, 0.15 – 0.20 per cent P_2O_5 and 0.5 – 0.6 per cent K_2O. The desired C:N ratio in FYM is 15 – 20 : 1. In addition to NPK, it may contain about 1500 mg/kg Fe, 7 mg/kg Mn, 5 mg/kg B, 20 mg/kg Mo, 10 mg/kg Co, 2800 mg/kg Al, 12 mg/kg Cr and up to 120 mg/kg lead (Pb).

Singh *et al*. (2008) reported that the organic manures, particularly green manures and FYM, not only supply macro nutrients but also meet the requirement of micro nutrients, besides improving soil health. Rakshit *et al*. (2008) found that organic sources offer more balanced nutrient to the plants, especially micro nutrients which has caused better tillering in rice plants grown with FYM. Kumar *et al*. (2008) found that the recycling of crop residues on long term basis along with application of FYM and green manure increased organic carbon and available P contents of the soil compared with chemical fertilizers alone. Green manuring increased the availability of Mn in soils, while application of FYM increased the DTPA – extractable Fe and Zn content of the soil.

2.3.1 Straw incorporation in rice

Incorporation of the remaining stubble and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long term. Short term effects of grain yield are often small (compared with straw removal or burning) but long – term benefits are significant. The return of plant nutrients absorbed by crops back to the soil is one of the basic principles in maintaining soil fertility. 80 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 the straw (Chatterjee and Maiti, 1981). Since one third of total rice plant N is in the straw, some N fertilizer requirements may be replaced by returning straw to the field (Cassman *et al*., 1998). Wheat – rice rotations in India have successfully reduced fertilizer N application by 29 to 40 kg N ha^{-1} when using straw as a replacement for fertilizer N (Singh, 1995). According to Bacon (1990) incorporation of straw has been followed by increases in microbial biomass and N mineralization. Therefore, straw incorporation has potential for significant residual effects on soil nutrient supply.

Ponnamperuma (1977) reported that application of crop residues such as rice straw has a beneficial effect of build up of organic matter and in increasing the N supplying capacity of wetland rice soils. This is due to the fact that there is a strong relationship between organic matter content and potentially mineralizable N. Singh and Yadav (2006) also reported increased organic carbon in the soil following straw incorporation. When cereal residues with a wide (70:1 or higher) C:N ratio are incorporated, there is excess C available and microorganisms rapidly oxidize it and multiply and use all released mineral N. This results in immobilization of mineralized or even part of added fertilizer N as indicated by pale green yellow plant patches in the field. Thus with incorporation of cereal straw insitu it is recommended to apply 15 – 20 kg ha^{-1} additional fertilizer (Samra *et al*., 2003).

Mathew *et al*. (2004) suggested rice straw was found more suitable for increasing and maintaining the pH in the laterite soils. Mathew and John (2004) reported that incorporation of kharif straw brought significant increase of grain yield during the three rabi seasons. Rice straw contains a good amount of K, Ca, Si, N, P and S absorbed by the crop and its application might have resulted in slow and steady availability of nutrients.

Applet *et al.* (1975) revealed that the addition of organic residues to acid soils improves P availability due to blocking of exposed hydroxyls on the surface of Fe and Al. Incorporation of crop residues in an alkaline soil, however, results in greater P absorption with a lower affinity coefficient than when it is removed or burned (Beri *et al*., 1995). Willet and Higgins (1978) and Phongpan (1989) reported that P adsorption increased with the addition of rice straw in several soils during the first week of incubation under flooded conditions. Beri *et al*. (1995) reported that in a soil where rice and wheat residues had been incorporated for 11 year, the soil maintained a higher concentration of HCO_3^- - extractable P during 90 days incubation period than soils with residue removed or burned.

Eagle *et al*. (2000) reported that total plant N uptake in the N fertilized plots was greater in the straw retained plots. In years 3 through 5, when straw retention began to significantly increase N uptake, the average increase in N uptake was 12 kg ha^{-1}. Eagle *et al*. (2001) found that incorporation of straw increased total plant N in N fertilized treatments by 13 and 23 kg N ha^{-1} in the fourth and fifth years of the study. After four and five seasons of straw incorporation in situ, greater N immobilization shortly after residue incorporation and greater N mineralization during the growing season was observed compared with where straw was burned (Bird *et al*., 2001). Bird *et al*. (2001) reported that long term incorporation of rice residue can increase readily mineralized organic soil N, suggesting the potential after several years for reducing fertilizer N rates for optimum rice yield. Thuy (2004) suggested that the application of crop residue in the absence of fertilizer N can depress total N accumulation and yield of crop. The incorporation of cereal residues often resulted in a short term immobilization of inorganic N and a temporary decrease in plant available N followed by net N mineralization (Singh *et al*., 2005).

Surekha (2007) found that N release from paddy straw applied plots was slow and less (43 – 69 mg N/kg soil) than that of the inorganic fertilizers (62 – 80 mg N/kg soil) when incorporated a day before transplanting, whereas when incorporated two weeks before transplanting the release was higher in paddy straw (186 – 281 mg N/kg soil) than that from inorganic fertilizers (95 – 140 mg N/kg soil). Bakht *et al*., (2009) found that the mineral N content of soil was significant during winter where crop residues incorporation resulted in 1.23 times increase in soil mineral N and soil organic C was 1.04 times greater over the residues removed treatment. Surekha *et al*. (2003) and Shafi *et al*. (2007) reported significant increase in N content of soil due to crop residue incorporation.

Dhiman *et al*. (2000) reported that rice grain yield was superior with incorporation of rice residues than burning and removal. Organic carbon and total N in the soil increased with the incorporation of crop residues but decreased with their burning. Rani *et al*. (2004) suggested that during rabi season the nutrient uptake of rice crop was higher for the treatment that received either 50 to 75 per cent of NPK + crop residues or green manure. Rajkhowa and Borah (2008) found that incorporation of rice straw significantly increased the grain and straw yields of wheat compared with straw removal. The increase in grain yield was attributed to improvement in different yield components. Thuy *et al*. (2008) revealed that the rice residue applied about 20 days before sowing wheat significantly decreased the yield of wheat by 0.2 Mg ha^{-1}. The rice residue incorporated to wheat significantly increased the yield of the following rice in 1 of 2 year.

2.3.2 FYM

Hedge (1998) evaluated the effects of different combinations of organic and inorganic fertilizers on rice – wheat crop rotation and found that wheat yield could be maintained while substituting 50 % of the N requirement of rice by farmyard manure rather than mineral N. The uptake of N, P and K by rice plants with FYM was significantly greater than all other commercial manures and inorganic manures (Bhadoria *et al*., 2003). Rajput and Singh (1995) reported that the maximum plant height was recorded under the application of FYM @ 10 t ha^{-1} as basal + full N as foliar in 3 splits. Jayakumar *et al*. (2004) found that the highest total dry matter accumulation of 5.33, 14.93 and 27.5 g hill^{-1} was produced with 100 N + 50 P_2O_5 + 50 K_2O kg ha^{-1} through fertilizers + 10 t ha^{-1} FYM at 30, 60 and 90 DAP.

According to Babu and Reddy (2000) among the different nutrient sources, higher grain (3826 kg ha^{-1}) as well as straw yields (6979 kg ha^{-1}) were obtained by applying 5 t FYM ha^{-1} + 50 kg N ha^{-1}. Sudha and Chandini (2002) reported that the enhanced NPK levels up to 105 : 52.5 : 52.5 kg ha^{-1} and sulphur levels up to 25 kg ha^{-1} along with organic manures either as 10 t ha^{-1} farmyard manure or vermicompost @ 5 t ha^{-1} were good in producing better grain yield of rice.

Pandey *et al*. (2007) reported that the application of FYM at $N_{150}P_{75}K_{60}$ or $N_{100}P_{60}K_{40}$ or inorganic fertilizer level of $N_{100}P_{60}$ K_{40} + FYM + Zn, being at par, produced significantly higher panicles/m^2 than that of other nutrient management practices. It could be due to slow release of nutrients for longer period for decomposition of FYM, which favoured better plant growth and improved the yield components of hybrid rice. Parihar (2004) also reported similar effect on rice.

Thakur *et al*. (1999) found that the number of grains panicle^{-1} and test weight were significantly higher with basal and split application of 30 and 45 kg N ha^{-1} with 5 t ha^{-1} FYM over control. Singh *et al*. (2001) revealed that yield attributing characters of rice *viz*., effective tillers/m^2, filled grains panicle^{-1} and grain weight panicle^{-1} were significantly higher due to FYM application to rice over control. Krishna *et al*. (2008) reported that the application of FYM and recommended dose of fertilizers under SRI cultivation produced seeds with better quality. Pandey and Tripathi (1993) reported a saving of 50 kg N, 15 kg P_2O_5 and 20 Kg K_2O could be possible due to application of FYM, because it might have supplied these nutrients and micronutrients. Kishor *et al*. (2008) noticed that the rain fed upland rice grown with either 150% NPK ($N_{90}P_{45}K_{30}$ kg/ha) or 5 t FYM/ha + 100 % NPK produced significantly higher grain (2020 and 1952 kg/ha, respectively) and straw yield (4978 and 4786 kg/ha respectively) than rest of the nutrient management practices, indicating that 50 % of NPK fertilizer can be substituted with the application of 5 t

FYM/ha. Kumar *et al*. (2000) also reported similar yield with 50 % substitution of NPK fertilizer through FYM source.

Thakur *et al*. (1999) found that the application of 45 kg K_2O ha^{-1} in 2 or 3 splits with FYM showed significant increase in K uptake compared with basal application of same dose of K and FYM. Senthilvelu and Prabha (2007) reported that united application of FYM @ 12.5 t ha^{-1} + 150:50:50 kg NPK ha^{-1} significantly influenced the higher N uptake (154.24 kg N ha^{-1}) P uptake (24.84 kg P ha^{-1}) and K uptake (171.60 kg K ha^{-1}) than other treatments. Singh *et al*. (2007) reported a significant increase in the Fe and Mn content of rice grains with FYM application compared with control.

Rathi *et al*. (2008) reported that the highest grain and straw yield of rice was obtained with application of 100 % recommended fertilizers + 10t FYM. Ghodake *et al*. (2008) stated that the application of FYM at 10 t ha^{-1} produced significantly higher yield of rice and improved nutrient uptake by grain and straw. Zhao *et al*. (2009) found that the highest rice yield of 7152 kg ha^{-1} was recorded under the application of FYM + inorganic N and P. Deqiang *et al*. (2009) reported that the highest grain yield of rice (11.28 t/ha) was obtained by the application of FYM in combination with inorganic fertilizer, it was significantly higher than 6.75 t/ha with only applying farmyard manure because combination application of farmyard manure and inorganic fertilizer could increase the nitrogen utilization rate after booting.

2.4 Mineral nutrition and rice

There are 17 elements needed by the rice plant to complete a healthy life cycle. They are generally grouped in to macro nutrients and micro nutrients. The most common limiting nutrients are nitrogen, phosphorus, potassium, sulphur and zinc. Mineral nutrient supply is one of the most important environmental factors affecting growth and productivity of a crop. The stage of growth also important as it decides the physiological requirement of each element. In addition to the specific functions of each nutrient, the interacting influences of the different nutrients, the nutrient ratios and their balances in the plant system are also important

2.4.1 Macro nutrients

2.4.1.1 Nitrogen

Nitrogen is a vitally important plant nutrient and is the most frequently deficient of all nutrients. Nitrogen is an essential component of different proteins and is present in many other compounds of great physiological importance in plant metabolism such as nucleotides, phosphatdes, alkaloids, enzymes, harmones, vitamins and other growth substances. It is therefore a basic constituent of 'life'. In addition to its role in the formation of proteins, N is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis.

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

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

Research Institute in the Philippines. Stone *et al*. (1999) studies the effects of N fertilization on grain yield of upland rice grown on an oxisol of Central Brazil for three consecutive under field conditions and concluded that maximum grain yield of 5523 kg ha^{-1} was obtained with application of 113 kg ha^{-1}. John *et al*. (1994) reported that yield components such as panicle m^{-2} and number of spikelets per panicle were significantly increasing with increasing N levels.

Alagesan and Siddeswaran (2002) who reported that wet direct seeded rice responded up to 120 kg/ha. Ghosh (2007) observed that N application results in maximum N use efficiency (27.12 kg grain/kg N), N uptake (0.46 kg ha^{-1}) and N recovery (16.81 %). Oo *et al*. (2007) indicated that the increase in grain yield due to application of 100 and 150 kg N/ha over control was 1.99 t/ha and 1.95 t/ha and in terms of percentage increase was 49.5 and 48.5 % respectively. Further increase in the rate of N to 150 kg/ha decreased the grain yield slightly. Yadav *et al*. (2007) found that the application of 80 kg N/ha gave the maximum grain yield and the straw yield and yield attributing characters *viz*., grains/ear heads and test weight. Patra *et al*. (2007) has reported that the application of N @ 60 kg/ha increased the plant height, number of tillers, number of panicles and grain yield in rice compared to other treatments. Becker *et al*. (2007) reported that the rough rice yield increased when N rate was increased 67 to 134 kg ha^{-1}, but there was likely no increase beyond 134 kg ha^{-1} rate due to the fact that panicle density was maximized at this level.

Bindu and Subramanian (2008) reported that the 150 kg N ha^{-1} applied in four splits led to the highest crop uptake of N (271 kg ha^{-1}) than the other nitrogen levels. According to Sathiya and Ramesh (2009) the different split doses of nitrogen, application of 150 kg ha^{-1} in four splits – 1/6 at 15 DAS, 1/3 at tillering, 1/3 at PI, 1/6 at flowering recorded higher tillers (361 m^{-2}), plant height (77.0 cm), dry matter at flowering (5.20 t ha^{-1}) and grain yield (2827 kg ha^{-1}) of aerobic rice over four equal splits where the grain yield was 2673 kg ha^{-1}. Yadav *et al*. (2009) suggested that application of N in three splits – ½ basal, ¼ at tillering and ¼ at panicle initiation produced significantly higher yield, yield attributing traits and protein production.

2.4.1.2 Phosphorus

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

Mosi *et al*. (1973) stated that lowland rice is not as likely to respond to addition of phosphatic fertilizers as upland rice crop. Release of soil P in a flooded soil might be attributed to reduction of ferric phosphate to the more soluble ferrous phosphate and displacement of phosphate from ferric and aluminium phosphates by organic anions (Islam and Elahi, 1954). Howerver, David (1960) reported that the beneficial effects of flooding on P availability depend on the intensity of reduction and on the iron content of the soil. Gupta and Singh (1989) observed that application of P decreased the toxic level of Fe and Al.

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

2.4.1.3 Potassium

Potassium unlike N, P and most other nutrients, does not form co-ordinated compounds in the plant. Instead, it exists solely as the K^+ ion, either in solution or bonded to negative charges such as organic radicals like the acid radical – R-COO-. As a result of its strictly ionic nature K^+ has functions particularly related to the ionic strength of solutions within plant cells (Tisdale *et al*., 1993). Potassium (K^+) is actively taken up from the soil solution by plant roots. The concentration of K^+ in vegetative tissue usually ranges from 1 to 4 % on dry matter basis. Thus plant requirements for available K are quite high. Potassium apparently does not form an integral part of any plant component and its function is catalytic in nature.

It is essential for the physiological functions of carbohydrate metabolism and synthesis of proteins, control and regulation of activities of various essential mineral elements, neutralization of physiologically important organic acids, activation of various enzymes, promotion of the growth of meristematic tissue and adjustment of stomatal movement and water relations (Tisdale *et al*., 1993).

Potassium is indispensable to the growth and grain production of rice. Tanaka *et al*. (1997) reported that the rice plant was characterized by its high capacity of absorbing as well as exhausting K and thereby tended to maintain the K concentration of the plant at a constant level. When the K concentration in the rice plant was forced to be low, its relative growth increment decreased drastically. A positive response of rice to K application was observed by Su (1976).

Significant increase in rice plant height with increase in the levels of K was observed by Vijayan and Sreedharan (1972) and Venkatasubbaiah *et al*. (1982). A positive correlation between K application and leaf area index in rice was observed by Mandal and Dasmahapatra (1983). Increase in chlorophyll content in the flag leaf due to K application was observed by Ray and Choudhari (1980). Potassium checks the chlorophyll degradation and promotes the synthesis of both chlorophyll "a" and "b". Increase in the rate of translocation of amino acids to the grain and higher protein formation due to K fertilization was reported by Mengel *et al*. (1981).

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). Verma *et al*. (1979) observed longer panicles with increased K rates. Noguchi (1940) reported increase in the lignin content in the stem with increased application of K. Mitra *et al*. (1990) evaluated the effects of higher level of K (0 to 160 kg ha^{-1}) on rice in an iron toxic laterite soil and reported that Fe toxicity symptoms decreased with increasing K application.

John *et al*. (2004) revealed that potassium has been found to influence the use efficiency of other nutrients. The ill effects of Fe can be reduced by K fertilization. High level of K is reported to decrease Fe uptake and helps maintain K/Fe ratio in plants. Higher rate of K application increased efficiency of N. P and Zn in laterite soils of Kerala (Bridgit, 1999; Mathew, 2002 and Deepa, 2002). Bridgit and Potty (2004) reported on the effect of increasing levels of K on yield attributes and yield of rice. Manzoor *et al*. (2008) found that the efficient potash uptake by rice when potash was applied at maximum tillering stage (25 DAT) and at panicle initiation stage (45 DAT).

2.4.1.4 Sulphur

Sulphur is recognized as the fourth major nutrient in addition to nitrogen, phosphorus and potassium. Hedge and Babu (2007) reported that sulphur ranks thirteenth in terms of abundance in the earth's crust and thus has a limitation in agriculture all over the world. For an optimum plant growth and yield all the essential nutrients are required in appropriate quantities.

Sulphur is usually required by crops in amounts comparable to P. Sulphur is a part of aminoacids cysteine (27 % S), cystine (26 % S) and methionine (21 % S), hence essential for protein production. It is involved in the formation of chlorophyll, activation of enzymes and in the formation of glucosides and glucosinolates. Sulphur is needed for synthesis of coenzyme A, which is involved in oxidation and synthesis of fatty acids, synthesis of amino acids and oxidation of intermediates of the citric acid cycle.

The mean total S content of Indian soils is about 30 – 300 mg kg^{-1}, although values can be as high as 6310 mg kg^{-1} and as low as 10 mg kg $^{-1}$ (Anandnarayan *et al*., 1986). Tandon (1986) and Nair (1995) reported that more than 80 % of soil is deficient in sulphur. Nair (1995) also reported that 56 % of the samples collected from alluvial soil and 83 % of the samples collected from brown hydromorphic soil in Kerala are sulphur deficient. Tandon and Messic (2002) reported that the total S content of surface soils in India varies from 19 to 9750 ppm. Sheela *et al*. (2006) and John *et al*. (2005) reported that 70 % of the soil samples collected from different parts of four districts *viz.,* Palghat, Thrissur, Kollam and Trivandrum are deficient in sulphur.

Rice plant requires 1.67 kg S to produce one tonne hulled grain (Suzuki, 1977). For rice the S removal varies from 7 to 35 kg ha^{-1} (Lakshmanan and Prasad, 2004). For a crop yielding 4 – 6 Mg ha^{-1} the S removal by rice is about 3 – 3.5 kg S Mg^{-1} of unhulled rice. Application of sulphur upto 60 kg ha^{-1} increased the growth attributes and yield of rice (Singh *et al*., 1993 and Raju *et al*., 1995). However Liu *et al*. (1989) reported that application of sulphur retarded organic matter accumulation in paddy soil, increased available phosphorus and sulphur and released potassium from the clay crystal lattice. Douli and Pradhan (2007) reported that the soil sulphur content is decreased with the increase in depth and is mainly due to a decrease in organic carbon content. Similar results with respect to change in S contents with depth were also reported by Pramanik and Douli (2001).

Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970 and Pillai, 1972). Singh *et al*. (1990) was of the view that steady supply of sulphur from elemental sulphur ensured better growth. Nanawati *et al*. (1973) showed that the content of chlorophyll, water soluble protein and peroxidase in rice were significantly reduced under conditions of sulphur deficiency. According to Sreedevi *et al*. (2006) sulfur nutrition helped the plant to maintain plant height and tillers, and produce more number of panicles, spikelets and grain weight. Similar beneficial effect of S in rice yield was observed by Oh (1991).

According to John *et al*. (2005) the application of sulphur @ 15 kg ha^{-1} increased the yield by 448 kg ha^{-1}. Sheela *et al*. (2006) reported that the three levels of sulphur application (15, 30, 45 kg ha^{-1}) were on par and superior to control, which indicated that application of S at the rate of 15 kg ha^{-1} is sufficient for realizing higher yield in rice. Rendig and Austin, (1968) cited by Tisdale *et al*., (1993) reported that the application of sulphur to a S deficient soil at 80 kg ha^{-1} improved chlorophyll content from 0.49 % to 1.18 %. Malavolta *et al*. (1987) reported a yield increase of 20 % in upland rice with the application of 20 kg S ha^{-1} in an oxisol of Brazil.

According to Rahman *et al*. (2007) the N, P and K uptake was increased by the application of S @ 20 Kg ha^{-1} and S uptake was increased by the application of S @ 40 kg ha^{-1} by boro rice. These results corroborates well with the findings of Islam *et al*. (1997). Uddin *et al*. (2002) found that the application of S, Zn and B along with NPK fertilizers recorded the highest number of effective tillers $plant^{-1}$ (12.5), number of filled grains $panicle^{-1}$ (99.9) and 1000 grain weight (24.4 g) and it was statistically identical with all other treatments except control. Sreedevi *et al*. (2006) reported that in sulfur deficient soils of Deccan plateau region, application of sulphur @ 20 kg ha^{-1} for rice hybrids and 40 kg ha^{-1} for conventional high yielding varieties were found to be effective. According to Wani and Rafique (2000) rice yield and S, N, P and K uptake increased with increasing S rate up to 40 kg, then decreased or remained the same.

Bhuvaneswari and Sriramachandrasekharan (2006) noticed that the highest grain (5065 kg ha^{-1}) and straw (7524 kg ha^{-1}) yields, and uptake of N, P, K and S were obtained with the application of 40 kg S ha^{-1}. Oo *et al* (2007) reported that application of 20 kg S/ha increased significantly P concentration in grain and straw over control but remained on par with 40 and 60 kg S/ha. Basumatary and Talukdar (2007) found that integrated use of 30 kg S ha^{-1} along with FYM at 1.5 or 3.0 t ha^{-1} resulted in the highest seed and straw yield, uptake of N,P,K and protein content rice than that of single application of sulfur or farmyard manure alone.

2.4.1.5 Calcium

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

A fairly large amount of Ca is present in soil as exchangeable Ca on silicate minerals in soils having pH 6.0 or above. Exchangeable Ca in soils can range from < 25 mg kg^{-1} to more than 5000 mg kg^{-1} and Ca in soil solution may range from 68 to 778 mg kg^{-1} (Prasad and Power, 1997). Ca in the exchange complex in acid soils is replaced by H^+ ions. Also as the soil acidity increases the proportion of exchangeable Al increases and Al toxicity is probably the major limiting factor to plant growth and crop production in strongly acidic soils (Foy, 1992). Alam *et al*. (2002) found that the application of calcium phosphate and calcium sulphate to rice increased N, P, K and Ca and decreased Na and Mg concentrations when compared to control plants grown on all soil types. Guanghui *et al*. (2003) found that the lime amendment in the acid soil improved P availability and promoted absorption of phosphorus, calcium and magnesium, leading to increase in yield. However excessive lime also reduced absorption of potassium, zinc, copper, manganese and Fe for upland rice.

Raising of green manure with the application of lime and ash @ 300 kg each per hectare has proved very good in laterite soil to give good rice growth and yield Vallalkannan (2004). Suswanto *et al*. (2007) reported that the best yield of rice 14.15 t/ha was obtained for treatment with 4 t/ha lime together with 120 kg N/ha + 16 kg P/ha + 120 Kg K/ha. This shows that liming together with prudent fertilizer management improves rice production on an acid sulphate soil.

2.4.2.2 Magnesium

Similar to K, Mg^{+2} is a counter ion for H^+ flux across the thylakoid membranes and is involved in activation of RuBP carboxylase and thus controls the CO_2 fixation in photosynthesis (Fang *et al*., 1995; Cakmak and Engels, 2002). Mg is a cofactor in almost all enzymes involved in photophosphorylation. Mg forms a bridge between the pyrophosphate structure of ATP and ADP and the enzyme molecule (Mengel and Kirkby, 1987). Mg fertilization had a significant effect of the nutrient content in straw and grain. Mg fertilization had a significant effect on the K, Mg, Zn and Mn content in grain (Brohi *et al*., 2000).

Choudhury and Khanif (2002) reported that the application of Mg fertilizer increased grain and straw yields of rice and Mg and K uptake significantly. Singh and Singh (2005) reported that the application of $MgSO_4$ @ 10 kg ha^{-1} promoted the absorption and translocation of Zn, Ca, P, K and that of Mg itself whereas Na accumulation was inhibited. Kobayashi *et al*. (2005) found that in rice, the excess Mg treatment increased the Mg content of shoots and roots, and the potassium and chloride contents of roots, but slightly decreased the Ca and K contents of shoots.

Kobayashi *et al*. (2005) reported that in rice, the excess Mg treatment increased the Mg content of shoots and roots, and the potassium and chloride contents of roots, but slightly decreased the Ca and K contents of shoots.

2.4.2.3 Iron

Iron is required for electron transport in photosynthesis and is a constituent of iron porphyins and ferredoxins, both of which are essential components in the light phase of photosynthesis. Fe is an important electron acceptor in redox reactions and an activator for several enzymes (e.g., catalase, succinic dehydrogenase and aconitase) (Dobermann and Fairhurst, 2000). Hassan (1977) has reported that iron content in laterite soils range in the order of 4 to 7 per cent. Singh (2009) reported that iron content in Indian soils is high, ranging from 4000 – 273000 mg kg^{-1} and that of available iron 0.36 – 174 mg kg^{-1} soil.

Tanaka *et al*. (1968) reported that excess Fe in the soil solution readily entered the shoot of rice plant causing Fe toxicity. Rice plants grown in solution containing more than 200 ppm Fe showed Fe toxicity symptoms and yield reduced and the uptake of other essential elements decreased (Saerayossakul, 1968). Due to the high content of the element in the soil, rice plants absorbed very large quantities of Fe (Anon., 1994). High yielding varieties tended to deposit two kg of Fe per ha on their roots which incapacitated the root system (Marykutty *et al*., 1993). Pathirana *et al*. (1995) found that Fe uptake was positively correlated with Fe concentration and deposition was greater in roots than shoots. Medhi *et al*. (1999) found that plant Fe concentration was highest at 45^{th} day. Das *et al*. (1997) reported that Fe content of plants significantly decreased in heavy textured soils indicating a positive influence of the soil clay content towards reducing Fe content in the plant. Olaleye *et al*. (2001) found that dry matter yield, number of tillers per pot and plant height of the two rice cultivars decreased with increasing Fe^{2+}. Mehraban *et al*. (2008) reported that maximum plant growth of rice occurred at iron concentration of 10 and 50 mg L^{-1} and growth reduction due to iron toxicity was observed at iron concentration of 250 and 500 mg L^{-1}.

2.4.2.4 Manganese

Manganese serves as an activator of several enzymes. This element also occurs in excess concentration in soils of many parts of the state and hence important in limited rice productivity. Hariguchi and Kitagishi (1976) reported that more than 60 per cent of Mn contained in the plant leaves is in chloroplast and Mn along with Fe and Cu take part in indispensable roles in the electron transport system.

Rice has a high degree of tolerance for high Mn concentration in its tissue. Cheng and Quellete (1971) reported that critical tissue content for Mn toxicity was 7000 ppm. According to De Datta (1981) the critical limits of deficiency and toxicity of Mn rice plants are 20 ppm and 2500 ppm, respectively. Manganese in Indian soils is adequate varying from 37 to 11500 mg kg^{-1} and available status 0.6 – 164 mg kg^{-1} to support optimum crop growth (Singh *et al*. 1995). Tadano and Yoshida (1978) suggested that a high Mn content in rice tissue was frequently associated with high yields; possibly indicating that a high Mn content in the plant was associated with various favourable soil conditions.

2.4.2.5 Zinc

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

Ghatak *et al*. (2005) revealed that zinc fertilizer application significantly increased the plant height, effective tillers, panicle length, grains per panicle, grain and straw yields, uptake of Zn, N and K by plant. Application of 30 kg $ZnSO_4$/ha recorded the highest values of yield attributes, yield, uptake of Zn, N and K by plant. Similarly, the net return was also maximum (Rs. 4832/ha) upon treatment with 30 kg $ZnSO_4$/ha. Slaton *et al*. (2005) found that zinc rate had the greatest influence on grain yields with near maximum yield produced when >9 kg Zn ha^{-1} was applied. Prado *et al*. (2008) reported that zinc sulfate provided greater production of total dry matter in rice seedlings in relation to zinc oxide. The application of 3.92 g Zn/kg of seed, using the zinc sulfate source provided the greatest increment in dry matter with values 48% higher than the control. Singh and Singh (2008) found that the application of $N_{160}P_{80}K_{60}Zn_{25}$ kg/ha produced highest grain yield of rice (60.46 q/ha) and maximum net profit (Rs. 440.53/ha) which being at par with treatment N_{160} P_{80} K_{60} (58.25 q/ha yield and Rs. 13174/ha net profit) was significantly higher than rest of the treatments of lower fertility. According to Ramadwivedi and Srivastava (2008) after two crop cycles of rice – wheat rotation, incorporation of straw @ 6.0 t ha^{-1} with Zn application to first year crop helped accumulation of higher available N in soil.

2.4.2.6 Copper

Copper is required for lignin synthesis (and thus cellular defense mechanisms) and is a constituent of ascorbic acid, the enzymes oxidase and phenolase and plastocyanin. It is a regulatory factor in enzyme reactions (effector, stabilizer and inhibitor) and a catalyst of oxidation reactions. It plays a key role in N, protein, hormone metabolism, photosynthesis, respiration, pollen formation and fertilization

(Dobermann and Fairhurst, 2000). Bertoni *et al*. (1999) reported that the copper application had significant effects of Cu, Zn, Fe and Mn uptake with no effect of B uptake in rice crop. According to Choudhury and Khanif (2002), single or combined application of Cu and Mg significantly increased rice yield and agronomic efficiency. Highest yields were obtained when Cu and mg were applied in combination.

2.4.2.7 Molybdenum

Molybdenum (Mo) is an essential component of NO_3^- reductase, an enzyme concentrated in chloroplasts, which catalyzes the conversion of NO_3^- to NO_2^-. Mo also is a structural component of nitrogenase, the enzyme essential of N_2 fixation by root – nodule bacteria of leguminous crops, by some algae and actinomycetes and by free living N_2 – fixing organism. Mo is also reported to have an essential role in Fe absorption and translocation in plants (Havlin, 2006).

Most of the Indian soils are adequate Mo but its deficiency was more in acidic, sandy and leached soils. Total and available Mo in Indian soils ranges between 0.1 to 0.12 mg kg^{-1} and available Mo content traces to2.8 mg kg^{-1} soil (Singh *et al*., 2006). Sundim *et al*. (2002) reported that the increased productivity of different rice cultivars such as primavera, maravilha and caiapo was observed with molybdenum fertilizer rates of 75, 150 and 300 g Mo/ha, respectively, in combination with *Herbaspirillum seropedicae*. Malik and Kumar (2006) found that the protein content in rice cultivars increased with increasing Zn concentration up to 15.0 ppm and Mo concentration up to 1.5 ppm.

2.4.2.8 Boron

Boron has a primary role in cell wall biosynthesis and structure and plasma membrane integrity. It is resulted for carbohydrate metabolism, sugar transport, lignification, nucleotide synthesis and respiration. It is relatively immobile in rice plants. Because B is not retranslocated to new growth, deficiency symptoms usually appear first on young leaves. B removal by rice is in the range of 0.01 – 0.10 kg B t^{-1}

grain yield. A rice crop yielding 6 t ha^{-1} takes up ~ 0.09 kg B ha^{-1} of which > 60 % remain in the straw at maturing (Dobermann and Fairhurst, 2000).

Gupta (1985) reported that during Rabi season, the highest grain yield of rice was obtained with combined application of S, Mg, Zn, Mn, Cu, B and Mo. Soil B application increased B, Cu, P, and K concentrations, but reduced the concentration of Fe. When Zn was not supplied, the application of 2.5 mg B kg^{-1} significantly increased the dry matter yields. In the presence of optimum amounts of Zn from either source (Zinc sulphate and zinc oxide), the increase in dry matter continued up to 5 mg B kg^{-1}. The results also showed that in soils with high levels of B, Zn application may reduce the adverse effects of B toxicity and increase rice yield (Hosseini *et al*., 2005).

Soil treated with boron showed a significant effect on the growth and yield of the crop. 2 kg B ha^{-1} produced the highest straw (10.01 g pot^{-1}) and grain (9.69 g pot^{-1}) yields and maximum uptake of N, P and K nutrients (193, 29 and 208 mg pot^{-1}) by the rice plants. The treatment (2 kg B ha^{-1}) increased about 139 and 149% more straw and grain, respectively over the control. The further increment in the dose of boron (i.e. 4 and 8 kg B ha^{-1}), however, reduced the growth and yield components of rice plant (Kabir *et al*., 2007).

2.4.2.9 Silicon

Rice is a known silicon accumulator and is benefited with Si nutrition (Takahashi, 1995). Si removal by rice is 50 – 110 kg Si Mg^{-1} grain, with an average of 80 kg Si Mg^{-1}. A rice crop yielding 6 Mg grain ha^{-1} is likely to remove about 480 kg Si ha^{-1}, 80 % of which remains in straw. Thus recycling of rice straw *in situ* is an excellent way of avoiding Si depletion of rice soils (Prasad, 2007a). Si required for the development of strong roots, stems and leaves. It is absorbed by rice as uncharged and undissociated mono silicic acid $Si(OH_4)$ and transported to shoot through transpiration (Miyake and Takahashi, 1978). Leaf drooping can be caused because of excess nitrogen which causes softening of systems and leaves. Better silicon supply effectively counteracts the excessive nitrogen by ionic interactions (Senthil *et al*., 2002).

Si deficiency leads to soft and droopy leaves resulting in reduced photosynthesis and lower grain yield. In rice, typical symptoms of Si deficiency are necrosis of the older leaves and wilting associated with a higher rate of transpiration (Mitsui and Takahashi, 1963). Mandal *et al*. (2004) observed, the silica rich plant material (rice crop residues) has the potential of transforming the electro chemical properties of acidic soils that reduces P fixation; improves base retention and increase the soil pH. Therefore, retention or incorporation of particularly the rice residues can manifest all the benefits of liming acidic soils.

According to Bridgit (1999), application of sodium silicate at 250 kg ha^{-1} in laterite soil significantly increased the yield of grain and the increase was to the tune of 619 kg ha^{-1}. Haldar and Maiti (2005) found that in low land rice an increase in application of Si and Fe, alone, increased the content of extractable Si in the soil compared to that of the control. A combined application of Si and Fe recorded a synergistic effect on the content of extractable Si in the soil.

Havlin *et al*. (2006) reported that in rice, Si helps maintain leaf erectness, increases photosynthesis through improved light interception, and results in greater resistance to diseases and insect pests. Silicon promoted growth attributes, photosynthetic activity of the lower leaves and improved leaf and stalk erectness of rice. Silicon improved the plant resistance to biotic and abiotic stresses such as soil aluminium, manganese and iron toxicities alleviation, plant pests and disease resistance and increased phosphorus availability (Singh *et al*., 2005).

Singh *et al*. (2006) reported that dry matter, flag leaf effectivity, yield attributes and yield of rice significantly increased with increasing Si dose upto 120 kg/ha, while test weight increased with increasing Si dose up to 180 kg/ha. Sudhakar *et al*. (2006) reported that silicon @ 120 kg/ha through basic slag or fly ash or enriched straw compost should be integrated as a component of balanced nutrition for sustained rice productivity for higher yielding rice cultivars. Malidareh *et al*. (2009) found that the Si fertilizer application decreased the straw and grain nitrogen. Si_0 and Si_{500} (kg ha^{-1}) had maximum and minimum grain nitrogen with 1.93 % and 1.91 % and straw nitrogen with 1.02 and 0.92 respectively. Junior *et al*. (2009) reported that the soil-applied silicon increased the foliar silicon content and reduced the severity of brown spot, in contrast to the results observed in the foliar-applied silicon treatments.

2.5 Nutrient interactions

An interaction occurs when the response of one or a series of factors is modified by the effect of one or more other factors. The interaction is positive (synergistic) when response to factors used together is greater than the sum of their individual responses. There is an add – on effect. The nature of other possible interactions can be negative (antagonistic) or no interaction. Interactions among plant nutrients are often overlooked though they have considerable positive effect on plant growth and development. Moreover, the physiological and biochemical processes within the plants are influenced both ways owing to nutrient interaction. The interplay of nutrients is best studied in multi factorial experiments which test each nutrient at three of more rates. The main effect of nutrients is often unrelated to their interaction and interactive effect may not decline with increasing rates of addition, as primary effects do (Mandal *et al*. 2002).

Apart from the availability of adequate quantities of nutrients in soil, it is also important to have a proper balance between the nutrient constituents present both in the soil and in the plant. It is well known that all the essential and other beneficial elements are involved in mutual interaction among themselves. Interaction between nutrient elements can be synergistic or antagonistic and the type of interaction is usually characteristic of the plant species (Emmert, 1961).

2.5.1 N × P

The majority of soils around the globe are deficient in available N and are either low or medium in available P. These two nutrients account for a major share of the current annual fertilizer consumption (IFA, 2003). The N × P interaction can therefore, be termed the single most important nutrient interaction of practical significance. This interaction is often synergistic, occasionally additive, and in rare cases, may be antagonistic. Sinha *et al*. (1973) observed a soil is more deficient in P than N, then application of N alone could cause a severe reduction in wheat grain yield. When N is provided as an ammonium or ammonium – producing fertilizer, the acidifying effect could enhance N concentrations in plants (Malhi *et al*., 1988) and P solubility in soil (Prasad and Power, 1997).

Tisdale *et al.* (1993) reported that nitrogen promotes phosphorus uptake by increasing top and root growth, altering plant metabolism and increasing the solubility and availability of P. In Vietnam, application of P reduced lodging and percentage of unfilled rice grains caused by the use of N alone, remarkably improving yield response as well as NUE (Vo *et al*., 1995). Luong *et al*. (2002) indicated that the optimum N and P fertilizer rates were determined as 90 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1} for rice grown in acid sulphate soil.

Dwivedi *et al*. (2003) reported that NUE of rice was only 22.4 kg $grain^{-1}$ with the application of N, when N and P was applied together NUE was increased 25.5 kg $grain^{-1}$ showed a synergistic relation between these two nutrients. Increased root mass is largely responsible for increased crop uptake of P. Iqbal (2004) revealed that the rice biomass increased rapidly with 180 kg N ha^{-1} and also positive effect of rice biomass for phosphorus application was observed. Both water and fertilizer (N and P) had a positive effect on yield, which increased form 5.8 to 7.8 t ha^{-1}.

Dwivedi *et al*. (2006) suggested that the interaction effect of nitrogen and phosphorus was significant in hybrid rice. Application of nitrogen and phosphorus increased the protein content in rice grains significantly. Ghosh (2007) revealed that application of both FYM and Sesbania in combination with fertilizers N and P in rice improved crop growth resulting in increasing grain yield and nutrient utilization in flood – prone situations. Vishwakarma *et al*. (2008) reported that the yield attributing characters, grain and straw yield and nutrient uptake of N and P by paddy was significantly higher under 120 kg N/ha and 80 kg P_2O_5/ha over its respective lower levels as well as control. Jianli *et al*. (2009) reported that the application of N along with P eliminated the conflict between productive tillers and per panicle average yield and therefore boosted the per hill yield of rice.

2.5.2 N × K

In addition to N, potassium (K) is the major plant nutrient absorbed and removed by crops in the largest amounts among all essential nutrients. Rice is a heavy remover of K from the soil, could absorb up to 30 kg K_2O t^{-1} grain produced, which is about 50 % higher than N uptake (Singh, 1992). After N × P interactions, N × K interactions are the second most important interaction in crop production. The significance of N × K interaction and its optimum management is increasing due to increasing cropping intensity, higher crop yield, and greater depletion of soil K. Crops with a high requirement of K such as corn and rice often show strong N × K interactions (Loue, 1979 and Singh, 1992).

Plants can absorb N either in cationic (NH_4^+) or in anionic (NO_3^-) form. There is a unique possibility of anion – cation as well as cation – cation interactions with K^+. Most of the findings have illustrated that K^+ does not compete with NH_4^+ for uptake, rather it increases NH_4^+ assimilation in the plants and avoids possible NH_4^+ toxicity (Aulakh and Malhi, 2005). According to PPI (1988), a positive N × K interaction in rice where a good response to K was obtained only when adequate N

(90 kg ha^{-1}) was applied. Also, the response to N increased as the level of K was increased; the highest rice yield as well as NUE and K use efficiency (KUE) were obtained when both N and K were applied.

Singh *et al*. (1999) concluded that combined application of 60 mg N kg^{-1} along with 30 mg K_2O kg $^{-1}$ proved most effective in increasing grain and straw yield of rice. Potassium increased rice yield by 250 kg ha^{-1} (7 %) when N and P_2O_5 were applied at 40 kg ha^{-1} each, but by 910 kg ha^{-1} (24 %) at 120 kg N + 40 kg P_2O_5 ha^{-1}. Increasing N and P application rates without K application is often not a sound proposition and does not increase crop yield beyond a certain level (Aulakh and Malhi, 2005). Manivannan *et al*. (2005) indicated that the superior performance of hybrid rice KRH2 with the different levels of N and K.

Salplalrinliana *et al*. (2006) reported that the combined application of N and K showed the highest percentage of soil organic matter with 60 kg N + 40 kg K/ha, while 90 kg N + 60 kg K/ha gave the highest soil available N, K and P, grain yield and straw yield of rice. Bahmaniar and Ranjbar (2007) found that the simultaneous application of N and K have increasingly affected grain yield, plant height, shoot dry matter and harvest index in field conditions and plant height, length of flag leaf and shoot dry matter under pot culture in rice.

Zhiming *et al*. (2007) found that the tiller number and, the area and dry weight of leaves of rice increased with the increased rate of N and K fertilizer application and they concluded that the optimum rates of application are 1.8 kg N and 1.6 kg K_2O for production of 100 kg grain in high yield cultivation. Das *et al*. (2008) found that the application of nitrogen and potassium significantly increased the grain yield and N, K uptake by hybrid rice upto 180 kg N/ha and 80 kg K_2O/ha, respectively. Kavitha *et al*. (2008) reported that the application of N and K in 4 equal splits at the active tillering, panicle initiation booting and flowering stages recorded higher yields of 7484 kg/ha in the kharif and 7154 kg/ha in the rabi, respectively. Qiangsheng *et al*. (2009) suggested that potassium, nitrogen and their interaction play important roles in plant growth, development and yield of rice. According to Qiangsheng *et al*. (2009)

appropriate quantity of potassium could stimulate nitrogen accumulation and translocation in rice. Potassium application enhanced nitrogen transport as well as nitrogen accumulation in different rice organs and nitrogen distribution percentage in leaves and panicles.

2.5.3 N × S

N and S are vital constituents of plant proteins and are closely associated in their synthesis and play a key role in plant oil production. Application of N in the absence of sufficient S leads to the production of amino acids that are not incorporated into proteins, and plants synthesize the required amounts of S – containing amino acids when S is applied (Finlayson *et al*., 1970). When soils are deficient in available S, growth of all crops is drastically reduced. While N directly affects the photosynthesis efficiency of plants, S affects the photosynthesis efficiency indirectly by improving the NUE of the plants, as was evident from the relationship between N content and photosynthetic rate in the leaves of "with S" – and "without S" – treated Brassica plants (Ahmad and Abdin, 2000). Sulfur and Nitrogen are essential nutrients for plants because they are the key components in the structure of plant enzymes and reserve proteins in grain (Tabe *et al*., 2002). Since S is an essential constituent of enzymes involved in N metabolism, i.e. nitrate reductase and nitrite reductase (Swamy *et al*., 2005), its deficiency would lead to a decrease in N assimilation.

Paliwal and Dikshit (1987) found that nitrogen and sulphur, which are absorbed as anions, are considered as the quality and quantity limiting factors for rice. Grain yield and biomass increments due to N and S fertilization were relatively similar, thus the harvest index was not modified. This indicated that the crop did not modify the proportion of carbohydrates translocated to the grains when N and S were deficient (Ehdaie and Waines, 2001).

Cereals, which have relatively low S requirement, have shown significant responses to applied S. Several studies are available revealing an average cereal grain yield response from 15 to 41 % (Aulakh, 2003 and Scherer, 2001). The high proportion of significant responses is particularly noteworthy in rice and wheat. Aulakh and Malhi (2005) suggested that N and S nutrition during plant growth is highly desirable and their application at optimum rates is required to improve NUE and SUE, as well as to maintain oil content and fatty acid quality in oilseeds and protein concentration in most of the crops. Sulphur interacted positively or synergistically with N, P, K, Zn and B. The level of imbalance of S with N in S deficient areas was not only responsible for lower crop yields but poor produce quality as well (Tiwari, 1997).

Jinfu *et al*. (2000) found that the application of S fertilizers increased the uptake rates of N and S for rice, which increased N utilization efficiency. Mingjuan *et al*. (2001) reported that the highest yield of rice (8850 kg/ha) was obtained with 150 kg N/ha + 60 kg S/ha. The optimum ratio for NS fertilizer was 4:1. Easily available forms of sulfur, like ammonium sulfate and gypsum, as compared to pyrite or elemental sulfur, maintained adequate N to S ratio in rice, resulting in a reduction in the percent of unfilled grain, a major consideration in rice yield (Nad *et al*., 2001). Mandal *et al*. (2000) found that the N applied alone to rice crop did not affect the S content of rice straw, but N and S fertilizer combinations increased straw S content during the tillering stage.

According to Singh and Singh (2002) the total nitrogen uptake, grain, straw, and grain protein yields of rice were significantly improved with increasing levels of nitrogen and sulfur application being maximum at 150 kg N ha^{-1} and 40 kg S ha^{-1}, respectively. Sulfur uptake was also augmented by nitrogen and sulfur application. Significant N × S interaction in rice yield was observed by (John *et al*., 2004) and the rice yield increased by 300 kg ha^{-1} when no N is given, but it increased by 900 kg ha^{-1} at 40 kg N with sulphur fertilization at 30 kg ha^{-1}. Hedge and Murthy (2005) reviewing the results for a number of crops also pointed out that P × S, Zn × S and B × S interactions could be positive or negative but N × S and K × S interactions were mostly positive. According to Srivastava and Singh (2007) reported the highest grain yield of aromatic rice was recorded at the treatments effect of 60 mg N + 15 mg S kg^{-1} or 45 mg N + 30 mg S kg ha^{-1}. The interaction effect of N and S influenced the N and S in rice grain, N content in straw, N:S ratio both in grain and straw, and also many grain quality characters significantly. Oo *et al* (2007) reported a synergistic report of N and S in rice. Salvagiotti and Miralles (2008) showed that S addition increased biomass and grain yield in wheat, reporting a positive interaction between N and S, which was reflected in a greater NUE. Salvagiotti *et al*. (2009) reported the increase in grain yield in response to S addition was associated with a higher N uptake rate before anthesis confirming the positive interaction between both nutrients.

2.5.4 P × K

Muthuswamy *et al*. (1974) indicated that potassium application was correlated with the uptake of N, P and K by rice. Wahid *et al*. (1977) found positive significant correlation between P and K contents in the 14^{th} leaf in coconut. Sindhu (1997) reported that in banana, with increased level of K, N content decreased, while P showed an increasing trend. Sindhu (2003) reported that P at 17.5 kg ha^{-1} and K at 70 Kg ha^{-1} interacted to produce highest content of 0.23 % K and 1182.50 mg/kg S in the kernel. Additional application of 35 kg ha^{-1} of K gave the highest Mg content of 0.08 %. The content remained same when P was applied at 35 kg ha^{-1} along with K at 70 kg ha^{-1}.

2.5.5 P × S

Aulakh and Pasricha (1977) observed antagonistic relationship between P and S in moongbean. Kumar and Singh (1980) observed synergistic effect of P and S in soybean. Aulakh *et al*. (1990) observed synergistic effect of P and S on the uptake of both when the nutrients were supplied at lower rates. He also pointed out that for soybean in P and S deficient soils P × S interaction was positive when levels of both these nutrients were low (35 kg P and 20 kg S ha^{-1}), however, when the level of P application was increased to 52.5 or S level was raised to 40 to 60 kg ha^{-1}, the interaction was negative. A higher P level of 52.5 kg ha-[1] had an antagonistic effect on S uptake in rice as reported by Nair (1995). Randhawa (1995) reported antagonistic effect of P × S application at higher rates of wheat. According to Ali *et al*. (2004) the combined effect of S and P found significant on both nutrient content and uptake by rice. The highest N content (2.96 %) and N uptake (39.07 kg ha^{-1}) was observed in $S_{40}P_{35}$ treatment. Islam *et al*. (2006) found the application of 35.2 kg P with 20 kg S ha^{-1} produced higher yield of wheat. Interactions between P and S showed additive and beneficial effects on both grain and straw yield of rice.

2.5.6 K × S

Sulphur has been reported to increase K absorption and productivity of oil seed crops by Daliparthy (1994). Prabhakumari (1992) observed antagonistic relationship between K and S in coconut. Kumar and Singh (1994) observed an increase in total potassium in sulphur deficient plants, because of improper utilization of potassium. Jaggi *et al*. (1995) have reported an increase in potassium concentration in plants due to sulphur application.

2.5.7 P × Ca

Synergistic relationship between P and Ca in coconut was reported by Prabhakumari (1992). Deguchi and Ota (1957) reported that Ca stimulated the absorption of P and K under certain concentration ranges of ions in nutrient solutions. Padmaja and Varghese (1972) observed as increase in phosphorus content of the grain and straw by the application of Calcium.

According to Erdei and Zsoldos (1977) calcium stimulated the absorption of P and K and accelerated more effectively the translocation of photosynthetic products as compared to K and Mg. An increase in the available N and P content of the soils by the application of graded levels of lime has been observed by Marykutty (1986). Seng *et al*. (2008) found that the increase in shoot dry matter of rice with lime and P application in non – flooded soil was associated with a significant decline in soluble Al in the soil and an increase in plant P uptake.

2.5.8 K × Ca

Deguchi and Ota (1957) observed increase in absorption of K by the addition of Ca. Ho (1968) observed a decrease in leaf Ca content by potassium application in banana. According to Nair and George (1960), resistance to bunchy top may really be correlated to the ratio of CaO + MgO/K_2O and not merely CaO/MgO ratio in the leaf. Jacobson *et al*. (1961) reported that Ca stimulates absorption of K and Rb while it inhibits the absorption of Na and Li in plant roots. Erdei and Zsoldos (1977) also observed the same stimulatory effect of Ca and uptake of K. 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. Sudhir *et al*. (1987) reported that absorption of K was stimulated by Ca ions at low concentrations and decreased at high concentrations. Applied K decreased Ca and Mg content in plants raised in alluvial soils (Chakravorti, 1989).

Prabhakumari (1992) observed antagonistic relationship between K and Ca in coconut. Daliparthy (1994) reported that magnesium (Mg) or calcium (Ca) deficiency occurs form ion antagonism in acid soils following K fertilization and in soils with high exchangeable K. According to Bridgit (1999) calcium application narrowed K/Ca. K/Mn, K/Fe, K/Zn and K/Cu ratios in plants. Bridgit (1999) observed that (Ca + Mg)/K ratio in the plant showed a negative correlation with yield and total biomass. According to Bridgit (1999) though the application of Ca reduced Fe content, it failed to improve yield because it increased Ca content and increase in calcium alone tilted the (Ca + Mg)/K balance. Fernandez *et al*. (1973) found that K was negatively correlated with Ca and Mg in all stages. Sindhu (1997) reported a decreasing trend of Ca and Mg contents in banana with increasing K.

2.5.9 S × Ca

Aulakh and Dev (1978) observed that when Ca content was increased in plants, sulphur uptake also increased, thus there was synergistic effect. Prabhakumari (1992) observed synergism between S and Ca. Studies conducted by Bridgit (1999) on the effect of Ca and S on nutrient ratios showed that application of S widened K/Mn, K/Fe, K/Zn, K/Cu and K/Ca ratios and narrowed N based ratios at panicle initiation and flowering stages.

2.5.10 Fe × K

Sahu (1968) reported that high K content of leaf decreased the bronzing in rice plant due to higher Fe content. In a healthy plant the Fe:K ratio is 1:9.5 to 1:22.9 while in an infected plant it is 1:1.3 to 1:6.3. Singh and Singh (1987) studied the effect of applied K on Fe toxicity and found that K content was increased with K application and was more pronounced at flowering stage. P content was increased with K application while Fe concentration reduced drastically indicating K – P synergism and K – Fe antagonism. The total uptake and percentage translocation of N, P and K by rice increased significantly with increasing levels of K.

Sreemannarayana and Sairam (1995) found that increasing K rate decreased leaf Fe and Mn contents while it increased leaf Zn content slightly. Bridgit and Potty (2004) studied the regulatory role on K on containing Fe, Mn, Ca and Mg showed significant relationships of K/Mg, K/Fe, K/Mn and Ca + Mg/K. This showed that the role of K is in regulating the limiting influences of increasing contents of Fe viz*.,* content of root at PI stage, leaf content of Fe at PI, Mn content of leaf at PI and boot leaf etc. Prasad (2007b) concluded that K is reported to decrease the iron toxicity effects in rice.

Iron toxicity in rice was accompanied by deficiency symptoms of N, P and K (Medhi *et al*. 1999). K deficiency reduced the iron excluding power of the rice roots (Chatterjee and Maiti, 1981). Tanaka *et al*. (1977) also reported that an interaction existed between Fe and K in the plant; plants exhibiting bronzing symptoms were usually low in K and application of K remedied the disorder. Application of lime and P also minimized the problem. Mathew and John (2004) reported that the higher dose of K (70 kg ha^{-1}) was found to have no appreciable effect on yield of paddy. Yield advantage with application of higher K dose in iron rich soils is reported to be due to its indirect effect on adsorption of other elements like iron. Mehraban *et al*. (2008) indicated that iron toxicity induced greater oxidative stress in rice plants and supplemental potassium was ineffective in preventing iron accumulation in shoots and consequently did not ameliorate plant growth under iron toxic levels.

2.5.11 Fe × Mn

Mn interacts negatively with a number of plant nutrients. Reduced uptake of Mn by plants has been reported by application of Fe (Baxter and Osman, 1988) and Zn (Haldar and Mandal, 1979). Bulbule and Despande (1989) reported that tolerant varieties maintained a high nutrient ratio of N/Fe, P/Fe, K/Fe, Mg/Fe and Mn/Fe. They also stated that excess Fe absorption was related with multiple nutritional stress and the resulting low K/Fe and P/Fe ratios led to more serious yield reduction than Ca/Fe and Mg/Fe ratios. Also higher uptake of Mn reduced the injurious effect of Fe. Both deficient and normal Mn levels antagonize Fe absorption, but the reverse influence was true when Mn reached toxic concentration in plants.

Application of $CaCO_3$ decreased concentration of Fe^{2+} in the soil solution and increased N and P contents of straw (Li, 1994). Addition of MnO_2 decreased Fe^{2+}:Mn ratio in plat tissue and increased grain yield. Pendias and Pendias (2001) reported Mn-Fe antagonism is widely known and is observed mainly in acidic soils that contain large amounts of available Mn. In general, Fe and Mn are interrelated in their metabolic functions, and their appropriate level (the Fe:Mn ratio should range from 1.5 to 2.5) is necessary for the healthy plant. Below this range, symptoms of Mn toxicity and Fe deficiency may occur; and above 2.5, toxic effects of Fe, associated with the Mn deficiency, will be observed.

2.5.12 N × P × K

Krishnakumar *et al*. (2005) found that the application of 150:75:50 kg N:P_2O5:K_2O ha^{-1} gave the highest grain yield of rice. The treatment with 150:50:50 kg N, P_2O_5 and K_2O ha^{-1} showed the highest total P and K uptake. The N:P_2O5:K_2O application rates of 200:75:75, 200:10:100 and 200:50:75 kg ha^{-1}, respectively, resulted to higher soil available N, P and K in post harvest soils. The optimum application rate to obtain the maximum grain yield for the CORH2 was 151:66:57 kg N:P_2O5:K_2O ha^{-1}. Kalita (2006) reported that the application of NPK at 40:20:20 kg/ha gave the highest nutrient uptake and grain yield of rice, when compared with the other fertilizer treatments. Sangwan *et al*. (2007) found that the higher grain yield of rice 68.0 q/ha was obtained with the application $N_{150}P_{60}K_{60}$ over N_{150} alone (61.5 q/ha) and the uptake of N, P and K were also increased with the same treatments.

Yunneng and Kun (2008) suggested that the optimum rates of N, P and K increased rice yield and output value by increasing the number of effective spikes, seed setting rate per spike, and 1000-grain weight. A yield of 562.72 kg/667 m^2 was obtained with the application of 9.083 kg N, 7.691 kg P_2O_5 and 14.013 kg K_2O/667 m^2. Jirui *et al*. (2008) reported that the maximum rice grain yield (10500.9 kg/ha) was obtained with N, P and K at rates of 205.2 kg/ha, 38.8 kg/ha and 158.6 kg/ha, respectively. Recommended fertilization combination to achieve more than 9750 kg/ha yield were N at 163.3-196.7 kg/ha, P_20_5 at 57.2-85.3 kg/ha, and K_20 at 175.5-214.5 kg/ha.

2.5.13 P × K × Ca

Deguchi and Ota (1957) reported that Ca stimulates the absorption of P and K under certain concentration ranges of ions in nutrient solutions. According to Erdei and Zsoldos (1977) calcium stimulated the absorption of P and K and accelerated more effectively the translocation of photosynthetic products compared to K and Mg.

2.5.14 Ca × Mg × K

A Ca:Mg ratio in soil solution greater than 7:1 is considered undesirable (Havlin *et al*., 2006). Continuous liming of acid soils can thus create Mg deficiency. On the other hand a C:Mg ratio less than about 2:1 can cause Ca deficiency. K^+ also antagonizes Mg uptake (Ologunde and Sorensen, 1982) and desirable K:Mg ratios are <5:1 for field crops, 3:1 for vegetables and sugarbeets and 2:1 for fruits and green house crops (Havlin *et al*., 2006). K concentrations >30 g kg^{-1} soil and K/(Ca+Mg) equivalent ratio >2.2 in forage tissue can lead to grass tetany in ruminants (Grunes and Mayland, 1975). Ding *et al*. (2006) found the antagonistic and moderately synergistic effects between K and Mg, but the effects of K were much more significant than those of Mg on their uptake, translocation and net photosynthetic rate in the leaves.

2.6 Nutrient ratios

2.6.1 N:S ratios

Douli and Pradhan (2007) observed the N:S ratio of the soils varies from 2.0 to 14.2 with a mean of 6.9. The N:S ratio tended to decrease with depth with a few exception in all the soil series. This may be due to proportional decrease in both N and S content (Tabatabai and Bremner, 1972). Havlin *et al*. (2006) concluded that the N:S ratio in most soils falls within the narrow range of 6 to 8:1. The N:S ratio varied form 1.81 to 5.6 with a mean of 2.94:1 in different soil bodies of Dharwad. In general, there seems to be less variation in the N:S ratio within the soil, which might be due to the dependence of this ratio on the nature of soils, the genesis and other environment factors (Venkatesh and Satyanarayana, 1999). Higher values of N:S ratio in surface were mainly due to high N content in upper layers and partly due to low S content in propotion to nitrogen content in the organic matter. On the other hand, lower values of N:S ratio in upper layers might be due to rapid leaching to the lower depths (Sharma *et al*., 2000).

The beneficial effect of sulphur fertilizers on improving crop quality through reduction in the N:S ratio is often overlooked. An N:S ratio between 9:1 to 12:1 is considered appropriate in the crop produce. Plant suffering from sulphur deficiency accumulates non protein nitrogen in the form of amide and nitrate (Tisdale *et al*., 1993). The N:S ratio in grain was changed from 17:1 to 13:1 and from 13:1 to 6:1 in straw by sulphur fertilization @ 40 kg ha^{-1} (Nair, 1995).

2.6.2 C:N:P:S ratios

Surekha (2007) indicated that nitrogen the key nutrient element for rice, is the major constituent of organic sources and its release from these organics depends mainly on their C:N ratio and lignin content. The C:N ratio is the most widely used index of residue quality and is the predictor of decomposition rate. Mineralization of N is generally rapid from plant residues with a low C:N ratio because N is in excess of the requirement for microbial growth and is slow from the residues with the high C:N ratio as the N is retained by the microbial biomass and released slowly. For lowering the C:N ratio, addition of fertilizer N or organics that are comparatively rich in N such as non edible cakes, legumes and grasses can be practiced.

Materials and Methods

Materials and Methods

III. Materials and Methods

The present study entitled "Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction" was carried at the Farmers' field, Pudhunagaram, Palakkad during the rabi seasons (*Mundakan*) Sep 2006 – Feb 07 and Sep 2007 – Feb 08 and the pot culture studies were conducted in the College of Horticulture, Vellanikkara, Thrissur during the same season of Sep 2007 – Feb 08. The materials used and the methodology adopted for the study is described in this chapter.

3.1 General details

3.1.1 Location

Palakkad district is situated in the South West Coast of India, bounded on the North by Malappuram in the East by Coimbatore of TamilNadu, in the South by Thrissur and in the West by Thrissur and Malappuram districts. The experimental field, Pudhunagaram lies between 10°68' N latitude and 76°70' E longitude.

3.1.2 Weather and Climate

The area enjoys tropical humid climate. The temperature of the district varies from 20 ºC to 45 ºC. The maximum temperature recorded was 43 ºC.

3.1.3 Soil

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

3.1.4 Crop and Variety

The rice cv. Uma (MO - 16), a red kernelled, medium duration variety was used for the experiment. The variety is suitable for all the three seasons, medium tillering, resistant to BPH and capable of producing a yield of over 5 t ha^{-1} under favourable situations.

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

Properties	Value
a. Physical properties	
Bulk density (g cc^{-1})	1.33
Particle density (g cc^{-1})	2.30
Porosity (%)	48.00
Water holding capacity (%)	49.20
Mechanical composition	
Sand (%)	55.20
Silt (%)	11.90
Clay (%)	32.90
b. Chemical properties	
Soil reaction (pH)	6.50
Electrical conductivity (dSm^{-1})	0.12
Organic carbon (%)	0.68
Available N (kg ha^{-1})	263.42
Available P_2O_5 (kg ha^{-1})	18.45
Available K_2O (kg ha^{-1})	80.39
Available Ca (kg ha^{-1})	128.00
Available Mg (kg ha^{-1})	43.00
Available S (kg ha^{-1})	7.58
Available Fe (0.1 N HCl extract) (kg ha^{-1})	690.12
Available Mn (kg ha^{-1})	119.25

3.1.5 Cropping history of the experimental site

The experimental area belongs to a typical double cropped wet land. The field was under bulk cropping of rice in the previous season. The first year experiment was transplanted on 01.11.06 and harvested on 05.02.07 and the second year experiment was transplanted on 31.10.07 and harvested on 03.02.08.

3.2 Experimental methods

3.2.1 Experiment I : Mineralization pattern of nitrogen and sulphur (Pot culture)

The pot culture experiment was conducted during the rabi season (*Mundakan*) Sep 2007 – Feb 08. The experimental design was CRD with 3 replications.

The top soil (0 – 15 cm) from the non experimental area of the field site was collected, dried, sieved and filled in 30 cm diameter and 40 cm height mud pots. Straw and dry cow dung were incorporated as per the treatment details and kept puddled for 10 days. Three hills and two seedlings/hill were planted in one pot. Soil samples were taken at 10 days intervals and analyzed for ammoniacal nitrogen, nitrate nitrogen and available sulphur.

3.2.1.1 Treatment details

a. Organic matter application

M_0 – No organic matter addition
M_1 – Straw incorporation @ 10 t ha^{-1}
M_2 – Cow dung application @ 10 t ha^{-1}

b. Levels of nitrogen

N_0 – No N, N_1 – 90 kg N ha^{-1}

c. Levels of sulphur

S_0 – No S, S_1 - 15 kg S ha^{-1}

3.2.2 Experiment II : Response of rice to nitrogen and sulphur mineralization from organic matter with varying C:N ratios (Field study)

The field experiment was conducted during the rabi seasons (*Mundakan*) Sep 2006 – Feb 07 and Sep 2007 – Feb 08. The experimental design was 3^3 partial confounding with 2 replications. The plot size was 5.0 m × 4.0 m and the spacing adopted was 20 cm × 10 cm. The net plot size was 4.4 m × 3.4 m. The layout of the experiment is depicted in Fig. 1. The treatment details for the crop are given below.

3.2.2.1 Treatment details

a. Organic matter application

M_0 – No organic matter addition
M_1 – Straw incorporation @ 10 t ha^{-1}
M_2 – Cow dung application @ 10 t ha^{-1}

b. Levels of nitrogen

N_0 – No N, N_1 – 45 kg N ha^{-1}, N_2 - 90 kg N ha^{-1}

c. Levels of sulphur

S_0 – No S, S_1 - 15 kg S ha^{-1}, S_2 - 30 kg S ha^{-1}

The general view of the experimental fields is given in plate 1 and 2.

3.3 Crop culture

The cultural operations were carried out as per the package of practices recommendations of the Kerala Agricultural University (KAU, 2007). Seeds of the variety Uma were obtained from RARS, Pattambi. Twenty five days old seedlings were transplanted from the nursery raised for the purpose into a well puddle and leveled field at a spacing of 20 cm × 10 cm @ 2 -3 seedlings per hill.

Fig. 1. Layout of the experimental field

Confounded treatment : MN^2S^2 Plot size : 5 × 4 m^2

Replication : I

Block III	$M_1N_0S_2$	$M_2N_2S_1$	$M_0N_0S_1$	$M_2N_1S_2$	$M_1N_2S_0$	$M_2N_0S_0$	$M_0N_1S_0$	$M_1N_1S_1$	$M_0N_2S_2$
Block II	$M_0N_1S_1$	$M_1N_0S_0$	$M_0N_0S_2$	$M_2N_0S_1$	$M_0N_2S_0$	$M_1N_1S_2$	$M_2N_1S_0$	$M_2N_2S_2$	$M_1N_2S_1$
Block I	$M_2N_0S_2$	$M_1N_2S_2$	$M_2N_1S_1$	$M_1N_1S_0$	$M_0N_0S_0$	$M_0N_2S_1$	$M_1N_0S_1$	$M_0N_1S_2$	$M_2N_2S_0$

Confounded treatment : MNS^2

Replication : II

Block III	$M_0N_0S_1$	$M_2N_1S_1$	$M_1N_0S_2$	$M_2N_2S_2$	$M_2N_0S_0$	$M_1N_1S_0$	$M_0N_1S_2$	$M_1N_2S_1$	$M_0N_2S_0$
Block II	$M_2N_1S_2$	$M_1N_0S_0$	$M_0N_2S_1$	$M_1N_2S_2$	$M_1N_1S_1$	$M_0N_0S_2$	$M_2N_2S_0$	$M_0N_1S_0$	$M_2N_0S_1$
Block I	$M_1N_2S_0$	$M_0N_1S_1$	$M_2N_0S_2$	$M_0N_0S_0$	$M_1N_0S_1$	$M_2N_1S_0$	$M_1N_1S_2$	$M_2N_2S_1$	$M_0N_2S_2$

Plate 1. General view of the pot culture experiment

Plate 2. General view of the field experiment

The organic manures like cow dung and paddy straw were applied 10 days before transplanting. The entire quantity of S and P was applied at the time of transplanting. The half quantity of N and K was applied at the time of transplanting and remaining quantity was applied as top dressing at maximum tillering and at panicle initiation stages. Fertilizers were applied as per the treatments.

The fields were kept weed free by hand weeding. Plant protection measures were taken up as per the need. The crops were harvested on maturity. Four rows adjoining the border rows in one side were kept for destructive sampling. Plants in two border rows and the destructive sampling area were eliminated and the grain and straw yields from the net plot area were recorded. Weight of grain is expressed at 14 per cent moisture content and that of straw as air dry weight.

3.4 Observations recorded

3.4.1 Biometric observations

1.	Height of plants (cm)	:	At active tillering, panicle initiation and harvest stage
2.	Tiller count (No./hill)	:	At active tillering, panicle initiation
3.	Dry mater production (kg/ha)	:	At active tillering, panicle initiation
4.	Productive tillers (No./hill)	:	At harvest
5.	Number of spikelets/panicle	:	At harvest
6.	Percentage of filled grains/panicle	:	At harvest
7.	1000 grain weight (g)	:	At harvest
8.	Grain yield (kg/ha)	:	At harvest
9.	Straw yield (kg/ha)	:	At harvest

3.4.2 Physiological characters

3.4.2.1 Chlorophyll content

Chlorophyll content of index leaves was estimated colorimetrically (Yoshida *et al*., 1972) in a spectronic – 20 spectrophotometer at active tillering and panicle initiation stage

3.4.3 Efficiency of nutrients

The efficiency of nitrogen and sulphur was estimated by using following indices with the consideration of fallow as a control field.

1. Agronomic efficiency (kg grain kg^{-1} nutrient applied)

2. Uptake efficiency (nutrient uptake / nutrient applied)

3. Physiological or utilization efficiency (kg grain kg^{-1} nutrient taken up)

3.4.4 Chemical observations

For chemical analysis five hills were selected at random from each plot. Plant samples were collected at maximum tillering stage, panicle stage and at harvest. After cleaning the samples, leaf blades and sheath were separated, dried in a hot air oven at 60 ± 5ºC, powdered well and analysed for different nutrients. The methods used for the analysis of different nutrients are given in Table 3.2 and 3.3.

3.4.4.1 Protein nitrogen and sulphur

3.4.4.1.1 Sample preparation

Rice grains were oven dried and the husk was removed from the grains and used for the protein nitrogen and protein sulphur estimation. 5 g grain sample was prepared using ice cold extraction buffer using 0.1 M sodium phosphate buffer at pH 7.0 (Appendix I) in a mortar following the procedure described by Sadasivam and Manickam (1996). The homogenate was spinned at 10000 rpm for 10 minutes at 4°C to remove the coarse materials. And the supernatant was precipitated by 5 % TCA

Table 3.2. Methods used for plant nutrient analysis

Sl No.	Nutrient	Method	Reference
1.	N	Microkjeldhal digestion and distillation method	Jackson, 1958
2.	P	Vanadomolybdo phosphoric yellow colour method using spectronic 20	Jackson, 1958
3.	K	Diacid extract using flame photometer	Cheng and Bray (1951)
4.	Ca	Diacid extract using atomic absorption spectrophotometer	Jackson, 1958
5.	Mg	Diacid extract using atomic absorption spectrophotometer	Jackson, 1958
6.	S	Turbidimetric method using spectronic 20 spectrophotometer	Williams and Steinbergs (1959)
7.	Fe	Diacid extract using atomic absorption spectrophotometer	Sims and Johnson (1991)
8.	Mn	Diacid extract using atomic absorption spectrophotometer	Sims and Johnson (1991)

Table 3.3. Methods used for soil nutrient analysis

Sl No.	Nutrient	Method	Reference
1.	Soil reaction (pH)	Soil water suspension of 1:2.5 and read in a pH meter	Jackson, 1958
2.	Electrical conductivity	Soil water suspension of 1:2.5 and read in a pH meter	Jackson, 1958
3.	Organic carbon	Walkley and Black method	Walkley and Black (1934)
4.	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
5.	Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue colour method	Watanabe and Olsen (1965)
6.	Available K_2O	Neutral normal ammonium acetate extract using flame photometer	Jackson, 1958
7.	Available S	$CaCl_2$ extract – turbidimetry method	Chesnin and Yien (1951)

and it was centrifuged at 12000 rpm for 10 minutes at 4°C. The supernatant was discarded and the precipitation was air dried and it was dissolved in 0.1 N NaOH. And the protein content was estimated as per Lowry *et al.* (1951). The intensity of blue colour developed was read in spectrophotometer at 660 nm absorbance and compared with the standard curve. After the estimation of protein the solution was digested with single acid for the estimation of protein nitrogen and digested with diacid for the estimation of protein sulphur.

3.4.4.1.2 Preparation of protein (BSA) standard

Bovine Serum Albumin (BSA) was used as standard. 50 mg of BSA was dissolved in the extraction buffer (50 M sodium phosphate buffer at pH 7.0) in a standard flask and kept as stock solution. From the 100 ml stock solution, 10 ml was drawn and made upto 50 ml with buffer in another standard flask. Different aliquots (200µl, 400 µl, 600 µl, 800 µl & 1000 µl) were pipetted out from the stock in different test tubes and the volume was made up to one ml with buffer. A test tube with extraction buffer (1 ml) alone served as blank. Reagent C (5 ml) (Appendix I) was added to each tube including blank and allowed to stand for 10 minutes. Further, Folin ciocalteau reagent (0.5 ml) was added and incubated for 30 minutes at room temperature. The values were plotted on the graph to serve as standard graph.

3.4.5 Yield

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

3.5 Statistical analysis

Statistical analysis was done as per the methods suggested by Panse and Sukhatne, 1978. Statistical packages such as MSTATC, STATISTICA, SPSS and microsoft excel spread sheets were used for computation and analysis. Per cent probability significance (PPS) is presented for each observation together with S.E, CD and CV. The CD values are presented if the treatment difference is significant at less than 5 % level.

Results

Results

IV. Results

4.1 Experiment I : Mineralization pattern of nitrogen and sulphur (Pot culture)

The experiment was aimed to study the mineralization pattern of nitrogen and sulphur. The mineralization pattern of ammoniacal nitrogen, nitrate nitrogen, total nitrogen and available sulphur is presented here.

4.1.1 Mineralization of ammoniacal nitrogen

The amount of mineralized NH_4^+ during a period of 110 days in the soil averaged over nitrogen and sulphur was significantly different except at observations on 90th and 100th day (Table 4.1). The 10th day observation taken before the addition of nitrogen and sulphur fertilizer reflected the trend in the mineralization pattern from the soil or soil + organics without any external nitrogen application. A difference of 19.90 NH_4^+ - N kg ha^{-1} between M_0 and M_2 shown the fast mineralization of NH_4^+ from cow dung. The reduction of 12.3 kg in M_1 from that of M_0 indicates the amount of NH_4^+ immobilized during the start of decomposition of paddy straw. On 40th day NH_4^+ content reached 75 kg ha^{-1} in M_0 (no manure) but reduced to 73.1 kg ha^{-1} on 50th day which again increased and attained a peak on 70th day and then started decreasing. In the case of M_1 (straw incorporation), the peak value of 94.5 kg ha^{-1} reached on 60th day and then it was decreasing. In the case of M_2 (cow dung), the peak value reached on 20th day and then started decreasing.

N application significantly influenced the mineralization as evidenced by NH_4^+ N content values averaged over organic manures and sulphur. Nitrogen split application on 11th day, 31st day and 51st day significantly increased the peak value of NH_4^+ content observed on 20th, 40th and 60th day. The variation in NH_4^+ content in N_0 treatment during the observation period was relatively less.

The added sulphur fertilizer was found to significantly influence the mineralized NH_4^+ content only on 90th day where in NH_4^+ content was 66.9 kg ha^{-1} in

Table 4.1. Effect of manurial management on the ammoniacal nitrogen (kg ha^{-1})

Treatments	Intervals (Days)										
	10	20	30	40	50	60	70	80	90	100	110
Main effects											
M_0	57.2	65.7	67.5	75.0	73.1	78.4	78.8	71.7	66.4	63.2	59.8
M_1	44.9	62.7	62.2	88.8	91.6	94.5	92.8	90.1	70.7	67.3	67.9
M_2	77.1	98.8	90.9	88.9	88.0	86.3	83.3	78.8	72.1	67.4	65.4
S.E	2.4	1.9	1.8	1.8	2.0	2.2	1.6	1.7	2.0	1.7	1.5
CD (0.05)	7.04	5.6	5.4	5.3	6.0	6.4	4.6	5.2	NS	NS	4.6
N_0	59.0	64.6	64.4	67.8	68.1	62.4	61.7	60.9	53.8	52.1	50.3
N_1	60.4	86.9	82.7	100.7	100.3	110.5	108.2	99.5	85.6	79.8	78.4
S.E	1.9	1.5	1.5	1.5	1.6	1.8	1.3	1.4	1.6	1.4	1.2
CD (0.05)	NS	4.6	4.4	4.3	4.9	5.3	3.8	4.2	NS	NS	3.7
S_0	58.9	74.2	71.4	83.6	83.1	85.0	85.2	79.7	66.9	64.3	63.8
S_1	60.6	77.6	75.6	84.9	85.4	87.9	84.8	80.7	72.5	67.6	64.9
S.E	1.9	1.5	1.5	1.5	1.6	1.8	1.3	1.4	1.6	1.4	1.2
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	4.9	NS	NS
Two factor effects											
M_0N_0	58.3	54.2	57.4	55.8	57.7	54.5	56.7	52.7	50.3	48.3	46.6
M_0N_1	56.1	77.3	77.7	94.1	88.5	102.3	100.9	90.6	82.4	78.2	73.1
M_1N_0	44.6	55.2	56.2	65.3	64.9	67.3	68.3	67.9	53.0	52.5	51.6
M_1N_1	45.3	70.1	68.2	112.4	118.3	121.7	117.4	112.2	88.3	82.0	84.2
M_2N_0	74.2	84.3	79.6	82.4	81.8	65.3	60.2	62.0	58.2	55.5	52.7
M_2N_1	79.9	113.2	102.1	95.4	94.2	107.3	106.3	95.7	86.0	79.3	78.0
S.E	3.4	2.7	2.6	2.6	2.9	3.1	2.2	2.5	2.9	2.4	2.2
CD (0.05)	NS	NS	NS	7.6	8.5	NS	NS	NS	NS	NS	NS
M_0S_0	59.0	64.3	67.4	73.4	72.8	75.8	78.9	70.8	61.0	58.5	57.9
M_0S_1	55.4	67.2	67.7	76.6	73.4	81.1	78.7	72.6	71.7	68.0	61.7
M_1S_0	43.8	61.2	61.2	88.8	89.8	93.0	93.6	89.8	70.4	67.0	69.7
M_1S_1	46.1	64.2	63.3	88.9	93.3	96.0	92.1	90.3	70.9	67.5	66.2
M_2S_0	74.0	97.3	85.7	88.6	86.5	86.2	83.0	78.4	69.1	67.5	63.9
M_2S_1	80.2	100.3	96.0	89.2	89.5	86.5	83.5	79.3	75.0	67.3	66.8
S.E	3.4	2.7	2.6	2.6	2.9	3.1	2.2	2.5	2.9	2.4	2.2
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	13.9	8.9	8.7	7.5	8.5	8.9	6.5	7.7	10.2	9.0	8.5

S_0 and 72.5 kg ha^{-1} in S_1 with 15 kg sulphur. In general, the NH_4^+ contents were higher in S_1 than S_0 throughout the period of 110 days.

M × N interactions were significantly evident on the NH_4^+ accumulation observed on 40^{th} and 50^{th} day. A shift in the pattern of NH_4^+ N mineralization is evident from 40^{th} day characterized by the NH_4^+ content in M_1 and M_2 treatments. On 30^{th} day the M_1N_0 and M_2N_0 values were 56.2 and 79.6 kg ha^{-1} which increased to 68.3 and 82.4 kg ha^{-1} on 40^{th} day and further reduced to 64.9 and 81.8 kg ha^{-1} on 50^{th} day. The M_1N_1 and M_2N_1 values were 68.2 and 102.1 kg ha^{-1} on 30^{th} day. On 40^{th} day the M_1N_1 increased to 112.4 kg ha^{-1} but the M_2N_1 reduced to 95.4 kg ha^{-1}. A similar increase for M_1N_1 and decrease for M_2N_1 were observed during 50^{th} day also. M × S interaction has not significantly increased the NH_4^+ N accumulation.

4.1.2 Mineralization of nitrate nitrogen

The NO_3 - N accumulation in soil as influenced by no organic manure, cow dung application and straw incorporation averaged over nitrogen and sulphur application were significantly different upto 50th day (Table 4.2). The NO_3 - N content during 1 – 10^{th} day of the study was higher in cow dung application which was at par with no manure treatment. These were significantly superior to that in the straw incorporated treatment. After addition of the first split of nitrogen also this trend continued. On 40^{th} day the content reached in the increasing order of no organic manure, straw incorporation and cow dung application. But on the 50^{th} day, the straw incorporated treatment accumulated the highest NO_3 - N followed by cow dung application and no organic manure treatment, the trend continued upto 70^{th} day.

The effect of nitrogen application on NO_3 - N accumulation was significant except for 80^{th} day. A higher NO_3 N was observed in the N_1 (90 kg ha^{-1}) from 20^{th} to 110^{th} day.

Table 4.2. Effect of manurial management on the nitrate nitrogen (kg ha^{-1})

Treatments	Intervals (Days)										
	10	20	30	40	50	60	70	80	90	100	110
Main effects											
M_0	32.9	35.3	31.5	26.5	25.3	26.8	29.8	34.6	36.2	37.7	39.1
M_1	29.1	27.9	29.2	29.0	30.3	31.2	30.8	30.9	34.1	37.9	40.3
M_2	34.7	37.9	34.8	31.9	27.6	28.2	30.8	29.7	37.6	39.0	41.0
S.E	1.4	1.4	1.5	1.0	1.3	1.3	1.2	1.8	1.0	1.1	1.2
CD (0.05)	4.3	4.1	3.6	3.2	3.9	NS	NS	NS	NS	NS	NS
N_0	32.9	31.9	29.4	27.1	25.7	25.4	27.6	30.2	32.5	36.0	36.7
N_1	31.6	35.4	34.3	31.2	29.7	32.1	33.3	33.2	39.5	40.5	43.6
S.E	1.2	1.1	1.2	0.8	1.0	1.0	0.9	1.4	0.8	0.9	0.9
CD (0.05)	NS	3.4	3.6	2.6	3.2	3.2	2.9	NS	2.6	2.8	2.9
S_0	31.8	32.6	31.5	28.7	27.8	27.8	29.0	31.6	35.2	38.1	39.3
S_1	32.7	34.7	32.2	29.6	27.7	29.7	32.0	31.8	36.8	38.3	40.9
S.E	1.2	1.1	1.2	0.8	1.0	1.0	0.9	1.4	0.8	0.9	0.9
CD (0.05)	NS	NS	NS	NS	NS	NS	2.9	NS	NS	NS	NS
Two factor effects											
M_0N_0	33.3	32.7	31.2	24.5	24.2	22.8	27.5	34.0	34.0	34.8	36.8
M_0N_1	32.6	37.9	31.9	28.5	26.3	30.8	32.2	35.1	38.3	40.7	41.3
M_1N_0	30.9	26.6	29.0	26.9	26.3	26.5	26.3	25.6	29.3	35.1	35.1
M_1N_1	27.4	29.1	29.4	31.2	34.3	36.0	35.4	36.1	39.0	40.6	45.6
M_2N_0	34.5	36.4	34.2	29.9	26.6	26.8	29.0	31.1	34.2	38.0	38.1
M_2N_1	34.9	39.4	35.4	33.9	28.6	29.6	32.5	28.3	41.1	40.1	43.8
S.E	2.0	1.9	2.1	1.5	1.8	1.8	1.7	2.5	1.5	1.6	1.7
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	7.5	NS	NS	NS
M_0S_0	32.8	34.7	30.0	25.9	25.4	25.8	28.5	33.0	35.1	37.6	37.3
M_0S_1	33.0	35.8	29.6	27.1	25.1	27.9	31.2	36.1	37.2	37.9	40.8
M_1S_0	29.0	26.3	32.5	28.2	30.8	31.0	29.6	30.3	34.0	39.3	41.8
M_1S_1	29.3	29.4	34.1	29.9	29.9	31.5	32.1	31.4	34.3	36.4	38.9
M_2S_0	33.7	36.9	26.4	32.1	27.1	26.8	28.9	31.6	36.4	37.3	38.8
M_2S_1	35.7	38.9	24.3	31.8	28.1	29.6	32.6	27.8	38.8	40.7	43.1
S.E	2.0	1.9	2.1	1.5	1.8	1.8	1.7	2.5	1.5	1.6	1.7
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	15.7	14.5	16.3	12.9	16.6	16.0	13.8	19.9	10.3	10.8	10.4

The effect of sulphur showed significant effect only on 70th day, however during all the observation, the NO_3 - N content was slightly higher in sulphur applied treatments.

The M × N interaction was significant only at 80th day but noticeably significant between M_1N_0 and M_1N_1 with a difference of 11.5 kg ha^{-1} NO_3 - N between them. The M × S interaction has not significantly influenced the NO_3 - N content throughout the period of 110 days.

4.1.3 Total mineral nitrogen

The mineral nitrogen (NH_4^+ + NO_3) content was significantly influenced by organic manure treatments averaged over nitrogen and sulphur except on 90th and 100th day during the 10 – 110 days observation period (Table 4.3). The effect of application of N_{90} in three equal splits on 11th, 21st and 51st day was evident from the mineral nitrogen content in the no manure treatment (M_0) during 20th, 40th and 60th day than the just previous ones (10th, 30th and 50th days).

During the 10th day, the content of 74.1 kg ha^{-1} in the straw incorporation was relatively less than even from no manure treatment (90.2 kg ha^{-1}), but that in the cow dung applied treatment was as high as 111.8 kg ha^{-1}. The peak mineral nitrogen accumulation of 136.7 kg ha^{-1} in the cow dung treatment was observed on 20th day which gradually decreased to 108.6 kg ha^{-1} on 80th day, whereas in the case of straw incorporation the highest peak of 125.8 kg ha^{-1}, gradually attained on 60th day and then decreased to 121.0 kg ha^{-1} on 80th day.

Nitrogen application significantly influenced the total mineral nitrogen content observed from 20th to 110th day. The total mineral nitrogen content averaged over manure and sulphur treatments ranged from 87.0 to 96.5 kg ha^{-1} in the no nitrogen treatments, where as it ranged from 92.0 to 142.7 kg ha^{-1} in the treatment which received 90 kg ha^{-1}.

Table 4.3. Effect of manurial management on the total mineral nitrogen (kg ha^{-1})

Treatments	Intervals (Days)										
	10	20	30	40	50	60	70	80	90	100	110
Main effects											
M_0	90.2	101.1	99.1	101.5	98.4	105.3	108.7	106.3	102.6	101.0	98.9
M_1	74.1	90.6	91.5	117.9	121.9	125.8	123.8	121.0	104.9	105.2	108.3
M_2	111.8	136.7	125.7	120.9	115.6	114.6	114.1	108.6	109.8	106.5	106.4
S.E	2.6	2.7	2.1	2.3	2.8	3.0	2.0	2.1	2.4	2.3	2.3
CD (0.05)	7.6	7.9	6.3	6.8	8.3	8.8	6.0	6.3	NS	NS	6.7
N_0	92.0	96.5	93.9	95.0	93.93	87.8	89.4	91.2	86.4	88.1	87.0
N_1	92.1	122.4	117.0	131.9	130.1	142.7	141.6	132.7	125.1	120.4	122.1
S.E	2.1	2.2	1.7	1.9	2.3	2.4	1.6	1.7	2.0	1.9	1.8
CD (0.05)	NS	6.5	5.2	5.5	6.7	7.2	4.9	5.1	5.1	5.5	5.5
S_0	90.8	106.9	103.0	112.4	110.9	112.9	114.2	111.3	102.1	102.5	103.2
S_1	93.3	112.0	107.9	114.5	113.1	117.6	116.8	112.6	109.4	106.0	105.9
S.E	2.1	2.2	1.7	1.9	2.3	2.4	1.6	1.7	2.0	1.9	1.8
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	5.1	NS	NS
Two factor effects											
M_0N_0	91.9	86.2	87.2	80.3	81.9	77.4	84.2	86.8	84.4	83.2	83.4
M_0N_1	88.7	115.2	111.1	122.7	114.9	133.2	133.2	125.8	120.8	118.9	114.5
M_1N_0	75.5	81.9	81.6	92.2	91.2	93.9	94.7	93.6	82.4	87.7	86.8
M_1N_1	72.8	99.3	101.4	143.7	152.7	157.8	152.8	148.4	127.4	122.7	129.9
M_2N_0	108.8	120.8	112.8	112.4	108.5	92.2	89.2	93.2	92.4	93.6	90.8
M_2N_1	114.9	152.6	138.6	129.4	122.8	137.0	138.9	124.0	127.1	119.5	121.9
S.E	3.7	3.8	3.0	3.2	4.0	4.2	2.9	3.0	3.4	3.3	3.2
CD (0.05)	NS	NS	NS	9.6	11.7	NS	NS	8.8	NS	NS	NS
M_0S_0	91.9	99.1	98.7	99.3	98.3	101.6	107.4	103.8	96.2	96.1	95.2
M_0S_1	88.5	103.1	99.6	103.8	98.6	109.0	110.0	108.8	109.0	106.0	102.6
M_1S_0	72.8	87.5	90.2	117.1	120.7	124.0	123.3	120.2	104.5	106.4	111.5
M_1S_1	75.4	93.7	92.7	118.8	123.3	127.6	124.2	121.8	105.3	103.9	105.1
M_2S_0	107.7	134.3	120.0	120.7	113.7	113.1	112.0	110.0	105.7	104.9	102.8
M_2S_1	116.0	139.2	131.4	121.1	117.6	116.2	116.2	107.2	113.9	108.1	110.0
S.E	3.7	3.8	3.0	3.2	4.0	4.2	2.9	3.0	2.0	3.3	3.2
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.8	8.6	7.1	7.1	8.7	9.0	6.1	6.6	8.0	7.7	7.6

Though the total mineral nitrogen content in sulphur applied treatments was higher than no sulphur treatment a significant difference was observed only on 90th day.

The interaction effects of manure and nitrogen treatments were significant only on 40th, 50th and 80th days. The difference worked out between M × N_1 and M × N_0 showed that on 40th day the total mineral nitrogen contribution from soil alone (M_0), soil + straw (M_1), and soil + cow dung (M_2) were 42.40, 51.50 and 17.00 kg ha^{-1} while that on 50th day these were 33.00, 61.50 and 14.30 kg ha^{-1}, respectively.

The interaction effect of M × S on total mineral nitrogen content was not significant.

4.1.4 Mineralization of sulphur

The available sulphur content as influenced by organic manures averaged over nitrogen and sulphur treatment was significant from 20th to 110th day and it was higher in organic manure applied treatments (Table 4.4). Till 40th day the available sulphur was more in cow dung applied treatments and then decreased. While in the straw incorporated treatments the higher concentration lasted till 110th day. On 110th day the contents were 8.6 kg ha^{-1} in no organic manure, 17.0 kg ha^{-1} in straw incorporation and 12.0 kg ha^{-1} in cow dung application.

The effect of nitrogen averaged over organic manure and sulphur showed the positive influence of nitrogen application on sulphur mineralization which was evident from the significantly higher sulphur content in nitrogen applied treatment from 40th day onwards.

The effect of sulphur averaged over organic manures and nitrogen was significant from 20th day onwards. On 110th day the sulphur contents were 9.1 and 15.1 kg ha^{-1}, respectively.

M × N interaction was significant on 70th and 80th day. In the presence of nitrogen, higher quantity of sulphur was mineralized from incorporated straw as evidenced by 18.7 and 13.3 kg available S content ha^{-1} in M_1N_1 and M_2N_1 treatments.

Table 4.4. Effect of manurial management on the available sulphur (kg ha^{-1})

Treatments	Intervals (Days)										
	10	20	30	40	50	60	70	80	90	100	110
Main effects											
M_0	6.7	7.3	7.8	9.3	9.3	8.9	9.6	9.1	9.0	8.9	8.6
M_1	4.2	7.7	9.1	13.2	15.8	16.5	16.3	16.9	17.0	16.9	17.0
M_2	4.4	8.6	12.7	15.9	14.3	13.2	13.0	12.4	11.9	12.1	12.0
S.E	1.3	0.3	0.5	0.5	0.4	0.4	0.4	0.3	0.4	0.4	0.3
CD (0.05)	NS	1.0	1.6	1.6	1.4	1.3	1.2	1.1	1.4	1.2	1.0
N_0	4.3	7.5	9.6	11.9	12.0	12.0	11.9	11.8	12.0	12.0	11.9
N_1	5.8	8.2	10.2	13.7	14.3	13.8	14.0	13.8	13.3	13.2	13.2
S.E	1.0	0.2	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2
CD (0.05)	NS	NS	NS	1.3	1.1	1.0	1.0	0.9	1.1	0.9	0.8
S_0	4.2	6.1	7.6	10.1	9.8	10.4	10.2	10.3	10.1	10.3	9.9
S_1	5.9	9.6	12.2	15.6	16.5	15.4	15.7	15.3	15.2	15.0	15.1
S.E	1.0	0.2	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2
CD (0.05)	NS	0.8	1.3	1.3	1.1	1.0	1.0	0.9	1.1	0.9	0.8
Two factor effects											
M_0N_0	4.2	7.2	7.8	8.6	8.1	8.6	9.2	8.5	8.7	8.4	8.3
M_0N_1	4.7	7.4	7.9	10.0	10.5	9.3	10.0	9.7	9.4	9.5	8.9
M_1N_0	4.4	7.1	8.7	12.2	14.1	14.8	13.8	15.1	15.6	15.8	15.8
M_1N_1	4.0	8.3	9.5	14.3	17.6	18.3	18.7	18.8	18.4	18.0	18.2
M_2N_0	4.3	8.2	12.3	15.0	13.8	12.5	12.6	11.7	11.8	11.9	11.6
M_2N_1	4.4	9.0	13.1	16.9	14.9	13.9	13.3	13.0	12.1	12.2	12.4
S.E	1.8	0.4	0.7	0.7	0.6	0.6	0.5	0.5	0.6	0.5	0.4
CD (0.05)	NS	NS	NS	NS	NS	NS	1.7	1.6	NS	NS	NS
M_0S_0	4.3	5.8	5.9	6.2	5.8	6.4	6.1	5.5	5.7	5.8	4.9
M_0S_1	4.7	8.8	9.8	12.4	12.7	11.5	13.1	12.7	12.3	12.0	12.3
M_1S_0	4.0	5.4	6.4	10.6	11.9	14.0	13.9	14.9	14.6	14.6	14.9
M_1S_1	4.5	10.0	11.8	15.8	19.7	19.1	18.7	19.0	19.4	19.2	19.1
M_2S_0	4.5	7.1	10.4	13.5	11.5	10.9	10.6	10.4	10.0	10.5	10.0
M_2S_1	4.2	10.1	15.0	18.4	17.1	15.6	15.3	14.4	13.9	13.7	14.1
S.E	1.8	0.4	0.7	0.7	0.6	0.6	0.5	0.5	0.6	0.5	0.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	1.5	NS	1.6	1.3
CV (%)	88.9	15.3	19.1	14.7	12.4	11.8	11.2	10.2	12.8	11.0	9.1

M × S interaction was significant on 80th day. The difference in available sulphur due to sulphur application in the presence and absence of organic manure was different. It was 7.2 kg ha^{-1} in no organic manure but 4.1 and 4.0 kg ha^{-1} in straw incorporated and cow dung applied treatments, respectively.

4.2 Experiment II : Response of rice to nitrogen and sulphur mineralization from organic matter with varying C:N ratios (Field study)

The experiment was aimed to study the response of rice to nitrogen and sulphur mineralization from organic matter with varying C:N ratios. Data on growth characters, plant elemental composition and yield and yield attributes are presented here.

4.2.1 Plant height at tillering stage

4.2.1.1 Main effects

4.2.1.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen at tillering stage was not significant in the first year but significant in the second year (Table 4.5). Straw and cow dung treatments were at par and significantly increased the height over no manure application. Though not statistically significant, the mean increase in the height due to cow dung application over no organics was 2.54 cm, a 4.56 % increase, in the first year.

4.2.1.1.2 Effect of nitrogen

The graded dose of nitrogen application at 45 and 90 kg ha^{-1} resulted in a statistically similar but significant increase over no nitrogen application in both the years, when averaged over organics and sulphur treatments.

Table 4.5. Effect of manurial management on the plant height (cm) of rice at tillering stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	51.07	54.81	61.05	**55.64**	46.90	46.54	49.84	**48.76**
Straw application (M_1)	53.44	59.38	59.85	**57.56**	47.32	50.85	53.81	**50.66**
Cow dung (M_2)	52.85	60.45	61.23	**58.18**	46.94	51.24	54.88	**51.02**
Mean	**52.45**	**58.21**	**60.71**		**47.05**	**50.55**	**52.85**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	52.03	56.08	58.82	**55.64**	47.30	48.25	50.73	**48.76**
Straw application (M_1)	56.05	57.52	59.09	**57.56**	46.26	51.80	53.93	**50.66**
Cow dung (M_2)	56.17	58.40	59.96	**58.18**	47.43	51.88	53.75	**51.02**
Mean	**54.75**	**57.33**	**59.29**		**47.00**	**50.64**	**52.80**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	49.53	52.36	55.48	**52.45**	45.25	46.87	49.04	**47.05**
N_{45}	56.30	58.48	59.86	**58.21**	47.42	50.36	53.87	**50.55**
N_{90}	58.42	61.17	62.55	**60.71**	48.33	54.71	55.51	**52.85**
Mean	**54.75**	**57.33**	**59.29**		**47.00**	**50.64**	**52.80**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	45.40	51.35	59.32	**52.02**	50.96	55.82	61.45	**56.07**	56.84	57.24	62.39	**58.82**
M_1	52.43	59.60	56.13	**56.05**	53.90	58.63	60.03	**57.52**	53.99	59.90	63.38	**59.09**
M_2	50.76	57.96	59.79	**56.17**	52.20	60.98	62.02	**58.40**	55.59	62.42	61.87	**59.96**
Mean	**49.53**	**56.30**	**58.41**		**52.35**	**58.48**	**61.16**		**55.47**	**59.85**	**62.54**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	44.89	48.85	48.18	**47.30**	45.48	48.99	50.29	**48.25**	50.33	50.80	51.08	**50.73**
M_1	44.90	46.49	47.39	**46.26**	47.49	51.01	56.92	**51.81**	49.58	55.07	57.14	**53.93**
M_2	45.96	46.92	49.43	**47.43**	47.66	51.08	56.92	**51.88**	47.22	55.74	58.31	**53.76**
Mean	**45.25**	**47.42**	**48.33**		**46.87**	**50.36**	**54.71**		**49.04**	**53.87**	**55.51**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)**	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	1.11	3.24	26, 1, 3	M or N or S	0.55	1.61	2, 1, 1
Two factor effects	M × N, M × S, N × S	1.92	NS	54, 89, 98	M × N, M × S, N × S	0.95	NS	15, 14, 13
Three factor effects (3 FE)	MNS, MN^2S	3.32	NS	61, 92	MNS, MN^2S	1.65	NS	34, 67
3 FE confounded	MNS^2, MN^2S^2	3.32	NS	88, 92	MNS^2, MN^2S^2	1.65	NS	58, 17
CV (%)	2.51				3.52			

** Percent probability significance

4.2.1.1.3 Effect of sulphur

The effect of sulphur application averaged over organic manure and nitrogen treatments was significant in both the years. The height at tillering was increased from 54.75 to 57.33 cm at 15 kg ha^{-1} and 59.29 cm at 30 kg ha^{-1}. Similar significant increases were observed in the second year also to the graded dose of sulphur application.

4.2.1.2 Two factor interaction effects

The two factor interactions such as organic manure × nitrogen, organic manure × sulphur and nitrogen × sulphur were not significantly different in the first and second years. However, the plant height increased with S_{15} and S_{30} application in the presence of organic manures than no organic manures.

4.2.1.3 Three factor interaction effects

Three factor interaction effects were not significant in the first and second years. However, when no organics were given the response to applied nitrogen was more in the absence of sulphur, than S_{15} and S_{30} application.

4.2.2 Plant height at PI stage

4.2.2.1 Main effects

4.2.2.1.1 Effect of organic manures

The effect of organic manures, either straw incorporation or cow dung application averaged over varied doses of sulphur and nitrogen at panicle initiation stage was not significant in both the years (Table 4.6). However, there was a noticeable increase in the height over no manure for paddy straw, but the cow dung application decreased the height when compared to paddy straw incorporation in both the years.

Table 4.6. Effect of manurial management on the plant height (cm) of rice at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	75.89	79.89	79.60	**78.46**	71.85	73.57	77.12	**74.18**
Straw application (M_1)	76.38	79.30	89.39	**81.69**	70.27	81.77	80.17	**77.40**
Cow dung (M_2)	71.45	85.16	83.76	**80.12**	70.10	75.79	78.12	**74.67**
Mean	**74.57**	**81.45**	**84.25**		**70.74**	**77.04**	**78.47**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	74.02	78.68	82.67	**78.46**	71.13	75.30	76.12	**74.18**
Straw application (M_1)	77.59	81.58	85.90	**81.69**	70.16	79.76	82.29	**77.40**
Cow dung (M_2)	75.10	79.47	85.80	**80.12**	71.86	74.96	77.19	**74.67**
Mean	**75.57**	**79.91**	**84.79**		**71.05**	**76.67**	**78.53**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	69.86	75.58	78.27	**74.57**	65.78	72.40	74.05	**70.74**
N_{45}	75.86	81.10	87.39	**81.45**	72.27	78.54	80.33	**77.04**
N_{90}	80.99	83.05	88.71	**84.25**	75.10	79.08	81.23	**78.47**
Mean	**75.57**	**79.91**	**84.79**		**71.05**	**76.67**	**78.53**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	70.63	73.37	78.07	**74.02**	79.25	79.13	77.67	**78.68**	77.78	87.18	83.06	**82.67**
M_1	71.41	76.73	84.64	**77.59**	78.22	76.88	89.63	**81.58**	79.51	84.30	93.89	**85.90**
M_2	67.56	77.48	80.26	**75.10**	69.27	87.30	81.85	**79.47**	77.52	90.70	89.18	**85.80**
Mean	**69.86**	**75.86**	**80.99**		**75.58**	**81.10**	**83.05**		**78.27**	**87.39**	**88.71**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	68.32	70.26	74.81	**71.13**	75.35	74.18	76.38	**75.30**	71.90	76.28	80.18	**76.12**
M_1	61.83	74.30	74.35	**70.16**	72.81	84.26	82.21	**79.76**	76.17	86.75	83.95	**82.29**
M_2	67.18	72.25	76.14	**71.86**	69.05	77.19	78.66	**74.96**	74.08	77.95	79.56	**77.19**
Mean	**65.78**	**72.27**	**75.10**		**72.40**	**78.54**	**79.08**		**74.05**	**80.33**	**81.23**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	0.92	2.96	7, 0, 0	M^{NS} or N* or S*	1.35	3.96	2, 1, 1
Two factor effects	M × N*, M × S^{NS}, N × S^{NS}	1.59	4.66	1, 93, 55	M × N, M × S, N × S	2.34	NS	37, 49, 98
Three factor effects (3 FE)	MNS, MN^2S	2.75	NS	47, 92	MNS, MN^2S	4.05	NS	88, 96
3 FE confounded	MNS^2, MN^2S^2	2.75	NS	38, 25	MNS^2, MN^2S^2	4.05	NS	51, 76
CV (%)	3.97				5.74			

4.2.2.1.2 Effect of nitrogen

The effect of nitrogen treatments averaged over organic manure and sulphur was significant. The plant height was increased from 74.57 cm at no nitrogen application to 81.45 cm at N @ 45 kg ha^{-1}. Similar trend was also seen in the second year. The plant height increased from 81.45 cm with N_{45} and 84.25 cm with N_{90} in the first year and in the second year it is 77.04 cm with N_{45} and 78.47 cm with N_{90}.

4.2.2.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant. The plant height was increased from no sulphur to S_{30} it was 12.20 % and 10.52 % in the first and second year respectively.

4.2.2.2 Two factor interaction effects

Two factor interaction effect M × N was significant in the first year, but not significant in the second year. The treatment receiving paddy straw increased the plant height significantly over cow dung application with the graded levels of nitrogen in both the years. The other two factor interactions such as M × S and N × S were not significant in both the years. The height significantly increased with graded levels of sulphur with organic manures and nitrogen in both the years.

4.2.2.3 Three factor interactions

Three factor interactions such as MNS, MN^2S, MNS^2 and MN^2S^2 were not significant in both the years. However in contrast with the response of the treatment combination at tillering stage, a notable differential response was observed at PI stage, where straw incorporation has resulted in more plant height than cow dung application. The maximum height of 93.89 cm was observed in straw incorporated treatments supplied with N_{90} + S_{30}, whereas the lowest height of 70.63 cm observed in no manure + no sulphur or nitrogen applied treatments.

4.2.3 Plant height at harvest stage

4.2.3.1 Main effects

4.2.3.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was not significant in the first year, but it was significant in the second year (Table 4.7). The plant height in the harvesting stage was higher in the straw incorporated treatment which was significantly higher with 81.06 cm over cow dung application or no manure application which were at par.

4.2.3.1.2 Effect of nitrogen

The effect of nitrogen treatments averaged over organic manure and sulphur was significant in both the years. In the first year N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} was at par and significantly increased the height over no nitrogen application. But in the second year a step wise increase of plant height was observed with 76.00 cm at no nitrogen application, 80.64 cm at N @ 45 kg ha^{-1} and 83.40 cm at N @ 90 kg ha^{-1}.

4.2.3.1.3 Effect of sulphur

The effect of sulphur averaged over organic manure and nitrogen was not significant in the first year but significant in the second year. In both the years there was a linear increase in the height with graded dose of sulphur.

4.2.3.2 Two factor interaction effects

The two factor interactions namely M × N, M × S and N × S were not significant in the first year, but in the second year M × N and N × S were significant. In the second year N @ 45 kg ha^{-1} with straw incorporation (83.43 cm) and N @ 90

Table 4.7. Effect of manurial management on the plant height (cm) of rice at harvesting stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	83.98	87.54	91.41	**87.64**	74.71	79.58	82.84	**79.04**
Straw application (M_1)	85.37	92.03	88.46	**88.62**	75.12	83.43	84.63	**81.06**
Cow dung (M_2)	83.49	89.16	92.22	**88.29**	78.15	78.93	82.74	**79.94**
Mean	**84.28**	**89.58**	**90.70**		**76.00**	**80.64**	**83.40**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	86.11	89.74	87.08	**87.64**	77.29	79.16	80.68	**79.04**
Straw application (M_1)	88.33	87.36	90.17	**88.62**	77.96	80.68	84.54	**81.06**
Cow dung (M_2)	85.36	89.09	90.42	**88.29**	76.58	79.16	84.08	**79.94**
Mean	**86.60**	**88.73**	**89.22**		**77.28**	**79.67**	**83.10**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	81.83	86.05	84.95	**84.28**	73.75	75.60	78.64	**76.00**
N_{45}	87.54	91.22	89.97	**89.58**	77.75	80.17	84.02	**80.64**
N_{90}	90.42	88.92	92.75	**90.70**	80.33	83.24	86.65	**83.40**
Mean	**86.60**	**88.73**	**89.22**		**77.28**	**79.67**	**83.10**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	82.89	84.42	91.02	**86.11**	88.70	89.96	90.56	**89.74**	80.34	88.24	92.66	**87.08**
M_1	83.67	90.88	90.44	**88.33**	84.79	93.34	83.95	**87.36**	87.64	91.87	90.99	**90.17**
M_2	78.95	87.33	89.80	**85.36**	84.66	90.35	92.27	**89.09**	86.86	89.80	94.60	**90.42**
Mean	**81.83**	**87.54**	**90.42**		**86.05**	**91.22**	**88.92**		**84.95**	**89.97**	**92.75**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	72.89	78.19	80.81	**77.29**	74.81	79.76	82.90	**79.16**	76.44	80.79	84.82	**80.68**
M_1	73.33	79.20	81.34	**77.96**	75.40	82.93	83.73	**80.68**	76.64	88.16	88.84	**84.54**
M_2	75.03	75.87	78.85	**76.58**	76.58	77.81	83.09	**79.16**	82.84	83.10	86.29	**84.08**
Mean	**73.75**	**77.75**	**80.33**		**75.60**	**80.17**	**83.24**		**78.64**	**84.02**	**86.65**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	1.17	3.42	84, 1, 26	M or N or S	0.27	0.80	1, 0, 0
Two factor effects	M × N, M × S, N × S	2.02	NS	36, 53, 57	M × N*, M × S*, N × S^{NS}	0.47	1.38	1, 1, 53
Three factor effects (3 FE)	MNS, MN^2S	3.50	NS	77, 56	MNS, MN^2S	0.82	NS	17, 9
3 FE confounded	MNS^2, MN^2S^2	3.50	NS	73, 81	MNS^2 *, $MN^2S^{2\ NS}$	0.82	2.40	4, 87
CV (%)	5.23				1.28			

kg ha^{-1} with straw incorporation (84.63 cm) were at par and significantly increased the plant height than other organic manure treatments.

In the first year, the plant height was decreased when the sulphur at higher dose with no nitrogen (84.95 cm) and N @ 45 kg ha^{-1} (89.97 cm) application. N_{90} + no sulphur increased the height (90.42 cm) compared to N_{90} + S_{15} (88.92 cm). But in the second year a step wise increase in the height was observed between nitrogen with sulphur treatments.

4.2.3.3 Three factor interactions

Three factor interactions were not significant in the first and second years. But in the second year the confounded effect MNS^2 was statistically significant. The result shows that when sulphur was not given, straw incorporation was better in increasing plant height even at no nitrogen application than cow dung, but in the presence of S_{15} and S_{30}, both were at par.

4.2.4 Number of tillers per hill at vegetative stage

4.2.4.1 Main effects

4.2.4.1.1 Effect of organic manures

The effect of no manures, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen at tillering stage was not significant in the first year, but significant in the second year (Table 4.8). Straw application reduced the tiller number by 1.4 % and 3.73 % in the first and second year compared to no manure application.

4.2.4.1.2 Effect of nitrogen

The effect of nitrogen application averaged over organic manure and sulphur was significant in the first and second years. The number of tillers increased from 9.36 with no nitrogen to 11.05 with N @ 45 kg ha^{-1}. Similar increase in the number of tillers was also observed in the second year but N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} was statistically at par.

Table 4.8. Effect of manurial management on the number of tillers per hill at vegetative stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	8.89	11.10	12.00	**10.66**	9.83	10.44	11.42	**10.56**
Straw application (M_1)	9.10	11.21	11.23	**10.51**	9.77	10.21	10.58	**10.18**
Cow dung (M_2)	10.10	10.83	11.84	**10.92**	10.06	11.30	11.24	**10.87**
Mean	**9.36**	**11.05**	**11.69**		**9.89**	**10.65**	**11.08**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	10.73	10.50	10.77	**10.66**	9.83	10.98	10.88	**10.56**
Straw application (M_1)	10.16	10.59	10.79	**10.51**	9.27	10.14	11.14	**10.18**
Cow dung (M_2)	9.87	11.21	11.69	**10.92**	10.67	10.93	11.00	**10.87**
Mean	**10.25**	**10.76**	**11.08**		**9.92**	**10.68**	**11.01**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	8.87	9.41	9.81	**9.36**	8.79	10.10	10.77	**9.89**
N_{45}	10.29	11.10	11.75	**11.05**	10.10	10.73	11.11	**10.65**
N_{90}	11.60	11.78	11.69	**11.69**	10.87	11.23	11.14	**11.08**
Mean	**10.25**	**10.76**	**11.08**		**9.92**	**10.68**	**11.01**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	8.87	11.12	12.19	**10.73**	8.69	10.94	11.88	**10.50**	9.12	11.25	11.94	**10.77**
M_1	8.81	10.37	11.31	**10.16**	9.31	11.06	11.39	**10.59**	9.19	12.19	11.00	**10.79**
M_2	8.94	9.37	11.31	**9.87**	10.25	11.31	12.06	**11.21**	11.12	11.81	12.15	**11.69**
Mean	**8.87**	**10.29**	**11.60**		**9.41**	**11.10**	**11.78**		**9.81**	**11.75**	**11.69**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	8.44	9.94	11.12	**9.83**	10.69	10.63	11.63	**10.98**	10.38	10.75	11.51	**10.88**
M_1	8.25	9.00	10.56	**9.27**	9.49	10.19	10.75	**10.14**	11.56	11.44	10.44	**11.14**
M_2	9.69	11.38	10.94	**10.67**	10.12	11.37	11.31	**10.93**	10.37	11.16	11.48	**11.00**
Mean	**8.79**	**10.10**	**10.87**		**10.10**	**10.73**	**11.23**		**10.77**	**11.11**	**11.14**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	0.23	0.68	47, 0, 6	M or N or S	0.17	0.50	3, 1, 1
Two factor effects	M × N, M × S, N × S	0.40	NS	24, 24, 58	M × N, M × S, N × S	0.29	NS	35, 10, 10
Three factor effects (3 FE)	MNS, MN^2S	0.70	NS	66, 83	MNS, MN^2S	0.51	NS	40, 67
3 FE confounded	MNS^2, MN^2S^2	0.70	NS	74, 100	MNS^2, MN^2S^2	0.51	NS	30, 46
CV (%)	5.31				6.10			

4.2.4.1.3 Effect of sulphur

The effect of sulphur application averaged over organic manure and nitrogen treatment was not significant in the first year, but significant in the second year. In the first year, there was a gradual increase in number of tillers with graded levels of sulphur. In the second year the treatments S @ 15 kg ha^{-1} (10.68) and S @ 30 kg ha^{-1} (11.01) were at par but significantly increased the tiller number over no sulphur application.

4.2.4.2 Two factor interaction effects

The two factor interactions such as M × N, M × S and N × S were not significant in both the years. However the interaction effect of M × N resulted in a variation of 8.89 to 12.00 tiller numbers in the first year and 9.83 to 11.42 in the second year. A more or less similar variation was observed for N × S interaction also in both years. However the variation due to M × S interaction effect was relatively less than that of M × N, 9.87 to 11.69 in first year and 9.27 to 11.14 in the second year.

4.2.4.3 Three factor interactions

Three factor interactions were not significant in the first and second years. In the first year the highest tiller production was with the application of paddy straw + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} (12.19). In both the years, straw incorporation + N_{45} + S_{30} produced more tiller than straw incorporation + N_{90} + S_{15}.

4.2.5 Number of tillers per hill at PI stage

4.25.1 Main effects

4.2.5.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was not significant in both the years (Table 4.9). However, it was to be noticed that the straw

Table 4.9. Effect of manurial management on the number of tillers per hill at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	8.52	10.29	10.64	**9.82**	8.41	9.19	10.42	**9.34**
Straw application (M_1)	8.50	9.89	10.40	**9.59**	8.48	8.83	9.77	**9.03**
Cow dung (M_2)	9.54	9.71	10.31	**9.85**	8.35	9.81	10.25	**9.47**
Mean	**8.85**	**9.96**	**10.45**		**8.42**	**9.28**	**10.14**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	9.74	9.79	9.92	**9.82**	8.80	9.81	9.41	**9.34**
Straw application (M_1)	9.19	9.85	9.74	**9.59**	8.52	9.40	9.16	**9.03**
Cow dung (M_2)	9.60	9.71	10.25	**9.85**	9.21	9.44	9.77	**9.47**
Mean	**9.51**	**9.78**	**9.97**		**8.84**	**9.55**	**9.45**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	8.48	8.73	9.35	**8.85**	8.00	8.81	8.44	**8.42**
N_{45}	9.52	10.10	10.26	**9.96**	8.81	9.54	9.48	**9.28**
N_{90}	10.53	10.52	10.29	**10.45**	9.71	10.29	10.43	**10.14**
Mean	**9.51**	**9.78**	**9.97**		**8.84**	**9.55**	**9.45**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	8.37	9.50	11.35	**9.74**	8.38	10.25	10.75	**9.79**	8.81	11.13	9.81	**9.92**
M_1	8.25	9.88	9.44	**9.19**	8.75	9.81	11.00	**9.85**	8.50	9.98	10.75	**9.74**
M_2	8.81	9.19	10.81	**9.60**	9.06	10.25	9.81	**9.71**	10.75	9.69	10.31	**10.25**
Mean	**8.48**	**9.52**	**10.53**		**8.73**	**10.10**	**10.52**		**9.35**	**10.26**	**10.29**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	8.00	8.75	9.64	**8.80**	8.81	9.75	10.87	**9.81**	8.44	9.06	10.74	**9.41**
M_1	7.50	8.69	9.37	**8.52**	9.00	9.00	10.20	**9.40**	8.94	8.81	9.75	**9.16**
M_2	8.50	9.00	10.13	**9.21**	8.63	9.87	9.81	**9.44**	7.94	10.56	10.81	**9.77**
Mean	**8.00**	**8.81**	**9.71**		**8.81**	**9.54**	**10.29**		**8.44**	**9.48**	**10.43**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	0.16	0.47	48, 0, 15	M^{NS} or N* or S*	0.20	0.58	29, 1, 40
Two factor effects	M × N, M × S, N × S	0.27	NS	6, 65, 27	M × N, M × S, N × S	0.34	NS	50, 76, 97
Three factor effects (3 FE)	MNS, MN^2S	0.48	NS	56, 38	MNS, MN^2S	0.59	NS	86, 13
3 FE confounded	MNS^2*, MN^2S^2	0.48	1.41	1, 47	MNS^2, MN^2S^2	0.59	NS	59, 94
CV (%)	8.20				7.97			

incorporation resulted the lowest tiller count at this stage and it reduced the number of tillers by 2.63 % over cow dung application and 2.34 % over no organic manures. In the second year also a similar trend was observed.

4.2.5.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was significantly different in first and second years. In the first year number of tillers increased from 8.85 to 9.96 by N @ 45 kg ha^{-1} and to 10.45 by N @ 90 kg ha^{-1}. In the second year also a similar trend was seen.

4.2.5.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was not significant in the first year, but significant in the second year. The number of tillers at panicle initiation stage was increased from 9.51 to 9.78 by S @ 15 kg ha^{-1} and 9.97 by S @ 30 kg ha^{-1}. In the second year S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} was statistically at par and significantly increased the number of tillers over no sulphur application.

4.2.5.2 Two factor interaction effects

Two factor interactions were not significant in the first and second years. In the first year, the highest number of tillers at panicle initiation stage was observed when no organics applied with N @ 90 kg ha^{-1}. It was 25.18 % higher when compared to paddy straw incorporated with no nitrogen. When no nitrogen was applied with the organic manures, it was found to reduce the number of tillers, however when graded doses of nitrogen was applied with organic manures, resulted in the increased tiller numbers.

In the first year, the highest number of tillers 10.25 was registered when cow dung applied with higher level of sulphur. The paddy straw incorporated with no sulphur, registered the lowest number of tillers (9.19). A similar effect was observed in the second year also.

Nitrogen @ 90 kg ha^{-1} with no sulphur registered the highest number of tillers (10.53) in the first year. In the second year, mean increase in the number of tillers increased due to N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1} over no nitrogen and no sulphur was 2.43, a 30.37 % increase. In both the years the number of tillers increased with the increasing levels of nitrogen.

4.2.5.3 Three factor interactions

Three factor interactions were not significant except the confounded treatment MNS^2 in the second year. Whereas, in straw incorporated treatment with N_{90} resulted in a relatively lower number of tillers at S_{30} than at S_{15} level.

4.2.6 Chlorophyll 'a' content of rice at tillering stage

4.2.6.1. Main effects

4.2.6.1.1 Effect of organic manures

The effect of organic manures on chlorophyll 'a' content of rice at tillering stage averaged over nitrogen and sulphur was significant at 15 % level of significance in the first year and highly significant in the second year (Table 4.10). In the first year, no organic manures (1.90 µg g^{-1}) was at par with straw incorporation (2.20 µg g^{-1}), which in turn at par with cow dung application (2.42 µg g^{-1}). In the second year, cow dung application significantly increased the chlorophyll 'a' content (2.23 µg g^{-1}) over straw incorporation (1.83 µg g^{-1}) and no organic manure application (1.55 µg g^{-1}).

4.2.6.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was highly significant in the second year. A step wise increase in the chlorophyll 'a' content was observed with 1.58 µg g^{-1} by N_0 followed by N_{45} with

Table 4.10. Effect of manurial management on the chlorophyll ‘a’ content (µg g^{-1}) of rice at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.60	2.29	1.81	**1.90**	1.33	1.49	1.83	**1.55**
Straw application (M_1)	2.21	2.09	2.29	**2.20**	1.66	1.72	2.12	**1.83**
Cow dung (M_2)	2.22	2.26	2.77	**2.42**	1.75	2.28	2.66	**2.23**
Mean	**2.01**	**2.21**	**2.29**		**1.58**	**1.83**	**2.20**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.40	2.05	2.24	**1.90**	1.33	1.50	1.83	**1.55**
Straw application (M_1)	1.52	2.70	2.37	**2.20**	1.35	1.88	2.27	**1.83**
Cow dung (M_2)	2.09	2.09	3.07	**2.42**	1.67	2.20	2.82	**2.23**
Mean	**1.67**	**2.28**	**2.56**		**1.45**	**1.86**	**2.31**	
Nitrogen (N)								
N_0	1.86	1.89	2.28	**2.01**	1.33	1.62	1.80	**1.58**
N_{45}	1.29	2.61	2.75	**2.21**	1.45	1.85	2.18	**1.83**
N_{90}	1.87	2.34	2.65	**2.29**	1.57	2.11	2.93	**2.20**
Mean	**1.67**	**2.28**	**2.56**		**1.45**	**1.86**	**2.31**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.29	1.25	1.67	**1.40**	1.51	2.62	2.02	**2.05**	1.98	3.01	1.74	**2.24**
M_1	1.78	0.99	1.80	**1.52**	2.87	2.90	2.33	**2.70**	2.00	2.39	2.73	**2.37**
M_2	2.51	1.62	2.15	**2.09**	1.28	2.30	2.68	**2.09**	2.86	2.86	3.48	**3.07**
Mean	**1.86**	**1.29**	**1.87**		**1.89**	**2.61**	**2.34**		**2.28**	**2.75**	**2.65**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.30	1.30	1.38	**1.33**	1.35	1.44	1.70	**1.50**	1.35	1.72	2.41	**1.83**
M_1	1.21	1.48	1.36	**1.35**	1.84	1.91	1.88	**1.88**	1.93	1.77	3.12	**2.27**
M_2	1.46	1.58	1.97	**1.67**	1.66	2.20	2.76	**2.20**	2.14	3.06	3.27	**2.82**
Mean	**1.33**	**1.45**	**1.57**		**1.62**	**1.85**	**2.11**		**1.80**	**2.18**	**2.93**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N^{NS} or S*	0.17	0.52	15, 52, 0	M or N or S	0.07	0.20	0, 0, 0
Two factor effects	M × N, M × S, N × S	0.31	NS	49, 27, 31	M × N^{NS}, M × S^{NS}, N × S*	0.11	0.34	24, 12, 12
Three factor effects (3 FE)	MNS, MN^2S	0.53	NS	52, 24	MNS, MN^2S	0.20	NS	14, 50
3 FE confounded	MNS^2, MN^2S^2	0.53	NS	60, 93	MNS^2, MN^2S^2	0.20	NS	37, 65
CV (%)	31.99				15.69			

1.83 μg g^{-1} and 2.20 μg g^{-1} by N_{90}. The corresponding values in the first year were 2.01, 2.21, and 2.29 μg g^{-1}, respectively.

4.2.6.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen were highly significant in both the years. A step wise increase in the chlorophyll a content was observed with 1.67 μg g^{-1} in S_0, 2.28 μg g^{-1} in S_{15} and 2.56 μg g^{-1} in S_{30}, latter two were at par, in the first year. The corresponding values in the second year were 1.45, 1.86 and 2.31 μg g^{-1}.

4.2.6.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were significant at 24, 12 and 2 %, respectively in the second year. The highest chlorophyll content was observed with M_2N_{90} (2.66 μg g^{-1}), M_2S_{30} (2.82 μg g^{-1}) and $N_{90}S_{30}$ (2.93 μg g^{-1}).

4.2.6.3 Three factor interactions

Three factor interaction MNS was significant at 14 % level of significance in the second year. $M_2N_{90}S_{30}$ significantly increased the chlorophyll 'a' content with 3.48 over other treatments and the lowest chlorophyll 'a' content was observed with $M_1N_{45}S_0$ (0.99 μg g^{-1}).

4.2.7 Chlorophyll 'b' content of rice at tillering stage

4.2.7.1 Main effects

4.2.7.1.1 Effect of organic manures

The effect of organic manures on chlorophyll 'b' content of rice at tillering stage averaged over nitrogen and sulphur was significant at 2 % level of significance in the first year (Table 4.11). No organic manure (1.40 μg g^{-1}) was at par with straw incorporation (1.74 μg g^{-1}), which in turn at par with cow dung application (1.87 μg g^{-1}).

Table 4.11. Effect of manurial management on the chlorophyll ‘b’ content (µg g^{-1}) of rice at tillering stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.41	1.01	1.78	**1.40**	1.05	1.48	1.76	**1.43**
Straw application (M_1)	1.40	1.62	2.20	**1.74**	1.43	1.27	1.72	**1.47**
Cow dung (M_2)	1.26	2.37	1.99	**1.87**	1.29	2.01	1.83	**1.71**
Mean	**1.36**	**1.67**	**1.99**		**1.26**	**1.59**	**1.77**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.13	1.42	1.65	**1.40**	1.25	1.42	1.61	**1.43**
Straw application (M_1)	1.29	1.72	2.21	**1.74**	1.23	1.42	1.77	**1.47**
Cow dung (M_2)	1.59	1.96	2.07	**1.87**	1.29	1.72	2.12	**1.71**
Mean	**1.34**	**1.70**	**1.97**		**1.26**	**1.52**	**1.84**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.01	1.32	1.75	**1.36**	0.96	1.28	1.53	**1.26**
N_{45}	1.56	1.52	1.92	**1.67**	1.28	1.52	1.96	**1.59**
N_{90}	1.45	2.27	2.25	**1.99**	1.53	1.76	2.01	**1.77**
Mean	**1.34**	**1.70**	**1.97**		**1.26**	**1.52**	**1.84**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.14	0.82	1.43	**1.13**	1.31	0.90	2.03	**1.42**	1.77	1.31	1.87	**1.65**
M_1	0.89	1.46	1.53	**1.29**	1.48	1.51	2.18	**1.72**	1.84	1.89	2.89	**2.21**
M_2	1.00	2.39	1.38	**1.59**	1.16	2.14	2.59	**1.96**	1.63	2.58	2.00	**2.07**
Mean	**1.01**	**1.56**	**1.45**		**1.32**	**1.52**	**2.27**		**1.75**	**1.92**	**2.25**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.83	1.40	1.53	**1.25**	0.98	1.44	1.83	**1.42**	1.33	1.59	1.92	**1.61**
M_1	1.05	1.09	1.53	**1.23**	1.51	1.14	1.62	**1.42**	1.72	1.59	2.01	**1.77**
M_2	0.99	1.36	1.54	**1.29**	1.34	1.97	1.84	**1.72**	1.54	2.71	2.12	**2.12**
Mean	**0.96**	**1.28**	**1.53**		**1.28**	**1.52**	**1.76**		**1.53**	**1.96**	**2.01**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.11	0.33	2, 0, 0	M^{NS} or N* or S*	0.13	0.39	30, 4, 2
Two factor effects	M × N*, M × S^{NS}, N × S^{NS}	0.19	0.57	1, 22, 28	M × N, M × S, N × S	0.23	NS	40, 90, 99
Three factor effects (3 FE)	MNS, MN^2S	0.33	NS	39, 56	MNS, MN^2S	0.40	NS	82, 72
3 FE confounded	MNS^2, MN^2S^2	0.33	NS	75, 53	MNS^2, MN^2S^2	0.40	NS	95, 81
CV (%)	26.66				24.11			

4.2.7.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was highly significant in the first year and 4 % level of significance in the second year. In the first year, N_0 (1.36 µg g^{-1}) was at par with N_{45} (1.67 µg g^{-1}), which in turn at par with N_{90} (1.99 µg g^{-1}). A similar trend was observed in the second year also and the corresponding values were 1.26, 1.59 and 1.77 µg g^{-1}, respectively.

4.2.7.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen were highly significant in both the years. In the first year, a step wise increase in the chlorophyll ‘b’ content was observed with 1.34 in S_0, 1.70 in S_{15} and 1.97 in S_{30}, the latter two being at par. In the second year, S_0 (1.26 µg g^{-1}) was at par with S_{15} (1.52 µg g^{-1}), which in turn at par with S_{30} (1.84 µg g^{-1}).

4.2.7.2 Two factor interaction effects

Two factor interaction M × N was highly significant in the first year. The highest chlorophyll content of 2.37 µg g^{-1} was observed with M_2N_{45}, which was at par with 2.20 µg g^{-1} of M_1N_{90}.

Three factor interactions were not significant in both the years.

4.2.8 Chlorophyll ‘a’ content of rice at PI stage

4.2.8.1 Main effects

4.2.8.1.1 Effect of organic manures

The effect of organic manures on chlorophyll ‘a’ content of rice at PI stage averaged over nitrogen and sulphur was significant at 2 % level of significance in the second year (Table 4.12). Cow dung application significantly increased the chlorophyll ‘a’ content to 1.66 µg g^{-1} compared to no organic manure (1.29 µg g^{-1}), which was in turn at par with straw incorporation (1.36 µg g^{-1}).

Table 4.12. Effect of manurial management on the chlorophyll ‘a’ content (µg g^{-1}) of rice at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.31	1.24	1.33	**1.30**	1.21	1.16	1.49	**1.29**
Straw application (M_1)	1.39	1.37	1.48	**1.41**	1.11	1.43	1.53	**1.36**
Cow dung (M_2)	1.24	1.43	1.58	**1.42**	1.36	1.55	2.07	**1.66**
Mean	**1.31**	**1.35**	**1.46**		**1.22**	**1.38**	**1.70**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.98	1.34	1.56	**1.30**	1.18	1.38	1.31	**1.29**
Straw application (M_1)	1.36	1.36	1.53	**1.41**	1.25	1.33	1.49	**1.36**
Cow dung (M_2)	1.58	1.33	1.34	**1.42**	0.98	1.84	2.16	**1.66**
Mean	**1.31**	**1.34**	**1.48**		**1.14**	**1.51**	**1.65**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.29	1.30	1.36	**1.31**	0.98	1.28	1.41	**1.22**
N_{45}	1.27	1.29	1.49	**1.35**	1.12	1.41	1.61	**1.38**
N_{90}	1.37	1.44	1.58	**1.46**	1.30	1.85	1.94	**1.70**
Mean	**1.31**	**1.34**	**1.48**		**1.14**	**1.51**	**1.65**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.94	0.92	1.09	**0.98**	1.39	1.24	1.40	**1.34**	1.61	1.57	1.50	**1.56**
M_1	1.29	1.36	1.41	**1.36**	1.35	1.30	1.43	**1.36**	1.52	1.46	1.60	**1.53**
M_2	1.63	1.52	1.59	**1.58**	1.15	1.34	1.50	**1.33**	0.95	1.43	1.65	**1.34**
Mean	**1.29**	**1.27**	**1.37**		**1.30**	**1.29**	**1.44**		**1.36**	**1.49**	**1.58**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.17	1.05	1.32	**1.18**	1.31	1.15	1.68	**1.38**	1.15	1.29	1.48	**1.31**
M_1	1.03	1.30	1.42	**1.25**	1.28	1.31	1.40	**1.33**	1.02	1.68	1.77	**1.49**
M_2	0.75	1.02	1.18	**0.98**	1.26	1.78	2.47	**1.84**	2.07	1.86	2.57	**2.16**
Mean	**0.98**	**1.12**	**1.30**		**1.28**	**1.41**	**1.85**		**1.41**	**1.61**	**1.94**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.06	NS	34, 25, 18	M or N or S	0.09	0.27	2, 0, 0
Two factor effects	$M \times N^{NS}$, $M \times S^{NS}$, $N \times S^{NS}$	0.11	0.33	65, 2, 96	$M^{NS} \times N$, $M \times S$*, $N \times S^{NS}$	0.16	0.47	53, 2, 92
Three factor effects (3 FE)	MNS, MN^2S	0.19	NS	53, 72	MNS, MN^2S	0.28	NS	96, 29
3 FE confounded	MNS^2, MN^2S^2	0.19	NS	85, 64	MNS^2, MN^2S^2	0.28	NS	43, 48
CV (%)	18.89				26.67			

4.2.8.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was highly significant in the second year. N_{90} registered the highest chlorophyll a content at PI stage with 1.70 µg g^{-1}, whereas N_0 (1.22 µg g^{-1}) was at par with (1.38 µg g^{-1}) N_{45}.

4.2.8.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen were significant at 18 % level in the first year and highly significant in the second year. In the second year, a step wise increase in the chlorophyll 'a' content was observed with 1.14 µg g^{-1} in S_0, with 1.51 µg g^{-1} in S_{15} and 1.65 µg g^{-1} with S_{30}, latter two were at par also.

4.2.8.2 Two factor interaction effects

Two factor interaction M × S was highly significant in both the years. In the first year the lowest chlorophyll 'a' content of 0.98 was observed with N_0S_0. Except this treatment all other treatments registered similar chlorophyll 'a' content at PI stage. But in the second year M_2S_{30} registered the highest chlorophyll 'a' content of 2.16 µg g^{-1}.

Three factor interactions were not significant in both the years.

4.2.9 Chlorophyll 'b' content of rice at PI stage

4.2.9.1 Main effects

4.2.9.1.1 Effect of organic manures

The effect of organic manures on chlorophyll 'b' content of rice at PI stage averaged over nitrogen and sulphur was significant at 14 % level in the second year (Table 4.13). The highest chlorophyll 'b' content of 1.25 µg g^{-1} was observed with cow dung application.

Table 4.13. Effect of manurial management on the chlorophyll ‘b’ content (µg g^{-1}) of rice at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.00	0.89	0.97	**0.96**	0.91	0.91	1.25	**1.02**
Straw application (M_1)	0.94	1.00	1.14	**1.02**	0.91	1.03	1.41	**1.12**
Cow dung (M_2)	0.88	0.99	1.11	**0.99**	0.96	1.23	1.57	**1.25**
Mean	**0.94**	**0.96**	**1.07**		**0.93**	**1.06**	**1.41**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.76	0.92	1.19	**0.96**	0.86	1.06	1.15	**1.02**
Straw application (M_1)	0.92	0.96	1.19	**1.02**	0.78	1.31	1.26	**1.12**
Cow dung (M_2)	0.83	0.94	1.20	**0.99**	0.93	1.28	1.55	**1.25**
Mean	**0.84**	**0.94**	**1.19**		**0.85**	**1.22**	**1.32**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.74	0.86	1.21	**0.94**	0.65	0.94	1.18	**0.93**
N_{45}	0.78	0.91	1.19	**0.96**	0.76	1.23	1.18	**1.06**
N_{90}	0.98	1.06	1.17	**1.07**	1.16	1.48	1.60	**1.41**
Mean	**0.84**	**0.94**	**1.19**		**0.85**	**1.22**	**1.32**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.74	0.62	0.92	**0.76**	0.95	0.79	1.02	**0.92**	1.31	1.27	0.98	**1.19**
M_1	0.88	0.80	1.07	**0.92**	0.86	1.01	1.02	**0.96**	1.06	1.18	1.32	**1.19**
M_2	0.61	0.93	0.96	**0.83**	0.76	0.92	1.14	**0.94**	1.26	1.13	1.23	**1.20**
Mean	**0.74**	**0.78**	**0.98**		**0.86**	**0.91**	**1.06**		**1.21**	**1.19**	**1.17**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.76	0.82	0.99	**0.86**	0.95	0.82	1.41	**1.06**	1.02	1.08	1.36	**1.15**
M_1	0.69	0.67	0.98	**0.78**	1.01	1.40	1.53	**1.31**	1.02	1.04	1.74	**1.26**
M_2	0.51	0.78	1.50	**0.93**	0.86	1.47	1.50	**1.28**	1.50	1.43	1.70	**1.55**
Mean	**0.65**	**0.76**	**1.16**		**0.94**	**1.23**	**1.48**		**1.18**	**1.18**	**1.60**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N^{NS} or S*	0.06	0.18	74, 28, 0	M^{NS} or N* or S*	0.07	0.22	14, 0, 0
Two factor effects	M × N, M × S, N × S	0.10	NS	74, 97, 70	M × N, M × S, N × S	0.13	NS	84, 59, 88
Three factor effects (3 FE)	MNS, MN^2S	0.18	NS	91, 21	MNS, MN^2S	0.23	NS	48, 74
3 FE confounded	MNS^2, MN^2S^2	0.18	NS	68, 50	MNS^2, MN^2S^2	0.23	NS	78, 32
CV (%)	24.44				26.82			

4.2.9.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was highly significant in the second year. A step wise increase in the chlorophyll b content was observed with N_0, N_{45} and N_{90} and the corresponding values were 0.93, 1.06 and 1.41 µg g^{-1}, respectively.

4.2.9.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen were highly significant in both the years. In the first year, a step wise increase in the chlorophyll b content was observed with 0.84 µg g^{-1} in S_0, with 0.94 µg g^{-1} in S_{15} and 1.19 µg g^{-1} in S_{30}. A similar effect was observed in the second year also and the corresponding values were 0.85, 1.22 and 1.32 µg g^{-1}, respectively.

Two factor and three factor interaction effects were not significant in both the years.

4.2.10 Dry matter production at tillering stage

4.2.10.1 Main effects

4.2.10.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur levels at tillering stage was significant at 6 % and 20 % levels of significance in the first and second years, respectively (Table 4.14). The straw incorporation treatments reduced the dry matter production (3840 kg ha^{-1} in the first year and 3896 kg ha^{-1} in the second year) at tillering stage when compared to no manure application (4150 kg ha^{-1} in the first year and 3924 kg ha^{-1} in the second year) and the cow dung application (4222 kg ha^{-1} in the first year and 4229 kg ha^{-1} in the second year).

Table 4.14. Effect of manurial management on the dry matter production (kg ha^{-1}) of rice at tillering stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	3613	4388	4450	**4150**	3604	3854	4313	**3924**
Straw application (M_1)	3563	3792	4167	**3840**	3500	3979	4208	**3896**
Cow dung (M_2)	4104	4104	4458	**4222**	4021	4313	4354	**4229**
Mean	**3760**	**4094**	**4358**		**3708**	**4049**	**4292**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	3638	4263	4550	**4150**	3417	3854	4500	**3924**
Straw application (M_1)	3458	4021	4042	**3840**	3479	3813	4396	**3896**
Cow dung (M_2)	3875	4063	4729	**4222**	3625	4313	4750	**4229**
Mean	**3657**	**4115**	**4440**		**3507**	**3993**	**4549**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	3358	3733	4188	**3760**	3229	3438	4458	**3708**
N_{45}	3754	4213	4317	**4094**	3646	4229	4271	**4049**
N_{90}	3858	4400	4817	**4358**	3646	4313	4917	**4292**
Mean	**3657**	**4115**	**4440**		**3507**	**3993**	**4549**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	3138	3825	3950	**3638**	3638	4638	4513	**4263**	4063	4700	4888	**4550**
M_1	3313	3563	3500	**3458**	3625	3875	4563	**4021**	3750	3938	4438	**4042**
M_2	3625	3875	4125	**3875**	3938	4125	4125	**4063**	4750	4313	5125	**4729**
Mean	**3358**	**3754**	**3858**		**3733**	**4213**	**4400**		**4188**	**4317**	**4817**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	3250	3250	3750	**3417**	3438	3875	4250	**3854**	4125	4438	4938	**4500**
M_1	2938	3688	3813	**3479**	3250	4125	4063	**3813**	4313	4125	4750	**4396**
M_2	3500	4000	3375	**3625**	3625	4688	4625	**4313**	4938	4250	5063	**4750**
Mean	**3229**	**3646**	**3646**		**3438**	**4229**	**4313**		**4458**	**4271**	**4917**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	111.96	328.38	6, 1, 1	M^{NS} or N* or S*	139.75	409.89	20, 3, 1
Two factor effects	M × N, M × S, N × S	193.92	NS	38, 51, 82	M × N, M × S, N × S	242.05	NS	88, 96, 33
Three factor effects (3 FE)	MNS, MN^2S	335.87	NS	82, 92	MNS, MN^2S	419.24	NS	78, 66
3 FE confounded	MNS^2, MN^2S^2	335.87	NS	98, 30	MNS^2, MN^2S^2	419.24	NS	100, 56
CV (%)	8.54				14.28			

4.2.10.1.2 Effect of nitrogen

The nitrogen treatments averaged over organic manure and sulphur was significant in first and second years. A step wise increase in dry matter production was noticed with the increasing levels of nitrogen. In the first year the treatments N @ 45 kg ha^{-1} (4094 kg ha^{-1}) was at par with N @ 90 kg ha^{-1} (4358 kg ha^{-1}). But in the second year, no nitrogen application (3708 kg ha^{-1}) was at par with N @ 45 kg ha^{-1} which was in turn at par with N @ 90 kg ha^{-1} (4292 kg ha^{-1}).

4.2.10.1.3 Effect of sulphur

The effects of sulphur application averaged over organic manure and nitrogen application was significant in both the years. Dry matter production was increased with the increasing levels of sulphur application in first and second years. But in the first year S @ 15 kg ha^{-1} (4115 kg ha^{-1}) and S @ 30 kg ha^{-1} (4440 kg ha^{-1}) were statistically at par and superior to no sulphur application (3657 kg ha^{-1}).

4.2.10.2 Two factor interaction effects

The two factor interactions such as M × N, M × S and N × S were not significant in first and second years. The dry matter production was found to be decreased when straw incorporation with or without nitrogen and sulphur at different levels compared to no organics and cow dung application with similar combination of N and S. Treatments receiving sulphur at higher levels resulted in highest dry matter production both in the first (4817 kg ha^{-1}) and second year (4917 kg ha^{-1}).

4.2.10.3 Three factor interactions

Three factor interactions and the confounded effects were not significant in first and second years. However, the highest dry matter production was observed in treatments receiving cow dung application combined with N_{90} with S_{15} or S_{30}, in both the years.

4.2.11 Dry matter production at PI stage

4.2.11.1 Main effects

4.2.11.1.1 Effect of organic manures

The effect of organic manure treatments such as no manure application, straw incorporation and cow dung application on the dry matter production at PI stage averaged over nitrogen and sulphur was significant in the first and second years (Table 4.15). In the first year no organic manure and straw incorporation treatments were statistically at par. The highest dry matter production of 8306 kg ha^{-1} was recorded under the application of cow dung. In the second year cow dung application (7951 kg ha^{-1}) and straw incorporation (7972 kg ha^{-1}) was statistically at par and significantly increased the DMP at PI stage over no manure application.

4.2.11.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur were highly significant in first year, whereas it was significant only at 9 % level of significance in the second year. In the first year the highest DMP was observed with the application of N @ 45 kg ha^{-1} (8021 kg ha^{-1}). The other treatments no nitrogen and N @ 90 kg ha^{-1} were statistically at par. A step wise increase in the DMP was observed with the application no nitrogen (7319 kg ha^{-1}), N @ 45 kg ha^{-1} (7722 kg ha^{-1}) and N @ 90 kg ha^{-1} (7785 kg ha^{-1}) in the second year.

4.2.11.1.3 Effect of sulphur

The effect of graded doses of sulphur was significant in first and second years. In the first year no sulphur application and S @ 30 kg ha^{-1} were statistically at par and S @ 30 kg ha^{-1} was in turn at par with S @ 15 kg ha^{-1}. In the second year also S @ 15 kg ha^{-1} (7653 kg ha^{-1}) and S @ 30 kg ha^{-1} (8278 kg ha^{-1}) were statistically at par and significantly increased the dry matter production over no sulphur.

Table 4.15. Effect of manurial management on the dry matter production (kg ha^{-1}) of rice at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	6750	7125	7063	**6979**	7250	7104	6354	**6903**
Straw application (M_1)	6917	8375	7219	**7503**	7333	8021	8563	**7972**
Cow dung (M_2)	8313	8563	8042	**8306**	7375	8042	8438	**7951**
Mean	**7326**	**8021**	**7441**		**7319**	**7722**	**7785**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	6458	7104	7375	**6979**	5729	7271	7708	**6903**
Straw application (M_1)	7521	8021	6969	**7503**	7292	8000	8625	**7972**
Cow dung (M_2)	7667	8396	8854	**8306**	7667	7688	8500	**7951**
Mean	**7215**	**7840**	**7733**		**6896**	**7653**	**8278**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	6708	7479	7792	**7326**	6854	7438	7667	**7319**
N_{45}	7354	8208	8500	**8021**	6667	8146	8354	**7722**
N_{90}	7583	7833	6906	**7441**	7167	7375	8813	**7785**
Mean	**7215**	**7840**	**7733**		**6896**	**7653**	**8278**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6125	6563	6688	**6458**	6938	7313	7063	**7104**	7188	7500	7438	**7375**
M_1	6500	7750	8313	**7521**	6938	8500	8625	**8021**	7313	8875	8938	**8375**
M_2	7500	7750	7750	**7667**	8563	8813	7813	**8396**	8875	9125	8563	**8854**
Mean	**6708**	**7354**	**7583**		**7479**	**8208**	**7833**		**7792**	**8500**	**8313**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6750	5438	5000	**5729**	7125	8250	6438	**7271**	7875	7625	7625	**7708**
M_1	6500	7188	8188	**7292**	7500	8000	8500	**8000**	8000	8875	9000	**8625**
M_2	7313	7375	8313	**7667**	7688	8188	7188	**7688**	7125	8563	9813	**8500**
Mean	**6854**	**6667**	**7167**		**7438**	**8146**	**7375**		**7667**	**8354**	**8813**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	181.76	533.33	1, 3, 1	M* or N^{NS} or S*	255.56	749.57	1, 9, 1
Two factor effects	M × N, M × S, N × S	314.82	NS	66, 99, 89	M × N, M × S, N × S	442.64	NS	17, 54, 44
Three factor effects (3 FE)	MNS, MN^2S	545.29	NS	89, 98	MNS, MN^2S	766.67	NS	76, 18
3 FE confounded	MNS^2, MN^2S^2	545.29	NS	79, 62	MNS^2, MN^2S^2	766.67	NS	55, 94
CV (%)	6.79				13.90			

4.2.11.2 Two factor interaction effects

The two factor interactions such as M × N, M × S and N × S was not significant in first and second years, however a significant effect at 17 % level of significance was observed for M × N interaction in the second year. Though N_{45} resulted in similar dry matter production under straw incorporation and cow dung, at N_{90}, higher dry matter production was observed with straw incorporation.

In the first year, cow dung applied in combination with S @ 30 kg ha^{-1} registered the highest dry matter production of 8854 kg ha^{-1}. But in the second year the same treatment resulted in a lower dry matter production of 8500 kg ha^{-1} compared to straw incorporation with S @ 30 kg ha^{-1} (8625 kg ha^{-1}). A step wise increase in the dry matter production was observed with the increasing levels of sulphur with all the sources of organic manures in the second year.

In the first year, the treatment N_{45} + S_{30} increased the dry matter production to 8500 kg ha^{-1} compared to N_{45} + no S (7354 kg ha^{-1}). In the second year, the highest dry matter production was registered with the application of nitrogen and sulphur at higher level. In both the years a step wise increase in the DMP was seen with the increasing levels of sulphur with all the levels of nitrogen except in the case of N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1} (6906 kg ha^{-1}) in first year. This treatment reduced the DMP to 23.08 % when compared to N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} and 13.42 % when compared to N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1}.

4.2.11.3 Three factor interactions

Three factor interactions were not significantly different in the first and second years. In the first year, the highest DMP of 9125 kg ha^{-1} was registered with the application of cow dung + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1}. The mean increase in the DMP at panicle initiation due to this treatment over cow dung + N @ 45 kg ha^{-1} + no sulphur was 17.74 %. In the second year the highest DMP of 9813 kg ha^{-1} was observed with the application of cow dung + N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}. In both the years, when no organics and no sulphur were applied with different levels of nitrogen, drastic reduction in the DMP was observed.

4.2.12 Total dry matter production of rice

4.2.12.1 Main effects

4.2.12.1.1 Effect of organic manures

Effect of organic manures on total dry matter production averaged over nitrogen and sulphur was significant only in the first year (Table 4.16). Straw incorporation significantly increased the total DMP to 12.46 t ha^{-1} followed by cow dung application with 11.65 t ha^{-1} and no organic manures with 11.05 t ha^{-1}.

4.2.12.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant in both the years. In the first year, N_0 registered the total DMP of 10.06 t ha^{-1} which increased to 11.98 t ha^{-1} at N_{45} and to 13.12 t ha^{-1} at N_{90}. In the second year also a similar trend was observed, however, N_{45} (13.42 t ha^{-1}) was at par with N_{90} (13.90 t ha^{-1}).

4.2.12.1.3 Effect of sulphur

The effect of sulphur was also similar to nitrogen. A stepwise increase in the total DMP was observed between S_0, S_{15} and S_{30} with 10.19, 12.28 and 12.69 t ha^{-1}, respectively. A similar trend was observed in the second year also.

4.2.12.2 Two factor interaction effects

Two factor interactions such as M × S and N × S were highly significant in the first year. Under S_{30}, straw incorporation significantly increased the total DMP to 13.65 t ha^{-1} over cow dung application (12.21 t ha^{-1}) and no organic manures (12.20 t ha^{-1}).

Table 4.16. Effect of manurial management on the total dry matter production (t ha^{-1}) of rice

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	9.18	11.47	12.49	**11.05**	10.91	13.78	13.69	**12.79**
Straw application (M_1)	11.07	12.57	13.74	**12.46**	11.19	13.31	14.15	**12.88**
Cow dung (M_2)	9.92	11.91	13.12	**11.65**	11.65	13.19	13.86	**12.90**
Mean	**10.06**	**11.98**	**13.12**		**11.25**	**13.42**	**13.90**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	9.00	11.94	12.20	**11.05**	10.67	13.55	14.16	**12.79**
Straw application (M_1)	11.06	12.68	13.65	**12.46**	11.02	13.57	14.06	**12.88**
Cow dung (M_2)	10.51	12.23	12.21	**11.65**	10.72	13.23	14.76	**12.90**
Mean	**10.19**	**12.28**	**12.69**		**10.80**	**13.45**	**14.32**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	8.78	10.38	11.01	**10.06**	9.39	11.75	12.61	**11.25**
N_{45}	10.21	12.73	13.00	**11.98**	11.54	13.94	14.79	**13.42**
N_{90}	11.58	13.72	14.05	**13.12**	11.47	14.66	15.58	**13.90**
Mean	**10.19**	**12.28**	**12.69**		**10.80**	**13.45**	**14.32**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	7.20	8.97	10.84	**9.00**	10.08	12.38	13.35	**11.94**	10.27	13.06	13.28	**12.20**
M_1	10.33	11.17	11.69	**11.06**	11.04	12.73	14.27	**12.68**	11.85	13.82	15.28	**13.65**
M_2	8.83	10.50	12.20	**10.51**	10.03	13.09	13.56	**12.23**	10.92	12.13	13.59	**12.21**
Mean	**8.78**	**10.21**	**11.58**		**10.38**	**12.73**	**13.72**		**11.01**	**13.00**	**14.05**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	8.33	11.52	12.17	**10.67**	11.61	14.74	14.32	**13.55**	12.80	15.07	14.59	**14.16**
M_1	9.87	11.93	11.26	**11.02**	11.87	13.76	15.08	**13.57**	11.82	14.24	16.12	**14.06**
M_2	9.98	11.18	10.98	**10.72**	11.77	13.34	14.58	**13.23**	13.20	15.05	16.03	**14.76**
Mean	**9.39**	**11.54**	**11.47**		**11.75**	**13.94**	**14.66**		**12.61**	**14.79**	**15.58**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.10	0.30	0, 0, 0	M^{NS} or N* or S*	0.27	0.79	96, 0, 0
Two factor effects	M × N^{NS}, M × S*, N × S*	0.18	0.51	23, 0, 0	M × N, M × S, N × S	0.46	NS	63, 75, 83
Three factor effects (3 FE)	MNS, MN^2S	0.30	NS	10, 8	MNS, MN^2S	0.81	NS	23, 63
3 FE confounded	$MNS^{2\ NS}$, MN^2S^2 *	0.30	0.89	40, 1	MNS^2, MN^2S^2	0.81	NS	81, 92
CV (%)	4.90				7.82			

But under S_{15}, all the organic manure treatments were at par. The total DMP was 13.72 t ha^{-1} at $N_{90}S_{15}$ which was at par with 14.05 t ha^{-1} at $N_{90}S_{30}$.

4.2.12.3 Three factor interaction effects

Three factor interactions such as MNS at 10 % level, MN^2S at 8 % level and MN^2S^2 at 1 % level were significant in the first year. The highest total DMP of 15.28 t ha^{-1} was observed with straw incorporation + N_{90} + S_{30}. Under S_{15} and S_{30}, straw incorporation + N_{90} significantly increased the total DMP production and the corresponding values were 14.27 and 15.28 t ha^{-1}, respectively.

4.2.13 Nitrogen content of plant at tillering stage

4.2.13.1 Main effects

4.2.13.1.1 Effect of organic manures

The effect of different sources of organic manures namely no organics, straw incorporation and cow dung application on the plant N content was highly significant in the first year and at 8 % level of significance in the second year (Table 4.17). In both the years, cow dung application resulted in the highest plant N content, 2.21 % in the first year and 2.77 % in the second year. The treatments no organics and straw incorporation resulted in lower N content of 1.79 % and 1.99 % respectively in first year and 2.50 % and 2.41 % respectively in the second year.

4.2.13.1.2 Effect of nitrogen

The effect of nitrogen application averaged over organic manure and sulphur treatments was significant in first and second years. In first and second years N @ 90 kg ha^{-1} increased the plant N content over the other nitrogen levels. The mean increase in the nitrogen content from N_{45} to N_{90} was 16 % in the first year, and 8 % in the second year. In the second year, the treatments N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1}

Table 4.17. Effect of manurial management on the nitrogen content (%) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.52	1.74	2.10	**1.79**	2.20	2.47	2.82	**2.50**
Straw application (M_1)	1.52	1.99	2.46	**1.99**	1.98	2.49	2.77	**2.41**
Cow dung (M_2)	2.03	2.17	2.42	**2.21**	2.38	2.92	3.00	**2.77**
Mean	**1.69**	**1.96**	**2.33**		**2.18**	**2.63**	**2.86**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.62	1.71	2.03	**1.79**	2.36	2.38	2.75	**2.50**
Straw application (M_1)	1.82	2.00	2.15	**1.99**	2.18	2.52	2.54	**2.41**
Cow dung (M_2)	1.93	2.16	2.53	**2.21**	2.33	2.89	3.08	**2.77**
Mean	**1.79**	**1.96**	**2.24**		**2.29**	**2.59**	**2.79**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.50	1.51	2.07	**1.69**	1.94	2.31	2.31	**2.18**
N_{45}	1.75	1.89	2.26	**1.96**	2.28	2.57	3.03	**2.63**
N_{90}	2.13	2.47	2.39	**2.33**	2.65	2.91	3.03	**2.86**
Mean	**1.79**	**1.96**	**2.24**		**2.29**	**2.59**	**2.79**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.49	1.46	1.90	**1.62**	1.38	1.60	2.15	**1.71**	1.70	2.16	2.24	**2.03**
M_1	1.23	1.88	2.35	**1.82**	1.43	1.96	2.60	**2.00**	1.90	2.12	2.43	**2.15**
M_2	1.76	1.90	2.12	**1.93**	1.71	2.12	2.65	**2.16**	2.60	2.49	2.49	**2.53**
Mean	**1.50**	**1.75**	**2.13**		**1.51**	**1.89**	**2.47**		**2.07**	**2.26**	**2.39**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	2.12	2.30	2.66	**2.36**	2.23	2.24	2.66	**2.38**	2.24	2.87	3.14	**2.75**
M_1	1.87	2.02	2.65	**2.18**	1.97	2.59	2.99	**2.52**	2.09	2.86	2.66	**2.54**
M_2	1.82	2.52	2.64	**2.33**	2.73	2.87	3.07	**2.89**	2.59	3.36	3.29	**3.08**
Mean	**1.94**	**2.28**	**2.65**		**2.31**	**2.57**	**2.91**		**2.31**	**3.03**	**3.03**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.07	0.22	0, 0, 0	M^{NS} or N* or S*	0.11	0.32	8, 1, 2
Two factor effects	M × N, M × S, N × S	0.13	NS	36, 85, 21	M × N, M × S, N × S	0.19	NS	92, 59, 74
Three factor effects (3 FE)	MNS, MN^2S	0.22	NS	18, 81	MNS, MN^2S	0.33	NS	49, 89
3 FE confounded	MNS^2, MN^2S^2	0.22	NS	63, 21	MNS^2, MN^2S^2	0.33	NS	73, 31
CV (%)	17.81				19.70			

were statistically at par and increased the nitrogen content over no nitrogen application.

4.2.13.1.3 Effect of sulphur

The different levels of sulphur averaged over organic manures and nitrogen was significant in both the years. In first year, there was an increase of 12.5 % in the plant nitrogen content from S_{15} to S_{30} and the same was in the 7.16 % in the second year. In the first year no sulphur application (1.79 %) and S @ 15 kg ha^{-1} (1.96 %) were statistically at par. In the second year, the plant N content in no sulphur application (2.29 %) was at par with S @ 15 kg ha^{-1} (2.59 %) which was in turn at par with S @ 30 kg ha^{-1} (2.79 %).

4.2.13.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were not significant in first and second years. However, the lowest N content of 1.52 in M_0N_0 increased to 2.46 % in M_1N_2 in the first year, the corresponding values were 1.98 % in M_1N_0 and 3.00 % in M_2N_2. The plant N content was the lowest with 1.62 % in M_0S_0 which increased to 2.53 % in M_2S_2 in the first year. The corresponding values were 2.18 % in M_1S_0 and 3.08 % in M_2S_2 in the second year.

In first year, N_{90} + S_{15} recorded the highest plant nitrogen content of 2.47 % at tillering stage. But in the second year, the treatments N_{90} + S_{30} and N_{45} + S_{30} registered the highest but similar plant N content. The other treatments no N + S_{15} and no N + S_{30} resulted similar but lower nitrogen content of 2.31 %.

4.2.13.3 Three factor interactions

The three factor interactions such as MNS, MN^2S, MNS^2 and MN^2S^2 were not significant in both the years. In the first year, cow dung applied with N_2S_1 (2.65 %) recorded the highest content of nitrogen at tillering stage, but in the second year cow dung applied with N_1S_2 (3.36 %) resulted in the highest plant nitrogen content at tillering stage. In both the years, the paddy straw incorporated treatment resulted in a lower plant nitrogen content compared to cow dung applied treatment, in general. In first and second year, cow dung applied with N_2S_0 resulted in lower nitrogen content than paddy straw incorporation at same level of nitrogen and sulphur. In the first year, it was 2.12 % and 2.35 % for $M_2N_2S_0$ and $M_1N_2S_0$, respectively. In the second year, it was 2.64 % and 2.65 % for $M_2N_2S_0$ and $M_1N_2S_0$, respectively.

4.2.14 Nitrogen content of plant at PI stage

4.2.14.1 Main effects

4.2.14.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur on the plant N content at PI stage was significant in both the years (Table 4.18). Straw incorporation @ 10 t ha^{-1} increased the nitrogen content of the plant at panicle initiation in the first year (1.76 %) and second year (1.68 %). In both the years no organics and cow dung treatments were statistically at par.

4.2.14.1.2 Effect of nitrogen

The different levels of nitrogen application averaged over organic manure and sulphur was not significant in the first year but significant in the second year. In the first year nitrogen application at 0, 45 and 90 kg ha^{-1} resulted in the N content of 1.41, 1.52 and 1.61 % respectively. In the second year, the corresponding values are 1.29, 1.59 and 1.66 % respectively, latter two were at par.

4.2.14.1.3 Effect of sulphur

The effect of different levels of sulphur averaged over organic manures and nitrogen was significant only at 9 and 29 % levels of significance in first and second years. S @ 30 kg ha^{-1} increased the nitrogen content of plant to 1.71 per cent in the first year and 1.60 per cent in the second year. In the first year, mean increase in the

Table 4.18. Effect of manurial management on the nitrogen content (%) of plant at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.26	1.36	1.36	**1.33**	1.15	1.46	1.51	**1.37**
Straw application (M_1)	1.62	1.76	1.90	**1.76**	1.48	1.63	1.94	**1.68**
Cow dung (M_2)	1.36	1.43	1.57	**1.45**	1.25	1.68	1.53	**1.49**
Mean	**1.41**	**1.52**	**1.61**		**1.29**	**1.59**	**1.66**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.24	1.19	1.55	**1.33**	1.35	1.48	1.30	**1.37**
Straw application (M_1)	1.55	1.78	1.95	**1.76**	1.55	1.67	1.82	**1.68**
Cow dung (M_2)	1.29	1.43	1.64	**1.45**	1.53	1.24	1.69	**1.49**
Mean	**1.36**	**1.47**	**1.71**		**1.48**	**1.46**	**1.60**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.29	1.38	1.57	**1.41**	1.28	1.19	1.41	**1.29**
N_{45}	1.26	1.55	1.74	**1.52**	1.50	1.50	1.76	**1.59**
N_{90}	1.52	1.48	1.83	**1.61**	1.65	1.70	1.63	**1.66**
Mean	**1.36**	**1.47**	**1.71**		**1.48**	**1.46**	**1.60**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.12	1.41	1.19	**1.24**	1.26	1.27	1.05	**1.19**	1.41	1.41	1.84	**1.55**
M_1	1.55	1.33	1.76	**1.55**	1.69	1.69	1.97	**1.78**	1.62	2.26	1.97	**1.95**
M_2	1.19	1.05	1.62	**1.29**	1.19	1.69	1.41	**1.43**	1.69	1.54	1.68	**1.64**
Mean	**1.29**	**1.26**	**1.52**		**1.38**	**1.55**	**1.48**		**1.57**	**1.74**	**1.83**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.23	1.40	1.43	**1.35**	1.05	1.54	1.84	**1.48**	1.18	1.45	1.26	**1.30**
M_1	1.40	1.33	1.93	**1.55**	1.41	1.65	1.96	**1.67**	1.62	1.90	1.93	**1.82**
M_2	1.20	1.79	1.59	**1.53**	1.12	1.31	1.29	**1.24**	1.43	1.93	1.71	**1.69**
Mean	**1.28**	**1.50**	**1.65**		**1.19**	**1.50**	**1.70**		**1.41**	**1.76**	**1.63**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N^{NS} or S^{NS}	0.11	0.32	3, 46, 9	M* or N* or S^{NS}	0.07	0.19	2, 1, 29
Two factor effects	M × N, M × S, N × S	0.19	NS	99, 96, 93	M × N, M × S, N × S	0.11	NS	43, 9, 61
Three factor effects (3 FE)	MNS, MN^2S	0.33	NS	14, 80	MNS, MN^2S	0.20	NS	35, 85
3 FE confounded	MNS^2, MN^2S^2	0.33	NS	49, 68	MNS^2, MN^2S^2	0.20	NS	54, 40
CV (%)	32.15				17.79			

plant nitrogen content with S @ 30 kg ha^{-1} over S @ 15 kg ha^{-1} was 0.24, a 14 per cent increase. In the second year S @ 15 kg ha^{-1} slightly reduced the plant nitrogen content (1.46 %) compared to no sulphur application (1.48 %).

4.2.14.2 Two factor interaction effects

The two factor interactions such as organic manure × nitrogen, organic manure × sulphur and nitrogen × sulphur were not significantly different in both the years, except that a significance of 9 % level of significance for M × S in the second year. Straw incorporation with N @ 90 kg ha^{-1} gave the highest content of nitrogen in the first year (1.90 %) as well as in the second year (1.94 %). In both the years cow dung applied with N @ 90 kg ha^{-1} reduced the nitrogen content when compared to cow dung applied with N @ 45 kg ha^{-1}. Nitrogen application at 45 and 90 kg ha^{-1} under no manure treatment resulted in the same nitrogen content of 1.36 % in the first year.

Straw incorporation with S @ 30 kg ha^{-1} increased the nitrogen content in the first (1.95 %) and the second year (1.82 %) over other treatments. Sulphur applied at higher dose (S_{30}) in no organic manure treatment plots resulted in relatively low plant nitrogen content (1.30) in second year.

The N × S interactions were not significant in both the years. In the first year, N @ 90 kg ha^{-1} applied along with S @ 30 kg ha^{-1} increased the nitrogen content to 1.83 %. In the second year, N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} increased the nitrogen content to 1.76 %.

4.2.14.3 Three factor interactions

The three factor interactions were not significant in both the years, except for MNS in the first year at 14 % level of significance. Straw incorporation along with N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} gave the highest nitrogen content of 2.26 %. But in the second year , straw incorporation along with N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1} gave the highest nitrogen content of 1.96 %, When nitrogen @ 90 kg ha^{-1} was given with cow dung + S @ 15 kg ha^{-1}, the N was content found to be reduced to 1.41 % in the first year and 1.29 % in second year.

4.2.15 Phosphorus content of plant at tillering stage

4.2.15.1 Main effects

4.2.15.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant only at 16 % level of significance in the first year but significant at 4 % level of significance in the second year (Table 4.19). In both the years, phosphorus content of plant at tillering stage was increased when cow dung was applied @ 10 t ha^{-1}. In the second year, the treatment no organics (0.27 %) was at par with straw incorporation (0.29 %) which in turn was at par with cow dung application (0.32 %).

4.2.15.1.2 Effect of nitrogen

The effect of different doses of nitrogen averaged over organics and sulphur was not significant in both the years.

4.2.15.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was not significant in first year, but it was significant at 7 % level of significance in the second year. In first year S @ 15 kg ha^{-1} increased the phosphorus content of plant (0.28 %) compared to other sulphur levels. However in the second year, S @ 30 kg ha^{-1} recorded the highest percentage of phosphorus (0.31 %). In the second year the treatments S @ 15 kg ha^{-1} (0.30 %) and S @ 30 kg ha^{-1} (0.31 %) were statistically at par.

Two factor and three factor interactions were not significant in both the years.

Table 4.19. Effect of manurial management on the phosphorus content (%) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.23	0.22	0.27	**0.24**	0.28	0.25	0.29	**0.27**
Straw application (M_1)	0.24	0.30	0.28	**0.27**	0.25	0.29	0.32	**0.29**
Cow dung (M_2)	0.27	0.31	0.28	**0.29**	0.35	0.31	0.32	**0.32**
Mean	**0.25**	**0.28**	**0.28**		**0.29**	**0.28**	**0.31**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.21	0.25	0.25	**0.24**	0.26	0.29	0.28	**0.27**
Straw application (M_1)	0.26	0.30	0.26	**0.27**	0.25	0.29	0.32	**0.29**
Cow dung (M_2)	0.27	0.29	0.31	**0.29**	0.30	0.32	0.35	**0.32**
Mean	**0.25**	**0.28**	**0.27**		**0.27**	**0.30**	**0.31**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.22	0.28	0.23	**0.25**	0.25	0.30	0.32	**0.29**
N_{45}	0.26	0.29	0.28	**0.28**	0.27	0.30	0.27	**0.28**
N_{90}	0.26	0.26	0.31	**0.28**	0.28	0.30	0.35	**0.31**
Mean	**0.25**	**0.28**	**0.27**		**0.27**	**0.30**	**0.31**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.21	0.16	0.27	**0.21**	0.24	0.29	0.23	**0.25**	0.24	0.22	0.31	**0.25**
M_1	0.21	0.32	0.24	**0.26**	0.31	0.27	0.30	**0.30**	0.20	0.29	0.30	**0.26**
M_2	0.24	0.29	0.27	**0.27**	0.30	0.33	0.25	**0.29**	0.27	0.32	0.33	**0.31**
Mean	**0.22**	**0.26**	**0.26**		**0.28**	**0.29**	**0.26**		**0.23**	**0.28**	**0.31**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.29	0.20	0.29	**0.26**	0.28	0.32	0.26	**0.29**	0.26	0.24	0.33	**0.28**
M_1	0.16	0.31	0.26	**0.25**	0.29	0.27	0.31	**0.29**	0.30	0.28	0.39	**0.32**
M_2	0.30	0.31	0.31	**0.30**	0.33	0.32	0.32	**0.32**	0.41	0.29	0.34	**0.35**
Mean	**0.25**	**0.27**	**0.28**		**0.30**	**0.30**	**0.30**		**0.32**	**0.27**	**0.35**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.02	NS	16, 32, 38	M* or N^{NS} or S*	0.01	0.04	4, 29, 7
Two factor effects	M × N, M × S, N × S	0.03	NS	67, 95, 58	M × N, M × S, N × S	0.02	NS	27, 63, 24
Three factor effects (3 FE)	MNS, MN^2S	0.05	NS	46, 64	MNS, MN^2S	0.04	NS	53, 32
3 FE confounded	MNS^2, MN^2S^2	0.05	NS	37, 75	MNS^2, MN^2S^2	0.04	NS	29, 14
CV (%)	25.22				17.51			

4.2.16 Phosphorus content of plant at PI stage

4.2.16.1 Main effects

4.2.16.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant in the first year at 7 % level of significance (Table 4.20). When straw was incorporated @ 10 t ha^{-1} the plant phosphorus content at panicle initiation stage increased to 0.20 % compared to no organics (0.19 %) and cow dung application (0.19 %).

4.2.16.1.2 Effect of nitrogen

The effect of different levels of nitrogen was significant in the first year and not significant in the second year. In the first year N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} was statistically at par and increased the phosphorus content over no nitrogen. In the second year, N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} have resulted in similar phosphorus content of plant.

4.2.16.1.3 Effect of sulphur

The effect of sulphur averaged over organics and nitrogen was significant in the first year. In the first and second years, S @ 30 kg ha^{-1} resulted in the highest phosphorus content of 0.21 % and 0.20 % respectively. In the first year, no sulphur and S @ 15 kg ha^{-1} were statistically at par.

Two factor and three factor interactions were not significant in both the years.

4.2.17 Potassium content of plant at tillering stage

4.2.17.1 Main effects

4.2.17.2 Effect of organic manures

The effect of organic manures over different levels of nitrogen and sulphur in the plant K content at tillering was not significant in first and second years (Table

Table 4.20. Effect of manurial management on the phosphorus content (%) of plant at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.17	0.20	0.19	**0.19**	0.18	0.19	0.19	**0.19**
Straw application (M_1)	0.20	0.20	0.21	**0.20**	0.20	0.19	0.21	**0.20**
Cow dung (M_2)	0.17	0.21	0.19	**0.19**	0.19	0.21	0.20	**0.20**
Mean	**0.18**	**0.20**	**0.20**		**0.19**	**0.20**	**0.20**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.19	0.18	0.19	**0.19**	0.19	0.20	0.17	**0.19**
Straw application (M_1)	0.18	0.21	0.22	**0.20**	0.19	0.20	0.21	**0.20**
Cow dung (M_2)	0.17	0.18	0.21	**0.19**	0.20	0.17	0.23	**0.20**
Mean	**0.18**	**0.19**	**0.21**		**0.19**	**0.19**	**0.20**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.16	0.17	0.20	**0.18**	0.18	0.18	0.21	**0.19**
N_{45}	0.19	0.20	0.21	**0.20**	0.19	0.19	0.21	**0.20**
N_{90}	0.19	0.19	0.21	**0.20**	0.21	0.20	0.19	**0.20**
Mean	**0.18**	**0.19**	**0.21**		**0.19**	**0.19**	**0.20**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.16	0.20	0.21	**0.19**	0.16	0.21	0.18	**0.18**	0.19	0.19	0.19	**0.19**
M_1	0.18	0.18	0.19	**0.18**	0.19	0.20	0.23	**0.21**	0.22	0.21	0.22	**0.22**
M_2	0.16	0.20	0.16	**0.17**	0.17	0.19	0.18	**0.18**	0.18	0.23	0.22	**0.21**
Mean	**0.16**	**0.19**	**0.19**		**0.17**	**0.20**	**0.19**		**0.20**	**0.21**	**0.21**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.17	0.17	0.21	**0.19**	0.17	0.22	0.22	**0.20**	0.18	0.18	0.14	**0.17**
M_1	0.17	0.18	0.21	**0.19**	0.20	0.19	0.23	**0.20**	0.22	0.20	0.21	**0.21**
M_2	0.19	0.21	0.20	**0.20**	0.18	0.17	0.16	**0.17**	0.21	0.25	0.23	**0.23**
Mean	**0.18**	**0.19**	**0.21**		**0.18**	**0.19**	**0.20**		**0.21**	**0.21**	**0.19**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	0.007	0.02	7, 1, 1	M or N or S	0.07	NS	35, 59, 35
Two factor effects	M × N, M × S, N × S	0.01	NS	24, 24, 100	M × N^{NS}, M × S*, N × S^{NS}	0.01	0.04	70, 1, 52
Three factor effects (3 FE)	MNS, MN^2S	0.02	NS	54, 84	MNS, MN^2S	0.02	NS	33, 72
3 FE confounded	MNS^2, MN^2S^2	0.02	NS	8, 21	MNS^2, MN^2S^2	0.02	NS	90, 53
CV (%)	11.17				15.71			

4.21). In the first year, straw incorporation increased the potassium content of plant to 1.93 % at tillering stage. But in the second year cow dung application increased the potassium content over straw incorporation by 13.5 %.

The effect of nitrogen, sulphur and two factor interactions were not significant in both the years.

4.2.17.2 Three factor interaction effects

Three factor interactions MNS at 13 % level of significance and MNS^2 at 3 % level of significance were significant in first year. The highest K content was observed with $M_1N_{90}S_{30}$ (2.67 %). Under S_{30}, M_1N_{90} was at par with all the treatments except for M_1N_0.

4.2.18 Potassium content of plant at PI stage

4.2.18.1 Main effects

4.2.18.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was highly significant in the first year, but significant at only 20 % level of significance in the second year (Table 4.22). The mean increase in the potassium content at PI stage due to straw incorporation over cow dung application was 24.82 %. In the second year also a similar trend was observed.

4.2.18.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was not significant in both the years.

4.2.18.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was not significant in both the years.

Table 4.21. Effect of manurial management on the potassium content (%) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.60	1.90	1.96	**1.82**	1.48	1.61	1.84	**1.64**
Straw application (M_1)	1.62	2.28	1.90	**1.93**	1.75	1.40	2.06	**1.74**
Cow dung (M_2)	1.59	1.86	1.79	**1.75**	2.03	1.96	2.04	**2.01**
Mean	**1.60**	**2.01**	**1.88**		**1.75**	**1.66**	**1.98**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.46	1.87	2.12	**1.82**	1.57	1.83	1.53	**1.64**
Straw application (M_1)	1.59	2.12	2.09	**1.93**	1.37	2.07	1.77	**1.74**
Cow dung (M_2)	1.72	1.71	1.82	**1.75**	1.86	1.88	2.29	**2.01**
Mean	**1.59**	**1.90**	**2.01**		**1.60**	**1.93**	**1.86**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.19	1.84	1.78	**1.60**	1.47	1.83	1.96	**1.75**
N_{45}	1.96	1.99	2.09	**2.01**	1.53	1.82	1.61	**1.66**
N_{90}	1.61	1.88	2.16	**1.88**	1.80	2.14	2.01	**1.98**
Mean	**1.59**	**1.90**	**2.01**		**1.60**	**1.93**	**1.86**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.77	1.90	1.72	**1.46**	1.68	2.08	1.86	**1.87**	2.35	1.74	2.29	**2.12**
M_1	1.44	1.95	1.38	**1.59**	2.32	2.39	1.66	**2.12**	1.10	2.50	2.67	**2.09**
M_2	1.36	2.04	1.74	**1.72**	1.52	1.48	2.12	**1.71**	1.89	2.05	1.52	**1.82**
Mean	**1.19**	**1.96**	**1.61**		**1.84**	**1.99**	**1.88**		**1.78**	**2.09**	**2.16**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.40	1.44	1.85	**1.57**	1.73	2.07	1.69	**1.83**	1.31	1.31	1.98	**1.53**
M_1	0.97	1.27	1.88	**1.37**	2.09	1.67	2.46	**2.07**	2.18	1.28	1.85	**1.77**
M_2	2.04	1.89	1.65	**1.86**	1.66	1.73	2.26	**1.88**	2.39	2.26	2.22	**2.29**
Mean	**1.47**	**1.53**	**1.80**		**1.83**	**1.82**	**2.14**		**1.96**	**1.61**	**2.01**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.16	NS	71, 19, 17	M or N or S	0.16	NS	37, 36, 34
Two factor effects	M × N, M × S, N × S	0.27	NS	92, 80, 79	M × N, M × S, N × S	0.28	NS	82, 57, 96
Three factor effects (3 FE)	MNS, MN^2S	0.47	NS	13, 46	MNS, MN^2S	0.48	NS	78, 82
3 FE confounded	MNS^2 *, $MN^2S^{2\ NS}$	0.47	1.39	3, 81	MNS^2, MN^2S^2	0.48	NS	89, 50
CV (%)	37.13				38.02			

Table 4.22. Effect of manurial management on the potassium content (%) of plant at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.22	1.33	1.43	**1.33**	1.73	1.75	1.64	**1.71**
Straw application (M_1)	1.86	1.75	1.66	**1.76**	1.77	1.85	1.84	**1.82**
Cow dung (M_2)	1.35	1.40	1.48	**1.41**	1.71	1.82	1.67	**1.73**
Mean	**1.47**	**1.49**	**1.52**		**1.74**	**1.81**	**1.72**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.33	1.37	1.28	**1.33**	1.79	1.73	1.59	**1.71**
Straw application (M_1)	1.47	1.74	2.06	**1.76**	1.86	1.88	1.72	**1.82**
Cow dung (M_2)	1.35	1.46	1.41	**1.41**	1.71	1.71	1.78	**1.73**
Mean	**1.39**	**1.52**	**1.58**		**1.79**	**1.77**	**1.70**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.40	1.38	1.65	**1.47**	1.75	1.74	1.72	**1.74**
N_{45}	1.41	1.61	1.46	**1.49**	1.80	1.88	1.74	**1.81**
N_{90}	1.35	1.59	1.63	**1.52**	1.82	1.70	1.63	**1.72**
Mean	**1.39**	**1.52**	**1.58**		**1.79**	**1.77**	**1.70**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.16	1.50	1.34	**1.33**	1.19	1.38	1.53	**1.37**	1.31	1.11	1.41	**1.28**
M_1	1.69	1.50	1.22	**1.47**	1.49	1.96	1.78	**1.74**	2.40	1.79	1.99	**2.06**
M_2	1.34	1.23	1.49	**1.35**	1.45	1.48	1.45	**1.46**	1.25	1.49	1.50	**1.41**
Mean	**1.40**	**1.41**	**1.35**		**1.38**	**1.61**	**1.59**		**1.65**	**1.46**	**1.63**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.76	1.78	1.84	**1.79**	1.75	1.74	1.71	**1.73**	1.67	1.74	1.36	**1.59**
M_1	1.71	1.90	1.98	**1.86**	1.77	1.94	1.94	**1.88**	1.84	1.72	1.61	**1.72**
M_2	1.79	1.71	1.64	**1.71**	1.70	1.98	1.45	**1.71**	1.65	1.76	1.92	**1.78**
Mean	**1.75**	**1.80**	**1.82**		**1.74**	**1.88**	**1.70**		**1.72**	**1.74**	**1.63**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N^{NS} or S^{NS}	0.08	0.23	0, 91, 21	M or N or S	0.05	NS	20, 38, 35
Two factor effects	M × N, M × S, N × S	0.13	NS	63, 18, 58	M × N, M × S, N × S	0.08	NS	84, 47, 70
Three factor effects (3 FE)	MNS, MN^2S	0.23	NS	96, 61	MNS, MN^2S	0.14	NS	36, 30
3 FE confounded	MNS^2, MN^2S^2	0.23	NS	65, 100	MNS^2, MN^2S^2	0.14	NS	17, 52
CV (%)	21.04				10.93			

4.2.18.2 Two factor interaction effects

The two factor interactions were not significantly different in both the years except a M × S interaction, significant at 18 % level of significance in the first year. A noticeable increase in K content of 2.06 % was observed with straw incorporation + S_{30}. The K content was relatively much lower in all other combinations.

4.2.18.3 Three factor interactions

Three factor interactions and confounded effects were not significant in both the years.

4.2.19 Sulphur content of plant at tillering stage

4.2.19.1 Main effects

4.2.19.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen on the plant N content at tillering stage was significant at 18 % level of significance in the first year (Table 4.23). Sulphur content was higher with 0.33 % in the straw incorporation treatments.

4.2.19.1.2 Effect of nitrogen

The different levels of nitrogen averaged over organic manures and sulphur was significant in the first year, but, not in the second year. In both the years, a step wise increase in sulphur content was observed with increasing levels of nitrogen, but, N_{45} and N_{90} was at par in the first year.

4.2.19.1.3 Effect of sulphur

The effect of different levels of sulphur was noticeably significant at 25 % of significance in the second year. A step wise increase in the sulphur content was observed between no sulphur (0.27 %), S @ 15 kg ha^{-1} (0.29 %) and S @ 30 kg ha^{-1}

Table 4.23. Effect of manurial management on the sulphur content (%) of plant at tillering stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.23	0.27	0.40	**0.30**	0.33	0.31	0.27	**0.30**
Straw application (M_1)	0.23	0.41	0.35	**0.33**	0.31	0.27	0.33	**0.30**
Cow dung (M_2)	0.24	0.23	0.29	**0.25**	0.21	0.30	0.31	**0.27**
Mean	**0.23**	**0.30**	**0.35**		**0.29**	**0.29**	**0.30**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.26	0.28	0.36	**0.30**	0.32	0.32	0.27	**0.30**
Straw application (M_1)	0.29	0.28	0.42	**0.33**	0.26	0.29	0.35	**0.30**
Cow dung (M_2)	0.27	0.30	0.19	**0.25**	0.22	0.26	0.33	**0.27**
Mean	**0.27**	**0.29**	**0.32**		**0.27**	**0.29**	**0.32**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.21	0.24	0.25	**0.23**	0.19	0.32	0.34	**0.29**
N_{45}	0.28	0.31	0.32	**0.30**	0.32	0.26	0.30	**0.29**
N_{90}	0.32	0.32	0.40	**0.35**	0.29	0.29	0.33	**0.30**
Mean	**0.27**	**0.29**	**0.32**		**0.27**	**0.29**	**0.32**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.19	0.17	0.40	**0.26**	0.21	0.30	0.33	**0.28**	0.28	0.33	0.46	**0.36**
M_1	0.18	0.37	0.32	**0.29**	0.16	0.40	0.29	**0.28**	0.36	0.47	0.43	**0.42**
M_2	0.27	0.30	0.23	**0.27**	0.33	0.22	0.33	**0.30**	0.11	0.17	0.31	**0.19**
Mean	**0.21**	**0.28**	**0.32**		**0.24**	**0.31**	**0.32**		**0.25**	**0.32**	**0.40**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.27	0.39	0.28	**0.31**	0.43	0.27	0.26	**0.32**	0.29	0.27	0.26	**0.27**
M_1	0.20	0.29	0.30	**0.26**	0.27	0.27	0.32	**0.29**	0.44	0.24	0.39	**0.36**
M_2	0.09	0.29	0.30	**0.22**	0.25	0.24	0.29	**0.26**	0.27	0.38	0.33	**0.33**
Mean	**0.19**	**0.32**	**0.29**		**0.32**	**0.26**	**0.29**		**0.33**	**0.30**	**0.33**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	0.03	0.08	18, 4, 46	M or N or S	0.04	NS	49, 82, 25
Two factor effects	M × N, M × S, N × S	0.05	NS	33, 16, 96	M × N, M × S, N × S	0.07	NS	19, 31, 13
Three factor effects (3 FE)	MNS, MN^2S	0.09	NS	36, 83	MNS, MN^2S	0.12	NS	78, 42
3 FE confounded	MNS^2, MN^2S^2	0.09	NS	53, 45	MNS^2, MN^2S^2	0.12	NS	49, 40
CV (%)	42.32				28.87			

(0.32 %) in the first year. The corresponding sulphur content in the second year was 0.27, 0.29 and 0.32 %, respectively.

4.2.19.2 Two factor interaction effects

The two factor interactions were not significant in both the years. Noticeable interaction effects for all the factors were observed with regard to sulphur content in both the years. M × S was significant at 16 % and 31 % level of significance in the first year and second year. M × N and N × S were significant at 19 and 31 % level of significance respectively, in the second year. Straw incorporation with S_{30} resulted in the highest sulphur content, like wise $N_{90}S_{30}$ also resulted in the highest content of sulphur.

4.2.19.3 Three factor interactions

The three factor interactions and confounded effects were not significant in both the years.

4.2.20 Sulphur content of plant at PI stage

4.2.20.1 Main effects

4.2.20.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen was significant at 11 % level of significance in the first year (Table 4.24). Sulphur at PI stage increased from 0.17 % to 0.20 % by straw incorporation and 0.21 % by cow dung application.

4.2.20.1.2 Effect of nitrogen

The effect of different doses of nitrogen averaged over organic manures and sulphur was significant in the first year, but, not in the second year. The highest sulphur content of 0.23 % was observed with application of N at 90 kg ha^{-1}.

Table 4.24. Effect of manurial management on the sulphur content (%) of plant at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.13	0.17	0.20	**0.17**	0.14	0.14	0.22	**0.17**
Straw application (M_1)	0.16	0.20	0.25	**0.20**	0.13	0.22	0.23	**0.19**
Cow dung (M_2)	0.22	0.20	0.23	**0.21**	0.13	0.15	0.22	**0.17**
Mean	**0.17**	**0.19**	**0.23**		**0.13**	**0.17**	**0.22**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.13	0.18	0.20	**0.17**	0.13	0.22	0.19	**0.25**
Straw application (M_1)	0.18	0.20	0.23	**0.20**	0.15	0.20	0.23	**0.19**
Cow dung (M_2)	0.17	0.23	0.23	**0.21**	0.10	0.18	0.22	**0.17**
Mean	**0.16**	**0.21**	**0.22**		**0.13**	**0.20**	**0.21**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.17	0.18	0.17	**0.17**	0.08	0.20	0.17	**0.22**
N_{45}	0.13	0.20	0.23	**0.19**	0.12	0.19	0.19	**0.17**
N_{90}	0.18	0.24	0.26	**0.23**	0.17	0.23	0.27	**0.22**
Mean	**0.16**	**0.21**	**0.22**		**0.13**	**0.21**	**0.21**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.12	0.12	0.14	**0.13**	0.15	0.18	0.21	**0.18**	0.14	0.20	0.26	**0.20**
M_1	0.16	0.14	0.23	**0.18**	0.15	0.21	0.25	**0.20**	0.16	0.26	0.28	**0.23**
M_2	0.22	0.14	0.16	**0.17**	0.23	0.20	0.27	**0.23**	0.20	0.25	0.26	**0.23**
Mean	**0.17**	**0.13**	**0.18**		**0.18**	**0.20**	**0.24**		**0.17**	**0.23**	**0.26**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.12	0.12	0.16	**0.13**	0.14	0.16	0.23	**0.21**	0.13	0.16	0.27	**0.19**
M_1	0.10	0.15	0.19	**0.15**	0.14	0.25	0.21	**0.20**	0.16	0.26	0.29	**0.23**
M_2	0.03	0.10	0.16	**0.10**	0.14	0.16	0.25	**0.18**	0.21	0.17	0.26	**0.22**
Mean	**0.08**	**0.12**	**0.17**		**0.14**	**0.19**	**0.23**		**0.17**	**0.19**	**0.27**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	0.01	0.04	11, 4, 3	M or N or S	0.06	NS	54, 76, 19
Two factor effects	M × N, M × S, N × S	0.03	NS	66, 95, 43	M × N, M × S, N × S	0.09	NS	41, 52, 53
Three factor effects (3 FE)	MNS, MN^2S	0.04	NS	100, 95	MNS, MN^2S	0.17	NS	37, 35
3 FE confounded	MNS^2, MN^2S^2	0.04	NS	75, 72	MNS^2, MN^2S^2	0.17	NS	35, 97
CV (%)	28.98				116.69			

4.2.20.1.3 Effect of sulphur

The effect of different doses of sulphur averaged over organic manures and nitrogen was highly significant in the first year and significant at 19 % level of significance in the second year. In the first year, S @ 15 kg ha^{-1} (0.21 %) and S @ 30 kg ha^{-1} (0.22 %) was statistically at par and significantly increased the sulphur content over no sulphur application (0.16 %).

Two factor and three factor interactions were not significant in both the years.

4.2.21 Calcium content of plant at tillering stage

4.2.21.1 Main effects

4.2.21.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was highly significant in the first year, whereas, in the second year, it was significant at 25 % level of significance (Table 4.25). In the first year, straw incorporation and cow dung application resulted in 618 and 671 ppm of plant calcium which were statistically at par. In the second year, cow dung application registered the highest calcium content of 670 ppm.

The different levels of nitrogen and sulphur were not significant in both the years.

4.2.21.2 Two factor interaction effects

The M × S interaction significantly affected the calcium content at 14 and 3 % level of significance in the first and second years, respectively. The cow dung applied with S_{30} resulted the highest calcium content.

N × S interaction was significant at 10 % level of significance in the first year. Combinations N_0S_{30}, $N_{90}S_0$ and $N_{45}S_{15}$ resulted in similar but lower calcium content.

Table 4.25. Effect of manurial management on the calcium content (ppm) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	591	536	482	**536**	599	579	690	**623**
Straw application (M_1)	596	633	624	**618**	644	635	602	**627**
Cow dung (M_2)	643	687	683	**671**	716	635	658	**670**
Mean	**610**	**619**	**596**		**653**	**616**	**650**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	533	502	574	**536**	638	627	604	**623**
Straw application (M_1)	601	666	586	**618**	629	648	603	**627**
Cow dung (M_2)	679	629	705	**671**	686	564	760	**670**
Mean	**604**	**599**	**622**		**651**	**613**	**655**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	646	600	584	**610**	663	607	688	**653**
N_{45}	634	579	643	**619**	612	602	635	**616**
N_{90}	534	618	638	**596**	677	629	643	**650**
Mean	**604**	**599**	**622**		**651**	**613**	**655**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	675	547	378	**533**	557	475	475	**502**	541	587	593	**574**
M_1	566	672	566	**601**	657	642	699	**666**	565	585	608	**586**
M_2	697	682	657	**679**	586	621	680	**629**	647	757	712	**705**
Mean	**646**	**634**	**534**		**600**	**579**	**618**		**584**	**643**	**638**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	577	702	634	**638**	672	495	713	**627**	548	541	723	**604**
M_1	730	490	668	**629**	520	825	600	**648**	681	590	537	**603**
M_2	683	645	730	**686**	630	486	575	**564**	836	773	670	**760**
Mean	**663**	**612**	**677**		**607**	**602**	**629**		**688**	**635**	**643**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^* or N^{NS} or S^{NS}	18.96	55.62	0, 71, 68	M or N or S	21.31	NS	25, 41, 32
Two factor effects	$M \times N^{NS}$, $M \times S^*$, $N \times S^*$	32.85	96.34	20, 14, 10	M × N, M × S, N × S	36.91	NS	20, 3, 84
Three factor effects (3 FE)	MNS, MN^2S	56.89	NS	100, 35	MNS^*, MN^2S^{NS}	63.94	187.54	1, 31
3 FE confounded	MNS^2, MN^2S^2	56.89	NS	88, 48	MNS^2, MN^2S^2	63.94	NS	18, 6
CV (%)	10.33				7.23			

M × N interaction were significant at 20 % level of significance in both the years. Calcium content below 600 ppm was observed in no organics combination with N_0 or N_{45} or straw incorporation with N_0.

4.2.21.3 Three factor interactions

The M × N × S interaction were highly significant in the second year. $M_1N_0S_0$, $M_2N_0S_0$, $M_0N_1S_0$, $M_1N_2S_0$, $M_2N_2S_0$, $M_0N_0S_1$, $M_1N_1S_1$, $M_0N_2S_1$, $M_1N_0S_2$, $M_2N_0S_2$, $M_2N_1S_2$, $M_0N_2S_2$, and $M_2N_2S_2$ were statistically at par. The lowest calcium content of 486 ppm was observed with cow dung + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1}.

4.2.22 Calcium content of plant at PI stage

4.2.22.1 Main effects

4.2.22.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant in the first year (Table 4.26). The highest plant calcium content (594 ppm) at PI stage was obtained with cow dung application.

4.2.22.1.2 Effect of nitrogen

The graded doses of nitrogen averaged over organic manures and sulphur was significant in the first year. The mean increase in the plant calcium content due to N @ 90 kg ha^{-1} over no nitrogen was 17.96 % and 4.31 % over N @ 45 kg ha^{-1}.

4.2.22.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was not significant in both the years.

Table 4.26. Effect of manurial management on the calcium content (ppm) of plant at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	521	541	610	**557**	616	606	615	**612**
Straw application (M_1)	476	534	621	**544**	601	586	579	**589**
Cow dung (M_2)	541	660	580	**594**	581	642	600	**607**
Mean	**512**	**579**	**604**		**599**	**611**	**598**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	556	556	560	**557**	607	612	618	**612**
Straw application (M_1)	552	556	522	**544**	589	626	552	**589**
Cow dung (M_2)	598	566	617	**594**	596	605	621	**607**
Mean	**569**	**559**	**567**		**597**	**614**	**597**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	510	482	546	**512**	636	611	550	**599**
N_{45}	599	585	553	**579**	576	639	619	**611**
N_{90}	598	611	602	**604**	579	593	623	**598**
Mean	**569**	**559**	**567**		**597**	**614**	**597**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	470	606	593	**556**	496	506	665	**556**	596	513	572	**560**
M_1	511	547	599	**552**	445	567	656	**556**	472	488	607	**522**
M_2	549	644	601	**598**	505	681	513	**566**	569	657	626	**617**
Mean	**510**	**599**	**598**		**482**	**585**	**611**		**546**	**553**	**602**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	661	580	580	**607**	602	622	611	**612**	584	616	654	**618**
M_1	608	532	626	**589**	668	632	578	**626**	527	595	534	**552**
M_2	640	618	530	**596**	563	663	590	**605**	539	645	680	**621**
Mean	**636**	**576**	**579**		**611**	**639**	**593**		**550**	**619**	**623**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N* or S^{NS}	11.63	34.11	2, 0, 83	M or N or S	14.35	NS	49, 78, 63
Two factor effects	M × N*, M × S^{NS}, N × S^{NS}	20.14	59.08	0, 36, 14	M × N, M × S, N × S	24.86	NS	55, 42, 7
Three factor effects (3 FE)	MNS, MN^2S	34.89	NS	53, 16	MNS, MN^2S	43.05	NS	59, 14
3 FE confounded	MNS^2 *, $MN^2S^{2\ NS}$	34.89	102.32	2, 77	MNS^2, MN^2S^2	43.05	NS	30, 91
CV (%)	7.30				6.56			

4.2.22.2 Two factor interaction effects

M × N was interaction was highly significant in the first year. N × S interaction was also significant at 14 and 7 % level of significance in the first and second years, respectively. In the first year, the highest calcium content (660 ppm) was registered with the combined application of straw + nitrogen @ 45 kg ha^{-1}. When nitrogen was increased to 90 kg ha^{-1} in the straw incorporated treatment, it was reduced by 12.12 % from that of straw incorporated + N_{45}. A step wise increase in the calcium content was noted with the increasing levels of nitrogen with no organic manures and straw incorporation.

In the first year, the highest content of calcium (611 ppm) was observed with N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1}. No nitrogen + S @ 15 kg ha^{-1} had shown significantly lower calcium content of 482 ppm. A step wise increase in the calcium content was observed with the increasing levels of nitrogen with S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1}. In the second year N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} showed significantly higher calcium content of 639 ppm.

4.2.22.3 Three factor interactions

The interaction effects of MN × S_{30} and $MN_{90}S$ at 2 and 14 % level of significance in the first year and $MN_{90}S$ at 14 % level of significance in the second year were found significant. In the first year cow dung + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} showed higher calcium content of 681 ppm. Straw incorporation + no nitrogen + S @ 15 kg ha^{-1} registered a lower calcium content and it was 53.03 % lesser than straw incorporation + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1}. In the second year, the highest calcium content of 680 ppm was found with the application of cow dung + N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}. It was 28.30 % higher than cow dung + N @ 90 kg ha^{-1} + no sulphur and 15.25 % higher than cow dung + N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1}. Straw incorporation + no nitrogen + S @ 30 kg ha^{-1}, cow dung + N @ 90 kg ha^{-1}

+ no sulphur, straw incorporation + N @ 45 kg ha^{-1} + no sulphur and straw incorporation + N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1} resulted in a noticeable lower calcium content.

4.2.23 Magnesium content of plant at tillering stage

4.2.23.1 Main effects

4.2.23.1.1 Effect of organic manures

The effect of different sources of organic manures averaged over nitrogen and sulphur was not significant in both the years (Table 4.27). The mean increase in the magnesium content at tillering stage due to straw incorporation over cow dung application was 7.41 % and 8.44 % over no organic manures.

4.2.23.1.2 Effect of nitrogen

The different levels of nitrogen averaged over organic manures and sulphur was highly significant in the first year and 16 % level of significance in the second year. In the first year, the highest magnesium content was observed with the treatment no nitrogen (1743 ppm) and it was 33.15 % higher than N @ 45 kg ha^{-1} and 28.35 % higher than N @ 90 kg ha^{-1}. In the second year, a step wise increase in the magnesium content was observed with the increasing levels of nitrogen.

4.2.23.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen was not significant in the first year, however, it was significant in the second year. In the first year, a step wise increase in the magnesium content was observed with the increasing levels of sulphur. In the second year, mean increase in the magnesium content due to S @ 30 kg ha^{-1} over no sulphur was 65.83 % and 51.04 % over S @ 15 kg ha^{-1}.

Table 4.27. Effect of manurial management on the magnesium content (ppm) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1742	1468	1053	**1421**	1020	1008	1550	**1193**
Straw application (M_1)	1562	1335	1758	**1552**	905	1027	1300	**1077**
Cow dung (M_2)	1927	1123	1262	**1437**	1258	1235	1051	**1181**
Mean	**1743**	**1309**	**1358**		**1061**	**1090**	**1300**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1367	1422	1475	**1421**	1013	1232	1333	**1193**
Straw application (M_1)	1410	1635	1610	**1552**	930	862	1440	**1077**
Cow dung (M_2)	1393	1443	1475	**1437**	813	933	1798	**1181**
Mean	**1390**	**1500**	**1520**		**919**	**1009**	**1524**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1742	1922	1567	**1743**	938	700	1545	**1061**
N_{45}	1242	1192	1494	**1309**	1067	1000	1203	**1090**
N_{90}	1187	1387	1500	**1358**	752	1326	1823	**1300**
Mean	**1390**	**1500**	**1520**		**919**	**1009**	**1524**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1695	1550	855	**1367**	1980	1305	980	**1422**	1550	1550	1325	**1475**
M_1	1555	1175	1500	**1410**	1805	1250	1850	**1635**	1325	1581	1925	**1610**
M_2	1975	1000	1205	**1393**	1980	1020	1330	**1443**	1825	1350	1250	**1475**
Mean	**1742**	**1242**	**1187**		**1922**	**1192**	**1387**		**1567**	**1494**	**1500**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1105	1030	905	**1013**	875	945	1875	**1232**	1080	1050	1870	**1333**
M_1	980	1240	570	**930**	455	850	1280	**862**	1280	990	2050	**1440**
M_2	730	930	780	**813**	770	1205	823	**933**	2275	1570	1550	**1798**
Mean	**938**	**1067**	**752**		**700**	**1000**	**1326**		**1545**	**1203**	**1823**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	124.86	366.22	72, 4, 74	M^{NS} or N^{NS} or S*	91.95	269.69	63, 16, 1
Two factor effects	M × N, M × S, N × S	216.26	NS	14, 100, 58	M × N, M × S, N × S	159.26	NS	14, 15, 3
Three factor effects (3 FE)	MNS, MN^2S	374.57	NS	70, 100	MNS, MN^2S	275.84	NS	40, 45
3 FE confounded	MNS^2, MN^2S^2	374.57	NS	100, 64	MNS^2, MN^2S^2	275.84	NS	78, 74
CV (%)	33.24				39.30			

4.2.23.2 Two factor interaction effects

The interaction M × N was significant at 14 % level of significance in both the years. M × S and N × S was not significant in the first year, but, significant at 15 % and 13 % levels of significance, respectively in the second year. The highest magnesium content of 1758 ppm was observed with the application of straw in combination with N @ 90 kg ha^{-1}. But in the second year, the highest magnesium content (1550 ppm) was observed with the application of N @ 90 kg ha^{-1} + no organic manures.

In the first year mean increase in the magnesium content at tillering stage due to straw incorporation + S @ 15 kg ha^{-1} over no organics + no sulphur was 16.39 %. Straw incorporated with higher dose of sulphur reduced the magnesium content (1610 ppm) when compared to straw incorporated with N @ 45 kg ha^{-1} (1635 ppm). In the second year, the highest magnesium content of 1798 ppm was observed with the application of cow dung + S @ 30 kg ha^{-1} and it was 121.15 % higher when compared to cow dung + no sulphur.

When no nitrogen was given in combination with S @ 15 kg ha^{-1} registered the highest magnesium content of 1922 ppm. But in the second year, the highest magnesium content was registered with the application of N_{90} + S_{30}.

4.2.23.3 Three factor interactions

Three factor interactions and confounded treatments were not significantly different in both the years.

4.2.24 Magnesium content of plant at PI stage

4.2.24.1 Main effects

Both organic manures and sulphur were not significant. However, the effect of nitrogen was significant in both the years (Table 4.28). A step wise increase in the

Table 4.28. Effect of manurial management on the magnesium content (ppm) of plant at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	885	1257	1440	**1194**	557	1368	1583	**1169**
Straw application (M_1)	1218	1318	1465	**1334**	1060	1178	1693	**1311**
Cow dung (M_2)	933	1410	1560	**1301**	943	1652	1358	**1318**
Mean	**1012**	**1328**	**1488**		**853**	**1399**	**1545**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1027	1227	1328	**1194**	1148	1342	1018	**1169**
Straw application (M_1)	1262	1413	1327	**1334**	1155	1382	1395	**1311**
Cow dung (M_2)	1175	1293	1435	**1301**	1195	1285	1473	**1318**
Mean	**1154**	**1311**	**1363**		**1166**	**1336**	**1296**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	827	1125	1085	**1012**	673	1010	877	**853**
N_{45}	1240	1327	1418	**1328**	1420	1500	1278	**1399**
N_{90}	1397	1482	1587	**1488**	1405	1498	1732	**1545**
Mean	**1154**	**1311**	**1363**		**1166**	**1336**	**1296**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	575	1240	1265	**1027**	1075	1105	1500	**1227**	1005	1425	1555	**1328**
M_1	1180	1105	1500	**1262**	1225	1495	1520	**1413**	1250	1355	1375	**1327**
M_2	725	1375	1425	**1175**	1075	1380	1425	**1293**	1000	1475	1830	**1435**
Mean	**827**	**1240**	**1397**		**1125**	**1327**	**1482**		**1085**	**1418**	**1587**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	515	1475	1455	**1148**	655	1725	1645	**1342**	500	905	1650	**1018**
M_1	655	1455	1355	**1155**	1370	900	1875	**1382**	1155	1180	1850	**1395**
M_2	850	1330	1405	**1195**	1005	1875	975	**1285**	975	1750	1695	**1473**
Mean	**673**	**1420**	**1405**		**1010**	**1500**	**1498**		**877**	**1278**	**1732**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N^* or S^{NS}	133.54	391.68	74, 6, 53	M^{NS} or N^* or S^{NS}	133.43	391.36	68, 1, 65
Two factor effects	M × N, M × S, N × S	231.30	NS	91, 92, 99	M × N, M × S, N × S	231.10	NS	32, 100, 79
Three factor effects (3 FE)	MNS, MN^2S	400.62	NS	72, 92	MNS, MN^2S	400.29	NS	66, 2, 4
3 FE confounded	MNS^2, MN^2S^2	400.62	NS	92, 80	MNS^2, MN^2S^2	400.29	NS	64, 93
CV (%)	42.03				41.07			

magnesium content at PI stage with increasing levels of nitrogen was observed in both the years, however N_0 and N_{45} was at par.

Two factor and three factor interaction effects were also not significant in both the years.

4.2.25 Iron content of plant at tillering stage

4.2.25.1 Main effects

4.2.25.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant only in the second year (Table 4.29). Organic manure application was found to decrease the iron content in plant. In both the years, no organic manure application resulted the highest iron accumulation. In the second year, the iron content was significantly lower with 739 ppm in straw incorporated treatments. Cow dung application and straw incorporation was statistically at par and cow dung application which in turn at par with no manure application.

4.2.25.1.2 Effect of nitrogen

The different levels of nitrogen averaged over organic manures and sulphur was significant at 22 and 9 % levels of significance in first and second year, respectively. In both the years, increasing nitrogen levels decreased the iron content. In the first year, it was 759, 681 and 653 ppm with N_0, N_{45} and N_{90} and the corresponding figure in the second year was 851, 777 and 775 ppm.

4.2.25.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was not significantly different in both the years.

Two factor and three factor interactions were not significant in both the years.

Table 4.29. Effect of manurial management on the iron content (ppm) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	802	737	708	**749**	910	875	780	**855**
Straw application (M_1)	746	685	661	**698**	810	717	691	**739**
Cow dung (M_2)	730	620	591	**647**	833	740	853	**809**
Mean	**759**	**681**	**653**		**851**	**777**	**775**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	728	725	794	**749**	827	878	860	**855**
Straw application (M_1)	715	669	708	**698**	784	702	733	**739**
Cow dung (M_2)	649	673	619	**647**	784	836	807	**809**
Mean	**697**	**689**	**707**		**798**	**805**	**800**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	758	710	810	**759**	828	874	852	**851**
N_{45}	660	693	690	**681**	770	788	775	**777**
N_{90}	675	665	621	**653**	797	754	773	**775**
Mean	**697**	**689**	**707**		**798**	**805**	**800**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	746	657	780	**728**	785	752	640	**725**	875	804	704	**794**
M_1	825	706	616	**715**	652	668	688	**669**	762	682	681	**708**
M_2	703	616	629	**649**	695	659	666	**673**	793	586	479	**619**
Mean	**758**	**660**	**675**		**710**	**693**	**665**		**810**	**690**	**621**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	846	828	807	**827**	931	944	760	**878**	953	854	773	**860**
M_1	849	756	746	**784**	852	631	624	**702**	731	765	703	**733**
M_2	789	725	840	**784**	839	790	878	**836**	871	707	842	**807**
Mean	**828**	**770**	**797**		**874**	**788**	**754**		**852**	**775**	**773**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	42.74	NS	26, 22, 96	M^* or N^{NS} or S^{NS}	26.37	77.34	2, 9, 99
Two factor effects	M × N, M × S, N × S	74.03	NS	100, 91, 87	M × N, M × S, N × S	45.67	NS	23, 59, 91
Three factor effects (3 FE)	MNS, MN^2S	128.23	NS	72, 50	MNS, MN^2S	79.11	NS	46, 73
3 FE confounded	MNS^2, MN^2S^2	128.23	NS	47, 96	MNS^2, MN^2S^2	79.11	NS	100, 100
CV (%)	20.81				13.55			

4.2.26 Iron content of plant at PI stage

4.2.26.1 Main effects

4.2.26.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was highly significant in first year and significant at 7 % level of significance in the second year (Table 4.30). In the first year iron content in the treatments no organic manure, paddy straw incorporation and cow dung application were 2126 ppm, 1911 ppm and 1399 ppm, respectively. The corresponding iron content in the second year were 2316, 1992, 1840 ppm indicating the efficiency of organic manures to reduce iron concentration in the plant.

4.2.26.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant in first year. The highest iron content of 2413 ppm was registered with N_0 treatment which was reduced to 1779 ppm to 1243 ppm at N_{45} and N_{90}.

4.2.26.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was not significant in both the years.

4.2.26.2 Two factor interaction effects

Only N × S interaction was relatively significant at 7 % and 18 % levels of significance in first and second year, respectively. High iron content obtained with higher level of sulphur (S_{30}) was found to decrease with increasing levels of nitrogen in both the years. In the first year, 3228 ppm of iron with N_0S_{30} was reduced to 1059

Table 4.30. Effect of manurial management on the iron content (ppm) of plant at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	2775	2129	1473	**2126**	2092	2727	2129	**2316**
Straw application (M_1)	2853	1625	1254	**1911**	1812	1942	2222	**1992**
Cow dung (M_2)	1610	1583	1003	**1399**	1610	2137	1773	**1840**
Mean	**2413**	**1779**	**1243**		**1838**	**2269**	**2041**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	2255	1797	2326	**2126**	2385	2141	2421	**2316**
Straw application (M_1)	1548	2215	1969	**1911**	2150	2211	1616	**1992**
Cow dung (M_2)	1265	1130	1802	**1399**	1652	1984	1885	**1840**
Mean	**1689**	**1714**	**2032**		**2062**	**2112**	**1974**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1716	2295	3228	**2413**	1670	1707	2137	**1838**
N_{45}	1891	1636	1810	**1779**	2242	2400	2165	**2269**
N_{90}	1461	1211	1059	**1243**	2275	2228	1620	**2041**
Mean	**1689**	**1714**	**2032**		**2062**	**2112**	**1974**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	2373	2242	2150	**2255**	1697	2479	1215	**1797**	4255	1668	1054	**2326**
M_1	1700	1626	1318	**1548**	3623	1694	1327	**2215**	3237	1555	1116	**1969**
M_2	1075	1807	914	**1265**	1564	734	1091	**1130**	2192	2209	1006	**1802**
Mean	**1716**	**1891**	**1461**		**2295**	**1636**	**1211**		**3228**	**1810**	**1059**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1526	2662	2968	**2385**	1946	2564	1914	**2141**	2805	2956	1504	**2421**
M_1	1959	2014	2477	**2150**	1671	2247	2715	**2211**	1807	1566	1475	**1616**
M_2	1525	2049	1381	**1652**	1506	2389	2056	**1984**	1799	1974	1882	**1885**
Mean	**1670**	**2242**	**2275**		**1707**	**2400**	**2228**		**2137**	**2165**	**1620**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N* or S^{NS}	185.15	543.05	3, 0, 36	M or N or S	139.64	NS	7, 12, 78
Two factor effects	M × N, M × S, N × S	320.68	NS	41, 41, 7	M × N, M × S, N × S	241.86	NS	49, 32, 18
Three factor effects (3 FE)	MNS, MN^2S	555.44	NS	6, 68	MNS, MN^2S	418.92	NS	81, 37
3 FE confounded	MNS^2, MN^2S^2	555.44	NS	17, 40	MNS^2, MN^2S^2	418.92	NS	38, 37
CV (%)	42.39				28.66			

ppm with $N_{90}S_{30}$. In the second year, 2137 ppm of iron in N_0S_{30} was reduced to 1620 ppm with $N_{90}S_{30}$.

4.2.26.3 Three factor interactions

The MNS interaction was significant at 6 % level of significance in the first year. The highest iron content of 4255 ppm was observed with $M_0N_0S_{30}$. The iron content was relatively low in treatments receiving organic manure and nitrogen but no sulphur.

4.2.27 Manganese content of plant at tillering stage

4.2.27.1 Main effects

4.2.27.1.1 Effect of organic manures

The effect of different sources of organic manures averaged over nitrogen and sulphur was significant only in first year (Table 4.31). The mean increase in the manganese content at tillering stage due to cow dung application over straw incorporation was 13.70 % and 47.24 % over no organic manures in the first year. The effect of nitrogen, sulphur, two factor and three factor interactions were not significant in both the years.

4.2.28 Manganese content of plant at PI stage

4.2.28.1 Main effects

4.2.28.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant at 9 % level of significance in first year (Table 4.32). Not as in the tillering stage, in the PI stage the least plant manganese content (802 ppm) was observed in

Table 4.31. Effect of manurial management on the manganese content (ppm) of plant at tillering stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	317	453	482	**417**	355	485	587	**476**
Straw application (M_1)	548	452	619	**540**	399	391	561	**450**
Cow dung (M_2)	675	574	592	**614**	596	493	417	**502**
Mean	**513**	**493**	**564**		**450**	**456**	**521**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	385	417	449	**417**	495	496	436	**476**
Straw application (M_1)	547	538	533	**540**	426	421	504	**450**
Cow dung (M_2)	647	539	655	**614**	503	507	495	**502**
Mean	**527**	**498**	**546**		**475**	**475**	**478**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	505	507	528	**513**	387	497	467	**450**
N_{45}	478	458	543	**493**	473	389	508	**456**
N_{90}	597	529	567	**564**	564	539	461	**521**
Mean	**527**	**498**	**546**		**475**	**475**	**478**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	186	474	496	**385**	254	472	524	**417**	510	412	426	**449**
M_1	586	333	723	**547**	648	456	511	**538**	410	566	623	**533**
M_2	743	626	572	**647**	618	446	553	**539**	664	650	652	**655**
Mean	**505**	**478**	**597**		**507**	**458**	**529**		**528**	**543**	**567**	

Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	148	526	812	**495**	464	474	550	**496**	454	456	398	**436**
M_1	444	282	552	**426**	482	198	584	**421**	272	694	546	**504**
M_2	570	610	328	**503**	544	494	484	**507**	674	374	438	**495**
Mean	**387**	**473**	**564**		**497**	**389**	**539**		**467**	**508**	**461**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N^{NS} or S^{NS}	51.72	151.69	4, 61, 81	M or N or S	66.58	NS	86, 71, 100
Two factor effects	M × N, M × S, N × S	89.57	NS	51, 93, 98	M × N, M × S, N × S	115.33	NS	44, 97, 83
Three factor effects (3 FE)	MNS, MN^2S	155.15	NS	70, 27	MNS, MN^2S	199.75	NS	57, 22
3 FE confounded	MNS^2, MN^2S^2	155.15	NS	35, 93	MNS^2, MN^2S^2	585.89	NS	79, 95
CV (%)	28.95				31.88			

Table 4.32. Effect of manurial management on the manganese content (ppm) of plant at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1087	944	808	**946**	963	892	605	**820**
Straw application (M_1)	933	866	607	**802**	820	768	912	**833**
Cow dung (M_2)	919	755	823	**832**	621	936	763	**774**
Mean	**980**	**855**	**746**		**801**	**865**	**760**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	923	976	940	**946**	817	793	849	**820**
Straw application (M_1)	864	760	782	**802**	1015	802	684	**833**
Cow dung (M_2)	879	825	792	**832**	737	835	749	**774**
Mean	**889**	**854**	**838**		**856**	**810**	**761**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1066	978	895	**980**	804	845	755	**801**
N_{45}	942	840	783	**855**	944	857	795	**865**
N_{90}	658	743	836	**746**	821	728	731	**760**
Mean	**889**	**854**	**838**		**856**	**810**	**761**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1023	993	752	**923**	1196	1076	656	**976**	1042	763	1016	**940**
M_1	980	1054	558	**864**	836	818	626	**760**	984	726	636	**782**
M_2	1196	778	664	**879**	902	626	948	**825**	659	861	856	**792**
Mean	**1066**	**942**	**658**		**978**	**840**	**743**		**895**	**783**	**836**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	682	984	786	**817**	1292	842	244	**793**	914	850	784	**849**
M_1	1142	1062	840	**1015**	556	923	926	**802**	762	320	970	**684**
M_2	588	786	836	**737**	686	806	1014	**835**	590	1216	440	**749**
Mean	**804**	**944**	**821**		**845**	**857**	**728**		**755**	**795**	**731**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	46.60	136.69	9, 1, 74	M or N or S	84.94	NS	87, 68, 73
Two factor effects	M × N, M × S, N × S	80.72	NS	36, 89, 23	M × N, M × S, N × S	147.13	NS	29, 68, 99
Three factor effects (3 FE)	MNS, MN^2S	139.80	NS	18, 41	MNS, MN^2S	254.83	NS	25, 5
3 FE confounded	MNS^2, MN^2S^2	139.80	NS	59, 26	MNS^2, MN^2S^2	254.83	NS	74, 30
CV (%)	23.24				48.17			

straw incorporation followed by cow dung application (832 ppm) and no organic manures (946 ppm).

4.2.28.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant in the first year. N_{90} resulted in the least manganese content of 746 ppm followed by N_{45} (855 ppm) and no nitrogen (980 ppm), the latter two were at par.

4.2.28.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was not significant in both the years. In the first year, no sulphur application increased the manganese content to 4.10 % over S @ 15 kg ha^{-1} and 6.08 % over S @ 30 kg ha^{-1}. A similar effect was identified in the second year also.

Two factor and three factor interactions were not significant in both the years.

4.2.29 Number of productive tillers/hill

4.2.29.1 Main effects

4.2.29.1.1 Effect of organic manures

The effect of organic manures such as no manure application, straw incorporation and cow dung application was significant at 7 % level of significance in the first year and it was highly significant in the second year (Table 4.33), when averaged over nitrogen and sulphur levels. In both the years straw incorporation produced more productive tillers (8.13- first year & 7.90 – second year) compared to other organic manure treatments.

4.2.29.1.2 Effect of nitrogen

The effect of nitrogen over organic manure and sulphur was significant in both the years. The productive tiller count was increased with the graded dose of

Table 4.33. Effect of manurial management on the productive tillers of rice

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	7.10	8.32	8.19	**7.87**	6.27	7.46	8.27	**7.33**
Straw application (M_1)	7.56	8.23	8.60	**8.13**	7.54	7.87	8.29	**7.90**
Cow dung (M_2)	7.79	7.83	8.17	**7.93**	6.71	7.69	8.36	**7.59**
Mean	**7.48**	**8.13**	**8.32**		**6.84**	**7.67**	**8.30**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	7.56	7.71	8.34	**7.87**	7.38	7.19	7.43	**7.33**
Straw application (M_1)	7.56	8.23	8.60	**8.13**	7.47	7.97	8.25	**7.90**
Cow dung (M_2)	7.16	7.87	8.75	**7.93**	7.19	7.67	7.90	**7.59**
Mean	**7.43**	**7.94**	**8.56**		**7.35**	**7.61**	**7.86**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	6.91	7.69	7.85	**7.48**	6.61	6.75	7.17	**6.84**
N_{45}	7.77	7.79	8.82	**8.13**	7.35	7.76	7.92	**7.67**
N_{90}	7.60	8.33	9.02	**8.32**	8.09	8.33	8.49	**8.30**
Mean	**7.43**	**7.94**	**8.56**		**7.35**	**7.61**	**7.86**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6.81	8.31	7.56	**7.56**	7.12	7.88	8.13	**7.71**	7.37	8.78	8.88	**8.34**
M_1	7.12	7.75	7.81	**7.56**	8.06	8.06	8.56	**8.23**	7.50	8.88	9.44	**8.60**
M_2	6.81	7.25	7.44	**7.16**	7.88	7.44	8.31	**7.87**	8.69	8.81	8.76	**8.75**
Mean	**6.91**	**7.77**	**7.60**		**7.69**	**7.79**	**8.33**		**7.85**	**8.82**	**9.02**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6.19	7.88	8.07	**7.38**	6.26	7.13	8.19	**7.19**	6.38	7.38	8.54	**7.43**
M_1	6.94	7.54	7.94	**7.47**	7.57	7.88	8.48	**7.97**	8.13	8.19	8.44	**8.25**
M_2	6.69	6.63	8.25	**7.19**	6.44	8.26	8.32	**7.67**	7.01	8.19	8.50	**7.90**
Mean	**6.61**	**7.35**	**8.09**		**6.75**	**7.76**	**8.33**		**7.17**	**7.92**	**8.49**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	0.23	0.68	7, 5, 1	M or N or S	0.04	0.14	0, 0, 1
Two factor effects	M × N, M × S, N × S	0.40	NS	67, 85, 78	M × N*, M × S*, N × S^{NS}	0.08	0.24	1, 1, 34
Three factor effects (3 FE)	MNS, MN^2S	0.70	NS	88, 95	MNS, MN^2S	0.14	0.41	1, 1
3 FE confounded	MNS^2, MN^2S^2	0.70	NS	69, 100	$MNS^{2\ NS}$, MN^2S^2 *	0.14	0.41	39, 1
CV (%)	4.97				3.17			

nitrogen at 45 and 90 kg ha^{-1}. The mean tiller count at no nitrogen increased from 7.48 to 8.13 and 8.32 at N_{45} and N_{90} levels in the first year, whereas, it was increased from 6.84 to 7.67 and 8.30, respectively in the second year.

4.2.29.1.3 Effect of sulphur

The effect of graded doses of sulphur was highly significant in the first and second years. In both the years, a step wise increase in the productive tillers was observed with the increasing levels of sulphur. In the first year, S @ 30 kg ha^{-1} produced higher number of productive tillers (8.56) compared to S @ 15 kg ha^{-1} (7.94) with an increase of 7.80 %. In the second year, a 3.28 % increase was observed.

4.2.29.2 Two factor interaction effects

The two factor interactions such as M × N, M × S and N × S were not significant in the first year, however, in the second year, M × N and M × S were significant. In the second year a step wise increase was observed with the graded dose of nitrogen with all the sources of organic manures. The treatment N @ 90 kg ha^{-1} along with all the organic manures treatments was statistically at par. The interaction between M × S was similar in both the years. In the second year, the paddy straw incorporation + all the levels of sulphur produced higher number of productive tillers when compared to other treatments. It was 7.43 in the treatment no organics + S_{30}, 8.25 in the treatment paddy straw + S_{15} and 7.90 with cow dung + S_{30}.

4.2.29.3 Three factor interactions

In the first year, three factor interactions and confounded treatments was not significant, but, in the second year, three factor interactions such as MNS, MN^2S was significant and the confounded treatment MN^2S^2 was significant. Higher levels of nitrogen and sulphur with straw incorporation resulted in significantly higher number of productive tillers than cow dung application or no manure application.

4.2.30 Percentage tiller decline from PI to harvest stage

4.2.30.1 Main effects

4.2.30.1.1 Effect of organic manures

The effect of organic manures on percentage tiller decline averaged over nitrogen and sulphur was significant in the second year (Table 4.34). Tiller decline was the least with the incorporation of straw (12.09 %) followed by cow dung application (19.44 %) and no organic manure application (21.01 %). A similar trend was observed in the first year also and the corresponding values were 15.14, 19.84 and 20.23 %, respectively.

4.2.30.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was not significant in both the years.

4.2.30.1.3 Effect of sulphur

The effect of graded levels of sulphur averaged over organic manures and nitrogen were significant at 19 % level of significance in the first year. Sulphur at higher level (S_{30}) registered the least tiller decline of 14.15 %.

4.2.30.2 Two factor interaction effects

Two factor interaction effects were not significant in both the years. However, the treatments straw + N_0, straw + S_{30} and N_0 + S_{15}/S_{30} registered the lower tiller decline.

Table 4.34. Effect of manurial management on percentage tiller decline from PI to harvest stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	16.73	19.35	24.61	**20.23**	24.93	18.05	20.03	**21.01**
Straw application (M_1)	10.97	17.33	17.13	**15.14**	10.42	10.78	15.06	**12.09**
Cow dung (M_2)	18.01	19.46	22.06	**19.84**	19.02	21.08	18.22	**19.44**
Mean	**15.24**	**18.71**	**21.27**		**18.12**	**16.64**	**17.77**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	23.53	21.30	15.85	**20.23**	15.50	26.68	20.84	**21.01**
Straw application (M_1)	17.27	16.04	12.12	**15.14**	11.76	14.87	9.63	**12.09**
Cow dung (M_2)	25.79	19.26	14.48	**19.84**	21.45	18.56	18.32	**19.44**
Mean	**22.20**	**18.87**	**14.15**		**16.23**	**20.03**	**16.26**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	17.80	12.13	15.78	**15.24**	16.83	23.05	14.50	**18.12**
N_{45}	18.72	23.39	14.04	**18.71**	15.66	18.35	15.89	**16.64**
N_{90}	30.08	21.09	12.63	**21.27**	16.21	18.71	18.39	**17.77**
Mean	**22.20**	**18.87**	**14.15**		**16.23**	**20.03**	**16.26**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	19.08	12.40	39.12	**23.53**	14.80	24.57	24.53	**21.30**	16.30	21.07	10.18	**15.85**
M_1	13.24	21.35	17.21	**17.27**	7.79	18.84	21.49	**16.04**	11.88	11.81	12.67	**12.12**
M_2	21.08	22.40	33.90	**25.79**	13.79	26.75	17.25	**19.26**	19.16	9.24	15.04	**14.48**
Mean	**17.80**	**18.72**	**30.08**		**12.13**	**23.39**	**21.09**		**15.78**	**14.04**	**12.63**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	22.04	9.11	15.34	**15.50**	28.96	26.82	24.26	**26.68**	23.80	18.23	20.49	**20.84**
M_1	7.46	12.84	14.99	**11.76**	15.30	12.44	16.86	**14.87**	8.50	7.04	13.34	**9.63**
M_2	20.98	25.04	18.32	**21.45**	24.89	15.78	15.00	**18.56**	11.19	22.41	21.34	**18.32**
Mean	**16.83**	**15.66**	**16.21**		**23.05**	**18.35**	**18.71**		**14.50**	**15.89**	**18.39**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	3.07	NS	43, 38, 19	M* or N^{NS} or S^{NS}	2.07	6.07	1, 87, 35
Two factor effects	M × N, M × S, N × S	5.33	NS	98, 98, 41	M × N, M × S, N × S	3.58	NS	56, 41, 84
Three factor effects (3 FE)	MNS, MN^2S	9.23	NS	100, 81	MNS, MN^2S	6.21	NS	35, 59
3 FE confounded	MNS^2, MN^2S^2	9.23	NS	16, 73	MNS^2, MN^2S^2	6.21	NS	64, 63
CV (%)	48.78				46.37			

4.2.30.3 Three factor interaction effects

Three factor interactions were not significant; however, MNS^2 was significant at 16 % level of significance in the first year. $M_1N_0S_{15}$ with 7.79 % in the first year and $M_1N_{45}S_{30}$ with 7.04 % in the second year recorded the least tiller decline.

4.2.31 Number of spikelets/panicle

4.2.31.1 Main effects

4.2.31.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur were significant in both the years (Table 4.35). The straw incorporated and cow dung applied treatment was at par and significantly increased the number of spikelets in the first year. In both the years, straw incorporation produced higher number of spikelets compared to cow dung application. In the first year, it was 102.77 and in the second year it was 106.80.

4.2.31.1.2 Effect of nitrogen

The effect of nitrogen application averaged over organic manure and sulphur was significant in both the years. A step wise increase in the number of spikelets was observed with the increase in nitrogen doses. In the first year, N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} was at par and significantly superior to no nitrogen. In second year, the increase in the spikelets due to N_{90} over N_{45} was 3.28 %.

4.2.31.1.3 Effect of sulphur

The graded level of sulphur application averaged over organic manure and nitrogen was significant in both the years. In the first year, application of S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} was statistically at par and significantly increased the spikelets over no sulphur application. In the second year no sulphur application (100.68) was at par with S @ 15 kg ha^{-1} (102.79) which was in turn at par with S @

Table 4.35. Effect of manurial management on the number of spikelets/panicle

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	88.93	89.90	100.81	**93.21**	91.18	96.28	104.72	**97.39**
Straw application (M_1)	99.20	102.62	106.48	**102.77**	103.67	106.50	110.23	**106.80**
Cow dung (M_2)	94.72	105.30	99.33	**99.79**	101.04	106.51	104.49	**104.01**
Mean	**94.29**	**99.27**	**102.21**		**98.63**	**103.10**	**106.48**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	87.55	94.21	97.87	**93.21**	94.08	99.22	98.89	**97.39**
Straw application (M_1)	94.88	105.19	108.25	**102.77**	105.51	108.26	106.63	**106.80**
Cow dung (M_2)	93.44	101.31	104.61	**99.79**	102.44	100.90	108.70	**104.01**
Mean	**91.96**	**100.24**	**103.58**		**100.68**	**102.79**	**104.74**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	88.17	94.76	99.92	**94.29**	97.30	100.03	98.57	**98.63**
N_{45}	91.18	104.49	102.15	**99.27**	99.28	104.00	106.02	**103.10**
N_{90}	96.52	101.46	108.66	**102.21**	105.45	104.35	109.63	**106.48**
Mean	**91.96**	**100.24**	**103.58**		**100.68**	**102.79**	**104.74**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	81.98	84.82	95.86	**87.55**	91.27	90.19	101.18	**94.21**	93.54	94.69	105.40	**97.87**
M_1	95.23	91.17	98.23	**94.88**	99.67	108.21	107.68	**105.19**	102.71	108.48	113.55	**108.25**
M_2	87.31	97.55	95.46	**93.44**	93.34	115.08	95.51	**101.31**	103.53	103.27	107.02	**104.61**
Mean	**88.17**	**91.18**	**96.52**		**94.76**	**104.49**	**101.46**		**99.92**	**102.15**	**108.66**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	89.88	90.18	102.18	**94.08**	92.95	99.90	104.80	**99.22**	90.73	98.78	107.18	**98.89**
M_1	101.95	100.73	113.85	**105.51**	107.75	108.70	108.33	**108.26**	101.30	110.08	108.50	**106.63**
M_2	100.08	106.93	100.33	**102.44**	99.38	103.40	99.93	**100.90**	103.68	109.20	113.23	**108.70**
Mean	**97.30**	**99.28**	**105.45**		**100.03**	**104.00**	**104.35**		**98.57**	**106.02**	**109.63**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	1.53	4.49	0, 1, 0	M or N or S	0.88	2.59	1, 1, 2
Two factor effects	M × N, M × S, N × S	2.65	NS	7, 97, 40	M × N*, M × S^{NS}, N × S^{NS}	1.53	4.48	1, 3, 13
Three factor effects (3 FE)	MNS, MN^2S	4.59	NS	19, 38	MNS, MN^2S	2.65	NS	19, 30
3 FE confounded	MNS^2, MN^2S^2	4.59	NS	66, 88	MNS^2, MN^2S^2	2.65	NS	43, 83
CV (%)	5.87				3.35			

30 kg ha^{-1} (104.74). In both the years, S @ 30 kg ha^{-1} produced the highest number of spikelets per panicle.

4.2.31.2 Two factor interaction effects

The M × N interaction was significant at 7 % level of significance, however M × S and N × S were not significant in the first year. In the second year M × N and M × S were highly significant and N × S was significant at 13 % level of significance. When no organic manures were given, higher nitrogen level resulted in significant increase in spikelet number, whereas, no nitrogen and N_{45} were at par with straw incorporation. N_{45} and N_{90} were at par and significantly superior to no nitrogen. In both the years, nitrogen application with straw incorporation resulted in greater positive response than nitrogen application with cow dung.

Sulphur applied at different levels in straw incorporated treatments resulted in higher spikelet number compared to the same in cow dung treatments with first year. In the second year also, a similar trend was observed except in the case of straw incorporation with S @ 30 kg ha^{-1}.

N @ 90 kg ha^{-1} with S @ 30 kg ha^{-1} produced the highest number of spikelets of 108.66 in the first year and 109.63 in the second year. Whereas, N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} produced 104.49 and 104.00 spikelets/panicles, respectively in the first and second years.

4.2.31.3 Three factor interactions

The three factor interaction M×N×S was significant at 19 % level of significance in first and second years. In the first year, cow dung application with N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} produced the highest number of spikelets (115.08). In the second year, straw applied with N @ 90 kg ha^{-1} + no sulphur (113.85) produced the highest number of spikelets per panicle.

4.2.32 Percentage of filled grains/panicle

4.2.32.1 Main effects

4.2.32.1.1 Effect of organic manures

The effect of organic manures such as no manure, straw incorporation and cow dung application averaged over nitrogen and sulphur was significantly different in first and second years (Table 4.36). In the first year, straw incorporation and cow dung application was statistically at par and significantly increased the filled grains percentage over no manure treatments. In the second year also, a similar trend was observed.

4.2.32.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant in the first year and second years. In the first year, N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} was statistically at par and significantly increased the percentage of filled grains over no nitrogen. In the second year, a significant mean increase of 3.27 % in the filled grains was observed with N_{90} over N_{45}.

4.2.32.1.3 Effect of sulphur

The effect of different levels of sulphur averaged over organic manures and nitrogen was significant in both the years. In both the years, S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} were statistically at par and significantly increased the filled grains percentage over no sulphur application.

4.2.32.2 Two factor interaction effects

Two factor interactions were not significant in both the years. However, the filled grain percentage increased from 78.97 % in M_0N_0 to 89.73 % in M_1N_{90} in the first year and 79.06 % in M_0N_0 to 90.20 % in M_1N_{90} in the second year. The corresponding values in $M_2 \times N$ treatments were relatively lower than $M_1 \times N$ treatments. With regard to $M \times S$, a response similar to $M \times N$ were observed when

Table 4.36. Effect of manurial management on the percentage of filled grains/panicle

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	78.97	83.18	86.60	**82.92**	79.06	80.47	83.01	**80.85**
Straw application (M_1)	85.30	88.77	89.73	**87.93**	85.02	87.38	90.20	**87.53**
Cow dung (M_2)	86.29	88.30	88.43	**87.67**	83.43	85.54	88.46	**85.81**
Mean	**83.52**	**86.75**	**88.25**		**82.50**	**84.46**	**87.22**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	79.24	84.30	85.21	**82.92**	79.17	81.84	81.53	**80.85**
Straw application (M_1)	84.41	88.95	90.44	**87.93**	85.33	89.44	87.84	**87.53**
Cow dung (M_2)	87.36	87.05	88.61	**87.67**	84.79	85.54	87.10	**85.81**
Mean	**83.67**	**86.77**	**88.09**		**83.09**	**85.61**	**85.49**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	79.81	84.44	86.31	**83.52**	81.17	82.65	83.69	**82.50**
N_{45}	84.52	87.69	88.05	**86.75**	82.90	85.49	84.99	**84.46**
N_{90}	86.67	88.18	89.90	**88.25**	85.21	88.69	87.78	**87.22**
Mean	**83.67**	**86.77**	**88.09**		**83.09**	**85.61**	**85.49**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	71.80	81.62	84.29	**79.24**	81.08	84.45	87.38	**84.30**	84.04	83.48	88.12	**85.21**
M_1	80.68	84.16	88.40	**84.41**	87.06	90.11	89.69	**88.95**	88.15	92.06	91.10	**90.44**
M_2	86.96	87.78	87.34	**87.36**	85.18	88.50	87.47	**87.05**	86.74	88.62	90.47	**88.61**
Mean	**79.81**	**84.52**	**86.67**		**84.44**	**87.69**	**88.18**		**86.31**	**88.05**	**89.90**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	74.78	80.08	82.65	**79.17**	80.80	81.05	83.68	**81.84**	81.61	80.28	82.69	**81.53**
M_1	85.04	85.82	85.12	**85.33**	84.94	89.91	93.48	**89.44**	85.09	86.41	92.02	**87.84**
M_2	83.70	82.81	87.85	**84.79**	82.20	85.50	88.91	**85.54**	84.38	88.30	88.63	**87.10**
Mean	**81.17**	**82.90**	**85.21**		**82.65**	**85.49**	**88.69**		**83.69**	**84.99**	**87.78**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.98	2.87	0, 1, 2	M or N or S	0.63	1.84	0, 1, 2
Two factor effects	M × N, M × S, N × S	1.69	NS	61, 45, 83	M × N, M × S, N × S	1.09	NS	98, 56, 88
Three factor effects (3 FE)	MNS, MN^2S	2.93	NS	81, 31	MNS, MN^2S	1.88	NS	11, 66
3 FE confounded	MNS^2, MN^2S^2	2.93	NS	83, 72	MNS^2, MN^2S^2	1.88	NS	61, 89
CV (%)	4.15				3.06			

compared to $M_0 \times N$ or $M_0 \times S$, however $M_1 \times S$ and $M_2 \times S$ values were relatively similar. Though not significant, the 79.81 % filled grains in N_0S_0 increased to 89.90 % in N_2S_2 in first year. The corresponding value in the second year was 81.17 % and 87.78 %, respectively.

4.2.32.3 Three factor interactions

Three factor interactions and confounded effects were not significant in first and second years. However, in the absence of sulphur and organic manure, the response to N_{45} to N_{90} were higher than in the presence of sulphur (S_{15} or S_{30}) and absence of organic manure with regard to filled grains. In both the years the lowest filled grains were observed when no organics + no nitrogen + no sulphur were applied.

4.2.33 Thousand grain weight

4.2.33.1 Main effects

4.2.33.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen was significant in both the years (Table 4.37). Straw incorporation and cow dung application was statistically at par and significantly increased the thousand grain weight over no manure application.

4.2.33.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was significant in both the years. N_{45} and N_{90} were statistically at par and significantly increased the thousand grain weight over no nitrogen.

Table 4.37. Effect of manurial management on the thousand grain weight (g) of rice

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	24.80	26.40	25.92	**25.71**	24.93	25.58	25.55	**25.36**
Straw application (M_1)	26.02	26.52	27.22	**26.58**	26.12	26.00	26.77	**26.29**
Cow dung (M_2)	25.90	26.45	26.28	**26.21**	25.88	27.12	26.72	**26.57**
Mean	**25.57**	**26.46**	**26.47**		**25.64**	**26.23**	**26.34**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	25.08	25.97	26.07	**25.71**	24.97	25.60	25.50	**25.36**
Straw application (M_1)	25.63	26.90	27.22	**26.58**	25.78	26.32	26.78	**26.29**
Cow dung (M_2)	25.32	26.57	26.75	**26.21**	26.45	26.68	26.58	**26.57**
Mean	**25.34**	**26.48**	**26.68**		**25.73**	**26.20**	**26.29**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	24.90	25.68	26.13	**25.57**	25.28	25.72	25.93	**25.64**
N_{45}	25.53	26.83	27.00	**26.46**	26.22	26.37	26.12	**26.23**
N_{90}	25.60	26.92	26.90	**26.47**	25.70	26.52	26.82	**26.34**
Mean	**25.34**	**26.48**	**26.68**		**25.73**	**26.20**	**26.29**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	24.00	25.90	25.35	**25.08**	25.05	26.70	26.15	**25.97**	25.35	26.60	26.25	**26.07**
M_1	25.60	24.85	26.45	**25.63**	26.00	27.10	27.60	**26.90**	26.45	27.60	27.60	**27.22**
M_2	25.10	25.85	25.00	**25.32**	26.00	26.70	27.00	**26.57**	26.60	26.80	26.85	**26.75**
Mean	**24.90**	**25.53**	**25.60**		**25.68**	**26.83**	**26.92**		**26.13**	**27.00**	**26.90**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	24.25	25.85	24.80	**24.97**	25.25	25.80	25.75	**25.60**	25.30	25.10	26.10	**25.50**
M_1	25.90	25.70	25.75	**25.78**	25.70	26.20	27.05	**26.32**	26.75	26.10	27.50	**26.78**
M_2	25.70	27.10	26.55	**26.45**	26.20	27.10	26.75	**26.68**	25.75	27.15	26.85	**26.58**
Mean	**25.28**	**26.22**	**25.70**		**25.72**	**26.37**	**26.52**		**25.93**	**26.12**	**26.82**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.15	0.43	0, 0, 0	M* or N* or S^{NS}	0.19	0.55	1, 3, 10
Two factor effects	M × N, M × S, N × S	0.25	NS	7, 80, 79	M × N, M × S, N × S	0.32	NS	30, 28, 48
Three factor effects (3 FE)	MNS, MN^2S	0.44	NS	71, 24	MNS, MN^2S	0.56	NS	77, 81
3 FE confounded	MNS^2, MN^2S^2	0.44	NS	83, 17	MNS^2, MN^2S^2	0.56	NS	53, 39
CV (%)	2.24				2.95			

4.2.33.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen was significant in first and second years. In the first year, S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} were statistically at par and significantly increased the thousand grain weight over no sulphur. In the second year, mean increase in the grain weight with S @ 30 kg ha^{-1} over no sulphur was 2.17 %, whereas it was 0.34 % over S @ 15 kg ha^{-1}.

4.2.33.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were not significant in the first and second years except for the significance at 7 % level of significance for M × N in the first year. In the first year, the highest grain weight of 27.22 g was observed with the incorporation of straw + N @ 90 kg ha^{-1}. When cow dung was applied with all the levels of nitrogen, it reduced the grain weight compared to straw incorporated ones. In the second year the mean increase in the grain weight due to cow dung + N @ 45 kg ha^{-1} over no manure + no nitrogen was 8.78 %.

When straw incorporated with S @ 30 kg ha^{-1} increased the grain weight to 27.22 g in the first year, a step wise increase in the grain weight was observed due to the increasing levels of sulphur with all the sources of organic manures. In the second year mean increase in the grain weight due to straw + S @ 30 kg ha^{-1} over no organics + no sulphur was 7.25 %.

In the first year, the highest grain weight (27.00 g) was observed with the combined application of N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1}. It was 8.43 % higher than no nitrogen + sulphur application. But in the second year, the highest grain weight of 26.82 g was registered with the application of nitrogen and sulphur at higher levels.

4.2.33.3 Three factor interactions

Three factor interactions were not significant in first and second years. However, in the first year, the highest grain weight of 27.60 g was registered with the incorporation of straw + N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1}, straw incorporation + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} and straw incorporation + N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}. In the second year, grain weight increased to 27.50 g with the incorporation of straw + N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}. In both the years, no organics + no nitrogen + no sulphur treatments reduced the thousand grain weight.

4.2.34 Grain yield of rice

4.2.34.1 Main effects

4.2.34.1.1 Effect of organic manures

Straw incorporation and cow dung application resulted in significant yield increase in first year (Table 4.38). But in the second year, all the manurial treatments were at par. In first year straw incorporation produced the highest grain yield of 5732 kg ha^{-1} and it was at par with cow dung application (5441 kg ha^{-1}). In second year, cow dung application produced the higher grain yield (5828 kg ha^{-1}) when compared to straw application (5703 kg ha^{-1}).

4.2.34.1.2 Effect of nitrogen

The graded dose of nitrogen application averaged over organic manure and sulphur levels was significant in first and second years. A step wise increase in grain yield was noticed with the increasing doses of nitrogen. N_{90} produced the highest grain yield of 6127 and 6060 kg ha^{-1}, respectively in first and second years. In the second year, N_{90} was statistically at par with N_{45}.

4.2.34.1.3 Effect of sulphur

The effect of sulphur application averaged over organic manure and nitrogen levels was significant in both the years. A step wise increase in grain yield was noticed with no sulphur, S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} in first and second years. In the first year, S @ 30 kg ha^{-1} increased the grain yield over S @ 15 kg ha^{-1} by 4.75 % and in the second year by 8.22 %.

Table 4.38. Effect of manurial management on the grain yield (kg ha^{-1}) of rice

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	4296	5780	5758	**5278**	4977	6289	5672	**5646**
Straw application (M_1)	4910	5789	6499	**5732**	5290	5736	6082	**5703**
Cow dung (M_2)	4595	5604	6123	**5441**	5273	5786	6426	**5828**
Mean	**4600**	**5724**	**6127**		**5180**	**5937**	**6060**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	4442	5520	5873	**5278**	4684	5841	6414	**5646**
Straw application (M_1)	5177	5815	6206	**5732**	4968	5833	6306	**5703**
Cow dung (M_2)	4973	5624	5726	**5441**	4998	5975	6511	**5828**
Mean	**4864**	**5653**	**5935**		**4883**	**5883**	**6410**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	3997	4671	5133	**4600**	4246	5423	5871	**5180**
N_{45}	5067	5992	6114	**5724**	5210	6018	6583	**5937**
N_{90}	5528	6295	6557	**6127**	5195	6209	6777	**6060**
Mean	**4864**	**5653**	**5935**		**4883**	**5883**	**6410**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	3432	4738	5157	**4442**	4456	6242	5861	**5520**	5000	6361	6258	**5873**
M_1	4432	5350	5749	**5177**	5000	5782	6663	**5815**	5298	6234	7085	**6206**
M_2	4126	5112	5680	**4973**	4558	5952	6361	**5624**	5102	5748	6327	**5726**
Mean	**3997**	**5067**	**5528**		**4671**	**5992**	**6295**		**5133**	**6114**	**6557**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	3657	5514	4881	**4684**	5306	6371	5847	**5841**	5970	6983	6289	**6414**
M_1	4619	5143	5143	**4968**	5520	5803	6177	**5833**	5732	6262	6925	**6306**
M_2	4463	4973	5560	**4998**	5443	5880	6603	**5975**	5913	6505	7116	**6511**
Mean	**4246**	**5210**	**5195**		**5423**	**6018**	**6209**		**5871**	**6583**	**6777**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	103.69	304.12	2, 0, 0	M^{NS} or N* or S*	114.02	334.43	52, 1, 0
Two factor effects	M × N, M × S, N × S	179.59	NS	31, 41, 91	M × N, M × S, N × S	197.49	NS	4, 90, 8
Three factor effects (3 FE)	MNS, MN^2S	311.06	NS	49, 80	MNS, MN^2S	342.06	NS	52, 72
3 FE confounded	MNS^2, MN^2S^2	311.06	NS	70, 24	MNS^2, MN^2S^2	342.06	NS	46, 90
CV (%)	7.80				8.38			

4.2.34.2 Two factor interaction effects

Two factor interactions such as organic manure × nitrogen, organic manure × sulphur and nitrogen × sulphur were not significantly different in the first year, however M × N and N × S were significant in the second year. In the first year, straw incorporation with N @ 90 kg ha^{-1} (6499 kg ha^{-1}) and the same with S @ 30 kg ha^{-1} (6206 kg ha^{-1}) produced the highest grain yields. But in the second year, cow dung applied with N @ 90 kg ha^{-1} (6426 kg ha^{-1}) and the same with S @ 30 kg ha^{-1} (6511 kg ha^{-1}) produced the highest grain yields. In the first year, N and S at higher levels produced the highest grain yield (6557 kg ha^{-1}). A similar trend was observed in the second year also with a grain yield of 6777 kg ha^{-1}.

4.2.34.3 Three factor interactions

Three factor interactions were not significant in first and second years. However, the grain yield of 3432 kg ha^{-1} obtained in $M_0N_0S_0$ treatment increased to 4456 kg ha^{-1} in $M_0N_0S_{15}$ and to 5000 kg ha^{-1} in $M_0N_0S_{30}$ in the first year. The corresponding grain yields for the above treatment respectively were 3657, 5306 and 5970 kg in the second year. When no sulphur was applied, the M_1N_{90} produced 5749 kg ha^{-1} of grain yield which increased to 6673 and 7085 kg with S_{15} and S_{30}, respectively in the first year. A similar response was observed in the second year too. N_{45} and N_{90} treatments differed more with cow dung than straw incorporation in the production of grain yield irrespective of the sulphur levels in both the years.

4.2.35 Straw yield of rice

4.2.35.1 Main effects

4.2.35.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur were significant in first year, but not in the second year (Table 4.39). In both the years, paddy straw incorporation resulted the highest straw yield and it was 6731 kg ha^{-1}, a

Table 4.39. Effect of manurial management on the straw yield (kg ha^{-1}) of rice

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	4885	5692	6730	**5769**	5937	7489	8020	**7149**
Straw application (M_1)	6163	6782	7246	**6731**	5896	7569	8071	**7179**
Cow dung (M_2)	5329	6302	6993	**6208**	6380	7404	7437	**7073**
Mean	**5459**	**6258**	**6990**		**6071**	**7487**	**7843**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	4560	6416	6331	**5769**	5991	7713	7742	**7149**
Straw application (M_1)	5885	6863	7444	**6731**	6048	7737	7752	**7179**
Cow dung (M_2)	5537	6602	6484	**6208**	5719	7253	8248	**7073**
Mean	**5328**	**6627**	**6753**		**5919**	**7568**	**7914**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	4788	5711	5879	**5459**	5149	6328	6736	**6071**
N_{45}	5146	6742	6888	**6258**	6333	7926	8202	**7487**
N_{90}	6049	7429	7492	**6990**	6275	8449	8804	**7843**
Mean	**5328**	**6627**	**6753**		**5919**	**7568**	**7914**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	3769	4232	5681	**4560**	5619	6140	7490	**6416**	5269	6704	7020	**6331**
M_1	5895	5820	5942	**5885**	6041	6946	7602	**6863**	6555	7582	8194	**7444**
M_2	4701	5388	6524	**5537**	5473	7140	7194	**6602**	5813	6378	7262	**6484**
Mean	**4788**	**5146**	**6049**		**5711**	**6742**	**7429**		**5879**	**6888**	**7492**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	4677	6007	7289	**5991**	6300	8371	8469	**7713**	6834	8089	8303	**7742**
M_1	5249	6782	6112	**6048**	6354	7953	8905	**7737**	6085	7973	9198	**7752**
M_2	5521	6211	5425	**5719**	6330	7456	7973	**7253**	7289	8544	8912	**8248**
Mean	**5149**	**6333**	**6275**		**6328**	**7926**	**8449**		**6736**	**8202**	**8804**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	81.97	240.44	0, 0, 0	M^{NS} or N* or S*	168.55	494.39	91, 0, 0
Two factor effects	$M \times N^{NS}$, M × S*, $N \times S^{NS}$	141.98	416.45	10, 1, 15	M × N, M × S, N × S	291.95	NS	36, 40, 46
Three factor effects (3 FE)	MNS, MN^2S	245.92	NS	12, 12	MNS, MN^2S	505.66	NS	13, 56
3 FE confounded	MNS^2, MN^2S^2	721.31	NS	66, 10	MNS^2, MN^2S^2	505.66	NS	63, 62
CV (%)	5.35				9.48			

7.8 per cent increase over the cow dung applied treatment (6208 kg ha^{-1}) in the first year.

4.2.35.1.2 Effect of nitrogen

The nitrogen treatments averaged over organic manure and sulphur was significant in first and second years. In the first year N_{45} produced 6258 kg ha^{-1} of straw which increased to 6990 kg ha^{-1} at N_{90}, a 11.70 per cent increase. In the second year N_{45} was statistically at par with N_{90} and significantly increased the straw yield over no nitrogen application.

4.2.35.1.3 Effect of sulphur

The graded levels of sulphur averaged over organic manure and nitrogen was significant in first and second years. A step wise increase was seen with the increasing levels of sulphur application in both the years. In the first year S @ 15 kg ha^{-1} (6627 kg ha^{-1}) was statistically at par with S @ 30 kg ha^{-1} (6753 kg ha^{-1}) and significantly increased the straw yield over no sulphur application. In the second year also, these treatments were at par and significantly increased the straw yield over no sulphur application.

4.2.35.2 Two factor interaction effects

The two factor interactions such as M × S was highly significant in the first year. M × N and N × S were significant at 10 and 15 % levels of significance. However, these were not significant in the second year. The treatment paddy straw incorporation with higher dose of nitrogen produced the highest straw yields of 7246 kg ha^{-1} in the first year and 8071 kg ha^{-1} in the second year. N_{45} applied along with paddy straw produced higher yield than N_{90} applied along with cow dung in both the years. A similar trend was followed in the second year also.

In the first year, straw incorporation + S @ 30 kg ha^{-1} produced higher straw yield of 7444 kg ha^{-1} compared to cow dung application + S @ 30 kg ha^{-1} (6484 kg ha^{-1}) and no organics + S @ 30 kg ha^{-1} (6331 kg ha^{-1}). The treatments cow dung application + S @ 30 kg ha^{-1} and no organics + S @ 30 kg ha^{-1} were statistically at par. The treatment S @ 15 kg ha^{-1} with no organics (6416 kg ha^{-1}) was statistically at par with S @ 30 kg ha^{-1} with no organics (6331 kg ha^{-1}). S @ 15 and 30 kg ha^{-1} with cow dung were statistically at par with a yield of 6602 and 6484 kg ha^{-1}, respectively. In the second year, cow dung application with S @ 30 kg ha^{-1} produced the highest straw yield of 8248 kg ha^{-1}.

When nitrogen was applied in combination with sulphur the straw yield was increased with the increasing levels of nitrogen and sulphur. The highest yield noticed with the treatment N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1} in the first (7492 kg ha^{-1}) and second year (8804 kg ha^{-1}). Comparable yields as that of $N_{90}S_{30}$ were obtained at the reduced sulphur level 15 kg ha^{-1} applied with N_{90}.

4.2.35.3 Three factor interactions

Three factor interactions were significant at 12 and 13 % levels of significance in the first and second years. The treatment paddy straw incorporation with N_2S_2 produced the highest straw yield of 8194 kg ha^{-1} in the first year and 9198 kg ha^{-1} in the second year. When cow dung was given as organic source it reduced the yield compared to paddy straw incorporation in both the years. When the fertilizer levels were increased the yield also increased the straw yield increased with increasing levels of nitrogen and sulphur. In second year, straw incorporation with N_{45} + S_{15} produced a straw yield of 7953 kg ha^{-1} and the yield did not increase much with higher sulphur level but a mere 0.25 %. But with no manure application higher level of sulphur + N_{45} produced 6.3 % increase over S_{15}.

4.2.36 Nitrogen content of grain

4.2.36.1 Main effects

4.2.36.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur were significant at 21 and 13 % levels of significance in the first and second years (Table 4.40). Organic manures significantly increased the nitrogen content of grain in both the years. Though at par, cow dung application resulted in the grain nitrogen contents of 1.15 and 1.19 % followed by straw incorporation with 1.07 and 1.15 % in the first and second year, respectively.

4.2.36.1.2 Effect of nitrogen

The effect of nitrogen was significant in both the years. In the first year, N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} with 1.10 and 1.18 % were statistically at par and significantly increased the nitrogen content of grain over no nitrogen application (0.96 %). In the second year also, N_{45} and N_{90} were at par with nitrogen contents of 1.19 and 1.18 %.

4.2.36.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant only in the first year. S @ 15 kg ha^{-1} (1.08 %) and S @ 30 kg ha^{-1} (1.19 %) were statistically at par and significantly increased the nitrogen content over no sulphur (0.97 %).

4.2.36.2 Two factor interaction effects

Two factor interactions were not significant in both the years.

4.2.36.3 Three factor interactions

The MNS^2 interaction was significant at 12 % level of significance in the first year. Under S_{30} and S_{15}, cow dung and straw incorporation combined with N_{90} resulted similar nitrogen content, but under S_0, cow dung × N_{90} resulted in significantly higher nitrogen content than straw incorporation × N_{90}.

Table 4.40. Effect of manurial management on the nitrogen content (%) of grain

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.97	1.01	1.08	**1.02**	0.95	1.07	1.12	**1.05**
Straw application (M_1)	0.93	1.11	1.16	**1.07**	1.05	1.26	1.16	**1.15**
Cow dung (M_2)	0.99	1.18	1.29	**1.15**	1.08	1.25	1.26	**1.19**
Mean	**0.96**	**1.10**	**1.18**		**1.03**	**1.19**	**1.18**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.89	1.11	1.06	**1.02**	1.06	1.05	1.04	**1.05**
Straw application (M_1)	0.90	1.10	1.20	**1.07**	1.10	1.11	1.26	**1.15**
Cow dung (M_2)	1.13	1.03	1.30	**1.15**	1.14	1.21	1.23	**1.19**
Mean	**0.97**	**1.08**	**1.19**		**1.10**	**1.13**	**1.17**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.90	0.94	1.05	**0.96**	0.96	1.08	1.03	**1.03**
N_{45}	0.98	1.11	1.21	**1.10**	1.19	1.11	1.28	**1.19**
N_{90}	1.04	1.20	1.29	**1.18**	1.14	1.18	1.22	**1.18**
Mean	**0.97**	**1.08**	**1.19**		**1.10**	**1.13**	**1.17**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.00	0.81	0.86	**0.89**	1.01	1.08	1.26	**1.11**	0.92	1.14	1.12	**1.06**
M_1	0.83	0.93	0.94	**0.90**	0.89	1.25	1.16	**1.10**	1.07	1.15	1.39	**1.20**
M_2	0.87	1.19	1.32	**1.13**	0.93	1.00	1.18	**1.03**	1.17	1.36	1.37	**1.30**
Mean	**0.90**	**0.98**	**1.04**		**0.94**	**1.11**	**1.20**		**1.05**	**1.21**	**1.29**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.93	1.19	1.05	**1.06**	0.95	0.98	1.24	**1.05**	0.98	1.05	1.09	**1.04**
M_1	0.91	1.23	1.16	**1.10**	1.09	1.16	1.09	**1.11**	1.15	1.39	1.24	**1.26**
M_2	1.05	1.16	1.23	**1.14**	1.22	1.20	1.23	**1.21**	0.98	1.39	1.32	**1.23**
Mean	**0.96**	**1.19**	**1.14**		**1.08**	**1.11**	**1.18**		**1.03**	**1.28**	**1.22**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N^* or S^*	0.05	0.15	21, 3, 3	M^{NS} or N^* or S^{NS}	0.05	0.15	13, 5, 56
Two factor effects	M × N, M × S, N × S	0.09	NS	82, 31, 97	M × N, M × S, N × S	0.09	NS	94, 82, 75
Three factor effects (3 FE)	MNS, MN^2S	0.16	NS	55, 40	MNS, MN^2S	0.15	NS	86, 38
3 FE confounded	MNS^2, MN^2S^2	0.16	NS	12, 74	MNS^2, MN^2S^2	0.15	NS	90, 76
CV (%)	21.36				15.76			

4.2.37 Phosphorus content of grain

4.2.37.1 Main effects

4.2.37.1.1 Effect of organic manures

The effect of organic manures was not significantly different in the first and second years (Table 4.41). However a noticeable step wise increase in the phosphorus content of grain was observed between no organic manures, straw incorporation and cow dung application in both the years which was 0.12, 0.13 and 0.15 % in the first year and 0.14, 0.15 and 0.17 %, respectively in the second year.

The effect of nitrogen, sulphur, two factor and three factor interactions were not significant in both the yeas.

4.2.38 Potassium content of grain

4.2.38.1 Main effects

4.2.38.1.1 Effect of organic manures

The effect of organic manure treatments averaged over nitrogen and sulphur was significant at 19 and 7 % level of significance in first and second year, respectively (Table 4.42). A step wise increase in the potassium content was observed due to no organic manures (0.36 %), straw incorporation (0.40 %) and cow dung application (0.41 %) in the first year. In the second year also such an increase was observed and the corresponding values were 0.31, 0.34 and 0.36 %.

4.2.38.1.2 Effect of nitrogen

The effect of different levels of nitrogen was not significant in both the years.

4.2.38.1.3 Effect of sulphur

The different levels of sulphur averaged over organic manures and nitrogen was highly significant in the second year and the sulphur application at 15 kg ha^{-1}

Table 4.41. Effect of manurial management on the phosphorus content (%) of grain

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.12	0.12	0.13	**0.12**	0.16	0.12	0.15	**0.14**
Straw application (M_1)	0.15	0.13	0.11	**0.13**	0.16	0.12	0.18	**0.15**
Cow dung (M_2)	0.13	0.16	0.16	**0.15**	0.18	0.16	0.18	**0.17**
Mean	**0.14**	**0.14**	**0.14**		**0.17**	**0.13**	**0.17**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.14	0.12	0.12	**0.12**	0.15	0.15	0.13	**0.14**
Straw application (M_1)	0.16	0.11	0.11	**0.13**	0.13	0.17	0.16	**0.15**
Cow dung (M_2)	0.13	0.16	0.16	**0.15**	0.16	0.17	0.18	**0.17**
Mean	**0.14**	**0.13**	**0.13**		**0.15**	**0.16**	**0.16**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.15	0.15	0.10	**0.14**	0.16	0.17	0.17	**0.17**
N_{45}	0.15	0.11	0.15	**0.14**	0.13	0.14	0.13	**0.13**
N_{90}	0.13	0.14	0.14	**0.14**	0.15	0.18	0.18	**0.17**
Mean	**0.14**	**0.13**	**0.13**		**0.15**	**0.16**	**0.16**	

Interactions between organic manures, nitrogen and sulphur

	S_0				S_{15}				S_{30}			
First Year												
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.14	0.15	0.13	**0.14**	0.12	0.08	0.16	**0.12**	0.12	0.12	0.12	**0.12**
M_1	0.20	0.18	0.11	**0.16**	0.16	0.10	0.09	**0.11**	0.09	0.12	0.14	**0.11**
M_2	0.12	0.12	0.16	**0.13**	0.18	0.15	0.17	**0.16**	0.10	0.22	0.17	**0.16**
Mean	**0.15**	**0.15**	**0.13**		**0.15**	**0.11**	**0.14**		**0.10**	**0.15**	**0.14**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.21	0.11	0.13	**0.15**	0.14	0.15	0.17	**0.15**	0.15	0.10	0.15	**0.13**
M_1	0.11	0.13	0.15	**0.13**	0.21	0.11	0.20	**0.17**	0.16	0.14	0.19	**0.16**
M_2	0.16	0.15	0.18	**0.16**	0.18	0.16	0.17	**0.17**	0.20	0.16	0.20	**0.18**
Mean	**0.16**	**0.13**	**0.15**		**0.17**	**0.14**	**0.18**		**0.17**	**0.13**	**0.18**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.01	NS	27, 100, 72	M or N or S	0.01	NS	35, 12, 63
Two factor effects	M × N, M × S, N × S	0.02	NS	50, 37, 27	M × N, M × S, N × S	0.02	NS	91, 76, 99
Three factor effects (3 FE)	MNS, MN^2S	0.04	NS	82, 92	MNS, MN^2S	0.04	NS	96, 45
3 FE confounded	MNS^2, MN^2S^2	0.04	NS	87, 87	MNS^2, MN^2S^2	0.04	NS	97, 66
CV (%)	38.29				35.23			

Table 4.42. Effect of manurial management on the potassium content (%) of grain

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.36	0.35	0.38	**0.36**	0.31	0.31	0.31	**0.31**
Straw application (M_1)	0.35	0.45	0.40	**0.40**	0.33	0.33	0.35	**0.34**
Cow dung (M_2)	0.42	0.43	0.40	**0.41**	0.34	0.35	0.39	**0.36**
Mean	**0.37**	**0.41**	**0.39**		**0.33**	**0.33**	**0.35**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.32	0.39	0.39	**0.36**	0.25	0.35	0.34	**0.31**
Straw application (M_1)	0.41	0.40	0.38	**0.40**	0.30	0.37	0.35	**0.34**
Cow dung (M_2)	0.42	0.40	0.42	**0.41**	0.34	0.33	0.41	**0.36**
Mean	**0.38**	**0.40**	**0.40**		**0.30**	**0.35**	**0.36**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.33	0.42	0.37	**0.37**	0.29	0.36	0.34	**0.33**
N_{45}	0.40	0.40	0.42	**0.41**	0.30	0.35	0.35	**0.33**
N_{90}	0.40	0.38	0.39	**0.39**	0.30	0.35	0.40	**0.35**
Mean	**0.38**	**0.40**	**0.40**		**0.30**	**0.35**	**0.36**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.29	0.32	0.34	**0.32**	0.41	0.37	0.39	**0.39**	0.39	0.38	0.40	**0.39**
M_1	0.31	0.44	0.48	**0.41**	0.39	0.43	0.39	**0.40**	0.34	0.48	0.32	**0.38**
M_2	0.41	0.46	0.39	**0.42**	0.46	0.41	0.35	**0.40**	0.39	0.42	0.45	**0.42**
Mean	**0.33**	**0.40**	**0.40**		**0.42**	**0.40**	**0.38**		**0.37**	**0.42**	**0.39**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.30	0.25	0.19	**0.25**	0.38	0.32	0.35	**0.35**	0.25	0.38	0.38	**0.34**
M_1	0.30	0.28	0.33	**0.30**	0.35	0.41	0.35	**0.37**	0.35	0.31	0.38	**0.35**
M_2	0.28	0.38	0.37	**0.34**	0.35	0.31	0.35	**0.33**	0.41	0.37	0.45	**0.41**
Mean	**0.29**	**0.30**	**0.30**		**0.36**	**0.35**	**0.35**		**0.34**	**0.35**	**0.40**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.01	NS	19, 46, 79	M^{NS} or N^{NS} or S*	0.01	0.04	7, 54, 0
Two factor effects	M × N, M × S, N × S	0.03	NS	41, 49, 49	M × N, M × S, N × S	0.03	NS	99, 19, 2
Three factor effects (3 FE)	MNS, MN^2S	0.05	NS	46, 22	MNS*, MN^2S^{NS}	0.04	0.13	4, 30
3 FE confounded	MNS^2, MN^2S^2	0.05	NS	54, 88	MNS^2, MN^2S^2	0.04	NS	62, 100
CV (%)	16.82				17.93			

increased the grain potassium content from 0.30 % to 0.35 % and further 0.36 % at S_{30} level. In the second year also, grain potassium content increased to 0.40 % at S_{15} and S_{30} levels.

4.2.38.2 Two factor interaction effects

Two factor interactions were not significant in both the years.

4.2.38.3 Three factor interactions

The MNS interaction was found significant in the second year. The grain potassium content was significantly increased with cow dung application combined with N_{90} and S_{30}. But under low level of nitrogen and sulphur, the values were at par for cow dung application and straw incorporation.

4.2.39 Sulphur content of grain

4.2.39.1 Main effects

4.2.39.1.1 Effect of organic manures

The effect of organic manure treatments such as no manures, paddy straw incorporation and cow dung application averaged over nitrogen and sulphur was significant in the first year (Table 4.43). In the first year, straw incorporation (0.44 %) and cow dung application (0.40 %) was statistically at par.

4.2.39.1.2 Effect of nitrogen

The different levels of nitrogen averaged over organic manures and sulphur was significant at 8 % level of significance in the first year and highly significant in the second year. N_{45} and N_{90} levels were at par in both the years, however step wise increase from 0.30 % at N_0, 0.38 % at N_{45} and 0.43 % at N_{90} was observed in the second year. In the first year, a 0.36 % at N_0 increased to 0.43 % at N_{45}.

Table 4.43. Effect of manurial management on the sulphur content (%) of grain

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.33	0.40	0.35	**0.36**	0.32	0.38	0.41	**0.37**
Straw application (M_1)	0.36	0.47	0.49	**0.44**	0.28	0.41	0.44	**0.38**
Cow dung (M_2)	0.39	0.40	0.42	**0.40**	0.31	0.36	0.45	**0.37**
Mean	**0.36**	**0.43**	**0.42**		**0.30**	**0.38**	**0.43**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.32	0.35	0.41	**0.36**	0.33	0.40	0.37	**0.37**
Straw application (M_1)	0.37	0.48	0.47	**0.44**	0.30	0.39	0.44	**0.38**
Cow dung (M_2)	0.31	0.44	0.46	**0.40**	0.31	0.39	0.42	**0.37**
Mean	**0.34**	**0.43**	**0.44**		**0.31**	**0.40**	**0.41**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.30	0.38	0.41	**0.36**	0.26	0.34	0.31	**0.30**
N_{45}	0.35	0.43	0.50	**0.43**	0.33	0.38	0.44	**0.38**
N_{90}	0.36	0.47	0.42	**0.42**	0.35	0.47	0.48	**0.43**
Mean	**0.34**	**0.43**	**0.44**		**0.31**	**0.40**	**0.41**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.28	0.35	0.35	**0.32**	0.34	0.38	0.35	**0.35**	0.38	0.49	0.36	**0.41**
M_1	0.33	0.42	0.37	**0.37**	0.37	0.47	0.61	**0.48**	0.40	0.53	0.49	**0.47**
M_2	0.28	0.30	0.37	**0.31**	0.43	0.44	0.46	**0.44**	0.47	0.48	0.43	**0.46**
Mean	**0.30**	**0.35**	**0.36**		**0.38**	**0.43**	**0.47**		**0.41**	**0.50**	**0.42**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.33	0.42	0.34	**0.36**	0.42	0.36	0.44	**0.40**	0.34	0.35	0.45	**0.38**
M_1	0.33	0.27	0.38	**0.33**	0.28	0.47	0.43	**0.39**	0.31	0.50	0.53	**0.44**
M_2	0.39	0.30	0.37	**0.35**	0.32	0.31	0.55	**0.39**	0.38	0.47	0.47	**0.44**
Mean	**0.35**	**0.33**	**0.36**		**0.34**	**0.38**	**0.47**		**0.34**	**0.44**	**0.48**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^* or N^{NS} or S^*	0.02	0.06	5, 8, 0	M^{NS} or N^* or S^*	0.02	0.07	95, 0, 2
Two factor effects	M × N, M × S, N × S	0.04	NS	48, 67, 56	M × N, M × S, N × S	0.04	NS	77, 72, 76
Three factor effects (3 FE)	MNS, MN^2S	0.06	NS	60, 63	MNS, MN^2S	0.07	NS	81, 50
3 FE confounded	MNS^2, MN^2S^2	0.19	NS	68, 49	MNS^2, MN^2S^2	0.07	NS	72, 81
CV (%)	22.31				29.63			

4.2.39.1.3 Effect of sulphur

The effect of graded doses of sulphur was significant in both the years and the higher levels of sulphur were at par.

Two factor and three factor interactions were not significant in both the years.

4.2.40 Calcium content of grain

4.2.40.1 Main effects

4.2.40.1.1 Effect of organic manures

The effect of organic manure treatments averaged over nitrogen and sulphur was highly significant in the first year and significant at 23 % level of significance in the second year (Table 4.44). Straw incorporation and cow dung application were statistically at par and significantly increased the calcium content of grain over no organics. In the second year, the calcium content in no organic manures of 242.00 ppm increased to 256.07 ppm by straw incorporation and 259.39 ppm by cow dung application. In the first year, 182.67 ppm calcium content in the no organic manure treatments increased to 233.31 with cow dung application and 234.89 ppm with straw incorporation.

4.2.40.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur on grain calcium content was highly significant in the first year and significant at 11 % level of significance in the second year. In the first year, N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} was statistically at par with 226.38 ppm and 239.82 ppm and significantly increased the calcium content of grain over no nitrogen (184.67 ppm). In the second year, the calcium content in N_0, N_{45} and N_{90} treatments were 240.56 ppm, 263.43 ppm and 253.47 ppm, respectively.

Table 4.44. Effect of manurial management on the calcium content (ppm) of grain

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	132.50	209.00	206.50	**182.67**	246.67	252.58	226.75	**242.00**
Straw application (M_1)	237.08	209.29	258.29	**234.89**	209.58	261.04	297.58	**256.07**
Cow dung (M_2)	184.42	260.83	254.67	**233.31**	265.42	276.67	236.08	**259.39**
Mean	**184.67**	**226.38**	**239.82**		**240.56**	**263.43**	**253.47**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	174.42	154.29	219.29	**182.67**	232.29	250.63	243.08	**242.00**
Straw application (M_1)	221.88	246.25	236.54	**234.89**	215.29	282.92	270.00	**256.07**
Cow dung (M_2)	209.46	224.33	266.13	**233.31**	248.96	230.83	298.38	**259.39**
Mean	**201.92**	**208.29**	**240.65**		**232.18**	**254.79**	**270.49**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	181.58	157.21	215.21	**184.67**	222.71	240.00	258.96	**240.56**
N_{45}	215.00	220.96	243.17	**226.38**	246.67	235.00	308.63	**263.43**
N_{90}	209.17	246.71	263.58	**239.82**	227.17	289.38	243.88	**253.47**
Mean	**201.92**	**208.29**	**240.65**		**232.18**	**254.79**	**270.49**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	121.38	235.00	166.88	**174.42**	78.00	187.25	197.63	**154.29**	198.13	204.75	255.00	**219.29**
M_1	261.25	165.00	239.38	**221.88**	237.50	240.63	260.63	**246.25**	212.50	222.25	274.88	**236.54**
M_2	162.13	245.00	221.25	**209.46**	156.13	235.00	281.88	**224.33**	235.00	302.50	260.88	**266.13**
Mean	**181.58**	**215.00**	**209.17**		**157.21**	**220.96**	**246.71**		**215.21**	**243.17**	**263.58**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	215.00	270.00	211.88	**232.29**	276.88	209.38	265.63	**250.63**	248.13	278.38	202.75	**243.08**
M_1	191.25	186.25	268.38	**215.29**	195.00	293.13	360.63	**282.92**	242.50	303.75	263.75	**270.00**
M_2	261.88	283.75	201.25	**248.96**	248.13	202.50	241.88	**230.83**	286.25	343.75	265.13	**298.38**
Mean	**222.71**	**246.67**	**227.17**		**240.00**	**235.00**	**289.38**		**258.96**	**308.63**	**243.88**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N* or S^{NS}	12.14	35.62	1, 1, 8	M^{NS} or N^{NS} or S*	7.29	21.40	23, 11, 0
Two factor effects	M × N, M × S, N × S	21.04	NS	12, 47, 65	M × N, M × S, N × S	12.64	37.06	0, 0, 0
Three factor effects (3 FE)	MNS, MN^2S	36.44	NS	36, 43	MNS, MN^2S	21.89	NS	12, 46
3 FE confounded	MNS^2, MN^2S^2	36.44	NS	30, 60	MNS^2, MN^2S^2	21.89	NS	43, 15
CV (%)	20.10				8.11			

4.2.40.1.3 Effect of sulphur

The effect of sulphur doses averaged over organic manures and nitrogen was significant at 8 % level of significance in the first year, and highly significant in the second year. In the first year there was a marked increase at S_{30} in the calcium content to 240.65 ppm from 201.92 ppm at S_0. The S_{15} resulted in a calcium content of 208.29 ppm. In the second year S_{15} and S_{30} were at par with 254.79 ppm and 270.49 ppm, respectively, the content in S_0 was 232.18 ppm.

4.2.40.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were highly significant and in the second year M × N was significant at 12 % level of significance. In the first year, the highest calcium content of 260.83 ppm was registered with the application of cow dung + N @ 45 kg ha^{-1}. When cow dung was applied with nitrogen at higher level, the calcium content was reduced by 2.36 % compared to cow dung + N @ 45 kg ha^{-1}. In the second year, straw + N @ 45 kg ha^{-1} and straw + N @ 90 kg ha^{-1} were statistically at par.

At S_{15} level straw incorporation resulted in significantly higher calcium content of grain of 282.92 ppm but, that of cow dung application was only 230.83 ppm. But at S_{30} level, both straw incorporation and cow dung application resulted similar contents of 270.00 ppm and 298.38 ppm.

Significant interaction between nitrogen and sulphur resulted in the similar calcium content of 289.38 ppm at $N_{90}S_{15}$ and 308.63 ppm with $N_{45}S_{30}$. When no sulphur was given all the nitrogen treatments resulted in similar calcium content.

4.2.40.3 Three factor interactions

The MNS and MN^2S^2 interaction were significant at 12 and 15 % level in the second year. Under S_{30}, straw incorporation + N_{90} and cow dung + N_{90} were at par but cow dung + N_{45} was significantly superior to straw incorporation + N_{45} in the calcium content.

4.2.41 Magnesium content of grain

4.2.41.1 Main effects

4.2.41.1.1 Effect of organic manures

The effect of organic manures averaged over varied doses of sulphur and nitrogen were significant in both the years (Table 4.45). In the first year, no organic manures (810 ppm) and straw incorporation (844 ppm) were statistically at par and the highest magnesium content of 966 ppm was registered with cow dung application. But in the second year, no organic manures (776 ppm) and cow dung application (765 ppm) was statistically at par and highest content of 986 ppm was registered with straw incorporation.

4.2.41.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant in both the years. In the first year, the highest magnesium content of 959 ppm was obtained with the application of N @ 45 kg ha^{-1}. N_{90} reduced the magnesium content by 8.65 % compared to N_{45}. In the second year, no nitrogen (781 ppm) and N_{90} (819 ppm) was statistically at par and the highest content of 928 ppm was registered with the application of N_{45}.

4.2.41.1.3 Effect of sulphur

The effect of different levels of sulphur averaged over organic manures and nitrogen was significantly different in both the years. In the first year, a step wise increase in the magnesium content of grain was noted with the increasing levels of sulphur. The mean increase in the magnesium content due to S @ 30 kg ha^{-1} over no sulphur was 25.25 % and 13.27 % over S @ 15 kg ha^{-1}. In the second year no sulphur and S @ 15 kg ha^{-1} were at par which was in turn at par with S @ 30 kg ha^{-1}.

Table 4.45. Effect of manurial management on the magnesium content (ppm) of grain

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	808	605	1016	**810**	800	729	799	**776**
Straw application (M_1)	623	1125	784	**844**	960	1079	920	**986**
Cow dung (M_2)	925	1146	826	**966**	582	975	736	**765**
Mean	**785**	**959**	**876**		**781**	**928**	**819**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	723	849	857	**810**	638	783	907	**776**
Straw application (M_1)	762	836	934	**844**	977	1002	980	**986**
Cow dung (M_2)	762	922	1214	**966**	725	769	800	**765**
Mean	**749**	**869**	**1002**		**780**	**851**	**896**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	735	820	801	**785**	754	784	804	**781**
N_{45}	819	851	1206	**959**	771	997	1016	**928**
N_{90}	693	935	999	**876**	815	773	868	**819**
Mean	**749**	**869**	**1002**		**780**	**851**	**896**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	721	478	970	**723**	943	522	1083	**849**	761	815	996	**857**
M_1	628	1142	516	**762**	653	1104	749	**836**	586	1128	1088	**934**
M_2	857	838	592	**762**	863	927	975	**922**	1056	1674	913	**1214**
Mean	**735**	**819**	**693**		**820**	**851**	**935**		**801**	**1206**	**999**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	780	604	531	**638**	797	763	790	**783**	824	821	1077	**907**
M_1	1036	856	1039	**977**	1016	1127	864	**1002**	829	1254	858	**980**
M_2	446	852	876	**725**	540	1101	665	**769**	760	972	668	**800**
Mean	**754**	**771**	**815**		**784**	**997**	**773**		**804**	**1016**	**868**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	27.88	81.78	0, 0, 0	M or N or S	30.00	87.99	0, 0, 4
Two factor effects	M × N, M × S, N × S	48.29	141.64	0, 2, 0	M × N*, M × S^{NS}, N × S^{NS}	51.96	152.41	0, 18, 12
Three factor effects (3 FE)	MNS, MN^2S	83.64	245.33	0, 2	MNS*, MN^2S^{NS}	90.00	263.98	0, 74
3 FE confounded	MNS^2, MN^2S^2	83.64	NS	72, 14	MNS^2*, MN^2S^2 ^{NS}	90.00	263.98	3, 81
CV (%)	12.39				13.45			

4.2.41.2 Two factor interaction effects

M × N interaction was highly significant in both the years, however M × S and N × S was highly significant in the first year and significant at 18 and 12 % levels of significance in the second year. In the first year, the treatments straw incorporation + N @ 45 kg ha^{-1} (1125 ppm) and cow dung + N @ 45 kg ha^{-1} (1146 ppm) were statistically at par and significantly increased the magnesium content over other treatments. The lowest content of 605 ppm was registered with the application of no organics + N @ 45 kg ha^{-1}. In the second year the highest magnesium content of 1079 ppm was recorded with straw incorporation + N @ 45 kg ha^{-1} and the lowest content (582 ppm) was recorded with cow dung with no manures.

In the first year, when cow dung applied with higher level of sulphur increased the magnesium content by 67.91 % over no organics + no sulphur. A step wise increase in the magnesium content was also seen with the increasing levels of sulphur with all the sources of organic manures. In the second year, mean increase in the magnesium content of grain due to straw incorporation + S @ 15 kg ha^{-1} over no organics + no sulphur was 57.05 %.

Nitrogen applied at 45 kg ha^{-1} with S @ 30 kg ha^{-1} increased the magnesium content by 64.08 % over no nitrogen + no sulphur by 50.56 % over no nitrogen + S @ 30 kg ha^{-1} and by 20.72 % over N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}. A similar effect was observed in the second year also.

4.2.41.3 Three factor interactions

MNS interaction was significant in both the years, MN^2S and MNS^2 were significant in the first and second year, respectively. In the first year, the highest magnesium content of 1674 ppm was registered with the application of cow dung + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1}. No manures + N @ 45 kg ha^{-1} + no sulphur, straw incorporation + N @ 90 kg ha^{-1} + no sulphur, no organics + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1}, straw incorporation + no nitrogen + S @ 30 kg ha^{-1}, straw incorporation + no nitrogen + no sulphur, straw incorporation + no nitrogen + S @ 15 kg ha^{-1} and no organics + no nitrogen + no sulphur registered relatively lower content of magnesium content by grain. In the second year, straw incorporation + no nitrogen + S @ 15 kg ha^{-1}, straw incorporation + no nitrogen + no sulphur, straw incorporation + N @ 90 kg ha^{-1} + no sulphur, no organics + N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}, cow dung + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1}, straw incorporation + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} and straw incorporation + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} were statistically at par and significantly increased the magnesium content over other treatments.

4.2.42 Iron content of grain

4.2.42.1 Main effects

4.2.42.1.1 Effect of organic manures

The effect of organic manures such as no manures, paddy straw incorporation and cow dung application averaged over nitrogen and sulphur were highly significant in first the year, however, significant at 21 % level of significance in the second year (Table 4.46). Organic manures increased the iron content of straw, higher content of 425.06 ppm was registered in the straw incorporated treatment.

4.2.42.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant at 16 % and 23 % levels of significance in the first and second years, respectively. In the first year the highest accumulation of 340.18 ppm was observed with N_{90} whereas in the second year the content was the highest (439.83 ppm) with N_{45}.

4.2.42.1.3 Effect of sulphur

The effect of of sulphur averaged organic manures and nitrogen was significant at 10 % level of significance in the second year. There was a step wise

Table 4.46. Effect of manurial management on the iron content (ppm) of grain

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	391.25	240.63	301.25	**311.04**	303.08	387.50	336.54	**342.38**
Straw application (M_1)	303.33	287.08	336.79	**309.07**	390.29	533.33	351.54	**425.06**
Cow dung (M_2)	309.38	221.04	382.50	**304.31**	411.00	398.67	409.46	**406.38**
Mean	**334.65**	**249.58**	**340.18**		**368.13**	**439.83**	**365.85**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	265.96	363.63	303.54	**311.04**	303.13	336.13	387.88	**342.38**
Straw application (M_1)	330.54	302.08	294.58	**309.07**	357.79	409.04	508.33	**425.06**
Cow dung (M_2)	324.79	288.75	299.38	**304.31**	355.38	421.04	442.71	**406.38**
Mean	**307.10**	**318.15**	**299.17**		**338.76**	**388.74**	**446.31**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	310.13	327.17	366.67	**334.65**	332.46	406.54	365.38	**368.13**
N_{45}	258.33	244.17	246.25	**249.58**	375.00	345.42	599.08	**439.83**
N_{90}	352.83	383.13	284.58	**340.18**	308.83	414.25	374.46	**365.85**
Mean	**307.10**	**318.15**	**299.17**		**338.76**	**388.74**	**446.31**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	176.63	293.13	328.13	**265.96**	512.75	250.00	328.13	**363.63**	484.38	178.75	247.50	**303.54**
M_1	357.50	281.88	352.25	**330.54**	260.63	281.25	364.38	**302.08**	291.88	298.13	293.75	**294.58**
M_2	396.25	200.00	378.13	**324.79**	208.13	201.25	456.88	**288.75**	323.75	261.88	312.50	**299.38**
Mean	**310.13**	**258.33**	**352.83**		**327.17**	**244.17**	**383.13**		**366.67**	**246.25**	**284.58**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	348.75	325.63	235.00	**303.13**	306.88	300.00	401.50	**336.13**	253.63	536.88	373.13	**387.88**
M_1	351.25	358.75	363.38	**357.79**	413.38	441.25	372.50	**409.04**	406.25	800.00	318.75	**508.33**
M_2	297.38	440.63	328.13	**355.38**	499.38	295.00	468.75	**421.04**	436.25	460.38	431.50	**442.71**
Mean	**332.46**	**375.00**	**308.83**		**406.54**	**345.42**	**414.25**		**365.38**	**599.08**	**374.46**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	35.83	NS	100, 16, 93	M or N or S	33.15	NS	21, 23, 10
Two factor effects	M × N, M × S, N × S	62.06	NS	62, 83, 80	M × N, M × S, N × S	57.43	NS	50, 96, 10
Three factor effects (3 FE)	MNS, MN^2S	107.50	NS	26, 50	MNS, MN^2S	99.46	NS	22, 95
3 FE confounded	MNS^2, MN^2S^2	107.50	NS	74, 67	MNS^2, MN^2S^2	99.46	NS	21, 74
CV (%)	52.00				34.53			

increase in the iron content of grain with 338.76, 388.74 and 446.31 ppm with S_0, S_{15} and S_{30} levels.

4.2.42.2 Two factor interaction effects

N × S interaction was significant at 10 % level of significance in the second year. The highest content of 599.08 ppm was observed with $N_{45}S_{30}$, which was significantly higher than other treatments. With S_{15} and S_{30}, the different nitrogen levels did not cause any significant difference.

4.2.42.3 Three factor interactions

Three factor interactions were relatively less significant, however MNS in both the years, was significant at 26 % and 22 % levels of significance and MN^2S at 21 % in the second year. Higher grain iron content was observed under S_{15} when combined with cow dung application + N_{90}.

4.2.43 Manganese content of grain

4.2.43.1 Main effects

4.2.43.1.1 Effect of organic manures

Organic manures significantly increased the manganese content, cow dung application in the first year and straw incorporation in the second year (Table 4.47). In the first year mean increase in the manganese content of grain due to cow dung application over no organics was 38.06 %. In the second year, the highest manganese content of 70.38 ppm was observed with the incorporation of straw whereas no organics and cow dung application were at par.

4.2.43.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur have shown significant difference in both the years. N @ 45 kg ha^{-1}

Table 4.47. Effect of manurial management on the manganese content (ppm) of grain

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	47.46	41.25	37.09	**41.93**	62.31	64.75	67.90	**64.99**
Straw application (M_1)	50.11	60.79	38.84	**49.91**	65.13	86.15	59.86	**70.38**
Cow dung (M_2)	51.46	62.67	59.54	**57.89**	61.96	61.00	69.73	**64.23**
Mean	**49.67**	**54.90**	**45.15**		**63.13**	**70.63**	**65.83**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	44.77	45.38	35.65	**41.93**	64.02	69.19	61.75	**64.99**
Straw application (M_1)	47.33	58.19	44.21	**49.91**	61.54	77.88	71.71	**70.38**
Cow dung (M_2)	63.15	52.69	57.84	**57.89**	64.44	64.96	63.29	**64.23**
Mean	**51.75**	**52.08**	**45.90**		**63.33**	**70.68**	**65.59**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	56.69	57.61	34.73	**49.67**	70.33	64.69	54.38	**63.13**
N_{45}	47.02	60.94	56.75	**54.90**	59.77	76.63	75.50	**70.63**
N_{90}	51.54	37.71	46.21	**45.15**	59.90	70.71	66.88	**65.83**
Mean	**51.75**	**52.08**	**45.90**		**63.33**	**70.68**	**65.59**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	52.38	30.38	51.57	**44.77**	53.75	48.94	33.44	**45.38**	36.25	44.44	26.25	**35.65**
M_1	48.13	53.25	40.63	**47.33**	66.63	70.88	37.07	**58.19**	35.57	58.25	38.82	**44.21**
M_2	69.57	57.44	62.44	**63.15**	52.44	63.00	42.63	**52.69**	32.38	67.57	73.57	**57.84**
Mean	**56.69**	**47.02**	**51.54**		**57.61**	**60.94**	**37.71**		**34.73**	**56.75**	**46.21**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	69.63	62.19	60.25	**64.02**	75.63	70.13	61.82	**69.19**	41.69	61.94	81.63	**61.75**
M_1	69.50	56.69	58.44	**61.54**	73.50	95.69	64.44	**77.88**	52.38	106.07	56.69	**71.71**
M_2	71.88	60.44	61.00	**64.44**	44.94	64.07	85.88	**64.96**	69.07	58.50	62.32	**63.29**
Mean	**70.33**	**59.77**	**59.90**		**64.69**	**76.63**	**70.71**		**54.38**	**75.50**	**66.88**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N* or S^{NS}	2.27	6.67	0, 2, 12	M or N or S	1.49	4.38	2, 0, 0
Two factor effects	M × N*, M × S^{NS}, N × S*	3.94	11.56	2, 8, 0	M × N*, M × S^{NS}, N × S*	2.58	7.58	0, 4, 0
Three factor effects (3 FE)	MNS, MN^2S	6.83	NS	9, 41	MNS, MN^2S	4.48	13.13	0, 0
3 FE confounded	MNS^2 *, $MN^2S^{2\ NS}$	6.83	20.02	4, 82	MNS^2, MN^2S^2	4.48	13.13	0, 5
CV (%)	20.05				6.93			

registered the highest manganese content of grain of 54.90 and 70.63 ppm in the first and second years, respectively.

4.2.43.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and sulphur was significant at 12 % level of significance in the first year, and highly significant in the second year. In the first year the highest manganese content of 52.08 ppm was observed with the application of S @ 15 kg ha^{-1}. It was 13.46 % higher when compared to S @ 30 kg ha^{-1}. In the second year also, the highest manganese content of 70.68 ppm was registered with S @ 15 kg ha^{-1}.

4.2.43.2 Two factor interaction effects

Two factor interactions were significantly different. In the first year, the highest manganese content was observed with cow dung + N @ 45 kg ha^{-1} (62.67 ppm). The lowest manganese content of 37.09 ppm was observed with no organics + N @ 90 kg ha^{-1}. In the second year, the mean increase in the manganese content due to straw + N @ 45 kg ha^{-1} over straw + N @ 90 kg ha^{-1} was 43.92 %.

No sulphur + cow dung has resulted in manganese content of 63.15 ppm which was 43.55 % higher than no organics + S @ 30 kg ha^{-1}. Under no organic manure application, the sulphur levels (S_0, S_{15} and S_{30}) did not manifest any significant quantitative change in manganese content, but the cow dung application and straw incorporation caused significant step wise increase in grain manganese content.

In the first year, the manganese uptake was registered with the application of N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} (60.94 ppm) and the lowest content of manganese registered with no nitrogen + S @ 30 kg ha^{-1} (34.73 ppm). A similar effect was identified in the second year also.

4.2.43.3 Three factor interactions

MNS interaction was significant at 9 % level of significance in the first year and highly significant in the second year. MNS^2 was significant in both the years. MN^2S^2 and MN^2S were highly significant in the second year. In the first year, the highest manganese content of grain was observed with straw + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} (70.88 ppm) a 33.11 % increase over straw incorporation + N @ 45 kg ha^{-1} + no sulphur. No organics + nitrogen and sulphur at higher level drastically reduced the manganese content to 26.25 ppm. In the second year, the highest manganese content of 106.07 ppm was observed with straw + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1}. The lowest content of 41.69 ppm was registered with no organics + no nitrogen + S @ 30 kg ha^{-1}.

4.2.44 Grain protein content

4.2.44.1 Main effects

4.2.44.1.1 Effect of organic manures

The effect of organic manures on grain protein content of rice averaged over nitrogen and sulphur were significant at 31 and 13 % levels of significance in the first and second year respectively (Table 4.48). Cow dung application registered the highest grain protein of 7.20 and 7.47 % in first and second years, respectively.

4.2.44.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant at 6 % levels of significance in both the years. In the first year, grain protein content increased from 6.02 to 6.86 % in N_{45} and to 7.36 in N_{90}. In the second year, N_{45} (7.45 %) increased the grain protein content compared to N_{90} (7.38 %).

Table 4.48. Effect of manurial management on the grain protein content of rice

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	6.08	6.29	6.75	**6.38**	5.94	6.71	7.02	**6.56**
Straw application (M_1)	5.80	6.92	7.27	**6.66**	6.54	7.85	7.25	**7.22**
Cow dung (M_2)	6.17	7.39	8.06	**7.20**	6.75	7.79	7.85	**7.47**
Mean	**6.02**	**6.86**	**7.36**		**6.41**	**7.45**	**7.38**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	5.56	6.96	6.60	**6.38**	6.59	6.58	6.49	**6.56**
Straw application (M_1)	5.63	6.85	7.51	**6.66**	6.85	6.93	7.86	**7.22**
Cow dung (M_2)	7.03	6.46	8.13	**7.20**	7.15	7.58	7.67	**7.47**
Mean	**6.07**	**6.76**	**7.41**		**6.86**	**7.03**	**7.34**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	5.61	5.86	6.57	**6.02**	6.01	6.76	6.46	**6.41**
N_{45}	6.10	6.91	7.58	**6.86**	7.44	6.95	7.97	**7.45**
N_{90}	6.50	7.50	8.08	**7.36**	7.15	7.39	7.59	**7.38**
Mean	**6.07**	**6.76**	**7.41**		**6.86**	**7.03**	**7.34**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6.25	5.06	5.38	**5.56**	6.28	6.72	7.88	**6.96**	5.72	7.09	7.00	**6.60**
M_1	5.19	5.81	5.88	**5.63**	5.53	7.78	7.25	**6.85**	6.69	7.16	8.69	**7.51**
M_2	5.41	7.44	8.25	**7.03**	5.78	6.22	7.38	**6.46**	7.31	8.50	8.56	**8.13**
Mean	**5.61**	**6.10**	**6.50**		**5.86**	**6.91**	**7.50**		**6.57**	**7.58**	**8.08**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	5.78	7.44	6.56	**6.59**	5.91	6.13	7.72	**6.58**	6.13	6.56	6.78	**6.49**
M_1	5.69	7.66	7.22	**6.85**	6.78	7.22	6.78	**6.93**	7.16	8.69	7.75	**7.86**
M_2	6.56	7.22	7.66	**7.15**	7.59	7.50	7.66	**7.58**	6.09	8.66	8.25	**7.67**
Mean	**6.01**	**7.44**	**7.15**		**6.76**	**6.95**	**7.39**		**6.46**	**7.97**	**7.59**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.38	NS	31, 6, 6	M or N or S	0.38	NS	13, 6, 56
Two factor effects	M × N, M × S, N × S	0.65	NS	89, 46, 98	M × N, M × S, N × S	0.65	NS	94, 81, 75
Three factor effects (3 FE)	MNS, MN^2S	1.13	NS	90, 90	MNS, MN^2S	1.13	NS	86, 38
3 FE confounded	MNS^2, MN^2S^2	1.13	NS	51, 83	MNS^2, MN^2S^2	1.13	NS	90, 76
CV (%)	21.35				15.74			

4.2.44.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant only at 6 % level of significance in the first year. A step wise increase in the grain protein content was observed with 6.07 % in S_0, 6.76 % in S_{15} and 7.41 % in S_{30}. A similar trend was observed in the second year also.

Two factor and three factor interaction effects were not significant in both the years.

4.2.45 Protein yield of rice

4.2.45.1 Main effects

4.2.45.1.1 Effect of organic manures

The effect of organic manures on grain protein yield (kg ha^{-1}) averaged over nitrogen and sulphur was significant at 12 % level of significance in the first year and highly significant in the second year (Table 4.49). In the second year, grain protein yield was the least in no organic manure treatment (370.43 kg ha^{-1}) which increased to 414.01 kg ha^{-1} with straw incorporation and to 437.52 kg ha^{-1} with cow dung application, latter two were at par.

4.2.45.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant. In the first year, a stepwise increase of grain protein yield was observed with 277.75 kg ha^{-1} in no nitrogen application treatment, 394.83 kg ha^{-1} in N_{45} and 454.42 kg at N_{90}. In the second year also a similar trend was observed, however N_{45} (441.61 kg ha^{-1}) was at par with N_{90} (449.37 kg ha^{-1}).

Table 4.49. Effect of manurial management on the protein yield (kg ha^{-1}) of rice

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	259.17	367.59	392.78	**339.84**	292.32	418.75	400.21	**370.43**
Straw application (M_1)	285.91	402.38	477.50	**388.60**	347.67	451.88	442.47	**414.01**
Cow dung (M_2)	288.19	414.53	492.98	**398.57**	352.93	454.20	505.43	**437.52**
Mean	**277.75**	**394.83**	**454.42**		**330.97**	**441.61**	**449.37**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	241.29	386.29	391.95	**339.84**	312.31	383.24	415.73	**370.43**
Straw application (M_1)	291.94	403.06	470.80	**388.60**	341.89	403.67	496.46	**414.01**
Cow dung (M_2)	359.77	367.63	468.30	**398.57**	361.29	447.69	503.58	**437.52**
Mean	**297.66**	**385.66**	**443.68**		**338.50**	**411.53**	**471.92**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	222.41	272.55	338.30	**277.75**	254.50	361.83	376.59	**330.97**
N_{45}	309.62	412.62	462.25	**394.83**	387.73	415.74	521.37	**441.61**
N_{90}	360.96	471.80	530.49	**454.42**	373.26	457.04	517.80	**449.37**
Mean	**297.66**	**385.66**	**443.68**		**338.50**	**411.53**	**471.92**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	212.86	233.10	277.91	**241.29**	278.84	417.66	462.36	**386.29**	285.80	452.00	438.06	**391.95**
M_1	230.15	309.15	336.51	**291.94**	274.94	449.91	484.32	**403.06**	352.63	448.09	611.67	**470.80**
M_2	224.21	386.61	468.47	**359.77**	263.87	370.30	468.72	**367.63**	376.48	486.67	541.75	**468.30**
Mean	**222.41**	**309.62**	**360.96**		**272.55**	**412.62**	**471.80**		**338.30**	**462.25**	**530.49**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	209.18	410.07	317.68	**312.31**	305.20	389.23	455.29	**383.24**	362.58	456.96	427.64	**415.73**
M_1	261.55	393.02	371.11	**341.89**	373.45	418.90	418.65	**403.67**	408.01	543.72	537.64	**496.46**
M_2	292.76	360.10	431.00	**361.29**	406.83	439.08	497.17	**447.69**	359.19	563.41	588.13	**503.58**
Mean	**254.50**	**387.73**	**373.26**		**361.83**	**415.74**	**457.04**		**376.59**	**521.37**	**517.80**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	20.68	60.67	12, 0, 0	M or N or S	13.93	40.86	1, 0, 0
Two factor effects	M × N, M × S, N × S	35.82	NS	87, 37, 91	M × N, M × S, N × S	24.13	NS	58, 73, 38
Three factor effects (3 FE)	MNS, MN^2S	62.05	NS	87, 40	MNS, MN^2S	41.79	NS	74, 14
3 FE confounded	MNS^2, MN^2S^2	62.05	NS	13, 100	MNS^2 *, $MN^2S^{2\ NS}$	41.79	122.58	2, 98
CV (%)								

4.2.45.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant in both the years. A stepwise increase in the grain protein yield was observed with 297.66 kg ha^{-1} in no sulphur application treatment, 385.66 kg ha^{-1} in S_{15} and 443.68 kg ha^{-1} in S_{30}. The corresponding values were 338.50, 411.53 and 471.92 kg ha^{-1}, respectively, in the second year.

4.2.45.2 Two factor interaction effects

Two factor interaction effects were not significant in both the years.

4.2.45.3 Three factor interaction effects

Three factor interactions such as MNS^2 at 13 % level of significance in the first year, MN^2S at 14 % and MNS^2 at 2 % level of significance in the second year were significant. In the first year, the highest grain protein yield of 611.67 kg ha^{-1} was observed with $M_1N_{90}S_{30}$. In the second year, $M_1N_{45}S_{30}$, $M_1N_{90}S_{30}$, $M_2N_{45}S_{30}$ and $M_2N_{90}S_{30}$ were at par and significantly increased the grain protein yield over other treatments.

4.2.46 True protein nitrogen content of grain

4.2.46.1 Main effects

4.2.46.1.1 Effect of organic manures

The effect of organic manures on true protein nitrogen content averaged over nitrogen and sulphur was significant (Table 4.50). Cow dung application registered the highest protein nitrogen content 0f 5.89 %.

4.2.46.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant. A step wise increase in the true protein nitrogen content was observed with N_0 and N_{90} and the corresponding values were 5.24 and 5.98 %.

4.2.46.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant. A step wise increase in the true protein nitrogen content was observed with S_0 and S_{15} and the corresponding values were 5.43 and 5.79 %.

4.2.46.2 Two factor interaction effects

Two factor interactions were not significant, however a noticeable increase in the true protein nitrogen content was observed with M_2N_{90}, M_2S_{15} and $N_{90}S_{15}$. The corresponding values were 6.38, 6.05 and 6.15 %, respectively.

4.2.46.3 Three factor interactions

Three factor interactions were not significant. Under S_0 and S_{15}, cow dung application registered the highest true protein nitrogen content and the corresponding values were 6.29 and 6.47 %, respectively.

4.2.47 True protein sulphur content of grain

4.2.47.1 Main effects

4.2.47.1.1 Effect of organic manures

The effect of organic manures on true protein sulphur content averaged over nitrogen and sulphur was significant (Table 4.51). Cow dung application registered the highest protein sulphur content of 0.035 %.

4.2.47.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant. A step wise increase in the true protein sulphur content was observed with N_0 and N_{90} and the corresponding values were 0.032 and 0.034 %.

Table. 4.50. Effect of manurial management on the true protein nitrogen (%) of grain

Organic manure	Nitrogen			Sulphur			Nitrogen	Sulphur		
	N_0	N_{90}	**Mean**	S_0	S_{30}	**Mean**		S_0	S_{30}	**Mean**
No organics (M_0)	5.07	5.59	**5.33**	5.13	5.53	**5.33**	N_0	5.05	5.43	**5.24**
Cow dung (M_2)	5.41	6.38	**5.89**	5.73	6.05	**5.89**	N_{90}	5.82	6.15	**5.98**
Mean	**5.24**	**5.98**		**5.43**	**5.79**			**5.43**	**5.79**	

Interactions between organic manures, nitrogen and sulphur

Organic manure	No sulphur			S @ 30 kg ha^{-1}		
	N_0	N_{90}	**Mean**	N_0	N_{90}	**Mean**
M_0	4.92	5.34	**5.13**	5.22	5.83	**5.52**
M_2	5.17	6.29	**5.73**	5.64	6.47	**6.05**
Mean	**5.04**	**5.81**		**5.43**	**6.15**	
	Main effects M or N or S		Two factor effects M × N, M × S, N × S		Three factor effects MNS	
S.E	0.10		0.14		0.21	
CD	0.35		NS		NS	
CV (%)	5.31					

Table 4.51. Effect of manurial management on the true protein sulphur (%) of grain

Organic manure	Nitrogen			Sulphur			Nitrogen	Sulphur		
	N_0	N_{90}	**Mean**	S_0	S_{30}	**Mean**		S_0	S_{30}	**Mean**
No organics (M_0)	0.30	0.32	**0.031**	0.29	0.33	**0.031**	N_0	0.30	0.34	**0.32**
Cow dung (M_2)	0.33	0.37	**0.035**	0.33	0.37	**0.035**	N_{90}	0.32	0.36	**0.34**
Mean	**0.32**	**0.34**		**0.31**	**0.35**			**0.31**	**0.35**	

Interactions between organic manures, nitrogen and sulphur

Organic manure	No sulphur			S @ 30 kg ha^{-1}		
	N_0	N_{90}	**Mean**	N_0	N_{90}	**Mean**
M_0	0.28	0.31	**0.029**	0.33	0.33	**0.33**
M_2	0.32	0.34	**0.033**	0.35	0.39	**0.37**
Mean	**0.30**	**0.32**		**0.34**	**0.36**	
	Main effects M or N or S		Two factor effects M × N, M × S, N × S		Three factor effects MNS	
S.E	0.04		0.05		0.08	
CD	0.013		NS		NS	
CV (%)	3.32					

4.2.47.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant. A step wise increase in the true protein sulphur content was observed with S_0 and S_{15} and the corresponding values were 0.031 and 0.035 %.

4.2.47.2 Two factor interaction effects

Two factor interactions were not significant, however cow dung applied with N_{90}, S_{15} and nitrogen at higher level (N_{90}) with S_{15} registered the highest true protein sulphur content. The corresponding values were 0.037, 0.037 and 0.036 %, respectively.

4.2.47.3 Three factor interactions

Three factor interactions were not significant. However, a noticeable increase in the true protein sulphur content was observed with cow dung + S_{15} (0.039).

4.2.48 Nitrogen content of straw

4.2.48.1 Main effects

4.2.48.1.1 Effect of organic manures

The effect of different sources of organic manures averaged over nitrogen and sulphur was not significant during both the years (Table 4.52). Paddy straw incorporation @ 10 t ha^{-1} registered the highest nitrogen content of straw in the first (0.62 %) and second year (0.69 %). No organic manure and cow dung application treatments resulted in similar N content (0.59 and 0.58 %, respectively) in the first year, however in the second year cow dung application resulted in higher N content (0.67 %) than no manures (0.61 %).

Table 4.52. Effect of manurial management on the nitrogen content (%) of straw

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.52	0.61	0.64	**0.59**	0.51	0.62	0.70	**0.61**
Straw application (M_1)	0.57	0.67	0.62	**0.62**	0.49	0.79	0.78	**0.69**
Cow dung (M_2)	0.54	0.54	0.67	**0.58**	0.56	0.75	0.72	**0.67**
Mean	**0.54**	**0.61**	**0.64**		**0.52**	**0.72**	**0.73**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.57	0.59	0.60	**0.59**	0.52	0.65	0.65	**0.61**
Straw application (M_1)	0.57	0.69	0.61	**0.62**	0.63	0.64	0.78	**0.69**
Cow dung (M_2)	0.56	0.62	0.57	**0.58**	0.60	0.69	0.74	**0.67**
Mean	**0.57**	**0.63**	**0.59**		**0.58**	**0.66**	**0.73**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.52	0.61	0.48	**0.54**	0.43	0.46	0.65	**0.52**
N_{45}	0.54	0.62	0.66	**0.61**	0.77	0.69	0.70	**0.72**
N_{90}	0.63	0.66	0.63	**0.64**	0.55	0.83	0.82	**0.73**
Mean	**0.57**	**0.63**	**0.59**		**0.58**	**0.66**	**0.73**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.53	0.53	0.64	**0.57**	0.59	0.53	0.65	**0.59**	0.42	0.76	0.62	**0.60**
M_1	0.53	0.63	0.53	**0.57**	0.67	0.72	0.67	**0.69**	0.50	0.67	0.65	**0.61**
M_2	0.51	0.45	0.73	**0.56**	0.57	0.62	0.66	**0.62**	0.53	0.54	0.63	**0.57**
Mean	**0.52**	**0.54**	**0.63**		**0.61**	**0.62**	**0.66**		**0.48**	**0.66**	**0.63**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.47	0.65	0.44	**0.52**	0.55	0.59	0.82	**0.65**	0.50	0.63	0.83	**0.65**
M_1	0.36	0.90	0.63	**0.63**	0.48	0.74	0.90	**0.64**	0.81	0.73	0.81	**0.78**
M_2	0.47	0.76	0.57	**0.60**	0.56	0.74	0.76	**0.69**	0.64	0.75	0.83	**0.74**
Mean	**0.43**	**0.77**	**0.55**		**0.46**	**0.69**	**0.83**		**0.65**	**0.70**	**0.82**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.03	NS	72, 15, 44	M^{NS} or N* or S^{NS}	0.05	0.14	47, 1, 11
Two factor effects	M × N, M × S, N × S	0.06	NS	67, 94, 66	M × N, M × S, N × S	0.08	NS	79, 91, 13
Three factor effects (3 FE)	MNS, MN^2S	0.10	NS	88, 80	MNS, MN^2S	0.14	NS	44, 41
3 FE confounded	MNS^2, MN^2S^2	0.10	NS	83, 55	MNS^2, MN^2S^2	0.14	NS	72, 67
CV (%)	23.79				29.39			

4.2.48.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant at 15 % level of significance in the first year and highly significant in the second year. A step wise increase in the nitrogen content was seen with the increasing levels of nitrogen. In the first year N @ 90 kg ha^{-1} gave the highest nitrogen content of straw (0.64 %). The corresponding figure in the second year was 0.73 %.

4.2.48.1.3 Effect of sulphur

The different levels of sulphur averaged over organics and nitrogen was not significant in the first year, but a significant at 11 % level of significance in the second year. In the first year, S @ 15 kg ha^{-1} increased the nitrogen content of straw (0.63 %) compared to S @ 30 kg ha^{-1} (0.59 %) and no sulphur application (0.57 %). In the second year, S @ 30 kg ha^{-1} registered the highest N content of straw of 0.73 % with mean increase of 9.6 %.

4.2.48.2 Two factor interaction effects

The two factor interactions were not significant in both the years except for N × S at 13 % significant level in the second year. In the first year, treatment with paddy straw incorporation + N @ 45 kg ha^{-1} and cow dung + N @ 90 kg ha^{-1} increased the nitrogen content to 0.67 %, but in the second year, paddy straw + N @ 45 kg ha^{-1} registered the highest nitrogen content of straw (0.79 %). Moderate level (N_{45}) of nitrogen was found better than N_{90} to be given with paddy straw incorporation in increasing the straw N content, but for cow dung application reverse trend was observed.

Straw incorporation together with S @ 15 kg ha^{-1} registered the highest nitrogen content of straw (0.69 %) in the first year, while in the second year, paddy straw applied with S @ 30 kg ha^{-1} registered the highest nitrogen content (0.78 %). In the first year, with all the combinations of organic manures S_{15} and S_{30} were at par, but in the second year, S_{30} resulted in increased N content.

N @ 45 kg ha^{-1} applied with S @ 30 kg ha^{-1} and N @ 90 kg ha^{-1} applied with S @ 15 kg ha^{-1} recorded a similar nitrogen content of 0.66 %. In the second year, N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1} registered the highest nitrogen content of 0.83 %.

4.2.48.3 Three factor interactions

When no sulphur was given the N content varied from 0.53 % in the M_0N_0 treatment to 0.73 % in the M_2N_2 treatment in the first year. The corresponding values were 0.47 % and 0.57 % in the second year. Under $S_{15,}$ the least N content of 0.53 % was observed for M_0N_{45} and the highest content of 0.72 % in M_1N_{45} in the first year. The corresponding values were 0.55 % in M_1N_0 and 0.90 % in M_1N_{90} in the second year. Under highest sulphur level (S_{30}), the least N content of 0.42 % was with M_0N_0 and the highest with M_0N_{45} (0.76 %) in first year and 0.5 % in M_0N_0 and 0.83 % in M_2N_2 in the second year.

4.2.49 Phosphorus content of straw

4.2.49.1 Main effects

4.2.49.1.1 Effect of organic manures

The different sources of organic manures averaged over nitrogen and sulphur was not significant in both the years (Table 4.53). However, the organic manure treatments resulted in lower straw P content than no organic manure application in both the years.

The effect of nitrogen, sulphur, two factor and three factor effects were not significant in both the years.

Table 4.53. Effect of manurial management on the phosphorus content (%) of straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.10	0.11	0.13	**0.12**	0.07	0.10	0.12	**0.10**
Straw application (M_1)	0.12	0.08	0.11	**0.10**	0.10	0.08	0.09	**0.09**
Cow dung (M_2)	0.11	0.12	0.12	**0.12**	0.07	0.06	0.08	**0.07**
Mean	**0.11**	**0.10**	**0.12**		**0.08**	**0.08**	**0.10**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.12	0.11	0.12	**0.12**	0.08	0.10	0.10	**0.10**
Straw application (M_1)	0.10	0.12	0.09	**0.10**	0.08	0.09	0.10	**0.09**
Cow dung (M_2)	0.13	0.13	0.10	**0.12**	0.05	0.05	0.11	**0.07**
Mean	**0.12**	**0.12**	**0.10**		**0.07**	**0.08**	**0.10**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.11	0.13	0.10	**0.11**	0.09	0.06	0.09	**0.08**
N_{45}	0.12	0.10	0.09	**0.10**	0.06	0.09	0.10	**0.08**
N_{90}	0.12	0.13	0.12	**0.12**	0.06	0.10	0.13	**0.10**
Mean	**0.12**	**0.12**	**0.10**		**0.07**	**0.08**	**0.10**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.10	0.13	0.13	**0.12**	0.10	0.11	0.13	**0.11**	0.11	0.10	0.14	**0.12**
M_1	0.09	0.10	0.11	**0.10**	0.16	0.07	0.13	**0.12**	0.11	0.07	0.10	**0.09**
M_2	0.15	0.12	0.12	**0.13**	0.13	0.12	0.13	**0.13**	0.07	0.11	0.12	**0.10**
Mean	**0.11**	**0.12**	**0.12**		**0.13**	**0.10**	**0.13**		**0.10**	**0.09**	**0.12**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.08	0.07	0.10	**0.08**	0.06	0.13	0.13	**0.10**	0.07	0.10	0.13	**0.10**
M_1	0.13	0.08	0.05	**0.08**	0.07	0.07	0.11	**0.09**	0.09	0.10	0.11	**0.10**
M_2	0.07	0.04	0.04	**0.05**	0.04	0.06	0.06	**0.05**	0.10	0.09	0.14	**0.11**
Mean	**0.09**	**0.06**	**0.06**		**0.06**	**0.09**	**0.10**		**0.09**	**0.10**	**0.13**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.007	NS	48, 33, 33	M or N or S	0.01	NS	45, 59, 31
Two factor effects	M × N, M × S, N × S	0.01	NS	36, 68, 68	M × N, M × S, N × S	0.03	NS	80, 75, 56
Three factor effects (3 FE)	MNS, MN^2S	0.02	NS	43, 31	MNS, MN^2S	0.04	NS	94, 100
3 FE confounded	MNS^2, MN^2S^2	0.02	NS	26, 86	MNS^2, MN^2S^2	0.04	NS	90, 34
CV (%)	33.34				69.01			

4.2.50 Potassium content of straw

4.2.50.1 Main effects

4.2.50.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen was significant at 6 % level in the first year and 4 % level of significance in the second year (Table 4.54). In the first year, the mean increase in the potassium content of straw due to straw incorporation over cow dung application was 0.29, a 21.48 % increase. A similar effect was observed in the second year also.

4.2.50.1.2 Effect of nitrogen

The different levels of nitrogen averaged over organic manures and sulphur was not significant in both the years. However, the lowest K content of straw was observed in no nitrogen treatment compared to N_{45} and N_{90} in both the years.

The effect of sulphur, two factor and three factor interactions were not significantly different in both the years.

4.2.51 Sulphur content of straw

4.2.51.1 Main effects

4.2.51.1.1 Effect of organic manures

The effect of different sources of organic manures averaged over nitrogen and sulphur was highly significant in the first year and significant at 26 % level of significance in the second year (Table 4.55). Straw incorporation was statistically at par with cow dung application in the first year, whereas in the second year straw incorporation registered the highest straw sulphur content (0.30 %).

Table 4.54. Effect of manurial management on the potassium content (%) of straw

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_{0}	N_{45}	N_{90}	**Mean**	N_{0}	N_{45}	N_{90}	**Mean**
No organics (M_{0})	1.24	1.40	1.20	**1.28**	1.29	1.38	1.35	**1.34**
Straw application (M_{1})	1.48	1.67	1.77	**1.64**	1.67	1.89	2.01	**1.86**
Cow dung (M_{2})	1.28	1.41	1.36	**1.35**	1.47	1.27	1.47	**1.40**
Mean	**1.33**	**1.50**	**1.44**		**1.48**	**1.51**	**1.61**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_{0}	S_{15}	S_{30}	**Mean**	S_{0}	S_{15}	S_{30}	**Mean**
No organics (M_{0})	1.28	1.41	1.16	**1.28**	1.27	1.38	1.36	**1.34**
Straw application (M_{1})	1.61	1.61	1.69	**1.64**	2.17	1.45	1.95	**1.86**
Cow dung (M_{2})	1.30	1.42	1.33	**1.35**	1.41	1.18	1.63	**1.40**
Mean	**1.40**	**1.48**	**1.39**		**1.62**	**1.34**	**1.65**	
Nitrogen (N)	S_{0}	S_{15}	S_{30}	**Mean**	S_{0}	S_{15}	S_{30}	**Mean**
N_{0}	1.54	1.35	1.11	**1.33**	1.63	1.13	1.67	**1.48**
N_{45}	1.27	1.60	1.62	**1.50**	1.59	1.40	1.56	**1.51**
N_{90}	1.38	1.50	1.45	**1.44**	1.63	1.49	1.72	**1.61**
Mean	**1.40**	**1.48**	**1.39**		**1.62**	**1.34**	**1.65**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_{0}				S_{15}				S_{30}			
	N_{0}	N_{45}	N_{90}	**Mean**	N_{0}	N_{45}	N_{90}	**Mean**	N_{0}	N_{45}	N_{90}	**Mean**
M_{0}	1.55	1.29	1.01	**1.28**	1.21	1.72	1.30	**1.41**	0.97	1.20	1.30	**1.16**
M_{1}	1.62	1.32	1.88	**1.61**	1.60	1.68	1.56	**1.61**	1.20	2.02	1.86	**1.69**
M_{2}	1.45	1.20	1.26	**1.30**	1.23	1.39	1.64	**1.42**	1.16	1.64	1.19	**1.33**
Mean	**1.54**	**1.27**	**1.38**		**1.35**	**1.60**	**1.50**		**1.11**	**1.62**	**1.45**	
	Second year											
	S_{0}				S_{15}				S_{30}			
	N_{0}	N_{45}	N_{90}	**Mean**	N_{0}	N_{45}	N_{90}	**Mean**	N_{0}	N_{45}	N_{90}	**Mean**
M_{0}	1.54	1.33	0.94	**1.27**	1.23	1.47	1.45	**1.38**	1.09	1.32	1.68	**1.36**
M_{1}	2.02	2.04	2.46	**2.17**	1.21	1.59	1.56	**1.45**	1.79	2.05	2.00	**1.95**
M_{2}	1.35	1.40	1.48	**1.41**	0.94	1.13	1.46	**1.18**	2.12	1.29	1.47	**1.63**
Mean	**1.63**	**1.59**	**1.63**		**1.13**	**1.40**	**1.49**		**1.67**	**1.56**	**1.72**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.10	NS	6, 53, 80	M* or N^{NS} or S^{NS}	0.15	0.43	4, 81, 28
Two factor effects	M × N, M × S, N × S	0.18	NS	90, 91, 31	M × N, M × S, N × S	0.25	NS	92, 55, 93
Three factor effects (3 FE)	MNS, MN^2S	0.31	NS	84, 92	MNS, MN^2S	0.44	NS	64, 96
3 FE confounded	MNS^2, MN^2S^2	0.31	NS	58, 81	MNS^2, MN^2S^2	0.44	NS	92, 89
CV (%)	26.86				39.67			

Table 4.55. Effect of manurial management on the sulphur content (%) of straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.10	0.14	0.17	**0.14**	0.19	0.19	0.24	**0.21**
Straw application (M_1)	0.17	0.20	0.20	**0.19**	0.21	0.30	0.38	**0.30**
Cow dung (M_2)	0.12	0.19	0.25	**0.19**	0.23	0.26	0.30	**0.26**
Mean	**0.13**	**0.18**	**0.21**		**0.21**	**0.25**	**0.31**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.09	0.16	0.16	**0.14**	0.13	0.17	0.31	**0.21**
Straw application (M_1)	0.17	0.21	0.20	**0.19**	0.27	0.31	0.31	**0.30**
Cow dung (M_2)	0.15	0.20	0.22	**0.19**	0.17	0.27	0.35	**0.26**
Mean	**0.14**	**0.19**	**0.19**		**0.19**	**0.25**	**0.33**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.10	0.15	0.14	**0.13**	0.13	0.20	0.30	**0.21**
N_{45}	0.18	0.17	0.18	**0.18**	0.21	0.24	0.29	**0.25**
N_{90}	0.14	0.24	0.25	**0.21**	0.22	0.31	0.39	**0.31**
Mean	**0.14**	**0.19**	**0.19**		**0.19**	**0.25**	**0.33**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.09	0.10	0.09	**0.09**	0.12	0.13	0.23	**0.16**	0.10	0.18	0.20	**0.16**
M_1	0.13	0.20	0.19	**0.17**	0.17	0.21	0.24	**0.21**	0.22	0.19	0.19	**0.20**
M_2	0.08	0.23	0.13	**0.15**	0.17	0.17	0.25	**0.20**	0.10	0.18	0.37	**0.22**
Mean	**0.10**	**0.18**	**0.14**		**0.15**	**0.17**	**0.24**		**0.14**	**0.18**	**0.25**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.12	0.16	0.12	**0.13**	0.11	0.23	0.19	**0.17**	0.34	0.19	0.41	**0.31**
M_1	0.16	0.32	0.31	**0.27**	0.23	0.29	0.42	**0.31**	0.23	0.29	0.42	**0.31**
M_2	0.12	0.15	0.23	**0.17**	0.26	0.22	0.33	**0.27**	0.32	0.39	0.35	**0.35**
Mean	**0.13**	**0.21**	**0.22**		**0.20**	**0.24**	**0.31**		**0.30**	**0.29**	**0.39**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N* or S	0.01	0.04	4, 1, 6	M or N or S	0.04	NS	26, 20, 6
Two factor effects	M × N, M × S, N × S	0.03	NS	41, 92, 24	M × N, M × S, N × S	0.06	NS	89, 75, 95
Three factor effects (3 FE)	MNS*, MN^2S^{NS}	0.04	0.13	4, 81	MNS, MN^2S	0.11	NS	70, 52
3 FE confounded	MNS^2, MN^2S^2	0.04	NS	26, 53	MNS^2, MN^2S^2	0.11	NS	100, 72
CV (%)	40.29				45.66			

4.2.51.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was highly significant in the first year and 20 % level significant in the second year. N_{45} was statistically at par with N_{90} and significantly increased the straw sulphur content over no nitrogen application in the first year. A step wise increase in the sulphur content was seen with the increasing levels of nitrogen in the second year.

4.2.51.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant at 6 % level of significance in both the years. S_{15} was statistically at par with S_{30} and significantly increased the straw sulphur content over no sulphur application in the first year. S_{30} registered the highest straw sulphur content (0.33 %) in the second year.

4.2.51.2 Two factor interaction effects

Two factor interactions were not significant except for N × S which was significant at 24 % level of significance in the first year. $N_{90}S_{15}$ and $N_{90}S_{30}$ registered high and similar sulphur content of straw over other treatments.

4.2.51.3 Three factor interactions

Three factor interactions were significant at 4 % level of significance in the first year. The highest sulphur content of 0.37 % was registered with $M_2N_{90}S_{30}$.

4.2.52 Calcium content of straw

4.2.52.1 Main effects

4.2.52.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant in both the years. In the first year, the highest calcium content of straw

(935 ppm) was observed with straw incorporation (Table 4.56). No organic manures (876 ppm) and cow dung application (895 ppm) were statistically at par.

In the second year, no organic manures (1028 ppm) and cow dung application (935 ppm) was at par which in turn was at par with straw incorporation (826 ppm).

4.2.52.1.2 Effect of nitrogen

Compared to manure and sulphur the effect of nitrogen was relatively lower on the calcium content of straw and was significant only at 15 and 34 % level of significance in the first and second year, respectively. A step wise increase in the calcium content of grain was observed between no nitrogen (882 ppm), N @ 45 kg ha^{-1} (899 ppm) and N @ 90 kg ha^{-1} (925 ppm) in the first year.

4.2.52.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen was significant in both the years. In the first year, S @ 15 kg ha^{-1} was highly significant and registered the highest calcium content of 954 ppm. The other treatments no sulphur (866 ppm) and S @ 30 kg ha^{-1} (887 ppm) was statistically at par. In the second year, no sulphur (840 ppm) and S @ 15 kg ha^{-1} (906 ppm) was statistically at par. The highest calcium content of 1044 ppm was registered with S @ 30 kg ha^{-1}.

4.2.52.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were significant in the first year, whereas it was relatively less significant in the second year. In the first year, straw incorporation + N @ 45 kg ha^{-1} (1020 ppm) and no organics + N @ 90 kg ha^{-1} (1085 ppm) was statistically at par and significantly increased the calcium content over other treatments. No organics + N @ 45 kg ha^{-1} significantly registered the lowest calcium content of 718 ppm. In the second year, the highest calcium content of straw was registered with no organic manures + N @ 90 kg ha^{-1} (1045

Table 4.56. Effect of manurial management on the calcium content (ppm) of straw

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	825	718	1085	**876**	999	1041	1045	**1028**
Straw application (M_1)	974	1020	812	**935**	930	721	828	**826**
Cow dung (M_2)	847	959	880	**895**	1035	931	839	**935**
Mean	**882**	**899**	**925**		**988**	**897**	**904**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	723	1053	852	**876**	879	993	1213	**1028**
Straw application (M_1)	955	968	883	**935**	819	846	814	**826**
Cow dung (M_2)	919	841	925	**895**	822	880	1104	**935**
Mean	**866**	**954**	**887**		**840**	**906**	**1044**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	896	913	836	**882**	835	1052	1077	**988**
N_{45}	821	942	934	**899**	799	796	1097	**897**
N_{90}	879	1008	889	**925**	886	870	956	**904**
Mean	**866**	**954**	**887**		**840**	**906**	**1044**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	796	302	1070	**723**	996	880	1283	**1053**	682	973	901	**852**
M_1	965	1201	698	**955**	996	1024	885	**968**	961	836	852	**883**
M_2	928	961	869	**919**	747	921	856	**841**	866	994	914	**925**
Mean	**896**	**821**	**879**		**913**	**942**	**1008**		**836**	**934**	**889**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	883	796	958	**879**	1032	773	1174	**993**	1084	1554	1002	**1213**
M_1	871	721	866	**819**	1159	672	706	**846**	760	769	913	**814**
M_2	751	881	834	**822**	966	944	731	**880**	1389	970	953	**1104**
Mean	**835**	**799**	**886**		**1052**	**796**	**870**		**1077**	**1097**	**956**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N^{NS} or S*	15.09	44.26	3, 15, 0	M* or N^{NS} or S*	46.77	137.19	2, 34, 2
Two factor effects	M × N, M × S, N × S	26.13	76.66	0, 0, 2	M × N, M × S, N × S	81.02	NS	42, 26, 30
Three factor effects (3 FE)	MNS, MN^2S	45.27	132.77	0, 0	MNS, MN^2S	140.32	NS	56, 9
3 FE confounded	MNS^2, MN^2S^2	45.27	132.77	0, 1	MNS^2, MN^2S^2	140.32	NS	66, 73
CV (%)	4.92				22.45			

ppm). It was 44.93 % higher than the lowest calcium content registered treatment straw + N @ 45 kg ha^{-1}.

In the first year, no organics + S @ 15 kg ha^{-1} was highly significant and increased the calcium content to 1053 ppm, a 31.34 % increase over no organics + no sulphur (723 ppm). In the second year, the highest calcium content of 1213 ppm was observed with no organics + S @ 30 kg ha^{-1} and the lowest calcium content was observed with straw + S @ 30 kg ha^{-1}. A step wise increase in the calcium content was also seen with the increasing levels of sulphur with all the sources of organic manures.

N @ 45 kg ha^{-1} + no sulphur (821 ppm), N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} (942 ppm), N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1} (1008 ppm) and N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} (934 ppm) were statistically at par in the first year. In the second year, the mean increase in the calcium content of straw due to N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} over N @ 45 kg ha^{-1} + no sulphur was 37.29 %, 37.81 % over N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1}, 1.85 % over no organics + S @ 30 kg ha^{-1}.

4.2.52.3 Three factor interactions

Three factor interactions and confounded effects were significant in the first year, whereas in the second year only $MN_{90}S$ was significant at 9 % level of significance. In the first year, mean increase in the calcium content due to straw incorporation + N @ 45 kg ha^{-1} + no sulphur over straw incorporation + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1} was 17.28 %, 43.66 % over straw + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1}, 24.45 % over straw incorporation + no nitrogen + no sulphur, 72.06 % over straw incorporation + N @ 90 kg ha^{-1} + no sulphur, 297.68 % over no organics + N @ 45 kg ha^{-1} + no sulphur and 24.97 % over cow dung + N @ 45 kg ha^{-1} + no sulphur. In the second year, the highest calcium content of 1554 ppm was observed with no organics + N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} and the lowest calcium content was observed with straw incorporation + N @ 45 kg ha^{-1} + S @ 15 kg ha^{-1}. When straw was incorporated + S @ 30 kg ha^{-1} with different levels of nitrogen reduced the calcium content compared to cow dung or no organics + S @ 30 kg ha^{-1} with different levels of nitrogen.

4.2.53 Magnesium content of straw

4.2.53.1 Main effects

4.2.53.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant in the first year and relatively less significant in the second year but at 16 % level of significance (Table 4.57). In the first year magnesium content of straw was increased from 2798 ppm to 3122 ppm by straw incorporation and 3700 ppm by cow dung application. In the second year also similar trend was observed.

4.2.53.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and nitrogen was also significant only in the second year. A step wise increase in the magnesium content 2934 ppm with N_0, 3168 ppm with N_{45} and 4012 ppm with N_{90} was observed, N_0 and N_{45} were at par too.

4.2.53.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant only in the second year. No Sulphur and S_{15} was at par, which in turn at par with S_{30}. The magnesium contents were 2766 ppm, 3415 ppm and 3933 ppm at S_0, S_{15} and S_{30} levels.

Table 4.57. Effect of manurial management on the magnesium content (ppm) of straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	2822	2713	2860	**2798**	2312	3067	3606	**2995**
Straw application (M_1)	3240	2957	3168	**3122**	3565	2810	3815	**3397**
Cow dung (M_2)	3478	4077	3545	**3700**	2925	3628	4614	**3723**
Mean	**3180**	**3249**	**3191**		**2934**	**3168**	**4012**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	2485	2917	2993	**2798**	2155	3227	3603	**2995**
Straw application (M_1)	2892	3187	3287	**3122**	2960	3162	4068	**3397**
Cow dung (M_2)	3648	3723	3729	**3700**	3183	3858	4127	**3723**
Mean	**3008**	**3275**	**3336**		**2766**	**3415**	**3933**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	3033	3472	3035	**3180**	2187	3252	3363	**2934**
N_{45}	3348	3165	3234	**3249**	2568	3355	3582	**3168**
N_{90}	2643	3190	3740	**3191**	3543	3639	4853	**4012**
Mean	**3008**	**3275**	**3336**		**2766**	**3415**	**3933**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	2825	2305	2325	**2485**	2805	2980	2965	**2917**	2835	2855	3290	**2993**
M_1	3120	2800	2755	**2892**	3655	2855	3050	**3187**	2945	3215	3700	**3287**
M_2	3155	4938	2850	**3648**	3955	3659	3555	**3723**	3325	3633	4230	**3729**
Mean	**3033**	**3348**	**2643**		**3472**	**3165**	**3190**		**3035**	**3234**	**3740**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1755	1725	2985	**2155**	2600	4030	3050	**3227**	2580	3445	4783	**3603**
M_1	2400	3130	3350	**2960**	4130	2455	2900	**3162**	4165	2845	5195	**4068**
M_2	2405	2850	4295	**3183**	3025	3580	4968	**3858**	3345	4455	4580	**4127**
Mean	**2187**	**2568**	**3543**		**3252**	**3355**	**3639**		**3363**	**3582**	**4853**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^* or N^{NS} or S^{NS}	136.19	399.46	0, 93, 22	M^{NS} or N^* or S^*	258.18	757.25	16, 2, 2
Two factor effects	M × N, M × S, N × S	235.89	NS	35, 91, 7	M × N, M × S, N × S	447.17	NS	37, 87, 72
Three factor effects (3 FE)	MNS, MN^2S	408.58	NS	31, 81	MNS, MN^2S	774.53	NS	20, 44
3 FE confounded	MNS^2, MN^2S^2	408.58	NS	26, 53	MNS^2, MN^2S^2	774.53	NS	24, 59
CV (%)	16.54				33.21			

4.2.53.2 Two factor interaction effects

Only N × S was significant at 7 % level of significance in the first year. Nitrogen @ 90 kg ha^{-1} + no sulphur registered significantly lower magnesium content of 2643 ppm whereas the highest magnesium content of 3740 ppm was registered with the application of N @ 90 kg ha^{-1} + S @ 30 kg ha^{-1}.

4.2.53.3 Three factor interactions

MNS interaction was found to be significant at 20 % level of significance in the second year. The highest magnesium content of 4968 ppm was observed with the application of cow dung + N @ 90 kg ha^{-1} + S @15 kg ha$^{-1.}$ It was 188 % higher than the lowest magnesium content treatment (no manures + N @ 45 kg ha^{-1} + no sulphur).

4.2.54 Iron content of straw

4.2.54.1 Main effects

4.2.54.1.1 Effect of organic manures

The effect of organic manures such as no organics, straw incorporation and cow dung application averaged over nitrogen and sulphur was significant only in first year (Table 4.58). The lowest iron content in straw of 1054 ppm was observed in straw incorporated treatment which was at par with cow dung application (1155 ppm) which was in turn at par with no manure application (1261 ppm).

4.2.54.1.2 Effect of nitrogen

The different levels of nitrogen averaged over organic manures and sulphur was highly significant in the first year. A reverse trend of that seen in the iron content at tillering and PI stage incase of straw iron content. The treatment which received no nitrogen resulted in lowest iron content (1007 ppm) followed by N_{45} (1183 ppm) and N_{90} (1279 ppm).

Table 4.58. Effect of manurial management on the iron content (ppm) of straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	950	1280	1552	**1261**	1004	1099	1293	**1132**
Straw application (M_1)	934	1139	1090	**1054**	986	1077	1113	**1059**
Cow dung (M_2)	1139	1131	1195	**1155**	1113	1217	971	**1100**
Mean	**1007**	**1183**	**1279**		**1034**	**1131**	**1126**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1247	1324	1211	**1261**	962	1268	1167	**1132**
Straw application (M_1)	1017	1055	1091	**1054**	1009	1078	1090	**1059**
Cow dung (M_2)	1089	1222	1154	**1155**	1087	1171	1043	**1100**
Mean	**1117**	**1200**	**1152**		**1019**	**1172**	**1100**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	971	1051	1000	**1007**	1024	1036	1044	**1034**
N_{45}	1088	1277	1185	**1183**	1087	1134	1173	**1131**
N_{90}	1293	1274	1271	**1279**	947	1347	1084	**1126**
Mean	**1117**	**1200**	**1152**		**1019**	**1172**	**1100**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1105	1057	1579	**1247**	920	1479	1574	**1324**	824	1306	1504	**1211**
M_1	814	1081	1155	**1017**	964	1138	1064	**1055**	1024	1197	1052	**1091**
M_2	996	1126	1145	**1089**	1268	1214	1184	**1222**	1154	1053	1257	**1154**
Mean	**971**	**1088**	**1293**		**1051**	**1277**	**1274**		**1000**	**1185**	**1271**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1093	929	864	**962**	1056	1003	1745	**1268**	864	1366	1272	**1167**
M_1	901	1079	1046	**1009**	980	1101	1154	**1078**	1078	1052	1139	**1090**
M_2	1077	1254	930	**1087**	1073	1297	1143	**1171**	1189	1100	841	**1043**
Mean	**1024**	**1087**	**947**		**1036**	**1134**	**1347**		**1044**	**1173**	**1084**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M* or N* or S^{NS}	39.54	115.97	1, 0, 35	M or N or S	69.38	NS	76, 56, 32
Two factor effects	M × N*, M × S^{NS}, N × S^{NS}	68.48	200.86	1, 79, 68	M × N, M × S, N × S	120.17	NS	37, 78, 49
Three factor effects (3 FE)	MNS, MN^2S	118.61	NS	19, 7	MNS, MN^2S	208.14	NS	33, 96
3 FE confounded	MNS^2, MN^2S^2	118.61	NS	15, 100	MNS^2, MN^2S^2	208.14	NS	86, 75
CV (%)	14.14				25.50			

4.2.54.1.3 Effect of sulphur

The effect of graded doses of sulphur was not significant in both the years.

4.2.54.2 Two factor interaction effects

M × N interaction was highly significant in the first year. In both the years, straw incorporation with no nitrogen resulted in the least iron content of straw followed by cow dung with no nitrogen. The combination of N_{45} and N_{90} showed step wise increase with iron content.

4.2.54.3 Three factor interactions

The interaction effect of MNS, $MN_{90}S$ and MNS_{30} was significant in the first year at 19, 7 and 15 % significance level. Under highest level of sulphur, straw incorporation with different levels of nitrogen (N_0, N_{45} and N_{90}) resulted in similar straw iron content and under no organic manure significant difference among nitrogen levels were observed. $N_{90}S_0$, $N_{90}S_{15}$ and $N_{90}S_{30}$ with no organic manures resulted in high iron content than cow dung application or straw incorporation.

4.2.55 Manganese content of straw

4.2.55.1 Main effects

4.2.55.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant at 9 % level of significance in the first year (Table 4.59). The straw incorporation and cow dung application resulted in the similar manganese content of 852 and 864 ppm respectively. The highest content of 1004 ppm was with no manure application.

4.2.55.1.2 Effect of nitrogen

The graded doses of sulphur doses averaged over organic manures and nitrogen was significant in the first year. A step wise decrease of manganese content

Table 4.59. Effect of manurial management on the manganese content (ppm) of straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1156	995	861	**1004**	994	952	646	**864**
Straw application (M_1)	988	918	651	**852**	858	841	914	**871**
Cow dung (M_2)	967	763	862	**864**	689	947	814	**816**
Mean	**1037**	**892**	**791**		**847**	**913**	**791**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	988	1030	995	**1004**	848	853	891	**864**
Straw application (M_1)	900	842	815	**852**	1017	838	758	**871**
Cow dung (M_2)	916	892	783	**864**	808	855	786	**816**
Mean	**935**	**921**	**864**		**891**	**849**	**812**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1021	1127	963	**1037**	881	886	773	**847**
N_{45}	1005	923	748	**892**	948	878	914	**913**
N_{90}	777	714	882	**791**	844	782	748	**791**
Mean	**935**	**921**	**864**		**891**	**849**	**812**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1081	959	923	**988**	1286	1141	662	**1030**	1101	886	998	**995**
M_1	954	1123	623	**900**	1013	893	620	**842**	998	739	709	**815**
M_2	1029	934	785	**916**	1081	734	861	**892**	790	620	939	**783**
Mean	**1021**	**1005**	**777**		**1127**	**923**	**714**		**963**	**748**	**882**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	722	1023	799	**848**	1324	901	334	**853**	936	932	804	**891**
M_1	1190	1021	839	**1017**	598	947	969	**838**	786	555	934	**758**
M_2	731	800	893	**808**	737	786	1043	**855**	598	1254	506	**786**
Mean	**881**	**948**	**844**		**886**	**878**	**782**		**773**	**914**	**748**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	51.30	150.48	9, 1, 60	M or N or S	82.81	NS	88, 49, 80
Two factor effects	M × N, M × S, N × S	88.86	NS	36, 93, 18	M × N, M × S, N × S	143.43	NS	41, 84, 100
Three factor effects (3 FE)	MNS, MN^2S	153.91	NS	60, 61	MNS, MN^2S	248.43	NS	25, 10
3 FE confounded	MNS^2, MN^2S^2	153.91	NS	36, 65	MNS^2, MN^2S^2	248.43	NS	79, 33
CV (%)	22.88				45.47			

was observed with the increasing levels of nitrogen. N_{90} resulted in the least manganese content (791 ppm), followed by N_{45} (892 ppm) and N_0 (1037 ppm).

The effect of sulphur, two factor and three factor interactions were not significant in both the years.

4.2.56 Nitrogen uptake by grain

4.2.56.1 Main effects

4.2.56.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen was significant at 10 % level of significance in the first year and highly significant in the second year (Table 4.60). Nitrogen uptake in the straw incorporated treatments were at par. The corresponding values in the second year were 57.75, 66.57 and 69.16 kg ha^{-1}, respectively. In the first yea,r a step wise increase in the nitrogen uptake was seen among no organics (54.04 kg ha^{-1}), straw application (62.17 kg ha^{-1}) and cow dung application (63.82 kg ha^{-1}).

4.2.56.1.2 Effect of nitrogen

No nitrogen treatment resulted in the lowest uptake of 44.44 and 52.49 kg ha^{-1} in the first and second year. N_{45} and N_{90} resulted similar uptake of 62.88 and 72.71 kg ha^{-1} in the first year and 69.92 and 71.06 kg ha^{-1} in the second year, respectively.

4.2.56.1.3 Effect of sulphur

Very similar to organic manures and nitrogen the sulphur effects revealed in the lowest nitrogen uptake in S_0, with step wise, but statistically similar values in S_{15} and S_{30}. The uptake was 47.92, 61.13 and 70.93 kg ha^{-1} in the first year and 53.75, 65.09 and 74.63 kg ha^{-1} in the second year for S_0, S_{15} and S_{30} level, respectively. Two factor and three factor interaction effects were not significant in both the years.

Table 4.60. Effect of manurial management on the nitrogen uptake (kg ha^{-1}) by grain

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	41.47	57.81	62.84	**54.04**	44.40	64.80	64.03	**57.75**
Straw application (M_1)	45.74	64.37	76.40	**62.17**	56.61	72.30	70.80	**66.57**
Cow dung (M_2)	46.11	66.47	78.88	**63.82**	56.47	72.67	78.35	**69.16**
Mean	**44.44**	**62.88**	**72.71**		**52.49**	**69.92**	**71.06**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	38.90	60.51	62.71	**54.04**	47.77	60.04	65.43	**57.75**
Straw application (M_1)	46.81	64.38	75.33	**62.17**	55.68	64.59	79.43	**66.57**
Cow dung (M_2)	58.04	58.49	74.93	**63.82**	57.81	70.65	79.03	**69.16**
Mean	**47.92**	**61.13**	**70.99**		**53.75**	**65.09**	**74.63**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	35.59	43.61	54.13	**44.44**	41.70	56.61	59.17	**52.49**
N_{45}	50.41	64.28	73.96	**62.88**	59.84	66.52	83.42	**69.92**
N_{90}	57.75	75.49	84.88	**72.71**	59.72	72.15	81.31	**71.06**
Mean	**47.92**	**61.13**	**70.99**		**53.75**	**65.09**	**74.63**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	34.06	38.17	44.47	**38.90**	44.61	62.94	73.98	**60.51**	45.73	72.32	70.09	**62.71**
M_1	36.82	49.75	53.84	**46.81**	43.99	71.65	77.49	**64.38**	56.42	71.69	97.87	**75.33**
M_2	35.87	63.30	74.96	**58.04**	42.22	58.25	75.00	**58.49**	60.24	77.87	86.68	**74.93**
Mean	**35.59**	**50.41**	**57.75**		**43.61**	**64.28**	**75.49**		**54.13**	**73.96**	**84.88**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	33.47	59.01	50.83	**47.77**	44.98	62.28	72.85	**60.04**	54.76	73.11	68.42	**65.43**
M_1	44.79	62.88	59.38	**55.68**	59.75	67.02	66.98	**64.59**	65.28	87.00	86.02	**79.43**
M_2	46.84	57.62	68.96	**57.81**	65.09	70.25	76.61	**70.65**	57.47	90.15	89.49	**79.03**
Mean	**41.70**	**59.84**	**59.72**		**56.61**	**66.52**	**72.15**		**59.17**	**83.42**	**81.31**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	3.28	9.62	10, 0, 0	M or N or S	2.86	8.39	3, 0, 0
Two factor effects	M × N, M × S, N × S	5.68	NS	88, 38, 93	M × N, M × S, N × S	4.95	NS	99, 99, 71
Three factor effects (3 FE)	MNS, MN^2S	9.84	NS	84, 38	MNS, MN^2S	8.58	NS	82, 54
3 FE confounded	MNS^2, MN^2S^2	9.84	NS	10, 100	MNS^2, MN^2S^2	8.58	NS	73, 86
CV (%)	24.66				17.33			

4.2.57 Nitrogen uptake by straw

4.2.57 Main effects

4.2.57.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant at 8 % level of significance in the first year (Table 4.61). In both the years straw incorporation resulted in the highest straw uptake of nitrogen by straw. In the first year the nitrogen uptake in the cow dung applied treatment was 36.50 kg ha^{-1} which increased to 42.00 kg ha^{-1} in the straw incorporated ones.

4.2.57.1.1 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant in both the years and N_{45} and N_{90} were at par. The straw uptake of nitrogen increased from 29.61 kg ha^{-1} in N_0 to 38.42 kg ha^{-1} in N_{45} and 45.04 kg ha^{-1} in N_{90} in the first year.

4.2.57.1.2 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant in both the years and the S_{15} and S_{30} levels were at par. The uptake increased from 30.56 kg ha^{-1} in S_0 to 42.06 kg ha^{-1} in S_{15} while it was only 40.45 kg ha^{-1} in S_{30}. But in the second year there was a step wise increase from 34.80 kg ha^{-1} in S_0, 51.39 kg ha^{-1} in S_{15} and 57.75 kg ha^{-1} in S_{30}.

4.2.57.2 Two factor interaction effects

Only N × S interaction was significant in the second year and the highest straw nitrogen uptake of 71.59 kg ha^{-1} was observed with $N_{90}S_{30}$. Under N_0, S_{15} and S_{30} resulted in significantly different straw nitrogen uptake, but at higher level of N_{45} and N_{90}, S_{15} and S_{30} were at par. In the second year also, such a similar trend was observed. The three factor interactions were not significant in both the years.

Table 4.61. Effect of manurial management on the nitrogen uptake (kg ha^{-1}) by straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	25.27	35.49	42.95	**34.57**	30.30	46.16	56.23	**44.23**
Straw application (M_1)	34.79	45.77	45.43	**42.00**	28.80	59.12	64.39	**50.77**
Cow dung (M_2)	28.76	33.99	46.74	**36.50**	36.72	55.16	54.93	**48.94**
Mean	**29.61**	**38.42**	**45.04**		**31.94**	**53.48**	**58.52**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	26.71	38.30	38.71	**34.57**	30.46	51.60	50.63	**44.23**
Straw application (M_1)	33.12	47.07	45.80	**42.00**	39.47	52.20	60.64	**50.77**
Cow dung (M_2)	31.85	40.81	36.83	**36.50**	34.47	50.36	61.98	**48.94**
Mean	**30.56**	**42.06**	**40.45**		**34.80**	**51.39**	**57.75**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	25.27	34.98	28.58	**29.61**	22.35	29.38	44.09	**31.94**
N_{45}	28.08	41.91	45.27	**38.42**	48.11	54.76	57.57	**53.48**
N_{90}	38.33	49.29	47.50	**45.04**	33.94	70.03	71.59	**58.52**
Mean	**30.56**	**42.06**	**40.45**		**34.80**	**51.39**	**57.75**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	20.41	23.11	36.60	**26.71**	33.19	32.68	49.02	**38.30**	22.19	50.69	43.24	**38.71**
M_1	31.05	37.00	31.31	**33.12**	40.55	49.46	51.19	**47.07**	32.77	50.85	53.77	**45.80**
M_2	24.33	24.14	47.08	**31.85**	31.18	43.59	47.66	**40.81**	30.76	34.26	45.47	**36.83**
Mean	**25.27**	**28.08**	**38.33**		**34.98**	**41.91**	**49.29**		**28.58**	**45.27**	**47.50**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	22.03	37.42	31.93	**30.46**	35.00	50.01	69.78	**51.60**	33.86	51.06	66.97	**50.63**
M_1	19.30	60.34	38.78	**39.47**	17.68	58.80	80.12	**52.20**	49.41	58.22	74.27	**60.64**
M_2	25.72	46.58	31.11	**34.47**	35.45	55.46	60.17	**50.36**	48.98	63.44	73.53	**61.98**
Mean	**22.35**	**48.11**	**33.94**		**29.38**	**54.76**	**70.03**		**44.09**	**57.57**	**71.59**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	2.29	6.71	8, 0, 0	M^{NS} or N* or S*	3.24	9.51	36, 0, 1
Two factor effects	M × N, M × S, N × S	3.96	NS	57, 87, 53	M × N, M × S, N × S	5.61	NS	50, 80, 5
Three factor effects (3 FE)	MNS, MN^2S	6.86	NS	67, 57	MNS, MN^2S	9.72	NS	80, 50
3 FE confounded	MNS^2, MN^2S^2	6.86	NS	76, 30	MNS^2, MN^2S^2	28.52	NS	68, 72
CV (%)	24.18				28.74			

4.2.58 Total uptake of nitrogen

4.2.58.1 Main effects

4.2.58.1.1 Effect of organic manures

The effects of organic manures were significant at 6 % level of significance in the first year and highly significant in the second year (Table 4.62). In the first year, total uptake of nitrogen was increased form 88.61 kg ha^{-1} to 100.32 kg ha^{-1} by cow dung application and 104.17 kg ha^{-1} by straw incorporation. In the second year, the uptakes were 101.97 kg ha^{-1} in no manure, 118.10 in cow dung application and 117.34 kg ha^{-1} in straw incorporated treatments. In both the years the effects of organic manures were at par.

4.2.58.1.2 Effect of nitrogen

The nitrogen levels averaged over organic manures and sulphur was highly significant in both the years. In the first year, a step wise increase in the total uptake of nitrogen was seen among no nitrogen (74.05 kg ha^{-1}), N @ 45 kg ha^{-1} (101.30 kg ha^{-1}) and N @ 90 kg ha^{-1} (117.75 kg ha^{-1}). In the second year N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} were at par with 123.40 and 129.58 kg ha^{-1} which was significantly superior to 84.43 kg ha^{-1} in N_0.

4.2.58.1.3 Effect of sulphur

The graded levels of sulphur averaged over organic manures and nitrogen was highly significant in both the years. In the first year, S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} was statistically at par with 103.18 and 111.44 kg ha^{-1} nitrogen uptake which was significantly superior to no sulphur (78.47 kg ha^{-1}). In the second year, a step wise increase in the total nitrogen uptake with 88.55 kg ha^{-1} in S_0, 116.48 kg ha^{-1} in S_{15} and 132.38 kg ha^{-1} in S_{30} was observed.

The two factor and three factor interactions were not significant in both the years.

Table 4.62. Effect of manurial management on the total uptake (kg ha^{-1}) of nitrogen

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	66.73	93.30	105.80	**88.61**	74.70	110.96	120.26	**101.97**
Straw application (M_1)	80.54	110.14	121.83	**104.17**	85.41	131.42	135.19	**117.34**
Cow dung (M_2)	74.87	100.46	125.61	**100.32**	93.19	127.83	133.29	**118.10**
Mean	**74.05**	**101.30**	**117.75**		**84.43**	**123.40**	**129.58**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	65.60	98.81	101.42	**88.61**	78.23	111.63	116.06	**101.97**
Straw application (M_1)	79.93	111.45	121.13	**104.17**	95.16	116.79	140.07	**117.34**
Cow dung (M_2)	89.89	99.30	111.76	**100.32**	92.28	121.01	141.02	**118.10**
Mean	**78.47**	**103.18**	**111.44**		**88.55**	**116.48**	**132.38**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	60.85	78.58	82.70	**74.05**	64.05	85.98	103.26	**84.43**
N_{45}	78.49	106.19	119.23	**101.30**	107.95	121.27	140.99	**123.40**
N_{90}	96.08	124.78	132.37	**117.75**	93.66	142.17	152.90	**129.58**
Mean	**78.47**	**103.18**	**111.44**		**88.55**	**116.48**	**132.38**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	54.47	61.28	81.06	**65.60**	77.81	95.63	123.00	**98.81**	67.92	123.01	113.33	**101.42**
M_1	67.88	86.76	85.15	**79.93**	84.54	121.11	128.68	**111.45**	89.19	122.55	151.64	**121.13**
M_2	60.21	87.43	122.04	**89.89**	73.40	101.84	122.65	**99.30**	91.00	112.12	132.15	**111.76**
Mean	**60.85**	**78.49**	**96.08**		**78.58**	**106.19**	**124.78**		**82.70**	**119.23**	**132.37**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	55.50	96.43	82.76	**78.23**	79.98	112.28	142.63	**111.63**	88.62	124.17	135.39	**116.06**
M_1	64.09	123.22	98.16	**95.16**	77.44	125.82	147.11	**116.79**	114.70	145.22	160.29	**140.07**
M_2	72.57	104.19	100.07	**92.28**	100.54	125.72	136.77	**121.01**	106.45	153.58	163.02	**141.02**
Mean	**64.05**	**107.95**	**93.66**		**85.98**	**121.27**	**142.17**		**103.26**	**140.99**	**152.90**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S*	4.38	12.85	6, 0, 0	M or N or S	3.48	10.20	0, 0, 0
Two factor effects	M × N, M × S, N × S	7.59	NS	88, 50, 77	M × N, M × S, N × S	6.02	NS	86, 56, 7
Three factor effects (3 FE)	MNS, MN^2S	13.15	NS	87, 33	MNS, MN^2S	10.44	NS	81, 44
3 FE confounded	MNS^2, MN^2S^2	13.15	NS	14, 70	MNS^2, MN^2S^2	10.44	NS	90, 82
CV (%)	19.51				12.55			

4.2.59 Sulphur uptake by grain

4.2.59.1 Main effects

4.2.59.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur levels were significant only in the first year (Table 4.63). Paddy straw incorporated treatment registered the highest uptake of sulphur by grain (25.71 kg ha^{-1}) followed by cow dung application (22.15 kg ha^{-1}) and no organic manures (19.37 kg ha^{-1}).

4.2.59.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant in both the years. A step wise increase in the sulphur uptake was observed with the increasing levels of nitrogen. The mean increase in the sulphur uptake due to N @ 90 kg ha^{-1} over no nitrogen was 54.80 % and 5.62 % over N @ 45 kg ha^{-1}. The mean increase in the sulphur uptake due to N @ 45 kg ha^{-1} over no nitrogen was 31.77 %. In the second year, N @ 45 kg ha^{-1} and N @ 90 kg ha^{-1} were statistically at par and significantly increased grain uptake of sulphur over no nitrogen.

4.2.59.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant in both the years. In the first year, a step wise increase in the sulphur uptake was shown with no sulphur (16.58 kg ha^{-1}), S @ 15 kg ha^{-1} (24.22 kg ha^{-1}) and S @ 30 kg ha^{-1} (26.43 kg ha^{-1}). The mean increase in the sulphur uptake due to S @ 30 kg ha^{-1} over S @ 15 kg ha^{-1} was 2.21, a 9.12 % increase. In the second year, S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} were statistically at par and significantly increased the sulphur uptake over no sulphur.

4.2.59.2 Two factor interaction effects

The two factor interactions such as M × N, M × S and N × S was significant in the first year. The highest sulphur uptake was registered with the incorporation of

Table 4.63. Effect of manurial management on the sulphur uptake (kg ha^{-1}) by grain

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	14.38	23.46	20.27	**19.37**	14.95	22.71	23.28	**20.31**
Straw application (M_1)	17.82	27.42	31.88	**25.71**	15.28	24.11	27.27	**22.22**
Cow dung (M_2)	18.06	22.76	25.62	**22.15**	16.27	21.14	27.94	**21.78**
Mean	**16.75**	**24.55**	**25.93**		**15.50**	**22.65**	**26.16**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	14.75	19.17	24.20	**19.37**	15.14	22.67	23.14	**20.31**
Straw application (M_1)	19.26	28.75	29.11	**25.71**	15.36	22.92	28.38	**22.22**
Cow dung (M_2)	15.72	24.75	25.96	**22.15**	15.11	23.15	27.08	**21.78**
Mean	**16.58**	**24.22**	**26.43**		**15.20**	**22.91**	**26.20**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	11.82	17.59	20.85	**16.75**	11.45	17.30	17.76	**15.50**
N_{45}	18.29	24.86	30.49	**24.55**	16.40	22.83	28.73	**22.65**
N_{90}	19.62	30.22	27.94	**25.93**	17.76	28.62	32.11	**26.16**
Mean	**16.58**	**24.22**	**26.43**		**15.20**	**22.91**	**26.20**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	9.35	17.24	17.66	**14.75**	14.98	21.89	20.63	**19.17**	18.82	31.26	22.53	**24.20**
M_1	14.66	22.61	20.49	**19.26**	18.48	27.01	40.76	**28.75**	20.31	32.63	34.39	**29.11**
M_2	11.44	15.01	20.71	**15.72**	19.32	25.68	29.26	**24.75**	23.41	27.59	26.89	**25.96**
Mean	**11.82**	**18.29**	**19.62**		**17.59**	**24.86**	**30.22**		**20.85**	**30.49**	**27.94**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	12.06	20.85	16.11	**16.34**	19.49	22.91	25.60	**22.67**	20.30	24.37	28.14	**24.27**
M_1	15.24	13.75	19.37	**15.36**	15.38	27.27	26.11	**22.92**	17.52	31.30	36.31	**28.38**
M_2	17.40	14.61	20.57	**17.53**	17.03	18.29	34.14	**23.15**	22.47	30.51	31.88	**28.29**
Mean	**14.90**	**16.40**	**17.76**		**17.30**	**22.83**	**28.62**		**17.76**	**28.73**	**32.11**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.46	1.36	0, 0, 0	M^{NS} or N* or S*	1.27	3.73	55, 0, 0
Two factor effects	M × N*, M × S*, N × S*	0.80	2.35	0, 2, 0	M × N, M × S, N × S	2.20	NS	65, 76, 37
Three factor effects (3 FE)	MNS, MN^2S	1.39	4.07	0, 1	MNS, MN^2S	3.81	NS	73, 41
3 FE confounded	$MNS^{2\ NS}$, MN^2S^2 *	1.39	4.07	47, 0	MNS^2, MN^2S^2	3.81	NS	56, 67
CV (%)	21.44				28.01			

straw along with N @ 90 kg ha^{-1} (31.88 kg ha^{-1}). The mean increase in the sulphur uptake due to straw + N @ 90 kg ha^{-1} over straw + N @ 45 kg ha^{-1} was 16.26 %, it was 24.43 % over cow dung + N @ 90 kg ha^{-1}. In the second year, cow dung applied with N @ 90 kg ha^{-1} registered the highest uptake of sulphur (27.94 kg ha^{-1}).

In the first year straw incorporated with S @ 15 kg ha^{-1} (28.75 kg ha^{-1}) and with S @ 30 kg ha^{-1} (29.11 kg ha^{-1}) were statistically at par and significantly superior to the same with no sulphur (19.26 kg ha^{-1}).

The highest uptake of sulphur was observed with N @ 45 kg ha^{-1} + S @ 30 kg ha^{-1} (30.49 kg ha^{-1}) in the first year. N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1} have also registered a similar sulphur uptake (30.22 kg ha^{-1}).

4.2.59.3 Three factor interactions

Interactions effects of MNS, MN^2S and MN^2S^2 were significant in the first year. The highest grain sulphur uptake was registered with the incorporation of straw + N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1}. When paddy straw incorporated with nitrogen and sulphur at higher levels the sulphur uptake was reduced by 18.52 % compared to straw + N @ 90 kg ha^{-1} + S @ 15 kg ha^{-1}. The confounded effect MN^2S^2 (22.53 kg ha^{-1}) was at par with MN^2S^1 (20.63 kg ha^{-1}) and significantly increased the sulphur uptake over MN^2S (17.66 kg ha^{-1}).

4.2.60 Sulphur uptake by straw

4.2.60.1 Main effects

4.2.60.1.1 Effect of organic manures

The straw sulphur uptake resulted by organic manure treatments such as no organics, straw incorporation and cow dung application was highly significant in the first year (Table 4.64). The straw incorporation and cow dung application was statistically at par. The 8.35 kg ha^{-1} sulphur uptake in the no manure treatment

Table 4.64. Effect of manurial management on the sulphur uptake (kg ha^{-1}) by straw

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	5.03	8.07	11.95	**8.35**	12.98	14.69	19.80	**15.82**
Straw application (M_1)	10.89	13.40	14.88	**13.06**	12.45	22.70	31.62	**22.26**
Cow dung (M_2)	6.24	11.98	18.11	**12.11**	15.87	19.62	23.14	**19.54**
Mean	**7.39**	**11.15**	**14.98**		**13.77**	**19.00**	**24.85**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	4.26	10.51	10.29	**8.35**	8.05	13.91	25.51	**15.82**
Straw application (M_1)	10.18	14.36	14.64	**13.06**	16.56	24.89	25.32	**22.26**
Cow dung (M_2)	8.25	13.22	14.85	**12.11**	9.43	19.97	29.23	**19.54**
Mean	**7.56**	**12.70**	**13.26**		**11.34**	**19.59**	**26.68**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	5.03	8.86	8.27	**7.39**	7.10	13.07	21.13	**13.77**
N_{45}	9.38	11.45	12.62	**11.15**	13.72	19.38	23.90	**19.00**
N_{90}	8.28	17.78	18.88	**14.98**	13.21	26.32	35.02	**24.85**
Mean	**7.56**	**12.70**	**13.26**		**11.34**	**19.59**	**26.68**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	3.29	4.38	5.10	**4.26**	6.64	8.01	16.88	**10.51**	5.17	11.81	13.88	**10.29**
M_1	7.90	11.58	11.04	**10.18**	10.66	14.29	18.15	**14.36**	14.11	14.34	15.47	**14.64**
M_2	3.90	12.17	8.70	**8.25**	9.28	12.05	18.32	**13.22**	5.52	11.72	27.31	**14.85**
Mean	**5.03**	**9.38**	**8.28**		**8.86**	**11.45**	**17.78**		**8.27**	**12.62**	**18.88**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6.02	9.57	8.54	**8.05**	6.94	18.81	15.98	**13.91**	25.98	15.67	34.87	**25.51**
M_1	8.55	22.46	18.67	**16.56**	14.75	22.88	37.03	**24.89**	14.05	22.76	39.15	**25.32**
M_2	6.73	9.14	12.42	**9.43**	17.51	16.46	25.95	**19.97**	23.37	33.27	31.05	**29.23**
Mean	**7.10**	**13.72**	**13.21**		**13.07**	**19.38**	**26.32**		**21.13**	**23.90**	**35.02**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	1.12	3.30	2, 0, 0	M^{NS} or N^{NS} or S*	3.05	8.95	35, 6, 1
Two factor effects	M × N, M × S, N × S	1.95	NS	40, 97, 24	M × N, M × S, N × S	5.29	NS	77, 78, 84
Three factor effects (3 FE)	MNS, MN^2S	3.37	NS	8, 82	MNS, MN^2S	9.16	NS	53, 59
3 FE confounded	MNS^2, MN^2S^2	3.37	NS	6, 73	MNS^2, MN^2S^2	9.16	NS	100, 70
CV (%)	43.08				51.39			

increased to 12.11 kg ha^{-1} by cow dung application and to 13.06 kg ha^{-1} by straw incorporation. A similar trend was seen in the second year also the corresponding values are 15.82, 19.54 and 22.26 kg ha^{-1}.

4.2.60.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was highly significant in the first year significant at 6 % level of significance in the second year. Sulphur uptake was least with 7.39 kg ha^{-1} in N_0 treatment which increased to 11.15 kg ha^{-1} and 14.98 kg ha^{-1} with the application of N_{45} and N_{90}, respectively in the first year. In the second year also, a similar trend was observed, the corresponding straw sulphur uptake was 13.77, 19.00 and 24.85 kg ha^{-1}.

4.2.60.1.3 Effect of sulphur

The effect of sulphur averaged over organics and nitrogen was highly significant in the both the years. In the first year, a step wise increase was seen with 7.56 kg ha^{-1} in S_0, 12.70 kg ha^{-1} in S_{15} and 13.26 kg ha^{-1} in S_{30}, the latter two were at par. In the second year, significant step wise increase with 11.34 kg ha^{-1} in S_0, 19.59 kg ha^{-1}in S_{15} and 26.68 kg ha^{-1} S_{30} were observed.

4.2.60.2 Two factor interaction effects

A noticeable increase was observed only with N × S, but at 24 % level significance in the first year. At S_0 and S_{15} levels all the combinations of nitrogen were at par. But at S_{30}, N_{90} resulted in the significant increase in sulphur uptake over other nitrogen levels.

4.2.60.3 Three factor interactions

MNS interaction at 8 % level and MNS^2 at 6 % level of significance were significant in the first year. Highest level of nitrogen and sulphur combined with cow dung application resulted in the highest straw sulphur uptake.

4.2.61 Total uptake of sulphur

4.2.61.1 Main effects

4.2.61.1.1 Effect of organic manures

The effect of organic manures averaged over varied doses of sulphur and nitrogen was highly significant in the first year and significant at 18 % level of significance in the second year (Table 4.65). Total sulphur uptake was increased from 27.73 kg ha^{-1} with no organic manures to 34.25 kg ha^{-1} with cow dung application and 38.76 kg ha^{-1} with straw incorporation. A similar effect was observed in the second year also.

4.2.61.1.2 Effect of nitrogen

The effect of graded doses of nitrogen was significant in both the years. In the first year a step wise increase in the sulphur uptake was observed with N_0 (24.14 kg ha^{-1}), N_{45} (35.70 kg ha^{-1}) and N_{90} (40.91 kg ha^{-1}). In the second year, the corresponding values are 29.27, 41.66 and 51.01 with N_0, N_{45} and N_{90}, respectively.

4.2.61.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant in both the years. In the first year, S @ 15 kg ha^{-1} and S @ 30 kg ha^{-1} was at par with 36.92 kg ha^{-1} and 39.68 kg ha^{-1} and significantly superior to S_0 (24.14 kg ha^{-1}). In the second year, a step wise increase in the sulphur uptake was seen among no sulphur (26.55 kg ha^{-1}), S @ 15 kg ha^{-1} (42.50 kg ha^{-1}) and S @ 30 kg ha^{-1} (52.88 kg ha^{-1}). Two factor and three factor interaction effects were not significant in both the years.

Table 4.65. Effect of manurial management on the total uptake of (kg ha^{-1}) sulphur

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	19.42	31.53	32.22	**27.73**	27.93	37.40	43.08	**36.14**
Straw application (M_1)	28.71	40.82	46.77	**38.76**	27.73	46.81	58.88	**44.47**
Cow dung (M_2)	24.29	34.74	43.73	**34.25**	32.14	40.76	51.07	**41.33**
Mean	**24.14**	**35.70**	**40.91**		**29.27**	**41.66**	**51.01**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	19.01	29.68	34.49	**27.73**	23.19	36.58	48.64	**36.14**
Straw application (M_1)	29.43	43.11	43.75	**38.76**	31.92	47.81	53.70	**44.47**
Cow dung (M_2)	23.98	37.97	40.81	**34.25**	24.54	43.12	56.31	**41.33**
Mean	**24.14**	**36.92**	**39.68**		**26.55**	**42.50**	**52.88**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	16.85	26.46	29.11	**24.14**	18.55	30.36	38.89	**29.27**
N_{45}	27.67	36.31	43.12	**35.70**	30.13	42.21	52.63	**41.66**
N_{90}	27.90	48.00	46.82	**40.91**	30.97	54.94	67.13	**51.01**
Mean	**24.14**	**36.92**	**39.68**		**26.55**	**42.50**	**52.88**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	12.64	21.62	22.76	**19.01**	21.63	29.91	37.50	**29.68**	23.99	43.07	36.41	**34.49**
M_1	22.57	34.19	31.54	**29.43**	29.14	41.29	58.91	**43.11**	34.42	46.97	49.86	**43.75**
M_2	15.34	27.18	29.41	**23.98**	28.60	37.72	47.58	**37.97**	28.93	39.31	54.20	**40.81**
Mean	**16.85**	**27.67**	**27.90**		**26.46**	**36.31**	**48.00**		**29.11**	**43.12**	**46.82**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	14.49	30.42	24.66	**23.19**	26.43	41.72	41.58	**36.58**	42.87	40.04	63.01	**48.64**
M_1	21.49	36.21	38.04	**31.92**	30.13	50.15	63.15	**47.81**	31.57	54.06	75.46	**53.70**
M_2	19.67	23.75	30.21	**24.54**	34.53	34.75	60.09	**43.12**	42.22	63.78	62.93	**56.31**
Mean	**18.55**	**30.13**	**30.97**		**30.36**	**42.21**	**54.94**		**38.89**	**52.63**	**67.13**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	1.65	4.84	0, 0, 0	M^{NS} or N* or S*	3.10	9.09	18, 0, 0
Two factor effects	M × N, M × S, N × S	2.86	NS	65, 94, 28	M × N, M × S, N × S	5.37	NS	63, 89, 59
Three factor effects (3 FE)	MNS, MN^2S	4.95	NS	68, 94	MNS, MN^2S	9.30	NS	36, 83
3 FE confounded	MNS^2, MN^2S^2	4.95	NS	37, 32	MNS^2, MN^2S^2	9.30	NS	93, 80
CV (%)								

4.2.62 Agronomic efficiency of nitrogen

4.2.62.1 Main effects

4.2.62.1.1 Effect of organic manures

The effects of organic manures on the use efficiency of nitrogen averaged over nitrogen and sulphur were not significant in both the years (Table 4.66). However, a noticeable increase in the nitrogen use efficiency due to straw incorporation was noticed.

4.2.62.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was significant in both the years. N_{45} significantly increased the NUE over N_{90}. In the first year a 70.16 % increase in the NUE was noticed by N_{45} over N_{90}. In the second year it was 89.77 % increase.

4.2.62.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant in both the years. In the first year, a step wise increase in the NUE was observed with 29.81 kg in S_0 followed by 44.34 kg in S_{15} and 47.16 kg in S_{30} and the latter two were at par. The corresponding values in the second year were 25.80, 40.41 and 49.85 kg.

4.2.62.2 Two factor interaction effects

Two factor interactions were not significant, except for M × N at 8.33 % level of significance in the second year. In the first year, Under N_{45}, no organics (52.18 kg) and straw (52.37 kg) registered a similar and higher NUE over cow dung. Under N_{90}, straw incorporation resulted in the highest efficiency of nitrogen over no organics and cow dung. In the second year, under N_{45}, no organic manure treatments registered the highest efficiency of 58.50 kg and under N_{90}, cow dung application registered the highest NUE of 30.76 kg.

Table 4.66. Effect of manurial management on the agronomic efficiency (kg grain kg^{-1} nutrient applied) of nitrogen

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	-	52.18	25.85	**39.01**	-	58.50	22.39	**40.45**
Straw application (M_1)	-	52.37	34.07	**43.22**	-	46.21	26.94	**36.57**
Cow dung (M_2)	-	48.26	29.89	**39.08**	-	47.32	30.76	**39.04**
Mean	**-**	**50.93**	**29.93**		**-**	**50.67**	**26.70**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	24.09	44.71	48.23	**39.01**	27.43	42.33	51.58	**40.45**
Straw application (M_1)	34.18	44.06	51.42	**43.22**	24.77	37.85	47.10	**36.57**
Cow dung (M_2)	31.15	44.27	41.81	**39.08**	25.20	41.07	50.86	**39.04**
Mean	**29.81**	**44.34**	**47.16**		**25.80**	**40.41**	**49.85**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	-	-	-	**-**	-	-	-	**-**
N_{45}	36.32	56.88	59.29	**50.93**	34.51	52.47	65.04	**50.67**
N_{90}	23.29	31.80	34.71	**29.93**	17.08	28.35	34.66	**26.70**
Mean	**29.81**	**44.34**	**47.16**		**25.80**	**40.41**	**49.85**	

Interactions between organic manures, nitrogen and sulphur

	S_0				S_{15}				S_{30}			
First Year												
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	29.02	19.16	**24.09**	-	62.44	26.98	**44.71**	-	65.07	31.40	**48.23**
M_1	-	42.62	25.74	**34.18**	-	52.22	35.90	**44.06**	-	62.26	40.58	**51.42**
M_2	-	37.33	24.97	**31.15**	-	56.00	32.54	**44.27**	-	51.46	32.17	**41.81**
Mean	**-**	**36.32**	**23.29**		**-**	**56.88**	**31.80**		**-**	**59.59**	**34.71**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	41.26	13.60	**27.43**	-	60.32	24.34	**42.33**	-	73.92	29.25	**51.58**
M_1	-	33.03	16.51	**24.77**	-	47.70	28.00	**37.85**	-	57.90	36.31	**47.10**
M_2	-	29.25	21.14	**25.19**	-	49.41	32.73	**41.07**	-	63.30	38.43	**50.86**
Mean	**-**	**34.51**	**17.08**		**-**	**52.47**	**28.35**		**-**	**65.04**	**34.66**	

Comparison	First year			Second year		
	Treatments	S.E	CD	Treatments	S.E	CD
Main effects	M or N or S	2.34, 1.91, 2.34	NS, 5.72, 7.07	M or N or S	1.97, 1.61, 1.97	NS, 4.81, 5.89
Two factor effects	M × N, M × S, N × S	3.32, 4.06, 3.32	NS, NS, NS	M × N, M × S, N × S	2.79, 3.42, 2.79	8.33, NS,NS
Three factor effects	MNS	5.75	NS	MNS	4.83	NS
CV (%)	20.12			17.69		

The Influence of no organic manure, straw incorporation and cow dung application on the use efficiency of nitrogen was at par in both the years, irrespective of the sulphur levels. However, the agronomic efficiency was increased with the increasing levels of sulphur.

N_{45} with $S_0/S_{15}/S_{30}$ registered the highest NUE over N_{90} with $S_0/S_{15}/S_{30}$. The treatment $N_{45} + S_{30}$ registered the highest NUE of 59.29 and 65.04 in first and second years, respectively. A step wise increase was observed with S_0, S_{15} and S_{30} in both the years.

4.2.62.3 Three factor interaction effects

Three factor interactions were not significant in both the years.

4.2.63 Uptake efficiency of nitrogen

4.2.63.1 Main effects

4.2.63.1.1 Effect of organic manures

The effect of organic manures on the uptake efficiency of nitrogen averaged over nitrogen and sulphur levels were not significant in both the years (Table 4.67), however, organic manures increased the apparent recovery. It was 42.39 % with no organic manures, 57.21 % with straw incorporation and 60.92 % with cow dung application in the first year. The corresponding values are 51.85, 63.75 and 68.50 % in the second year.

4.2.63.1.2 Effect of nitrogen

The effect of graded doses of nitrogen on the uptake efficiency of nitrogen averaged over organic manures and sulphur was not significant. However, a noticeable increase in the recovery of nitrogen was observed with N_{45} in both the years.

Table 4.67. Effect of manurial management on the uptake efficiency (nutrient uptake / nutrient applied) of nitrogen

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	-	52.80	31.99	**42.39**	-	69.70	34.00	**51.85**
Straw application (M_1)	-	67.37	47.05	**57.21**	-	86.30	41.20	**63.75**
Cow dung (M_2)	-	72.04	49.80	**60.92**	-	87.00	50.00	**68.50**
Mean	**-**	**64.07**	**42.95**		**-**	**81.00**	**41.70**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	10.36	54.28	62.54	**42.39**	38.00	54.00	63.50	**51.85**
Straw application (M_1)	28.44	65.91	77.28	**57.21**	47.00	55.80	88.50	**63.75**
Cow dung (M_2)	55.22	49.63	77.92	**60.92**	46.50	64.80	94.20	**68.50**
Mean	**31.34**	**56.61**	**72.58**		**43.80**	**58.20**	**82.10**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	-	-	-	**-**	-	-	-	**-**
N_{45}	36.34	67.18	88.69	**64.07**	58.70	73.30	111.00	**81.00**
N_{90}	26.33	46.04	56.47	**42.95**	29.00	43.00	53.20	**41.70**
Mean	**31.34**	**56.61**	**72.58**		**43.80**	**58.20**	**82.10**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	9.14	11.57	**10.35**	-	64.20	44.36	**54.28**	-	85.04	40.44	**62.74**
M_1	-	34.89	21.99	**28.44**	-	83.56	48.26	**65.91**	-	83.65	70.90	**77.27**
M_2	-	64.99	45.45	**55.22**	-	53.77	45.49	**49.63**	-	97.37	58.47	**77.92**
Mean	**-**	**36.34**	**26.33**		**-**	**67.17**	**46.03**		**-**	**88.68**	**56.60**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	57.00	19.00	**38.00**	-	64.00	44.00	**54.00**	-	88.00	39.00	**63.50**
M_1	-	65.50	28.50	**47.00**	-	74.50	37.00	**55.75**	-	119.00	58.00	**88.50**
M_2	-	53.50	39.50	**46.50**	-	81.50	48.00	**64.75**	-	126.00	62.50	**94.25**
Mean	**-**	**58.66**	**29.00**		**-**	**73.33**	**43.00**		**-**	**111.00**	**53.16**	

Comparison	**First year**			**Second year**		
	Treatments	S.E	CD	Treatments	S.E	CD
Main effects	M or N or S	7.85, 6.41, 7.85	NS, 19.14, 23.44	M or N or S	5.38, 4.39, 5.38	NS, 13.09, 16.05
Two factor effects	M × N, M × S, N × S	11.11, 13.61, 11.11	NS, NS, NS	M × N, M × S, N × S	7.61, 9.32, 7.61	NS. NS. NS
Three factor effects	MNS	19.24	NS	MNS	13.18	NS
CV (%)	50.54			30.37		

4.2.63.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen were not significant in both the years. A step wise increase in the uptake efficiency of N was observed with 31.34 % in S_0, 56.61 % in S_{15} and 72.58 % in S_{30} in the first year. The corresponding values are 43.80, 58.20 and 82.10 % in the second year.

4.2.63.2 Two factor interaction effects

Two factor interactions were not significant. However, N_{45} applied with organic manures or sulphur increased the uptake efficiency of nitrogen over N_{90} applied with organic manures or sulphur.

4.2.63.3 Three factor interaction effects

Three factor interactions were not significant in both the year. However, the highest uptake efficiency of nitrogen was observed with organic manures + N_{45} + S_{30}.

4.2.64 Physiological efficiency of nitrogen

4.2.64.1 Main effects

4.2.64.1.1 Effect of organic manures

The effect of organic manures on the physiological efficiency of nitrogen averaged over nitrogen and sulphur were not significant in both the years (Table 4.68). However, a stepwise increase in the physiological efficiency with no organic manures (60.32 kg), followed by straw incorporation (70.38 kg) and cow dung application was observed in the first year. The corresponding values are 64.41, 71.54 and 75.51 kg, respectively, in the second year.

4.2.64.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was not significant. However, a noticeable increase in the recovery of nitrogen with N_{90} over N_{45} was observed in both the years.

Table 4.68. Effect of manurial management on the physiological efficiency of N (kg grain kg^{-1} nutrient taken up)

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	-	57.81	62.84	**60.32**	-	64.79	64.03	**64.41**
Straw application (M_1)	-	64.36	76.40	**70.38**	-	72.30	70.79	**71.54**
Cow dung (M_2)	-	66.47	78.87	**72.67**	-	72.67	78.35	**75.51**
Mean	**-**	**62.88**	**72.70**		**-**	**69.92**	**71.06**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	41.31	68.46	71.20	**60.32**	54.91	67.56	70.76	**64.41**
Straw application (M_1)	51.79	74.57	84.78	**70.38**	61.13	67.05	86.50	**71.54**
Cow dung (M_2)	69.12	66.62	82.27	**72.67**	63.28	73.43	89.81	**75.51**
Mean	**54.08**	**69.88**	**79.42**		**59.77**	**69.33**	**82.36**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	-	-	-	**-**	-	-	-	**-**
N_{45}	50.40	64.28	73.96	**62.88**	59.83	66.51	83.41	**69.92**
N_{90}	57.75	75.48	84.87	**72.70**	59.72	72.14	81.31	**71.06**
Mean	**54.08**	**69.88**	**79.42**		**59.77**	**69.33**	**82.36**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	38.16	44.46	**41.31**	-	62.94	73.97	**68.45**	-	72.32	70.09	**71.20**
M_1	-	49.75	53.84	**51.79**	-	71.65	77.49	**74.57**	-	71.69	97.86	**84.77**
M_2	-	63.29	74.95	**69.12**	-	58.24	74.99	**66.61**	-	77.86	86.68	**82.27**
Mean	**-**	**50.40**	**57.75**		**-**	**64.27**	**75.48**		**-**	**73.95**	**84.87**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	59.00	50.82	**54.91**	-	62.27	72.84	**67.55**	-	73.11	68.42	**70.76**
M_1	-	62.88	59.37	**61.12**	-	67.02	66.98	**67.00**	-	89.99	86.02	**88.00**
M_2	-	57.61	68.96	**63.28**	-	70.25	76.60	**73.42**	-	90.14	89.48	**89.81**
Mean	**-**	**59.83**	**59.71**		**-**	**66.51**	**72.14**		**-**	**84.41**	**81.30**	

Comparison	**First year**			**Second year**		
	Treatments	S.E	CD	Treatments	S.E	CD
Main effects	M or N or S	5.01, 4.09, 5.01	NS, NS, 14.95	M or N or S	3.65, 2.98, 3.65	NS, NS, 10.91
Two factor effects	M × N, M × S, N × S	7.08, 8.68, 7.08	NS, NS, NS	M × N, M × S, N × S	5.17, 6.33, 5.17	NS, NS, NS
Three factor effects	MNS	12.27	NS	MNS	8.95	NS
CV (%)	25.61			17.97		

4.2.64.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen were not significant in both the years. A stepwise increase in the physiological efficiency of N was observed with 54.08 kg in S_0, 69.88 kg in S_{15} and 79.42 kg in S_{30}, in the first year. The corresponding values were 59.77, 69.33 and 82.36 kg, in the second year.

4.2.64.2 Two factor interaction effects

Two factor interactions were not significant in both the years. However a noticeable increase in the physiological efficiency of N was observed with cow dung + N_{90} (78.35) in the second year and N_{90} + S_{30} (84.87) in the first year

Three factor interactions were also not significant in both the years.

4.2.65 Agronomic efficiency of sulphur

4.2.65.1 Main effects

4.2.65.1.1 Effect of organic manures

The effect of organic manures on agronomic efficiency of S averaged over nitrogen and sulphur was not significant in both the years (Table 4.69). However, SUE was highest with 125.65 kg by straw incorporation and 124.86 kg with cow dung application in first and second year, respectively.

4.2.65.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant in both the years. SUE was the least with 69.66 kg ha^{-1} in N_0 treatment which increased to 122.11 kg and 147.50 kg with the application of N_{45} and N_{90}, respectively in the first year. In the second year also, a similar trend was observed, the corresponding SUE was 95.79, 127.49 and 137.07 kg, but the latter two were at par.

Table 4.69. Effect of manurial management on the agronomic efficiency of sulphur (kg grain kg^{-1} nutrient applied)

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	60.27	118.71	128.05	**102.34**	93.53	145.92	116.89	**118.78**
Straw application (M_1)	83.36	125.03	168.57	**125.65**	96.70	114.97	138.49	**116.72**
Cow dung (M_2)	65.36	122.60	145.88	**111.28**	97.15	121.59	155.85	**124.86**
Mean	**69.66**	**122.11**	**147.50**		**95.79**	**127.49**	**137.07**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	-	123.32	81.36	**102.34**	-	145.65	91.91	**118.78**
Straw application (M_1)	-	158.86	92.45	**125.65**	-	145.12	88.32	**116.72**
Cow dung (M_2)	-	146.11	76.45	**111.28**	-	154.57	95.15	**124.86**
Mean	**-**	**142.76**	**83.42**		**-**	**148.45**	**91.79**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	-	82.62	56.71	**69.66**	-	117.76	73.82	**95.79**
N_{45}	-	154.82	89.40	**122.11**	-	157.43	97.56	**127.49**
N_{90}	-	190.85	104.15	**147.50**	-	170.15	10.00	**137.07**
Mean	**-**	**142.76**	**83.42**		**-**	**148.45**	**91.79**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	-	-	-	68.27	139.81	161.90	**123.32**	52.27	97.61	94.20	**81.36**
M_1	-	-	-	-	104.53	156.66	215.40	**158.86**	62.20	93.40	121.75	**92.45**
M_2	-	-	-	-	75.07	168.00	195.26	**146.11**	55.66	77.20	96.50	**76.45**
Mean	**-**	**-**	**-**	**-**	**82.62**	**154.82**	**190.85**		**56.71**	**89.40**	**104.15**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	-	-	-	109.96	180.96	146.03	**145.65**	77.10	110.88	87.75	**91.91**
M_1	-	-	-	-	124.23	143.10	168.03	**145.12**	69.17	86.85	108.95	**88.32**
M_2	-	-	-	-	119.10	148.23	196.40	**154.57**	75.20	94.95	115.30	**95.15**
Mean	**-**	**-**	**-**	**-**	**117.76**	**157.43**	**170.15**		**73.82**	**97.56**	**104.00**	

Comparison	**First year**			**Second year**		
	Treatments	S.E	CD	Treatments	S.E	CD
Main effects	M or N or S	8.09, 8.09, 6.61	NS, 24.16, 19.72	M or N or S	5.30, 5.30, 4.33	NS, 15.83, 12.92
Two factor effects	M × N, M × S, N × S	14.02, 11.45, 11.45	NS, NS, 34.17	M × N, M × S, N × S	9.18, 7.50, 7.50	27.42, NS, NS
Three factor effects	MNS	19.83	NS	MNS	12.99	NS
CV (%)	24.80			15.30		

4.2.65.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was significant in both the years. S_{15} registered the highest SUE of 142.76 kg compared to S_{30} with 83.42 kg in the first year. The corresponding values were 148.75 kg with S_{15} and 91.79 kg with S_{30}, in the second year.

4.2.65.2 Two factor interaction effects

Two factor interactions were not significant, except for N × S and M × N in first and second year, respectively. The highest SUE of 155.85 kg was observed with cow dung + N_{90}, which was at par with no organics + N_{45} (145.92 kg) and straw + N_{90} (138.49 kg) in the second year. SUE was least with 82.62 kg in N_0 + S_{30} which increased 190.85 kg in $N_{90}S_{15}$ in the first year. In the second year also, the highest SUE of 170.15 kg was observed with $N_{90}S_{15}$.

4.2.65.3 Three factor interaction effects

Three factor interactions were not significant and the highest SUE was observed under S_{15} with N_{90} + straw incorporation or cow dung application.

4.2.66 Uptake efficiency of sulphur

4.2.66.1 Main effects

4.2.66.1.1 Effect of organic manures

The effect of organic manures on uptake efficiency of sulphur averaged over nitrogen and sulphur was significant in the first year (Table 4.70). No organic manures registered the lowest recovery of sulphur with 57.73 % and it was at par with cow dung application (79.28 %) which was in turn at par with straw incorporation (97.85 %).

Table 4.70. Effect of manurial management on the uptake efficiency (nutrient uptake / nutrient applied) of sulphur

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	34.80	78.50	59.80	**57.73**	50.76	74.64	89.87	**71.76**
Straw application (M_1)	48.94	97.90	146.70	**97.85**	38.10	100.73	105.22	**81.35**
Cow dung (M_2)	56.92	85.07	95.85	**79.28**	45.82	69.48	124.58	**79.96**
Mean	**46.89**	**87.18**	**100.78**		**44.89**	**81.62**	**106.56**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	-	65.79	49.67	**57.73**	-	94.63	48.88	**71.76**
Straw application (M_1)	-	129.66	66.03	**97.85**	-	96.34	66.36	**81.35**
Cow dung (M_2)	-	103.02	55.54	**79.28**	-	97.88	62.04	**79.96**
Mean	**-**	**99.49**	**57.08**		**-**	**96.28**	**59.09**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	-	55.29	38.48	**46.89**	-	58.84	30.95	**44.89**
N_{45}	-	103.73	70.64	**87.18**	-	95.70	67.53	**81.62**
N_{90}	-	139.45	62.12	**100.78**	-	134.31	78.80	**106.56**
Mean	**-**	**99.49**	**57.08**		**-**	**96.28**	**59.09**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	-	-	-	37.89	83.96	75.52	**65.79**	31.72	73.19	44.09	**49.66**
M_1	-	-	-	-	61.19	118.04	209.76	**129.66**	36.70	77.76	83.64	**66.03**
M_2	-	-	-	-	66.80	109.19	133.07	**103.02**	47.04	60.96	58.63	**55.54**
Mean	**-**	**-**	**-**	**-**	**55.29**	**103.73**	**139.45**		**38.48**	**70.63**	**62.12**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	-	-	-	73.44	96.28	114.18	**94.63**	28.08	53.01	65.57	**48.88**
M_1	-	-	-	-	46.04	125.36	117.63	**96.34**	30.16	76.11	92.81	**66.36**
M_2	-	-	-	-	57.04	65.48	171.14	**97.88**	34.61	73.48	78.03	**62.04**
Mean	**-**	**-**	**-**	**-**	**58.84**	**95.70**	**134.31**		**30.95**	**67.53**	**78.80**	

Comparison	**First year**			**Second year**		
	Treatments	S.E	CD	Treatments	S.E	CD
Main effects	M or N or S	7.71, 7.71, 6.30	23.03, 23.03, 18.80	M or N or S	11.07, 11.07, 9.03	NS, 33.03, 26.97
Two factor effects	M × N, M × S, N × S	13.37, 10.91, 10.91	NS, NS, 32.57	M × N, M × S, N × S	19.17, 15.65, 15.65	NS, NS, NS
Three factor effects	MNS	18.90	NS	MNS	27.11	NS
CV (%)	34.16			49.36		

4.2.66.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was significant in both the years. Uptake efficiency of sulphur of 46.89 % in N_0 increased to 87.18 % by N_{45} and 100.78 % by N_{90} however, the latter two were at par. In the second year also, a similar trend was observed and the corresponding values were 44.89, 81.62 and 106.56 % with N_0, N_{45} and N_{90}, respectively.

4.2.66.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant in both the years. S_{15} significantly increased the SUE over S_{30}. In the first year, a 74.30 % increase in the SUE was noticed by S_{15} over S_{30}. In the second year it was 62.94 % increase.

4.2.66.2 Two factor interaction effects

Two factor interactions were not significant, except for N × S in the first year. Under S_{15} all the nitrogen levels were significantly different and the highest uptake efficiency of 139.45 % was observed in $N_{90}S_{15}$ treatment. Under S_{30}, level all the nitrogen levels reduced the recovery of sulphur compared to S_{15}.

4.2.66.3 Three factor interaction effects

Three factor interactions were not significant however, a noticeable increase in the uptake efficiency of sulphur was observed under S_{15} with N_{90} + straw incorporation (209.76 %) in the first year and S_{15} with N_{90} + cow dung application (171.14 %) in the second year.

4.2.67 Physiological efficiency of sulphur

4.2.67.1 Main effects

4.2.67.1.1 Effect of organic manures

The effect of organic manures on physiological efficiency of sulphur averaged over nitrogen and sulphur was significant in the first year (Table 4.71). No organic manure (21.68) was at par with cow dung application (25.35), which was in turn at par with straw application (28.93). The corresponding values were 22.90, 25.65 and 25.12 in the second year.

4.2.67.1.2 Effect of nitrogen

The effects of graded doses of nitrogen were significant in the first year. A step wise increase in the physiological efficiency was observed with N_0 (19.22 kg) followed by N_{45} (27.67 kg) and N_{90} (29.07 kg) and the latter two were at par. In the second year also the similar trend was observed and the corresponding values are 17.52, 25.78 and 30.36 kg, respectively.

4.2.67.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was not significant. S_{15} and S_{30} registered a similar physiological efficiency of sulphur with 24.22 kg and 26.42 kg, respectively. In the second year, S_{30} (22.91 kg) increased the physiological efficiency over S_{15} (26.20 kg).

Two factor and three factor interactions were not significant in both the years.

4.2.68 N : P ratio

4.2.68.1 Main effects

4.2.68.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant at 15 and 25 % level in the first and second years (Table 4.72). Straw

Table 4.71. Effect of manurial management on the physiological efficiency of S (kg grain kg^{-1} nutrient taken up)

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	16.90	26.57	21.57	**21.68**	18.19	23.64	26.86	**22.90**
Straw application (M_1)	19.39	29.81	37.58	**28.93**	16.45	29.29	31.21	**25.65**
Cow dung (M_2)	21.36	26.63	28.07	**25.35**	17.94	24.40	33.01	**25.12**
Mean	**19.22**	**27.67**	**29.07**		**17.52**	**25.78**	**30.36**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	-	19.16	24.20	**21.68**	-	22.66	23.13	**22.90**
Straw application (M_1)	-	28.75	29.11	**28.93**	-	22.92	28.38	**25.65**
Cow dung (M_2)	-	24.75	25.96	**25.35**	-	23.15	27.08	**25.12**
Mean	**-**	**24.22**	**26.42**		**-**	**22.91**	**26.20**	
Nitrogen (N)	S_0	S_{15}	S_{30}	Mean	S_0	S_{15}	S_{30}	Mean
N_0	-	17.59	20.84	**19.22**	-	17.29	17.75	**17.52**
N_{45}	-	24.85	30.49	**27.67**	-	22.82	28.73	**25.78**
N_{90}	-	30.21	27.93	**29.07**	-	28.61	32.12	**30.36**
Mean	**-**	**24.22**	**26.42**		**-**	**22.91**	**26.20**	

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First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	-	-	-	14.98	21.89	20.62	**19.16**	18.81	31.26	22.52	**24.19**
M_1	-	-	-	-	18.48	27.00	40.76	**28.74**	20.31	32.63	34.63	**29.19**
M_2	-	-	-	-	19.32	25.67	29.26	**24.75**	23.41	27.59	26.89	**25.96**
Mean	**-**	**-**	**-**	**-**	**17.59**	**24.85**	**30.21**		**20.84**	**30.49**	**28.01**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	-	-	-	-	19.48	22.91	25.59	**22.66**	16.89	24.37	28.14	**23.13**
M_1	-	-	-	-	15.38	27.27	26.11	**22.92**	17.52	31.30	36.31	**28.67**
M_2	-	-	-	-	17.03	18.29	34.14	**23.15**	18.85	30.51	31.88	**27.08**
Mean	**-**	**-**	**-**	**-**	**17.29**	**22.82**	**28.61**		**17.75**	**28.72**	**32.11**	

Comparison	First year			Second year		
	Treatments	S.E	CD	Treatments	S.E	CD
Main effects	M or N or S	1.48, 1.48, 1.20	4.49, 4.49, NS	M or N or S	1.79, 1.79, 1.46	NS, 5.34, NS
Two factor effects	M × N, M × S, N × S	2.56, 2.09, 2.09	NS, NS, NS	M × N, M × S, N × S	3.10, 2.53, 2.53	NS, NS, NS
Three factor effects	MNS	3.62	NS	MNS	4.38	NS
CV (%)	20.26			25.27		

Table 4.72. Effect of manurial management on the N : P ratio of leaf at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	7.50	6.83	7.09	**7.14**	6.57	7.93	8.10	**7.53**
Straw application (M_1)	8.33	8.93	9.03	**8.76**	7.61	8.61	9.39	**8.54**
Cow dung (M_2)	7.94	6.87	8.56	**7.79**	6.48	7.98	8.03	**7.49**
Mean	**7.92**	**7.54**	**8.22**		**6.89**	**8.17**	**8.51**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	6.64	6.56	8.22	**7.14**	7.42	7.23	7.95	**7.53**
Straw application (M_1)	8.55	8.54	9.20	**8.76**	8.41	8.16	9.04	**8.54**
Cow dung (M_2)	7.66	7.89	7.82	**7.79**	7.75	7.43	7.30	**7.49**
Mean	**7.61**	**7.66**	**8.41**		**7.86**	**7.61**	**8.10**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	7.79	7.91	8.07	**7.92**	7.25	6.56	6.84	**6.89**
N_{45}	6.65	7.61	8.37	**7.54**	8.08	7.88	8.55	**8.17**
N_{90}	8.41	7.47	8.80	**8.22**	8.25	8.38	8.89	**8.51**
Mean	**7.61**	**7.66**	**8.41**		**7.86**	**7.61**	**8.10**	

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First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	7.16	7.06	5.68	**6.64**	7.88	5.94	5.87	**6.56**	7.46	7.49	9.71	**8.22**
M_1	8.89	7.46	9.29	**8.55**	8.68	8.33	8.61	**8.54**	7.41	11.01	9.19	**9.20**
M_2	7.32	5.42	10.25	**7.66**	7.18	8.56	7.92	**7.89**	9.32	6.63	7.50	**7.82**
Mean	**7.79**	**6.65**	**8.41**		**7.91**	**7.61**	**7.47**		**8.07**	**8.37**	**8.80**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	7.16	8.25	6.85	**7.42**	6.20	7.16	8.33	**7.23**	6.36	8.38	9.11	**7.95**
M_1	8.24	7.60	9.40	**8.41**	7.21	8.72	8.55	**8.16**	7.38	9.50	10.22	**9.04**
M_2	6.36	8.40	8.48	**7.75**	6.28	7.75	8.27	**7.43**	6.79	7.78	7.34	**7.30**
Mean	**7.25**	**8.08**	**8.25**		**6.56**	**7.88**	**8.38**		**6.84**	**8.55**	**8.89**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.57	NS	15, 70, 55	M or N or S	0.48	NS	25, 7, 78
Two factor effects	M × N, M × S, N × S	0.99	NS	86, 93, 86	M × N, M × S, N × S	0.84	NS	100, 97, 98
Three factor effects (3 FE)	MNS, MN^2S	1.71	NS	7, 93	MNS, MN^2S	1.46	NS	71, 92
3 FE confounded	MNS^2, MN^2S^2	1.71	NS	60, 97	MNS^2, MN^2S^2	1.46	NS	59, 61
CV (%)	31.33				26.68			

incorporation significantly increased the N : P ratio to 8.76 compared to cow dung application (7.79) and no organic manures (7.14). The corresponding values are 8.54, 7.49 and 7.53, respectively in the second year.

4.2.68.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur were significant only at 7 % level of significance in second year. A step wise increase in the N : P ratio was observed among no nitrogen (6.89), N @ 45 kg ha^{-1} (8.17) and N @ 90 kg ha^{-1} (8.51).

4.2.68.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was not significant in both the years.

4.2.68.2 Two factor interaction effects

Two factor interactions were not significant in both the years.

4.2.68.3 Three factor interactions

Three factor interaction MNS was significant at 7 % level of significance in the first year. Under S_{30}, straw + N_{45} significantly differed over other treatments and registered the highest N : P ratio of 11.01. The least N: P ratio of 5.42 was obtained with the application of cow dung + N_{90} + S_0

4.2.69 N : K ratio

4.2.69.1 Main effects

4.2.69.1.1 Effect of organic manures

The effect of no manure application, straw incorporation and cow dung application averaged over varied doses of sulphur and nitrogen was significant only at 26 % level of significance in the second year (Table 4.73). In both the years, N : K

Table 4.73. Effect of manurial management on the N : K ratio of leaf at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.04	1.04	0.97	**1.01**	0.66	0.86	0.93	**0.82**
Straw application (M_1)	0.91	1.13	1.28	**1.10**	0.83	0.90	1.09	**0.94**
Cow dung (M_2)	1.02	1.01	1.06	**1.03**	0.73	0.94	0.93	**0.86**
Mean	**0.99**	**1.06**	**1.10**		**0.74**	**0.90**	**0.98**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.94	0.89	1.22	**1.01**	0.75	0.86	0.84	**0.82**
Straw application (M_1)	1.08	1.13	1.10	**1.10**	0.83	0.90	1.08	**0.94**
Cow dung (M_2)	0.94	0.99	1.17	**1.03**	0.90	0.74	0.95	**0.86**
Mean	**0.99**	**1.00**	**1.16**		**0.83**	**0.83**	**0.96**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	0.92	1.01	1.03	**0.99**	0.73	0.69	0.81	**0.74**
N_{45}	0.89	1.02	1.27	**1.06**	0.84	0.81	1.03	**0.90**
N_{90}	1.14	0.99	1.17	**1.10**	0.92	1.00	1.03	**0.98**
Mean	**0.99**	**1.00**	**1.16**		**0.83**	**0.83**	**0.96**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.97	0.93	0.91	**0.94**	1.07	0.92	0.68	**0.89**	1.08	1.26	1.31	**1.22**
M_1	0.92	0.89	1.44	**1.08**	1.12	0.98	1.30	**1.13**	0.68	1.52	1.09	**1.10**
M_2	0.88	0.85	1.09	**0.94**	0.82	1.16	0.98	**0.99**	1.35	1.03	1.12	**1.17**
Mean	**0.92**	**0.89**	**1.14**		**1.01**	**1.02**	**0.99**		**1.03**	**1.27**	**1.17**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.70	0.78	0.78	**0.75**	0.60	0.89	1.09	**0.86**	0.70	0.90	0.94	**0.84**
M_1	0.82	0.70	0.97	**0.83**	0.80	0.88	1.03	**0.90**	0.88	1.10	1.27	**1.08**
M_2	0.67	1.05	0.99	**0.90**	0.66	0.66	0.89	**0.74**	0.86	1.10	0.90	**0.95**
Mean	**0.73**	**0.84**	**0.92**		**0.69**	**0.81**	**1.00**		**0.81**	**1.03**	**1.03**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.09	NS	81, 72, 40	M^{NS} or N^* or S^{NS}	0.05	0.15	26, 1, 15
Two factor effects	M × N, M × S, N × S	0.17	NS	77, 86, 81	M × N, M × S, N × S	0.08	NS	81, 40, 84
Three factor effects (3 FE)	MNS, MN^2S	0.29	NS	29, 76	MNS, MN^2S	0.15	NS	92, 86
3 FE confounded	MNS^2, MN^2S^2	0.29	NS	74, 83	MNS^2, MN^2S^2	0.15	NS	24, 50
CV (%)	41.61				24.97			

ratio was highest with the incorporation of straw. It was 1.10 and 0.94 in first and second years, respectively.

4.2.69.1.2 Effect of nitrogen

The effect of different levels of nitrogen averaged over organic manures and sulphur was significant only in the second year. A step wise increase in the N : K ratio was observed among N_0, N_{45} and N_{90}, latter two were at par too . The corresponding values are 0.74, 0.90 and 0.98, respectively.

4.2.69.1.3 Effect of sulphur

The effect of sulphur application averaged over organic manure and nitrogen treatments were significant at 15 % level of significance in the second year. S_{30} registered the highest N : K ratio of 0.96.

4.2.69.2 Two factor interaction effects

Two factor interactions were not significant in both the years.

4.2.69.3 Three factor interactions

Three factor interactions MNS^2 was significant at 24 % in the second year. Under S_{30}, straw incorporation + N_{90} registered the highest ratio of 1.27 and significantly differed with no organic manures + N_{90} (0.94) and cow dung application + N_{90} (0.90). However, under the same level of sulphur (S_{30}), straw incorporation or cow dung + N_{45} or N_0 did not differ in the N : K ratio.

4.2.70 N : S ratio

4.2.70.1 Main effects

4.2.70.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant at 30 and 12 % levels of significance in first and second years (Table 4.74). Straw incorporation (11.20) in the first year and cow dung application (12.53)

Table 4.74. Effect of manurial management on the N : S ratio of leaf at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	9.95	8.83	6.86	**8.55**	8.54	10.87	9.05	**9.49**
Straw application (M_1)	17.31	8.69	7.61	**11.20**	13.76	7.77	8.66	**10.07**
Cow dung (M_2)	6.75	7.87	7.48	**7.37**	17.70	12.66	7.25	**12.53**
Mean	**11.34**	**8.46**	**7.31**		**13.33**	**10.43**	**8.32**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	10.23	6.98	8.43	**8.55**	12.59	8.13	7.74	**9.49**
Straw application (M_1)	14.86	9.86	8.88	**11.20**	13.13	8.71	8.36	**10.07**
Cow dung (M_2)	7.91	6.79	7.39	**7.37**	21.90	6.99	8.72	**12.53**
Mean	**11.00**	**7.88**	**8.23**		**15.87**	**7.94**	**8.27**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	14.62	9.09	10.30	**11.34**	23.00	8.02	8.98	**13.33**
N_{45}	9.64	8.38	7.37	**8.46**	13.06	8.35	9.88	**10.43**
N_{90}	8.75	6.17	7.03	**7.31**	11.55	7.47	5.95	**8.32**
Mean	**11.00**	**7.88**	**8.23**		**15.87**	**7.94**	**8.27**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	10.40	11.98	8.31	**10.23**	8.42	7.45	5.08	**6.98**	11.04	7.06	7.18	**8.43**
M_1	27.71	9.34	7.51	**14.86**	13.55	8.03	8.01	**9.86**	10.67	8.69	7.29	**8.88**
M_2	5.75	7.58	10.41	**7.91**	5.29	9.66	5.42	**6.79**	9.20	6.37	6.61	**7.39**
Mean	**14.62**	**9.64**	**8.75**		**9.09**	**8.38**	**6.17**		**10.30**	**7.37**	**7.03**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	10.67	12.59	14.50	**12.59**	5.63	10.72	8.05	**8.13**	9.32	9.29	4.60	**7.74**
M_1	20.16	9.15	10.07	**13.13**	10.48	6.50	9.16	**8.71**	10.65	7.66	6.76	**8.36**
M_2	38.18	17.45	10.07	**21.90**	7.95	7.83	5.19	**6.99**	6.96	12.69	6.50	**8.72**
Mean	**23.00**	**13.06**	**11.55**		**8.02**	**8.35**	**7.47**		**8.98**	**9.88**	**5.95**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	1.74	NS	30, 27, 40	M^{NS} or N* or S*	1.06	3.12	12, 1, 0
Two factor effects	M × N, M × S, N × S	3.02	NS	43, 91, 96	M × N^{NS}, M × S^{NS}, N × S*	1.84	5.41	6, 6, 3
Three factor effects (3 FE)	MNS, MN^2S	5.24	NS	31, 82	MNS*, MN^2S	3.19	9.37	5, 19
3 FE confounded	MNS^2, MN^2S^2	5.24	NS	84, 35	MNS^2, MN^2S^2	3.19	NS	19, 13
CV (%)	77.61				43.20			

in the second year registered the highest N : S ratio. However straw incorporation was at par with cow dung application in the second year.

4.2.70.1.2 Effect of nitrogen

The effect of nitrogen averaged over organic manures and sulphur was significant at 27 % level of significance in the first year and highly significant in the second year. A step wise decrease in the N : S ratio was observed with increasing rates of nitrogen. The N : S ratio was 13.33 with N_0, 10.43 with N_{45} and 8.32 with N_{90} in the second year. The corresponding values are 11.34, 8.46 and 7.31, respectively in the first year.

4.2.70.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant in the second year. S_{15} (7.94) and S_{30} (8.27) were statistically at par and significantly reduced the N : S ratio over no sulphur application (15.87).

4.2.70.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were significant at 6, 6 and 3 % level, respectively in the second year. M_2N_0 with 17.70, M_2S_0 with 21.90 and N_0S_0 with 23.00 registered the highest N : S ratio.

4.2.70.3 Three factor interactions

Three factor interactions such as MNS at 5 % level, MN^2S at 19 % level, MNS^2 with 19 % level of significance and MN^2S^2 with 13 % level of significance were significant in second year. The highest N : S ratio of 38.18 was observed with cow dung + no nitrogen + no sulphur. Increase in nitrogen dose to 45 and 90 kg ha^{-1} or increase in sulphur dose to 15 and 30 kg ha^{-1} resulted in a decreased N : S ratio.

4.2.71 N : Fe ratio

4.2.71.1 Main effects

4.2.71.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur was significant at 13 % level of significance in the first year and highly significant in the second year (Table 4.75). In the first year, N : Fe ratio was increased from 8.45 to 11.65 by straw incorporation and 13.77 by cow dung application. No organic manure was at par with straw incorporation which in turn at par with cow dung application. In the second year also, a similar trend was obtained. However, straw incorporation registered the highest ratio of 9.28.

4.2.71.1.2 Effect of nitrogen

The effect of graded doses of nitrogen averaged over organic manures and sulphur was significant in the first year. No nitrogen (7.36) was at par with N_{45} (11.58) which in turn at par with N_{90} (14.93).

4.2.71.1.3 Effect of sulphur

The effect of sulphur averaged over organic manures and nitrogen was not significant in both the years. However, a noticeable increase in the N : Fe ratio was observed with 9.04 by S_{30} in the second year.

4.2.71.2 Two factor interaction effects

The two factor interaction M × S was significant at 7 % level of significance in the second year. The highest N : Fe ratio was observed with 12.20 by M_1S_{30} followed by M_2S_0 with 10.13.

Table 4.75. Effect of manurial management on the N : Fe ratio of leaf at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	6.47	8.22	10.65	**8.45**	6.07	5.61	7.74	**6.47**
Straw application (M_1)	6.33	12.13	16.50	**11.65**	8.98	9.08	9.78	**9.28**
Cow dung (M_2)	9.26	14.41	17.63	**13.77**	7.84	8.48	9.20	**8.51**
Mean	**7.36**	**11.58**	**14.93**		**7.63**	**7.73**	**8.91**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	7.65	7.85	9.85	**8.45**	6.21	7.24	5.97	**6.47**
Straw application (M_1)	10.33	9.86	14.77	**11.65**	7.48	8.17	12.20	**9.28**
Cow dung (M_2)	13.22	17.09	10.98	**13.77**	10.13	6.44	8.96	**8.51**
Mean	**10.40**	**11.60**	**11.87**		**7.94**	**7.28**	**9.04**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	9.14	7.60	5.32	**7.36**	8.05	7.63	7.21	**7.63**
N_{45}	8.49	15.13	11.14	**11.58**	7.55	6.34	9.29	**7.73**
N_{90}	13.56	12.08	19.14	**14.93**	8.22	7.88	10.62	**8.91**
Mean	**10.40**	**11.60**	**11.87**		**7.94**	**7.28**	**9.04**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	6.22	11.22	5.50	**7.65**	9.91	5.00	8.64	**7.85**	3.29	8.44	17.83	**9.85**
M_1	9.30	8.27	13.41	**10.33**	4.63	10.11	14.85	**9.86**	5.07	18.01	21.23	**14.77**
M_2	11.90	5.99	21.78	**13.22**	8.27	30.27	12.74	**17.09**	7.61	6.96	18.37	**10.98**
Mean	**9.14**	**8.49**	**13.56**		**7.60**	**15.13**	**12.08**		**5.32**	**11.14**	**19.14**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	8.10	5.77	4.77	**6.21**	5.48	6.16	10.08	**7.24**	4.63	4.89	8.38	**5.97**
M_1	7.89	6.75	7.80	**7.48**	9.97	7.39	7.15	**8.17**	9.09	13.11	14.40	**12.20**
M_2	8.16	10.13	12.09	**10.13**	7.44	5.46	6.41	**6.44**	7.93	9.86	9.09	**8.96**
Mean	**8.05**	**7.55**	**8.22**		**7.63**	**6.34**	**7.88**		**7.21**	**9.29**	**10.62**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	1.79	5.27	13, 2, 83	M* or N^{NS} or S^{NS}	0.73	2.16	4, 41, 26
Two factor effects	M × N, M × S, N × S	3.13	NS	90, 51, 27	M × N, M × S, N × S	1.27	NS	97, 7, 61
Three factor effects (3 FE)	MNS*, MN^2S^{NS}	5.39	15.81	3, 40	MNS, MN^2S	2.21	NS	95, 81
3 FE confounded	MNS^2, MN^2S^2	5.39	NS	11, 87	MNS^2, MN^2S^2	2.21	NS	30, 100
CV (%)	69.83				36.97			

4.2.71.3 Three factor interactions

Three factor interactions MNS and MNS_2 were significant at 3 and 11 % level of significance in first year. The highest N : Fe ratio was observed with cow dung + N_{45} + S_{15} (30.27). However, sulphur increased to 30 kg or no sulphur was given with cow dung the N : Fe ratio was reduced.

4.2.72 P : S ratio

4.2.72.1 Main effects

4.2.72.1.1 Effect of organic manures

The effect of organic manures was not significantly different in both the years (Table 4.76).

4.2.72.1.2 Effect of nitrogen

The effect of nitrogen doses averaged over organic manures and sulphur was significant at 14 % level of significance in the first year and highly significant in the second year. The highest P : S ratio was observed with no nitrogen (2.02) and decreased with N @ 45 kg ha^{-1} (1.30) and N @ 90 kg ha^{-1} (1.09). N_{45} and N_{90} were at par too.

4.2.72.1.3 Effect of sulphur

The effect of graded doses of sulphur was significant in the second year. S_0 registered the highest P : S ratio of 2.27. S_{15} and S_{30} were statistically at par and registered the similar P : S ratio of 1.07.

4.2.72.2 Two factor interaction effects

The two factor interactions such as organic manure × nitrogen, organic manure × sulphur and nitrogen × sulphur were significant at 10, 6 and 10 % level of

Table 4.76. Effect of manurial management on the P : S ratio of leaf at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	1.41	1.27	1.04	**1.24**	1.33	1.42	1.38	**1.38**
Straw application (M_1)	1.94	1.02	0.84	**1.27**	1.91	0.92	0.96	**1.27**
Cow dung (M_2)	0.86	1.15	0.89	**0.96**	2.81	1.56	0.93	**1.77**
Mean	**1.40**	**1.15**	**0.92**		**2.02**	**1.30**	**1.09**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	1.59	1.05	1.08	**1.24**	1.92	1.16	1.05	**1.38**
Straw application (M_1)	1.54	1.22	1.04	**1.27**	1.71	1.09	1.00	**1.27**
Cow dung (M_2)	1.11	0.86	0.93	**0.96**	3.17	0.97	1.16	**1.77**
Mean	**1.41**	**1.04**	**1.02**		**2.27**	**1.07**	**1.07**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.64	1.24	1.33	**1.40**	3.47	1.26	1.32	**2.02**
N_{45}	1.45	1.08	0.90	**1.15**	1.64	1.08	1.19	**1.30**
N_{90}	1.14	0.81	0.81	**0.92**	1.69	0.89	0.71	**1.09**
Mean	**1.41**	**1.04**	**1.02**		**2.27**	**1.07**	**1.07**	

Interactions between organic manures, nitrogen and sulphur

First Year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.58	1.66	1.51	**1.59**	1.10	1.20	0.86	**1.05**	1.55	0.95	0.74	**1.08**
M_1	2.53	1.29	0.81	**1.54**	1.79	0.96	0.92	**1.22**	1.51	0.82	0.79	**1.04**
M_2	0.81	1.39	1.11	**1.11**	0.83	1.09	0.65	**0.86**	0.94	0.95	0.90	**0.93**
Mean	**1.64**	**1.45**	**1.14**		**1.24**	**1.08**	**0.81**		**1.33**	**0.90**	**0.81**	
Second year												
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	1.47	1.62	2.66	**1.92**	1.06	1.46	0.97	**1.16**	1.46	1.17	0.52	**1.05**
M_1	2.81	1.21	1.10	**1.71**	1.45	0.75	1.07	**1.09**	1.48	0.81	0.72	**1.00**
M_2	6.15	2.08	1.29	**3.17**	1.27	1.03	0.62	**0.97**	1.02	1.58	0.89	**1.16**
Mean	**3.47**	**1.64**	**1.69**		**1.26**	**1.08**	**0.89**		**1.32**	**1.19**	**0.71**	

Comparison	First year				Second year			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	0.16	NS	38, 14, 20	M^{NS} or N* or S*	0.19	0.58	20, 1, 0
Two factor effects	M × N, M × S, N × S	0.28	NS	26, 96, 99	M × N, M × S, N × S	0.34	NS	10, 6, 10
Three factor effects (3 FE)	MNS, MN^2S	0.49	NS	86, 94	MNS*, MN^2S^{NS}	0.59	1.74	4, 28
3 FE confounded	MNS^2, MN^2S^2	0.49	NS	76, 40	MNS^2, MN^2S^2	0.59	NS	22, 12
CV (%)	54.08				60.67			

significance, respectively in the second year. M_2N_0 with 2.81, M_2S_0 with 3.17 and N_0S_0 with 3.47 registered the highest P : S ratio and the lowest ratio was registered by M_2N_{90} with 0.93, M_2S_{15} with 0.97 and $N_{90}S_{15}$ with 0.89.

4.2.72.3 Three factor interactions

Three factor interactions MNS, MN^2S, MNS^2 and MN^2S^2 were significant at 4, 28, 22 and 12 % level of significance in the second year. The highest P : S ratio of 6.15 was observed with cow dung + no sulphur + no nitrogen.

4.2.73 K : S ratio

4.2.73.1 Main effects

4.2.73.1.1 Effect of organic manures

The effect of organic manures on K : S ratio was significant at 25 and 19 % levels of significance in first and second years (Table 4.77). In the first year, straw incorporation registered the highest K : S ratio of 11.86 and in the second year the ratio was increased by cow dung application (15.72) over straw application (11.62).

4.2.73.1.2 Effect of nitrogen

The effect of graded doses of nitrogen was significant at 16 % level of significance in the first year and highly significant in the second year. N_{90} (9.27) was at par with N_{45} (11.98) and significantly superior over no nitrogen (18.50). In the first year also increasing levels of nitrogen decreased the K : S ratio and the corresponding values were 7.07, 8.46 and 12.43, respectively.

4.2.73.1.3 Effect of sulphur

The effect of graded doses of sulphur averaged over organic manures and nitrogen was significant in the second year. S_{15} (9.96) and S_{30} (9.00) were at par and decreased the K : S ratio compared to no sulphur application (20.78).

Table 4.77. Effect of manurial management on the K : S ratio of leaf at PI stage

Treatments	First Year				Second year			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	10.49	8.71	7.55	**8.92**	12.68	13.01	11.53	**12.41**
Straw application (M_1)	19.98	9.09	6.51	**11.86**	17.10	9.38	8.38	**11.62**
Cow dung (M_2)	6.83	7.57	7.14	**7.18**	25.71	13.55	7.89	**15.72**
Mean	**12.43**	**8.46**	**7.07**		**18.50**	**11.98**	**9.27**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	11.45	7.92	7.39	**8.92**	17.81	9.60	9.82	**12.41**
Straw application (M_1)	15.24	10.16	10.19	**11.86**	16.52	10.12	8.22	**11.62**
Cow dung (M_2)	8.59	6.77	6.19	**7.18**	28.02	10.15	8.97	**15.72**
Mean	**11.76**	**8.28**	**7.92**		**20.78**	**9.96**	**9.00**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	16.25	9.74	11.31	**12.43**	32.65	11.76	11.08	**18.50**
N_{45}	10.66	8.45	6.26	**8.46**	15.37	10.60	9.97	**11.98**
N_{90}	8.36	6.66	6.19	**7.07**	14.33	7.51	5.96	**9.27**
Mean	**11.76**	**8.28**	**7.92**		**20.78**	**9.96**	**9.00**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	11.96	12.64	9.74	**11.45**	8.49	7.87	7.40	**7.92**	11.02	5.63	5.52	**7.39**
M_1	29.97	10.54	5.21	**15.24**	13.56	9.68	7.23	**10.16**	16.41	7.05	7.10	**10.19**
M_2	6.81	8.82	10.14	**8.59**	7.17	7.79	5.35	**6.77**	6.51	6.11	5.95	**6.19**
Mean	**16.25**	**10.66**	**8.36**		**9.74**	**8.45**	**6.66**		**11.31**	**6.26**	**6.19**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	15.16	16.11	22.15	**17.81**	9.66	11.63	7.50	**9.60**	13.23	11.27	4.95	**9.82**
M_1	25.92	13.31	10.32	**16.52**	13.30	7.87	9.19	**10.12**	12.08	6.96	5.62	**8.22**
M_2	56.87	16.68	10.52	**28.02**	12.32	12.29	5.84	**10.15**	7.93	11.68	7.30	**8.97**
Mean	**32.65**	**15.37**	**14.33**		**11.76**	**10.60**	**7.51**		**11.08**	**9.97**	**5.96**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M or N or S	1.95	NS	25, 16, 33	M^{NS} or N* or S*	0.48	1.41	19, 0, 0
Two factor effects	M × N, M × S, N × S	3.38	NS	29, 99, 95	M × N, M × S, N × S	0.83	NS	7, 18, 6
Three factor effects (3 FE)	MNS, MN^2S	5.85	NS	73, 85	MNS*, MN^2S^{NS}	1.44	4.24	3, 12
3 FE confounded	MNS^2, MN^2S^2	5.85	NS	94, 48	MNS^2, MN^2S^2	1.44	NS	11, 9
CV (%)	80.50				54.01			

Table 4.78. Effect of manurial management on the S : Fe ratio of leaf at PI stage

Treatments	**First Year**				**Second year**			
Organic manure	Nitrogen (N)				Nitrogen (N)			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
No organics (M_0)	0.69	1.06	1.64	**1.13**	1.85	0.53	1.20	**1.19**
Straw application (M_1)	0.74	1.34	2.11	**1.40**	0.74	1.25	1.21	**1.07**
Cow dung (M_2)	1.59	1.62	2.68	**1.96**	0.78	0.71	1.26	**0.92**
Mean	**1.01**	**1.34**	**2.14**		**1.13**	**0.83**	**1.22**	
Organic manure	Sulphur (S)				Sulphur (S)			
	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
No organics (M_0)	0.83	1.21	1.36	**1.13**	0.60	2.03	0.94	**1.19**
Straw application (M_1)	1.33	1.16	1.71	**1.40**	0.66	0.94	1.59	**1.07**
Cow dung (M_2)	1.73	2.51	1.64	**1.96**	0.66	0.95	1.14	**0.92**
Mean	**1.30**	**1.63**	**1.57**		**0.64**	**1.31**	**1.23**	
Nitrogen (N)	S_0	S_{15}	S_{30}	**Mean**	S_0	S_{15}	S_{30}	**Mean**
N_0	1.39	1.05	0.58	**1.01**	0.50	2.03	0.84	**1.13**
N_{45}	0.98	1.63	1.41	**1.34**	0.59	0.82	1.08	**0.83**
N_{90}	1.53	2.19	2.71	**2.14**	0.82	1.08	1.76	**1.22**
Mean	**1.30**	**1.63**	**1.57**		**0.64**	**1.31**	**1.23**	

Interactions between organic manures, nitrogen and sulphur

	First Year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.57	1.26	0.66	**0.83**	1.18	0.73	1.72	**1.21**	0.32	1.20	2.55	**1.36**
M_1	1.34	0.88	1.78	**1.33**	0.39	1.23	1.85	**1.16**	0.50	1.91	2.71	**1.71**
M_2	2.26	0.79	2.15	**1.73**	1.59	2.94	3.00	**2.51**	0.93	1.13	2.88	**1.64**
Mean	**1.39**	**0.98**	**1.53**		**1.05**	**1.63**	**2.19**		**0.58**	**1.41**	**2.71**	
	Second year											
	S_0				S_{15}				S_{30}			
	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**	N_0	N_{45}	N_{90}	**Mean**
M_0	0.84	0.45	0.51	**0.60**	4.25	0.60	1.25	**2.03**	0.48	0.53	1.82	**0.94**
M_1	0.46	0.74	0.78	**0.66**	0.91	1.14	0.78	**0.94**	0.86	1.86	2.06	**1.59**
M_2	0.22	0.58	1.17	**0.66**	0.93	0.71	1.22	**0.95**	1.18	0.85	1.40	**1.14**
Mean	**0.50**	**0.59**	**0.82**		**2.03**	**0.82**	**1.08**		**0.84**	**1.08**	**1.76**	

Comparison	**First year**				**Second year**			
	Treatments	S.E	CD	PPS (%)	Treatments	S.E	CD	PPS (%)
Main effects	M^{NS} or N* or S^{NS}	0.23	0.68	6, 1, 58	M or N or S	0.25	NS	75, 53, 15
Two factor effects	M × N, M × S, N × S	0.40	NS	94, 50, 21	M × N, M × S, N × S	0.44	NS	32, 36, 28
Three factor effects (3 FE)	MNS, MN^2S	0.70	NS	33, 50	MNS, MN^2S	0.76	NS	26, 45
3 FE confounded	MNS^2, MN^2S^2	0.70	NS	72, 81	MNS^2, MN^2S^2	0.76	NS	58, 100
CV (%)	55.14				99.59			

4.2.73.2 Two factor interaction effects

Two factor interactions such as M × N, M × S and N × S were significant at 7, 18 and 6 % levels of significance, respectively in the second year. M_2N_0 with 25.71, M_2S_0 with 28.02 and N_0S_0 with 32.65 registered the highest K : S ratio.

4.2.73.3 Three factor interactions

Three factor interactions such as MNS at 3% level, MN^2S at 12 % level, MNS^2 with 11 % level and MN^2S^2 with 9 % level were significant in second year. Cow dung + no nitrogen + no sulphur (56.87) was highly significant and increased the K : S ratio over other treatments. Increasing levels of N or S reduced the K : S ratio in both the years.

4.2.74 S : Fe ratio

4.2.74.1 Main effects

4.2.74.1.1 Effect of organic manures

The effect of organic manures averaged over nitrogen and sulphur were significant at 6 % level of significance in the first year (Table 4.78). S : Fe ratio increased from 1.13 to 1.40 by straw incorporation and 1.96 by cow dung application.

4.2.74.1.2 Effect of nitrogen

The graded doses of nitrogen averaged over organic manures and sulphur was significant in the first year. A step wise increase in the S : Fe ratio was observed with N_0 (1.01), N_{45} (1.34) and N_{90} (2.14).

4.2.74.1.3 Effect of sulphur

The graded doses of sulphur averaged over organic manures and nitrogen was significant at 15 % level of significance in the second year. S_{15} registered the highest S : Fe ratio of 1.31.

Two factor and three factor interaction effects were not significant in both the years.

Discussion

V. Discussion

5.1 Mineralization of nitrogen and sulphur

The mineralization pattern of ammoniacal and nitrate nitrogen, and available sulphur during rice growth was studied in pot culture experiment. The treatments included factorial combinations of no organics, straw incorporation and cow dung application each at 10 t ha^{-1}, N at 0 and 90 kg ha^{-1} and S at 0 and 15 kg ha^{-1}. Rice was transplanted on the 10^{th} day after incorporation (DAI) of organics, N at 11^{th}, 31^{th} and 51^{st} in 3 equal splits and S at 11^{th} DAI were applied. The results obtained are discussed here.

5.1.1 Mineralization of nitrogen

The mineralization of NH_4^+ - N from the soil (Table 4.1 and Fig. 2) during rice growth varied between 58.3 to 46.6 kg ha^{-1} depending on physical and chemical conditions prevailed in the soil and N uptake by crop at its different stages. The ups and downs in the NH_4^+ - N with soil + N_{90} treatment (M_0N_1) during 20 – 60 days period was due to N split applications received on 11^{th}, 31^{st} and 51^{st} DAI coupled with simultaneous N uptake by crop and possible losses due to volatilization of NH_3^- and nitrification. Mikkelsen (1987) showed that higher concentration of NH_4 – N in rice flood water increased the ammonia volatilization losses. Low land rice crop is conducive to N losses through ammonia volatilization, nitrification, denitrification, leaching and run off (Singh *et al.*, 1998).

The mineralization pattern of straw and cow dung either in the absence (M_1N_0 & M_2N_0) or in the presence of N (M_1N_1 & M_2N_1) were entirely different as seen from the Table 4.1. On 10^{th} DAI, the NH_4^+ accumulation ranged from 44.6 to 45.3 kg ha^{-1} in straw incorporation, while it was changed to 74.2 to 79.9 kg ha^{-1} in cow dung application. A comparison of these with soil alone treatments brought out the extent of immobilization happened upto 35 DAI in case of straw incorporation and fast decomposition of mineralization in case of cow dung. This

Fig. 2. Ammoniacal N content as influenced by organic manure sources

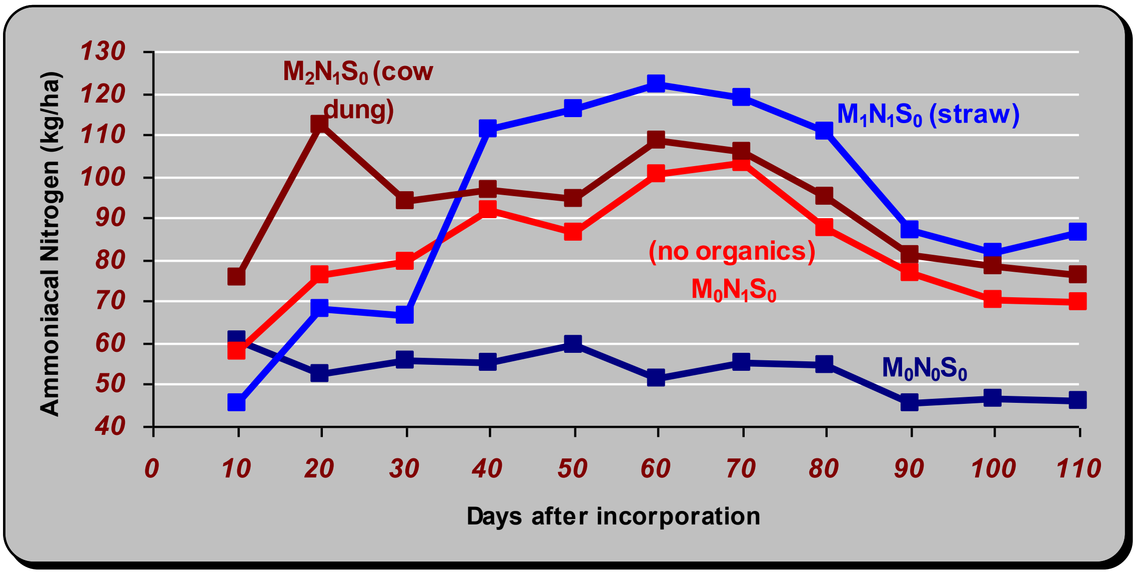
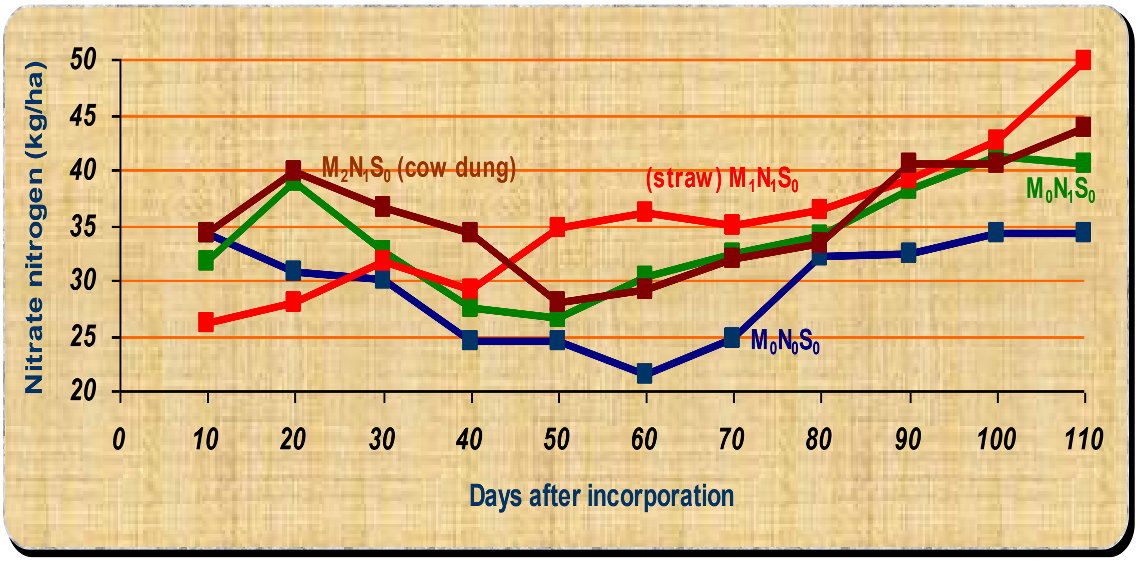


Fig. 3. Nitrate N content as influenced by organic manure sources



immobilization could negatively affect the growth of rice as evidenced by the reduced height, tiller number and dry matter production of plants during vegetative stage observed in the field experiment (Section 4.2.1, 4.2.4 & 4.2.10). Azam *et al*. (1991) reported that the depression of nitrogen in the initial stages of crop growth has been mitigated by adding mineral nitrogen, however the first split application of nitrogen at 30 kg ha^{-1} on 11^{th} DAI could not compensate for the immobilization happened in the straw incorporated treatments as observed from the quantity and NH_4^+ in M_1N_1 and M_1N_2 treatments during the 10 – 30 DAI. The second and the third split applications of N could very well supplement the nitrogen to the one mineralized from straw and maintain highest level of NH_4^+ - N from 40^{th} day till the end of the crop. In general organic materials with a C:N ratio >30 will cause immobilization of soil or fertilizer N and a ratio of 20 or less will result in net mineralization (Jenkinson, 1984). Crop residue is a poor quality source of nitrogen and the incorporation of crop residue with high C:N ratio into either aerobic or submerged soil, typically results in microbial nitrogen immobilization and a temporary decrease in plant available nitrogen and sulphur (Singh *et al*., 2005).

The NH_4^+ mineralization from cow dung was fast and reached the peak on 20 DAI either with or without added fertilizer nitrogen. When no fertilizer N was applied, the mineralized N was noticeably lesser in cow dung incorporated plot than straw incorporated ones from 50 DAI onwards. In the graph (Fig. 4), the area in between the two lines showing mineralization in straw + applied N and straw – applied N represents greater N mineralization in the presence of applied N. Such an added N interaction effect on mineralization of wide C:N ratio was reported by Samra *et al*. (2003).

Addition of sulphur fertilizer on 11^{th} day consistently resulted in higher NH_4^+ accumulation during the entire rice growth period in the soil alone, soil + straw or soil + cow dung treatment, with significant variations on 60^{th} and 70^{th} DAI. Adequate sulphur availability and balanced soil N:S ratio can enhance mineralization of nutrients from soil (Prasanth, 2002).

Nitrate content to the extent of 22.8 to 36.8 kg ha^{-1} was observed on soil during rice growth which increased to 26.3 to 41.3 kg ha^{-1} when supplemented with fertilizer nitrogen mainly due to nitrification of the mineralized NH_4 (Table 4.2 and Fig. 3). The avoidance of a continuously flooded situation in order to facilitate straw decomposition favoured nitrification process in the soil. A comparison of the NO_3 accumulation till 30 DAI among organics showed that NO_3 is also immobilized during decomposition of straw. From 30 DAI onwards, the differences in NO_3 accumulation among different treatments were considerably less, indicating similar pattern of nitrification and fate of formed nitrate. Sulphur application was not found to affect the nitrification of mineralized NH_4^+.

5.1.2 Apparent nitrogen mineralization

Apparent N mineralization from soil incorporated straw and cow dung during rice growth was quantified by difference method. The comparison of mineralized nitrogen ($NH_4^+ + NO_3^-$) from straw and cow dung in the presence and absence of applied N fertilizer is presented in the Fig. 4. The straw incorporated treatments both in the presence or absence of nitrogen showed a negative value during the initial period (10 to 30 DAI) which can be attributed to the nitrogen immobilization by the soil microbes involved in the decomposition. Appreciable quantities of mineralized nitrogen from straw were observed only from 40 days due to its wide C: N ratio of > 80, which reached its peak during 60 DAI. In the case of cow dung, the immobilization phase was absent both in the presence or absence of nitrogen and the peak mineralization reached on 20^{th} day. An examination of the effect of applied nitrogen on straw mineralization showed noticeably enhanced nitrogen mineralization from cow dung during 10 – 20 days which drastically reduced. After 20^{th} day the nitrogen content was drastically reduced with the cow dung + nitrogen treatment and it was comparable with the mineralization in the absence of nitrogen. After the split application of nitrogen on 31^{st} day the mineralization was fast in the straw and it was higher compared to cow dung in the presence of N. Another split application of nitrogen on 51^{st} day

Fig. 4. Apparent nitrogen mineralization from soil incorporated straw and cow dung during rice growth

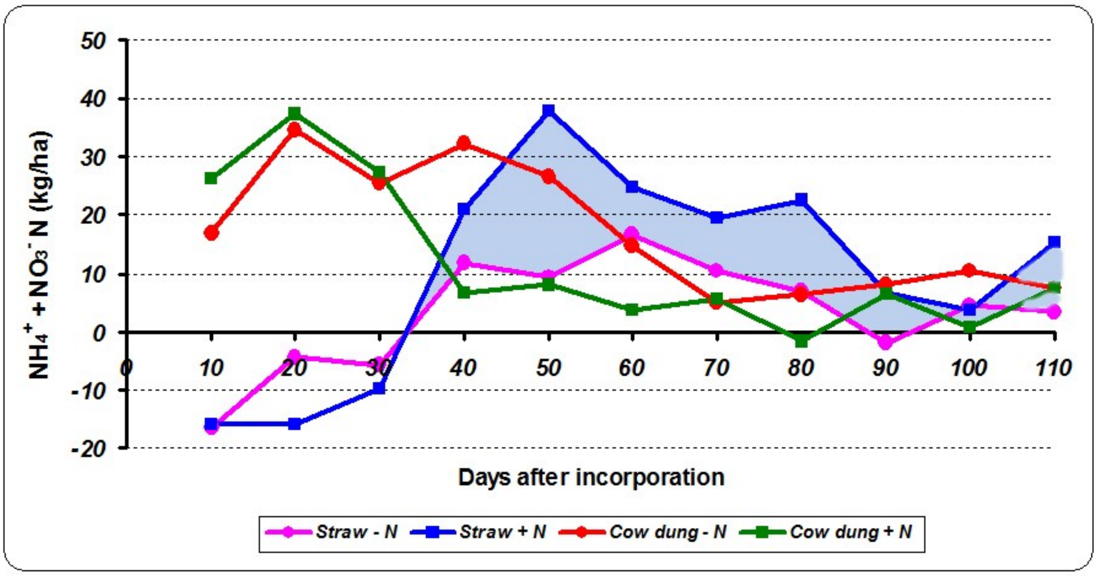
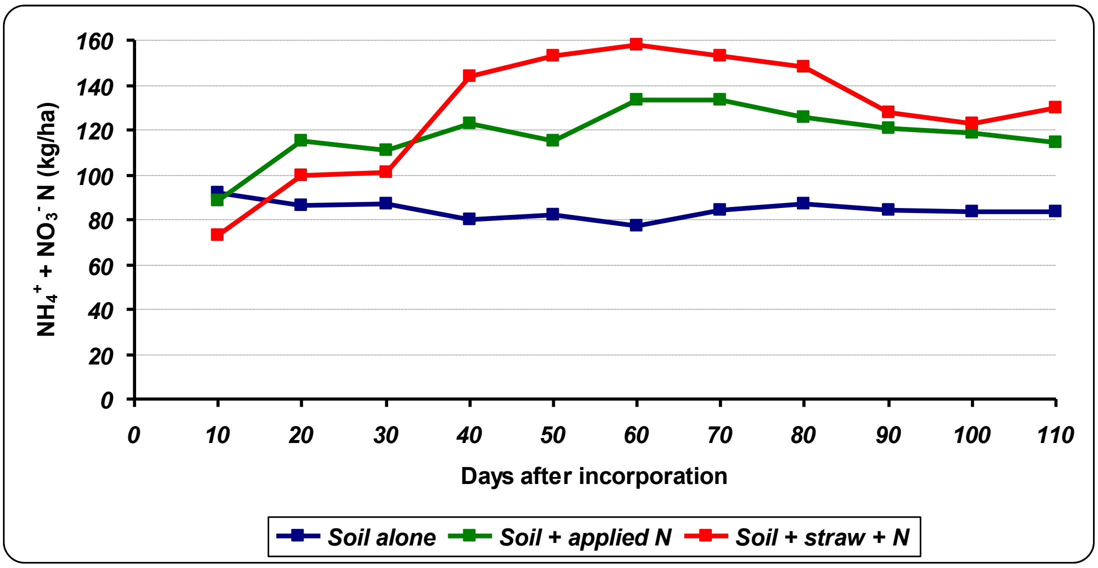


Fig. 5. Apparent N ($NH_4^+ + NO_3^-$) accumulation in soil as influenced by straw incorporation and nitrogen application during rice growth



still hastened the mineralization of straw and over taken the cow dung and attained the maximum on 60th day. Since then, higher mineralized nitrogen was maintained till the end in the straw than cow dung application.

An analysis of the apparent nitrogen accumulation in soil as depicted in Fig. 5 & 6 brings out certain important observations. The contribution of nitrogen from soil during crop growth was substantial and it varied between 92 to 83 kg ha^{-1} through out the growth period. 90 kg N application at three equal splits increased this quantity even to 133 kg ha^{-1} on 60th day and this level was more or less maintained during 40 – 80 days of rice growth. The cow dung application increased the nitrogen accumulation to a peak of 152 kg on 20th day (Fig. 5) and decreased fast without much contribution from 40th day. But in the case of straw incorporation (Fig. 5) it maintained higher mineral nitrogen content than soil alone or soil + applied N treatments from 30 to 110 days.

In Fig. 7, the two lines representing N accumulation in the soil + straw + N and soil + cow dung + N, respectively in Fig. 5 and 6 are brought together. The portion of the lines showing N accumulation till 30th day in case of cow dung and that during 30 to 110th days in the case of straw incorporation are combined together, it will represent a continuous high mineral N availability throughout the growth period of rice. This will also explain the reason for higher growth and dry matter production of rice during tillering in cow dung + N_{90} treatment and enhanced growth and productivity during PI to harvest stage in straw incorporation + N_{90} treatments (Section 4.2.30 & 4.2.35). Avinmelech (1986) who reported that a fast decomposition leads to a high rate of nutrient release only when the organic substrate is rich in nutrient (low C:N ratios). It was also observed that from the materials having high C:N and C:P ratios, nutrients will first be immobilized by growing microbial biomass and then released from the manures to the soil. If the difference between cow dung and straw incorporation treatments in the case of mineral N accumulation till 40th day (shaded portion) is compensated either by application of cow dung or by additional N dose together with straw incorporation, the present yield level obtained in the straw incorporated

Fig. 6. Apparent N ($NH_4^+ + NO_3^-$) accumulation in soil as influenced by cow dung application and nitrogen application during rice growth

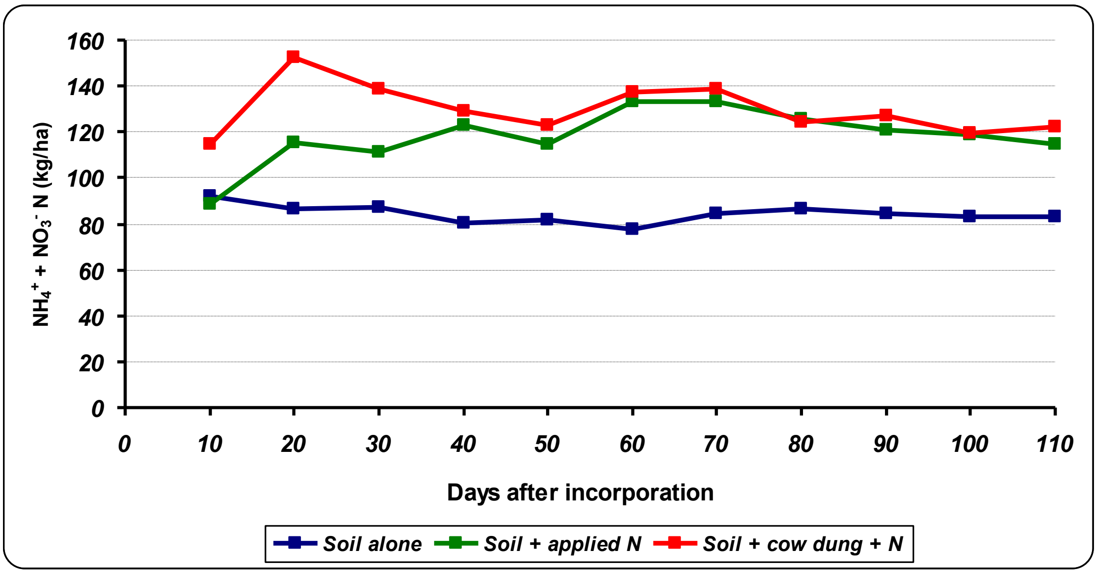
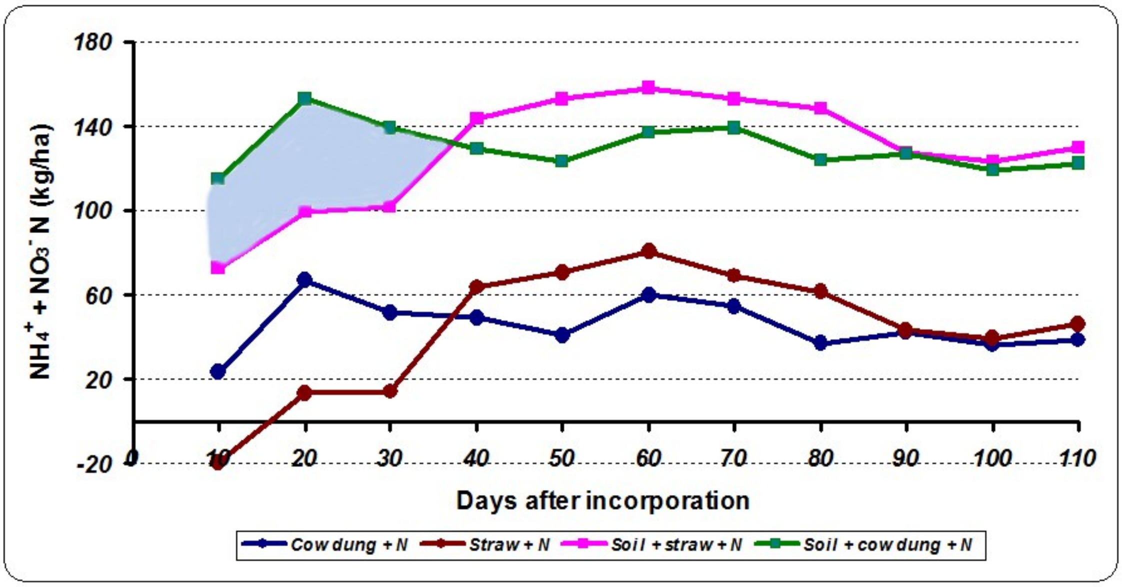


Fig. 7. Apparent N ($NH_4^+ + NO_3^-$) accumulation in soil during rice growth



treatments could be further improved. Surekha (2007) has reported proper mixing of wide and narrow C:N ratios with low and high lignin content regulates the release of nutrients from these sources and make them available for longer periods.

Straw takes more time to decompose due to the wide variation in the C:N ratio of incorporated straw. When straw with a wide C:N ratio are incorporated, there is an excess C available and micro organisms rapidly oxidize it and multiply and use all released mineral nitrogen. The immobilization of mineralized N or added fertilizer N is reported by Prasad (2007a). When cereal straw is incorporated it is recommended to apply 15 – 20 kg ha^{-1} additional fertilizer N (Samra *et al*., 2003). On 20^{th} day soil alone reduced the nitrogen accumulation compared to soil + applied N and soil + straw + N treatments and similar trend lasted till the end of the crop. But the soil + applied N registered the higher accumulation on 20^{th} day compared to soil + straw + applied nitrogen.

5.2.1 Minerlization of sulphur

The mineralization pattern of sulphur (Table 4.4 and Fig. 8) was also similar to that of NH_4^+ - N and NO_3 – N. During 1^{st} to 10^{th} day the available sulphur was similar in all the treatments. Till 40^{th} day the available sulphur was more in cow dung applied treatments and then decreased, while in the straw incorporated treatments, higher concentration of available sulphur lasted till 110^{th} day. The data revealed that at active growth period of the crop, the availability of sulphur was more in the straw incorporated treatments. The highest available sulphur content was observed on 40^{th} day in the cow dung applied treatments and it was 20.45 % higher than straw incorporated ones. With the straw incorporated treatment, the highest content was observed at 90^{th} day and it was 42.86 % higher than cow dung applied ones. The available sulphur content in soil during rice growth varied from 4.2 to 17.0 kg ha^{-1} in the straw incorporated ones, whereas in the cow dung applied treatments it varied from 4.4 to 15.9 kg ha^{-1} only.

Fig. 8. Available S content in soil as influenced by organic manure sources

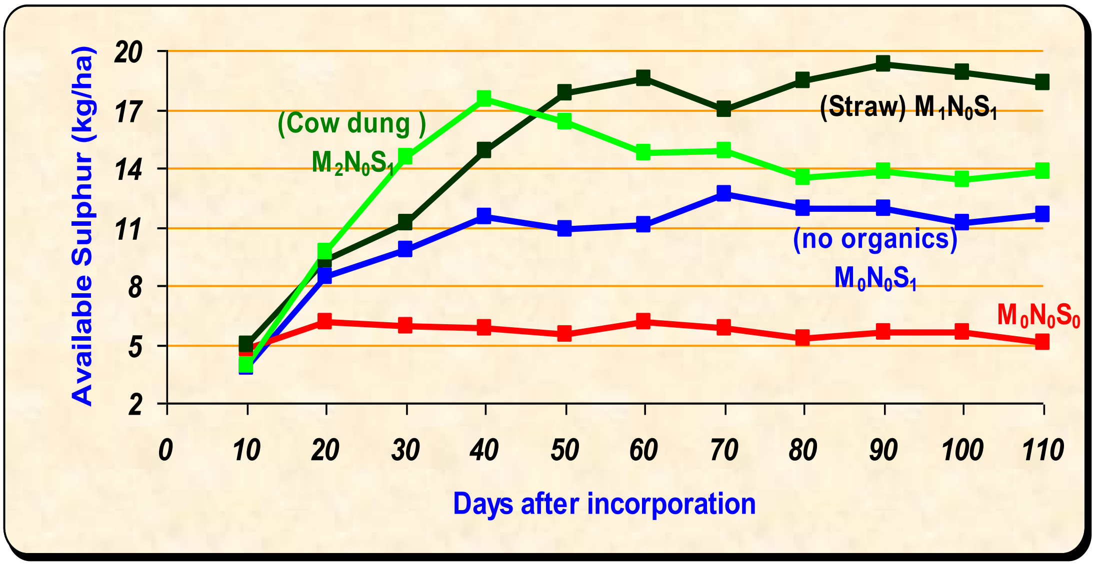
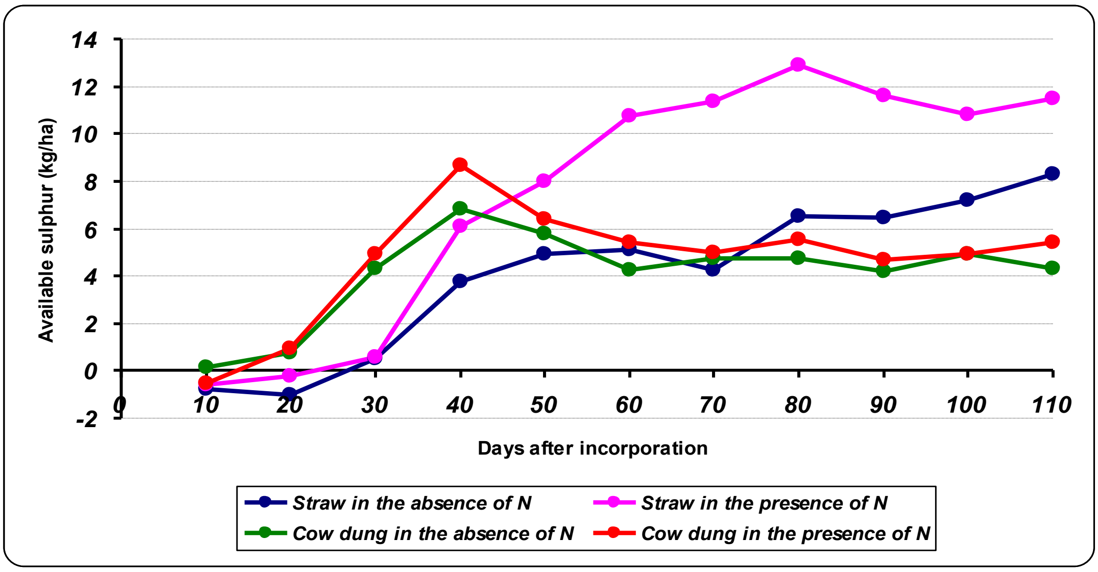


Fig. 9. Apparent sulphur mineralization from soil incorporated straw and cow dung in the absence and presence of applied N during rice growth



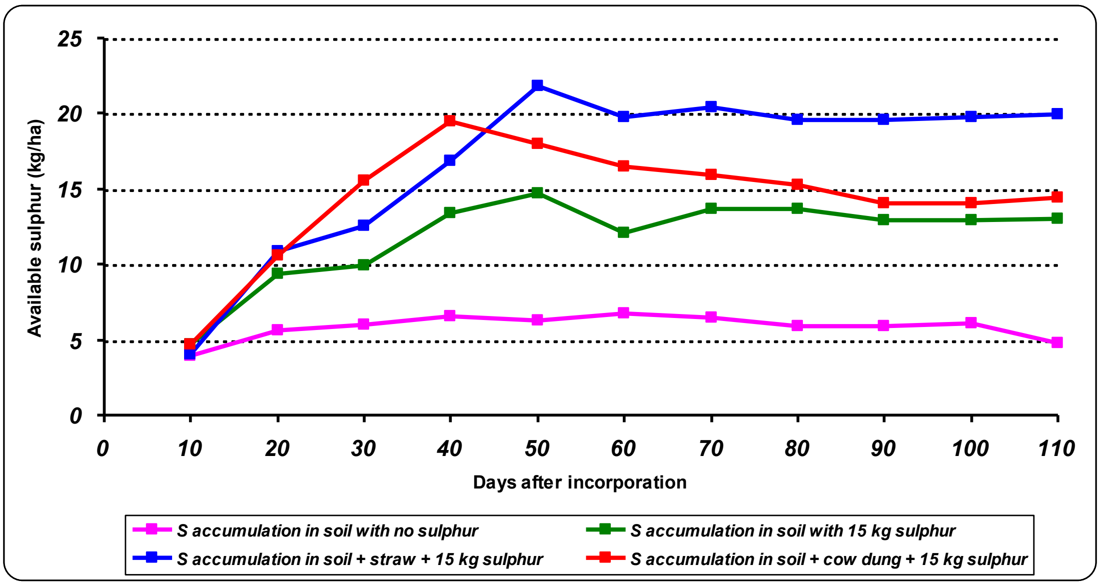
Apparent sulphur mineralization from soil incorporated straw and cow dung in the absence and presence of applied N was computed by difference method (Fig. 9). As in the case of nitrogen mineralization, straw incorporation either with or without external nitrogen application resulted in negative values which indicated the possibility of sulphur immobilization. Immobilization of sulphur was observed from cow dung also for a short period of 5 days but only in the presence of applied fertilizer nitrogen. Sulphur mineralization from cow dung reached its peak on 40^{th} day, reduced by 60 days and it went down even lesser than soil sulphur level by 55^{th} day then gradually maintained the same as that of soil alone treatment. S mineralization from straw with or without added nitrogen was slow and similar till 40^{th} DAI, which took a different pattern later. In the presence of nitrogen applied on 31^{st} and 51^{st} day, the mineral sulphur reached upto 13 kg ha^{-1} on 80^{th} day which decreased later. But in the absence of nitrogen, the mineralized S content was less with only 6.4 kg on 80^{th} day. Thereafter it showed a small linear increase (Douli and Pradhan, 2007).

The available sulphur content in the soil ranged from 4.2 to 6.4 kg ha^{-1} (Table 4.4 & Fig. 10). The quantity reached upto 19.5 kg ha^{-1} during 40^{th} day in cow dung incorporated plot, then it reduced and maintained a medium level. Sulphur application at 15 kg ha^{-1} maintained average sulphur level between 10 and 15 kg ha^{-1}. Soil incorporated with straw maintained S level at about 20 kg ha^{-1} from 40 to 110 days. Choudhari *et al*. (2002) suggested that the application of plant residues enhanced S content of soil.

5.2 Effect of treatments on plant growth and related characters

A perusal of the data on the plant height at tillering, PI and harvest stages (Tables 4.5, 4.6 and 4.7) shows significant effect at several instances due to organic manure addition. The lowest plant height was observed in the no organic manure applied treatments, irrespective of the stages. Among the straw incorporated and cow dung applied treatments, differential growth in terms of plant height at different growth stages was observed. Lower plant height was

Fig. 10. Available sulphur content in cow dung and straw incorporated soil with sulphur @ 15 kg during rice growth



observed in straw incorporated treatments at vegetative stage was increased at PI stage and reached at a significantly increased height by harvest stage than cow dung applied ones.

The effects of graded doses of nitrogen on plant height at all the stages were more prominent than the organic manure sources. A similar response to nitrogen was observed for graded doses of sulphur too, irrespective of stages with regard to the height of plants.

Organic manures, though considered as nutrient source, may not fully meet the plant demand for major and secondary nutrients at active growth stage. However, their complementary role in enhancing soil productivity due to improvement in soil physical and biological properties is well established. This might be the reason for significant plant height differences as observed with external application of nitrogen and sulphur, were not observed in the case of either straw incorporation or cow dung application.

Similar to the plant height, straw incorporation reduced the tiller production at vegetative stage to the extent of significance, in the second year compared to cow dung application. A similar difference was noticed during PI stage also, but not significant (Table 4.5, 4.6, 4.7, 4.8 & 4.9 and Fig. 11 & 12). But in the case of nitrogen and sulphur, as observed in the case of plant height, a step wise increase was seen during both vegetative and PI stage.

The enhanced growth reflected by the increased height and tiller number is a direct effect of absorption of nitrogen and sulphur supplied either through straw or cow dung or directly through the fertilizers. Other nutrients mineralized from incorporated straw or applied cow dung or mineralized from soil as modified by the decomposing straw or cow dung also have favoured the growth of plant.

The role of nitrogen as a component of chlorophyll, protoplasm, amino acids and enzymes etc. in plant is well established and it promotes rapid growth of rice by increased height and tiller numbers. A linear response to nitrogen given at

Fig. 11. Effect of organic manures on plant height

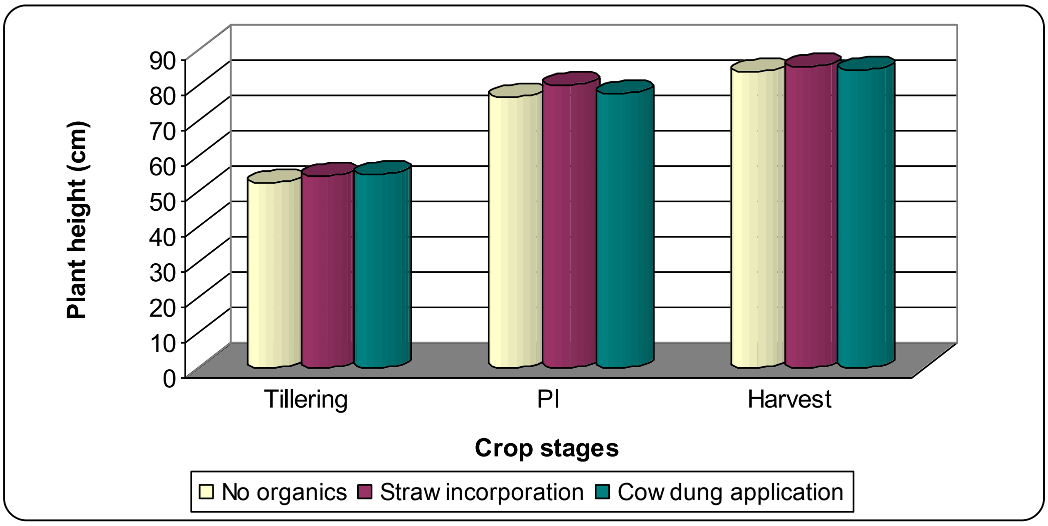
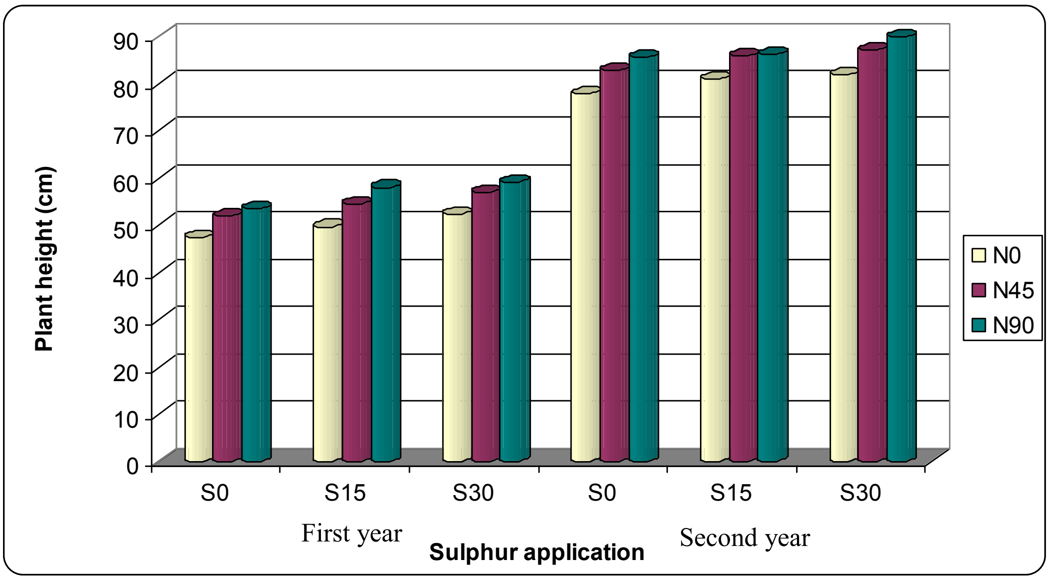


Fig.12. Interactive effects of nitrogen and sulphur on the plant height



120 kg ha^{-1} was reported with regard to rice tiller number for various varieties (De Datta, 1981).

Sulphur as a constituent of the amino acids, cystiene, cystine and methionine and the plant hormones thiamine and biotin and as an important factor in the functioning of many plant enzymes, enzyme activations and oxidation reduction reactions can increase plant height and tiller umber (De Datta, 1981). The soil of the experimental field was having only 8.2 kg of available sulphur/ha which is rated as low sulphur soil and a good response to the applied or mineralized sulphur could be expected.

The reduced plant height and tiller number at vegetative stage in straw incorporated plots might be due to low availability of nitrogen during the initial phase after incorporation of straw, which is due to the immobilization of nitrogen. The crop residue containing 0.5 to 0.6 % nitrogen decreases inorganic nitrogen in the soil with an increased ratio of residues added to soil (Ogawa and Dei, 1965) and during decomposition of straw, it immobilized nitrogen both from soil and added fertilizers nitrogen (Yoneyama and Yoshida, 1977). In this experiment too the nitrogen concentration of straw was 0.6 % and it was incorporated at 10 t ha^{-1}. The results of the mineralization studies (Section 5.1.1) has clearly brought out the negative balance of nitrogen is observed due to immobilization which extended upto 40 days after incorporation of straw (Beena and Mercy,1999). Once sufficient nitrogen is not made available to the plant, it directly affects the root growth which in turn affect absorption of all the nutrients and the overall growth.

The dry matter production at tillering and PI (Table 4.14, 4.15) as influenced by organic manures, nitrogen or sulphur, just followed the trend seen in the case of plant height and tiller number, since it is the product of enhanced growth in terms of height and tillers.

5.2.1 Percentage tiller decline

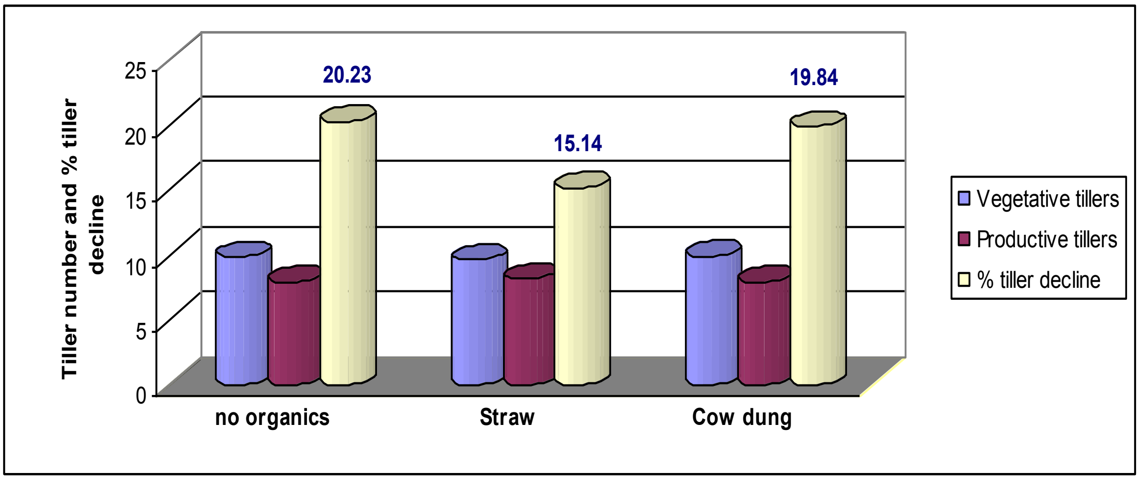
The vegetative growth characters observed in the cow dung incorporated treatments were significantly higher than in the straw incorporated ones, which was attributed to a favourable nutritional environment in the rhizosphere due to greater mineralized nutrients in the former complemented by external N and S application. Towards PI and subsequent growth period a similar or more favourable environment was produced in the straw incorporated treatment also, which resulted in a take over on cow dung application in growth and yield attributing characters. This is more evident in the case of the productive tillers bearing panicles. The ratio of conversion of vegetative tillers, to productive tillers is represented as tiller decline. The data on the tiller decline as influenced by the organics and N and S fertilizer is presented in table 4.34 and the tiller decline is depicted in Fig. 13. The tiller decline in the straw incorporated treatments was considerably lower with 31.04 % in the first year and 60.79 % in the second year than cow dung applied ones. A similar effect was found for increasing sulphur doses also in the first year, however it was not consistent. Also it was indicated that high N doses increased the tiller decline. The production of more vegetative tillers need not be complementary to enhanced rice yields. The availability and absorption of nutrients particularly N and S is known to favour tiller production (Tisdale *et al*., 1993). However an unbalanced accumulation of these elements in plant may result in an increased tiller decline and consequently low number of panicle bearing tillers and reduced yield (Vallalkannan, 2004). Higher rate of tiller decline has been reported to be to exclude excess of Fe in the plant though the plant is found to shed other nutrients also in this process (Musthafa, 1995). Several reports reveals that impropotional concentration of Fe and Mn reduce the rice yield in lateritic alluvium (Mathew, 2002 Bridigit, 1999 and Vallalkannan, 2004).

5.3 Elemental composition

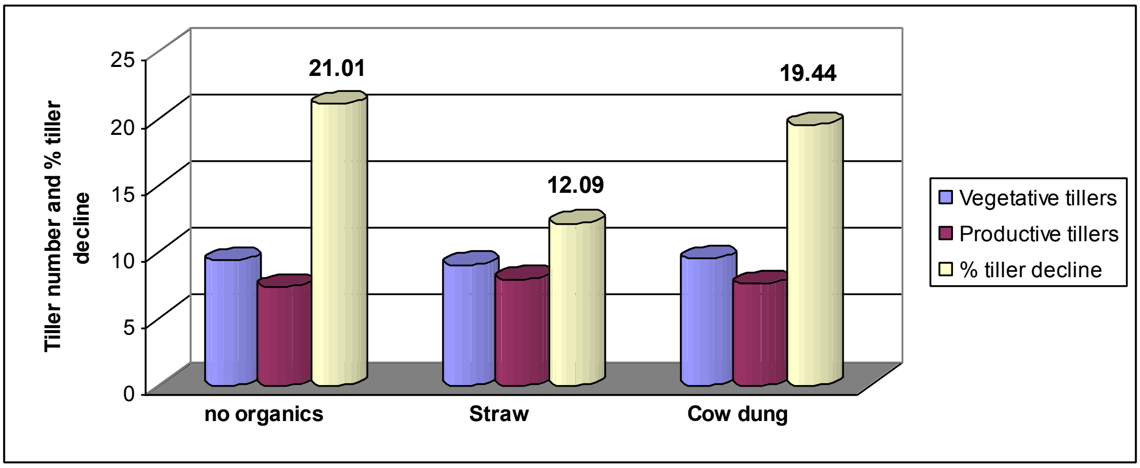
The optimum nitrogen concentration specific to different stages is very much required for maintaining higher growth rate and proper development of rice. The N contents observed both at tillering and PI stage were below the critical limits, in the case of no organics and no nitrogen treatments. Under tropical

Fig. 13. Effect of organic manures on the tiller number and per cent tiller decline

a. First year



b. Second year



conditions a total N accumulation of 144 kg ha^{-1}estimated by multiplying the plant N and dry matter production at vegetative and PI stage is required to produce an yield of 10 t ha^{-1} (Sheehy *et al.*, 1998). The critical N accumulation thus calculated in the present investigation was higher in most cases for the treatments which received straw incorporation or cow dung application in combination with N_{90}. However, the yield of 10 t ha^{-1} were not attained under any of the treatment combinations, probably due to an unfavourable nutritional environment present in laterite alluvium. At the vegetative stage (Table 4.17) the cow dung application resulted in a significantly higher N in both the years, however at PI stage the same resulted out of straw incorporation were significantly higher. The nitrogen availability in the soil amended with straw or cow dung were different in the pre tillering and pre PI stage. The uptake and utilization also probably followed the pattern of N release and hence the difference. There was a spectacular difference in the stage wise nitrogen contents also, primarily due to the nitrogen dilution happening with in the plant during growth. The internal cycling of nitrogen from aging to young developing tissues may cause this, as aging root system may play a part in the decline. The rate of demand for nitrogen by the panicle exceeds the rate of uptake which highlights the importance of having a larger reservoir of nitrogen in vegetative tissues. This ensures that the N demand of the panicle can be met without undue loss of photosynthetic activity (Sheehy *et al.*, 1998).

Sulphur application significantly increased the plant nitrogen content. At tillering both the levels (S_{15} & S_{30}) behaved similarly, but at PI stage the effect of S_{30} was pronounced indicating the long term availability and utilization. The complementary role of nitrogen and sulphur on plant growth is well established. Both are structural elements. N being a constituent of all amino acids, hormones, enzymes and enzymes activation and sulphur a component of amino acids, cystiene, cystine and methionine and the plant hormones - thiamine and biotin and many enzymes, they are complementary and owns a specific N:S ratio. The presence of either N or S in optimum quantity enhances content, uptake and efficiency of other (John *et al.*, 2006).

The cow dung application increased the plant phosphorus content than straw incorporation during tillering (Table 4.19), but this difference was levelled off during PI stage. P is taken up in large quantity during initial stages and P uptake in the initial stages was high due to more availability of P. The content later decreased due to cessation of P mineralization in soil and P dilution with in the plant. The slow P mineralization and simultaneous uptake can be attributed to higher P content at PI stage in the straw incorporated treatment. Nitrogen and sulphur application did not significantly influence the P concentration, however the increasing trend might be due to the enhanced uptake due to N and S favoured plant root growth (Singh *et al*., 1997). In the case of plant K concentration a very similar trend as that of P was observed.

The S content both at tillering and PI stage were increased due to external application of S, but the cow dung application did not bring any improvement in S content compared to no organic manures, possibly due to very low S content in cow dung. However incorporation of straw improved the S content. External application of N also caused a stepwise increase in plant S content. The complementary effect of N and S towards increasing the plant height was already discussed.

The Ca contents in the plant was not influenced by organic manure sources or N or S application in general, but the plant Mg content at tillering was significantly increased by sulphur application. The same at PI stage was significantly increased by straw incorporation and cow dung application, and graded doses of N and S application. The plant Mg content, mostly governed by the requirement as in the case of any nutrient is almost double than Ca and the Mg requirement is continuous due to the continuing synthesis of chlorophyll. The Mg mineralized from straw available from cow dung may be taken up in higher quantities, where the growth of plants is enhanced by adequate N and S availability (Kobayashi *et al*., 2005).

The plant Fe content was 2 - 3 times higher in the PI stage than tillering probably resulting in continuous uptake. The organic matter additions either through straw or cow dung was found to lower the uptake significantly (Brancher *et al*., 1996) at both of these stages. Increasing N rates also decreased Fe content probably due to dilution effect caused by higher dry matter production. However, application of sulphur did not significantly influence the plant Fe content. It was also noticeable that under higher sulphur rate, higher N rates reduced Fe concentration, indicating the need for sulphur application with sufficient N supply (Sindhu, 2003). The Mn content was increased by organic manures and the content reduced at PI. The organic acids produced during decomposition of straw and cow dung, may increase Fe and Mn solubility and hence higher uptake of this elements. But by PI stage, this condition may not prevail and the concentration can be decreased by dilution with in the plant.

5.3.1 Chlorophyll content

A perusal of data on chlorophyll 'a' and 'b' contents of rice leaves at tillering and PI stage (Table 4.10, 4.11, 4.12 & 4.13) shows that incorporation of organics, either straw or cow dung enhanced the chlorophyll content irrespective of stages. However, cow dung application has resulted in higher chlorophyll content than straw incorporation. The increasing doses of N and S also increased the chlorophyll contents. A close examination of the ratio of chlorophyll 'a' to b'revealed that the ratio increases with sulphur doses but decreases with nitrogen doses and application of organics. A decrease in the ratio would mean that the chlorophyll 'b' increase is not proportional with the increase in chlorophyll 'a'. It also indicates that chlorophyll 'b' production efficiency is more than chlorophyll 'a'. As chlorophyll 'a' is the precursor of chlorophyll 'b', the decline in the conversion of chlorophyll 'a' to 'b' result in lower vegetative growth. A higher chlorophyll 'a' content together with constant high rate of production and content of chlorophyll 'b' will ultimately lead to high productivity.

Chlorophyll 'b' is known to be the acceptor of radiant energy which is subsequently funnelled to the real sites of synthesis. Higher photosynthesis efficiency is observed under the treatments where both chlorophyll 'a' and 'b' synthesis were active. Mayers and French (1960) reported that photosynthetic efficiency will be maximum only in the two pigment system process. A deficiency in one will bring about more than proportionate reduction in assimilation rate. Bridgit and Potty (1992) attributed the causes of improportional reduction in chlorophyll ‘b’ to inhibition on concerned reactions mediated by several enzymes and influenced by elemental concentrations in plant. Though the chlorophyll ‘a’ production increasing with S doses the increasing ratio of chlorophyll ‘a’ to ‘b’ with increasing S doses may result in partial lowering of productivity. Singh (1970) has reported increased chlorophyll content due to sulphur nutrition.

5.4 Yield and yield attributes

A perusal of the data in table 4.37 brings out spectacular response to organic manures either as straw or cow dung and applied fertilizers N and S. The effect of organics, N and S and its combinations on grain yield improvement is depicted in Fig. 14, 15, 16 & 17. The mean yield increase averaged over two years was 4.8 and 3.2 % for straw and cow dung application. N at 90 kg ha^{-1} resulted in a 25 % mean increase in the yield and S at 30 kg ha^{-1} increased the mean yield by 26.6 %. The highest dry matter production (Table 4.38 & 4.39) was observed with the treatment straw incorporation + N_{90} + S_{30} partitioned between 7085 kg ha^{-1} grain and 8194 kg ha^{-1} straw in the first year and 6925 kg grain and 9198 kg straw in the second year. The grain yield in the cow dung + N_{90} + S_{30} was higher than straw incorporation in the second year due to a higher harvest index associated with the treatment. The significant superiority manifested in the tiller count, height and dry matter production at vegetative and PI stage of their treatments (Section 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.2.5, 4.2.10 & 4.2.11) pointed out that high yield is due to a higher metabolic activity manifested through better morphological development throughout the growth of the crop. The increase in yield could be due to its indirect role played during vegetative phase. It has a key role in formation of chlorophyll, activation of enzymes, synthesis of amino acids and other assimilates.

Fig. 14. Effect of organic manures, N & S on grain yield

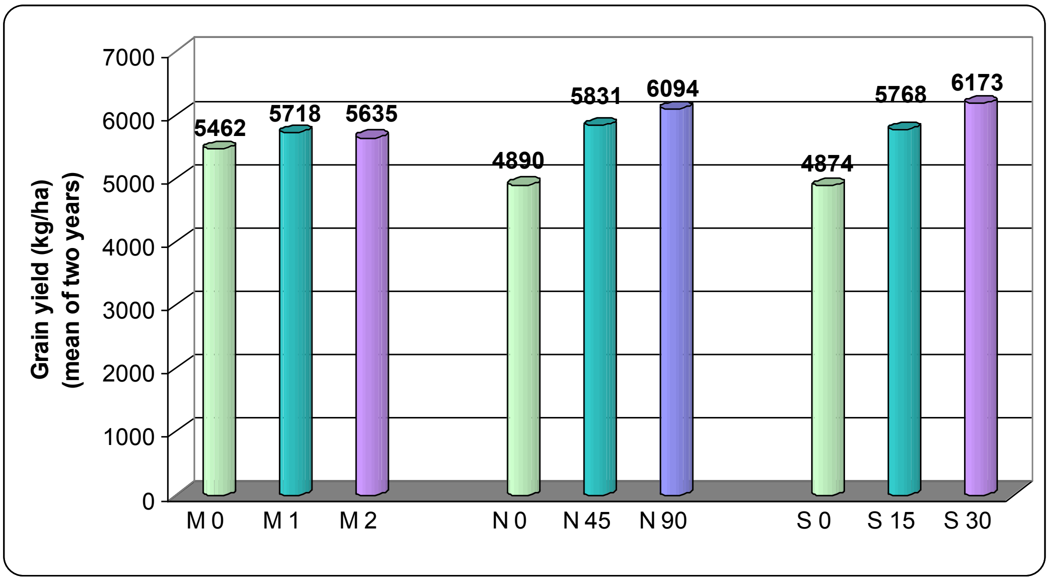


Fig. 15. Effect of graded doses of N & S without organic manure application on grain yield

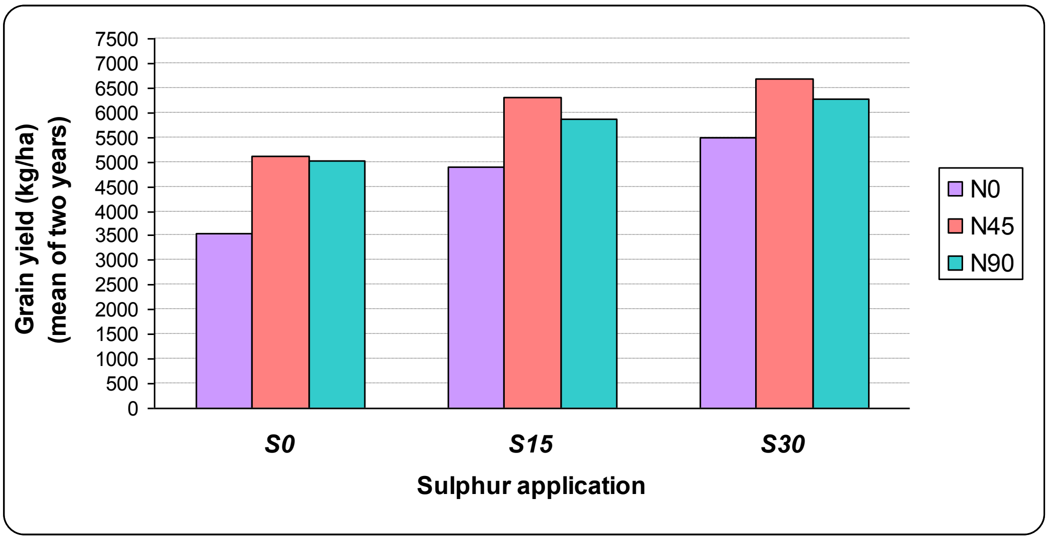


Fig. 16. Effect of graded doses of N & S with straw incorporation on grain yield

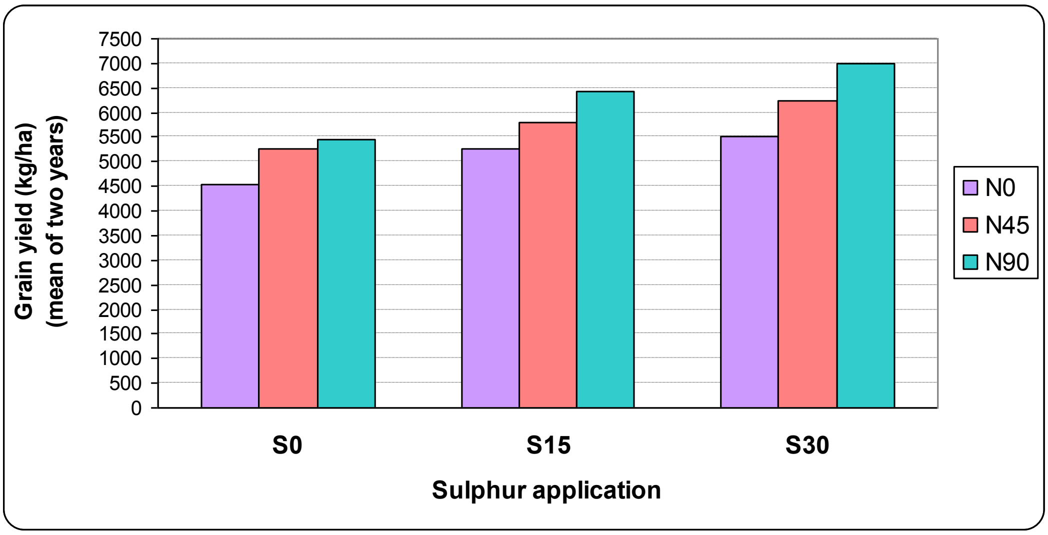
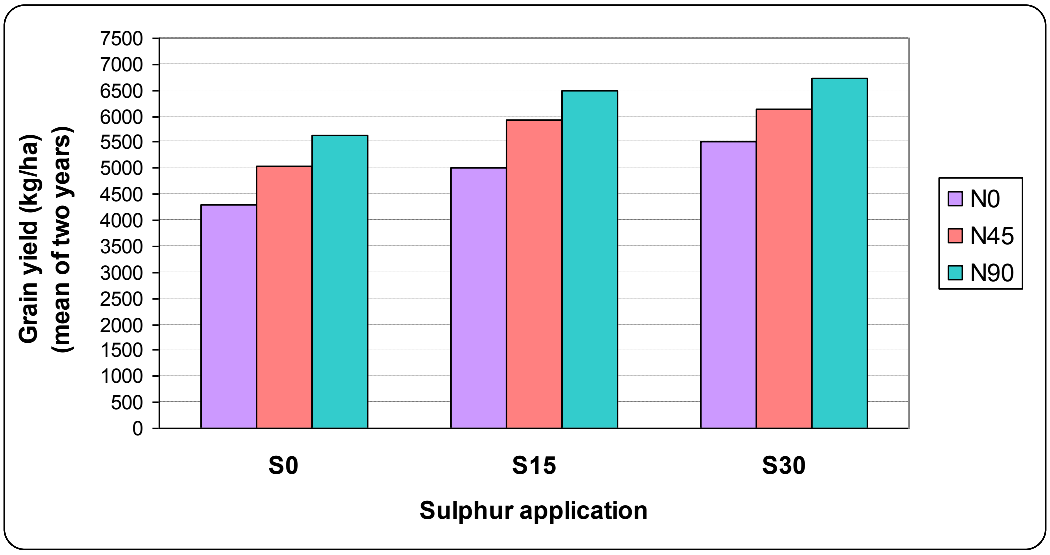


Fig. 17. Effect of graded doses of N & S with cow dung application on grain yield



Cultural and nutritional management can alter the metabolic process through modifying the soil plant interactions. The grain yield ultimately is the product of number of productive tillers, spikeltes/panicle, test weight of grain and fertility percentage. These yield attributes are decided by the morphological development of the plant which is an expression of plant metabolic process as well as their rate.

Straw incorporation resulted in significant increase in both the years of productive tillers (7.87 to 8.13 and 7.33 to 7.90), number of spikelets (93.21 to 102.77 and 97.39 to 106.80), percentage of filled grains (82.92 to 87.93 and 80.85 to 87.53) and 1000 grain weight (25.71 to 26.58 and 25.36 to 26.29) than no organic matter addition. Cow dung application also closely followed and this trend clearly exhibited the merit of organic manure use. Ismunadji (1978) and Surekha (2007) have highlighted the gradual and increased nutrient availability from organic sources including straw which influence the yield parameters to produce high yield. Sulphur at 15 and 30 kg ha^{-1} and nitrogen at 45 and 90 kg ha^{-1} also significantly enhanced the productive tiller count. The interactive influence of organics, nitrogen and sulphur has resulted in an increase in the productive tillers in the first year from 6.81 in $M_0N_0S_0$ to 9.44 in $M_2N_{90}S_{30}$ and 6.19 to 8.44 in the second year.

The spikelet number also was significantly higher in the straw incorporated treatments followed by the cow dung. The lowest spikelet number of 81.98 and 81.88 with $M_0N_0S_0$ was increased to 108.25 with $M_1N_{90}S_{30}$ and 104.61 and 108.70 with $M_2N_{90}S_{30}$, respectively in the first and second year. Nitrogen absorbed at PI stage increases spikelet number and that absorbed at maturity helps better filling of grains (De Datta, 1981). Early nitrogen absorption is known to favour tiller production and panicle (Tisdale *et al*., 1993). Similar improvement in the percentage of filled grains and 1000 grain weight was also observed with organics and higher rate of sulphur and nitrogen. Oh (1991) observed enhanced growth and improved yield attributes due to sulphur nutrition.

A rice crop having 50 hills/m^2 with 7 panicles, 100 grains/panicle, 25 g for 1000 grain weight and 80 % fertility can theoretically yield 7 tonnes. The individual influence of these attributes can be understood from the fact that a mean increase in number of panicles by one can result in an additional yield of one tonne, increase in the number of spikelets by 10 numbers can result in additional yield of 700 kg ha^{-1}, increase in 1000 grain weight from 25 to 27 g can result in an added increase of 560 kg and an increase in fertility percentage by 10 % can bring about additional yield by 750 kg. The combined effect of this improvement brought about by this yield attributes is the reason for significantly higher yield observed. The Fig. 18 also shows the positive correlation between the yield attributes and their yield.

5.4.1 Correlation of plant nutrients with grain yield

The plant elemental composition with in the plant has been significantly correlated with grain yield (Table 5.1) except for Fe and Mn. Even with an expected favourable nutritional environment as evidenced by the nitrogen and sulphur mineralization process of straw and cow dung, supplementation with adequate nitrogen and sulphur fertilizers, balanced elemental composition with in the plant and favourable correlation among nutrient contents, the barriers for higher yield is not broken but lies round about 6 – 7 tonnes/ha. Though nitrogen and sulphur application could reduce the Fe and Mn content as shown by the negative correlation, the Fe and Mn content in the plant was relatively high. The non - beneficial effects of higher contents were not completely contained or substantially reduced by any of the treatment or its combination, though a reduction in Fe in plant tissues was observed with application of organics and nitrogen, due to the specific nutritional environment of laterite alluvium characterised by excess of Fe, Mn and Al. On an individual basis Fe, Mn and Zn excesses had the most pronounced factors for low yield and nitrogen use efficiency (Sindu, 2003).

Sulphur application reduced plant content of Fe by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970 and Pillai, 1972). Addition of

Fig. 18. Correlation of yield and yield attributes

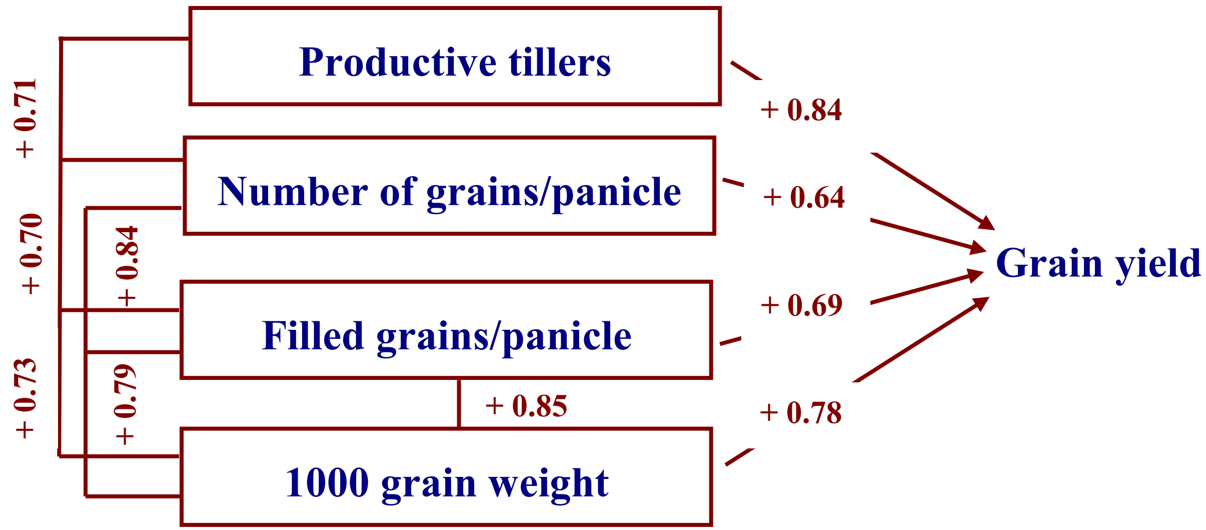


Table 5.1 Correlation of plant nutrients with grain yield

	Nitrogen	Phosphorus	Potassium	Sulphur	Calcium	Magnesium	Iron	Manganese	Grain yield
Nitrogen	-								
Phosphorus	0.304 (0.025)	-							
Potassium	0.150 (0.279)	0.402 (0.003)	-						
Sulphur	0.151 (0.276)	-0.073 (0.601)	-0.042 (0.760)	-					
Calcium	0.187 (0.176)	0.185 (0.180)	-0.115 (0.407)	0.029 (0.835)	-				
Magnesium	0.373 (0.005)	0.327 (0.016)	0.129 (0.353)	0.083 (0.551)	0.417 (0.002)	-			
Iron	-0.078 (0.575)	0.153 (0.269)	0.125 (0.368)	-0.196 (0.155)	-0.083 (0.548)	-0.174 (0.209)	-		
Manganese	-0.382 (0.004)	-0.143 (0.304)	0.105 (0.450)	0.084 (0.546)	-0.132 0.343	0.000 (0.998)	0.168 (0.225)	-	
Grain yield	0.494 (0.000)	0.387 (0.004)	0.206 (0.135)	0.148 (0.286)	0.120 (0.388)	0.517 (0.000)	-0.076 (0.585)	-0.141 (0.311)	-

* Figure in parenthesis is probability level of significance

NPK with or without manure reduced Fe concentration in plants while manure alone increased Fe concentration (Brancher *et al.*, 1996). The negative influence of Mn and Fe were felt at PI stage signifying their influence on differentiation. Fe is an immobile element in the plant. Its significant negative influence on productivity pointed out to its continued absorption in the latter stages to levels beyond critical levels. The present trial had recorded higher Fe in the plant against 300 mg kg^{-1} as the upper critical limit suggested by Yoshida (1981). The negative effect of Fe can be seen on the plant not merely from its direct effect but also through its limiting influences on absorption of N and Ca as well as positive influence on Mn. There are reports on reduced Fe content due to S application (Singh, 1970) however remarkable influence of S in lowering Fe content in rice growing in laterite alluvium was not observed.

5.5 Interactions among the treatments

The plant height at PI stage was statistically similar under N_{45} and N_{90} levels and significantly superior to N_0 applied in the no organics or cow dung incorporated treatments. However under straw incorporation, the height was at par under N_0 and N_{45} and significantly lower than N_{90} indicating the requirement of higher doses of external nitrogen application under straw incorporation. Number of tillers at PI stage also showed an interaction effect of organics × nitrogen indicating reduction in tillers under no N or N_{45} under straw incorporation than no organics treatment. Under no organics or cow dung application either S_{15} or S_{30} resulted in similar chlorophyll content, but under straw incorporation only S_{30} level brought about a significantly higher chlorophyll 'a' content signifying the importance of higher level of sulphur application. Similarly under straw incorporation, N_{90} level was needed to produce significantly higher chlorophyll 'b' content at tillering stage.

Under no organics or cow dung application the productive tiller count showed a step wise increase in the response to applied N, but under straw incorporation only N_{90} could brought out a significant increase in the tiller count.

Similarly, only S_{30} could result in a significantly higher tiller count. In the case of number of spikelets also, under straw incorporation only N_{90} resulted in the highest number of spikelets with significantly lower and similar values for N_0 and N_{45}. Sulphur application at 15 kg ha^{-1} was found sufficient to produce statistically similar spikelet number under straw incorporation, to S_{30} under cow dung application. N × S interaction was significant in the grain yield also. When no nitrogen was given the grain yield were at par with S_{15} or S_{30} level, but under N_{45} and N_{90}, S_{30} resulted in the significantly higher yield than S_{15}.

The interactive effects of organics × N and organics × S were observed in the case of elemental compositions also. In general the interactive effectives of organics × N and organics × S were more pronounced than N × S. The analysis on the interaction effects pointed to the need of higher nitrogen dose under straw incorporation and moderately higher sulphur doses with higher levels of nitrogen.

5.6 Nutrient use efficiency

5.6.1 Nutrient use efficiency of nitrogen

The effectiveness of fertilizer N and S alone or in combination with soil incorporated straw and cow dung was assayed by measuring the ratio of grain yield to the applied quantity of nutrients, which is termed as 'Agronomic Efficiency' (AE). The AE of nitrogen was highly influenced by the rate, soil incorporation of organics and sulphur supply (Table 4.66 & Fig. 19 & 20). The agronomic efficiency was almost double with the lower nitrogen rate of 45 kg ha^{-1} than N_{90}. Hossian (2009) reported that the nitrogen use efficiency decreased as N rate increased. When N was applied alone without any organics, the efficiency of lower dose was as high as 55 % which reduced to 24 % at N_{90}. N at 90 kg ha^{-1} is the normal recommendation rate for rice and the efficiency of N was increased from 24 to 30 % with cow dung application and further to 39 % with straw incorporation.

Fig. 19. Agronomic efficiency of nitrogen influenced by organic sources

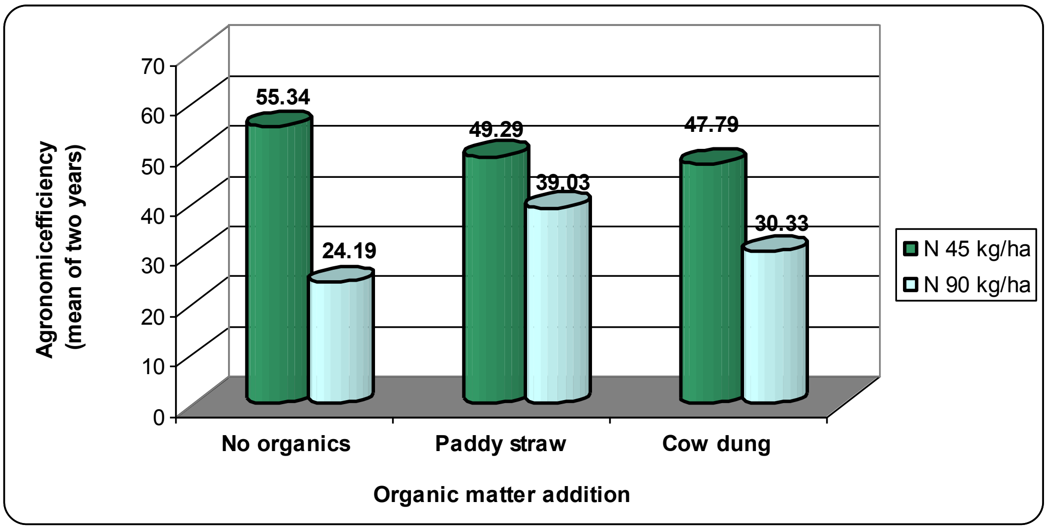
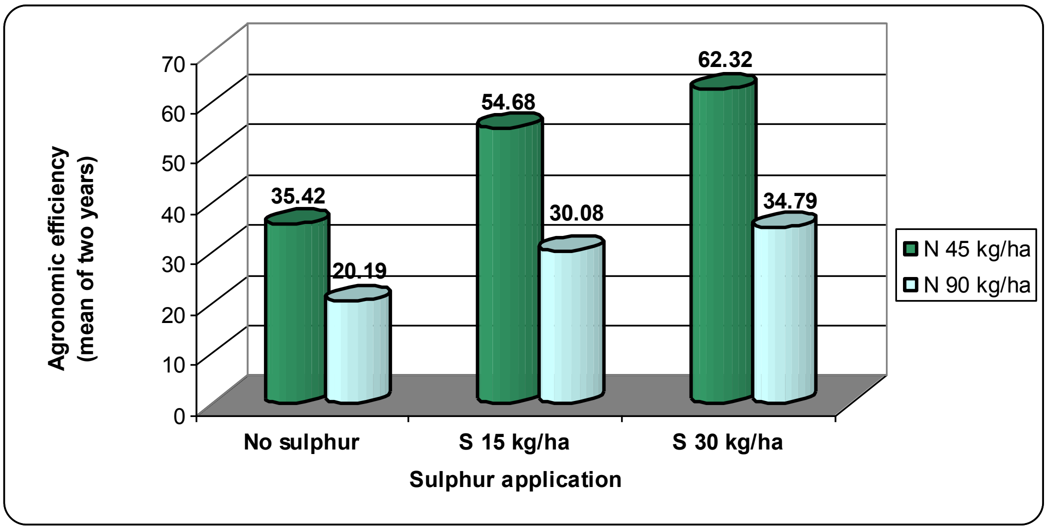


Fig. 20. Agronomic efficiency of nitrogen influenced by sulphur application



The higher AE of N_{90} with soil incorporated organics is due to higher uptake efficiency and physiological efficiency, the product of these two constitutes the agronomic efficiency. The ratio of nutrients absorbed (taken up) to the quantity of nutrient applied is termed as uptake efficiency, which is a function of the proportion of root surface area, distribution and uptake per unit area. These factors are dependent upon soil physical and chemical status, and health and growth characters of the plant. The positive influence of soil incorporation of organics on plant growth is already discussed (Section 5.2).

The uptake efficiency (Table 4.67 & Fig. 21 & 22) of N_{90} was considerably higher with organics, but among them it was higher for cow dung with 79.5 % followed by straw incorporation with 71.8 %. The enhanced vegetative growth observed in the cow dung incorporated treatments compared to straw incorporated ones justifies the higher uptake efficiency.

The second factor of AE is the Physiological Efficiency or Utilization Efficiency which is the ratio of the grain yield to the nutrient absorbed or taken up, which is more related to the internal nutritional environment of the plant. A well balanced elemental composition coupled with adequate chlorophyll content, and optimum cell sap pH decides the physiological efficiency. The data presented in the Table 4.68 and the Fig. 23 & 24 shows that physiological efficiency did not vary depending on the applied N dose, but soil incorporation of organic manures enhanced the efficiency with out much variation between the sources. The role of organics in the supply of mineral nutrients particularly micro nutrients in required quantity is well established. The positive influence of organics (straw or cow dung) on chlorophyll content and elemental composition is discussed else where (Section 5.3). John *et al*. (1989) and John *et al*. (1992) have reported the enhanced agronomic efficiency of applied nitrogen in the presence of organics like cowpea crop residue or cowpea green manure grown as a pre rice crop which were incorporated into the soil under both low land and upland conditions.

The role of sulphur in increasing the AE is evidenced from the table 4.66 and Fig. 20. S at 15 kg ha^{-1} enhanced the use efficiency of N_{90} from 35.4 to 54.7,

Fig. 21. Uptake efficiency of nitrogen influenced by organic sources

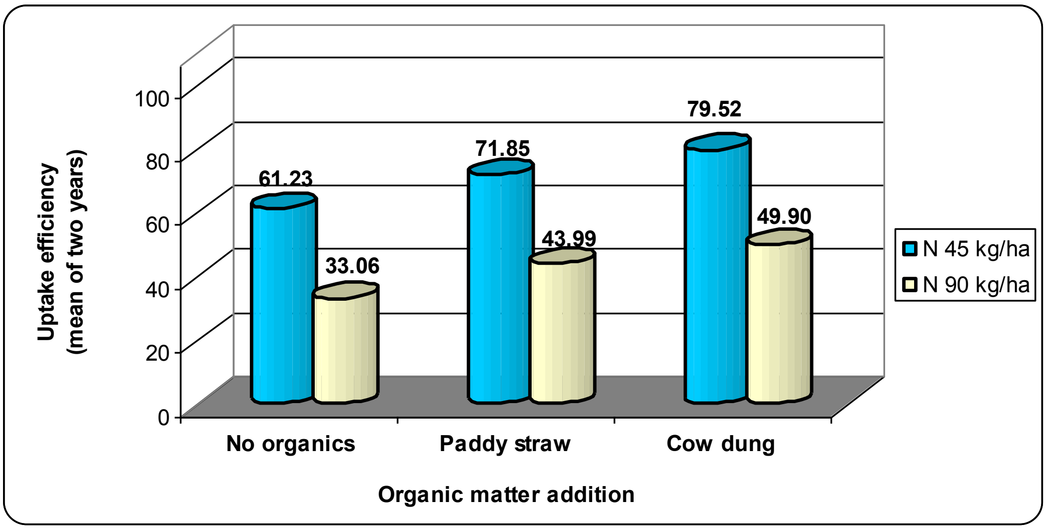


Fig. 22. Uptake efficiency of nitrogen influenced by sulphur application

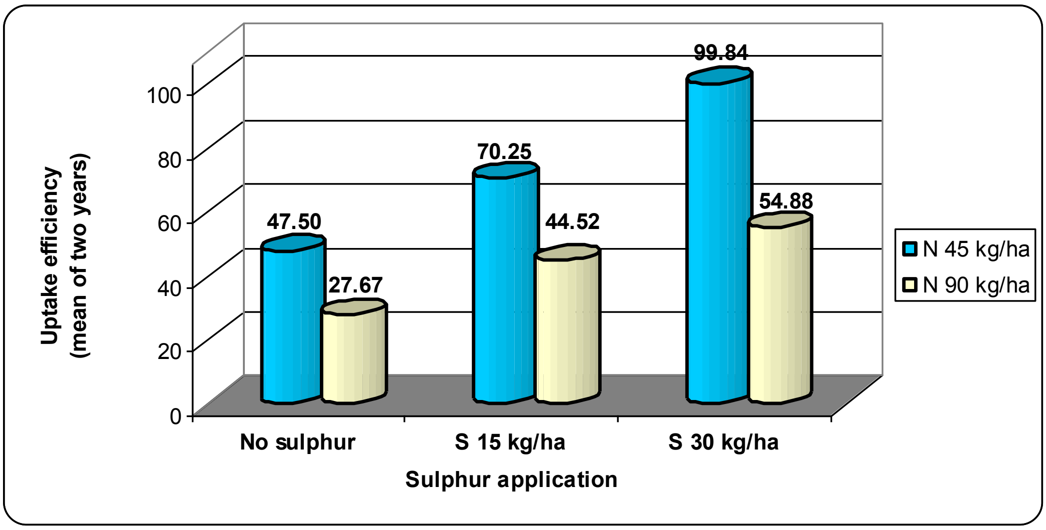


Fig. 23. Physiological efficiency of nitrogen influenced by organic sources

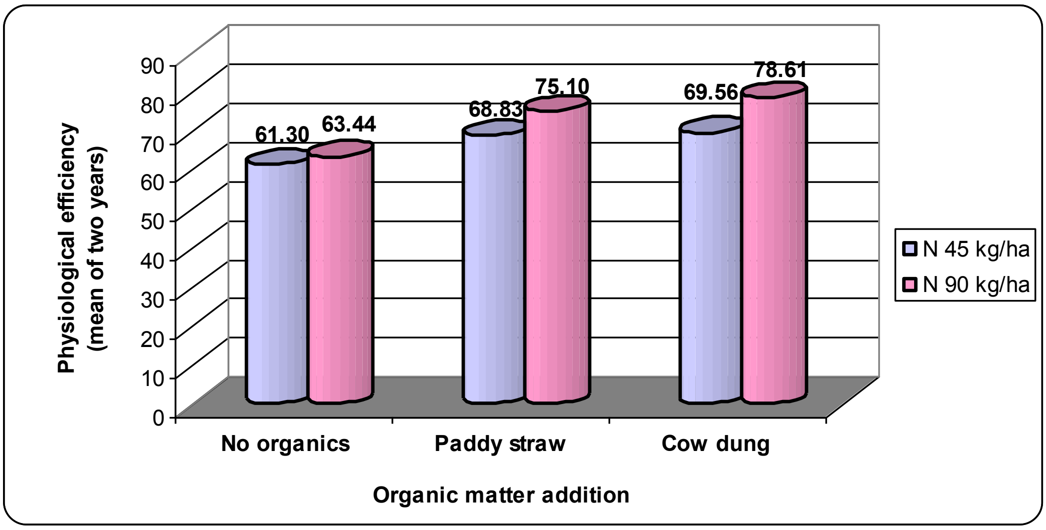
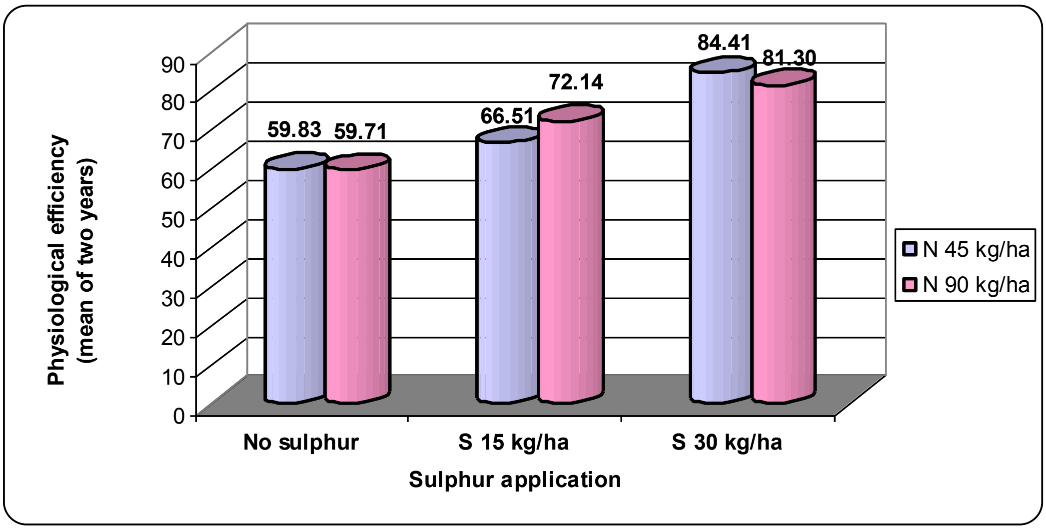


Fig. 24. Physiological efficiency of nitrogen influenced by sulphur application



which was further enhanced to 62.3 with S at 30 kg ha^{-1}. The role of sulphur in enhancing the uptake of N by improved growth facilitating the internal nutritional environment and consequent higher physiological efficiency (Section 4.2.56) has caused a higher AE.

5.6.2 Nutrient use efficiency of sulphur

The AE of S expressed in terms of kg grain per kg of applied sulphur was round about 150 at S 15 kg ha^{-1} and applied together with soil incorporated cow dung or paddy straw. The AE of S in the absence of either soil incorporated cow dung or straw is relatively low. The higher AE is due to the proportionally higher uptake efficiency and physiological efficiency as observed from Fig. 25, 26, 27 & 28. Similar to N, sulphur is also a structural element and constituent of certain amino acids, the reason attributed for higher AE of N is valid in the case of S also. An inadequate S supply appears to limit the plants capacity to synthesize protein to a much greater extent than it inhibits the nitrogen uptake mechanism (Rendig *et al*., 1976).

The AE of S influenced by the N application (Table 4.69 & Fig. 29 & 30) was similar in its pattern to that of N as influenced by S application, but for the quantity of grain produced per kg of each nutrient. This is happening only because these nutrients are complementary in their functions towards growth and development of the plant.

5.7. Quality characters

5.7.1 Protein content and protein yield

Yield has two dimensions – quantity and quality. Naturally they may appear unrelated but beyond marginal levels they will be universally related. An optimum combination of qualitative and quantitative combination is the best yield.

The protein content of rice is one of the most important quality parameters. The protein content and protein yield/ha presented in table 4.48 and

Fig. 25. Uptake efficiency of sulphur influenced by organic sources

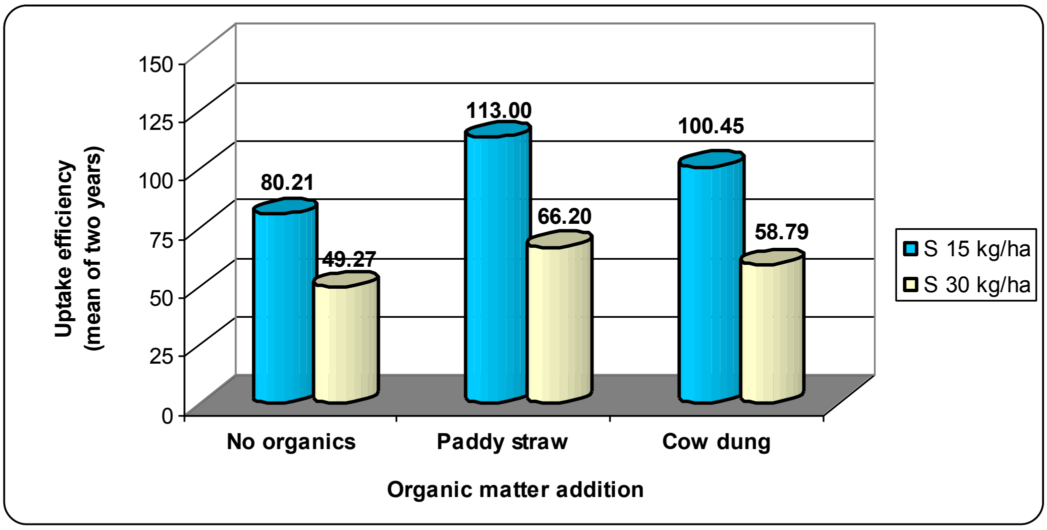


Fig. 26. Uptake efficiency of sulphur influenced by nitrogen application

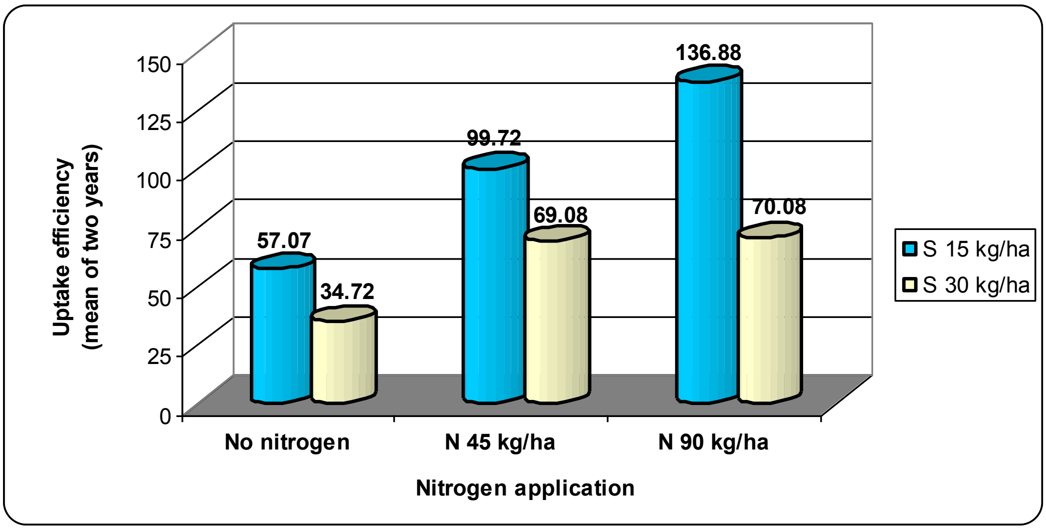


Fig. 27. Physiological efficiency of sulphur influenced by organic sources

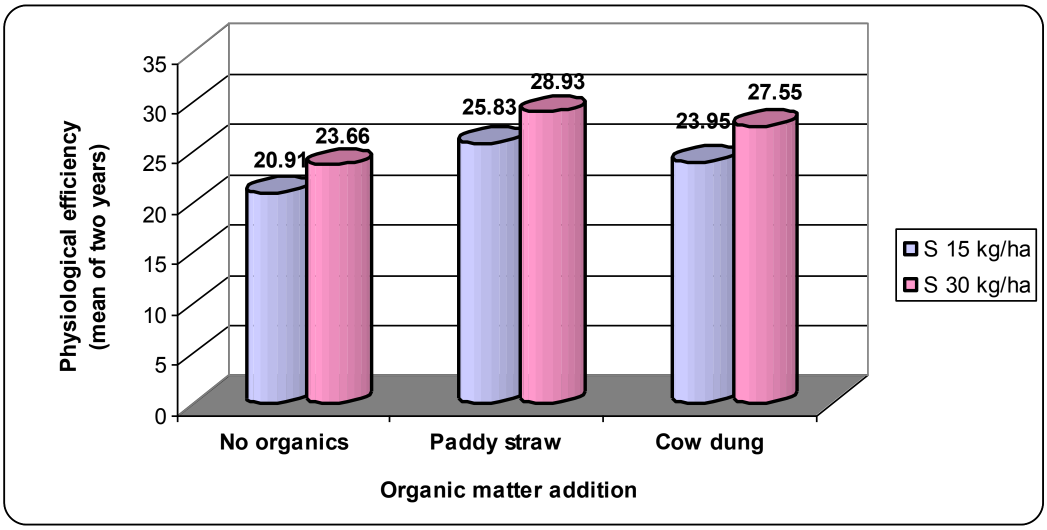


Fig. 28. Physiological efficiency of sulphur influenced by nitrogen application

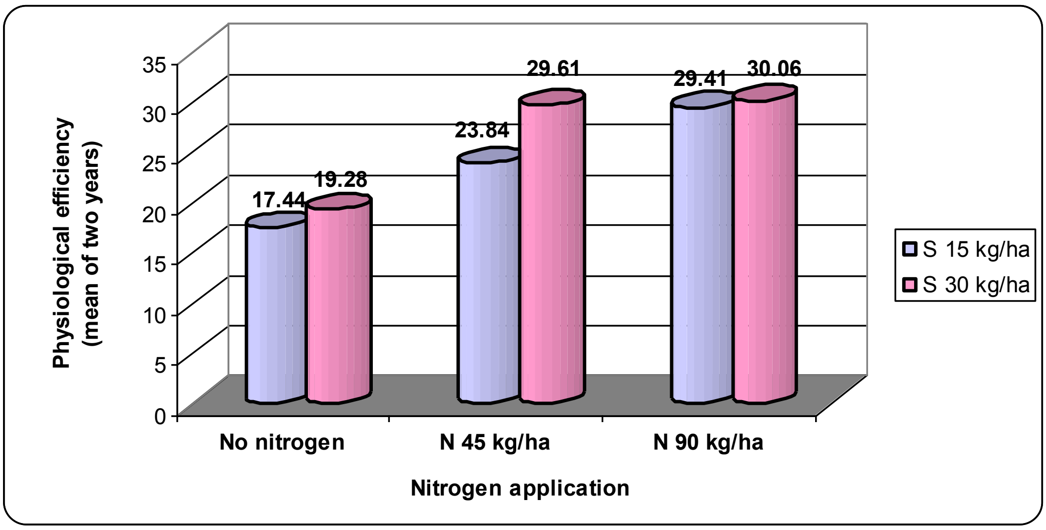


Fig. 29. Agronomic efficiency of sulphur influenced by organic sources

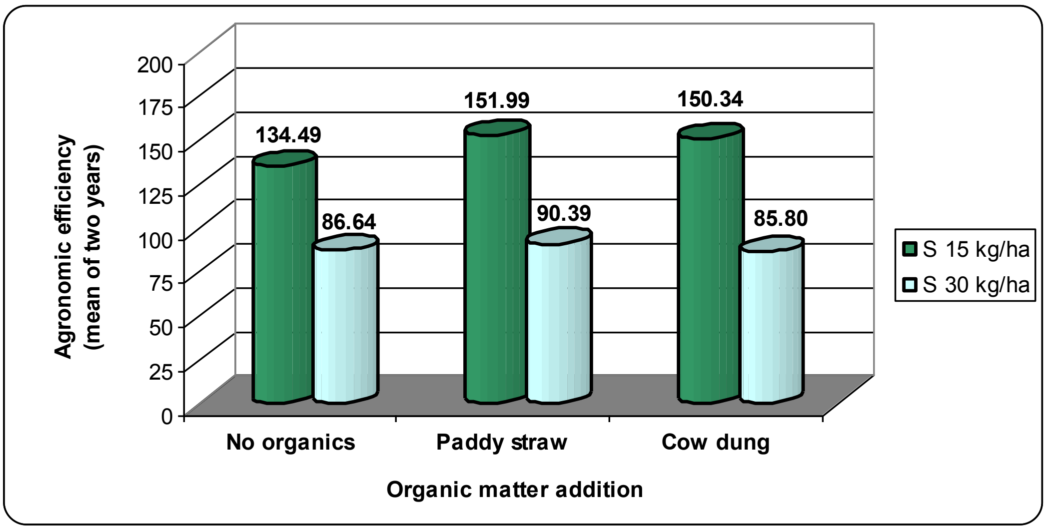
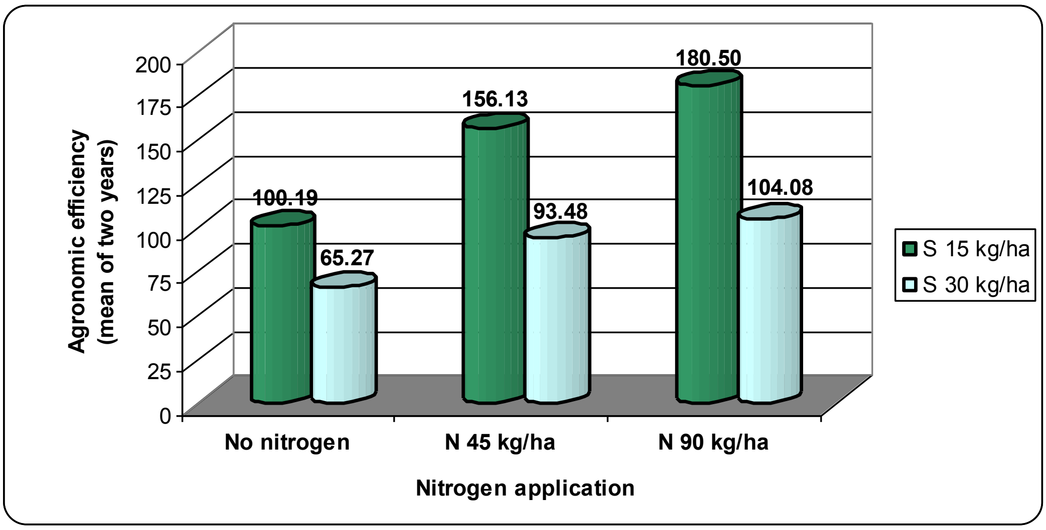


Fig. 30. Agronomic efficiency of sulphur influenced by nitrogen application



4.49 shows that soil incorporation of cow dung has considerably higher protein content (7.20 & 7.42 % in first and second year) than straw incorporated ones (6.66 & 7.22 %). When no organic manure was applied the protein content was lowest with 6.38 and 6.56 % in the first and second year, respectively. With increasing doses of N as well as S protein content also increased. However, the complementary effect of combinations of organics, N and S was far beyond the individual effects. The rice protein content of 6.25 % observed in no organic manure + N_0 + S_0 treatment was increased to 8.69 % in straw incorporation + N_{90} + S_{30} treatment clearly brings out the complementary role of nutrients or its source. The corresponding protein yield/ha was 212.86 and 470.80 kg, a 121.17 % increase.

5.7.2 Protein nitrogen and protein sulphur

The protein contents of grain given in Table 4.48 are estimated by multiplying the N contents estimated by kjeldhal method (Table 4.40) by a factor 6.25 based on the assumption that protein contains approximately 16 % N. Since the amino acid composition varied from one protein source to another, and in the kjeldhal method the non protein N also enter in the estimation, the true protein content may be over estimated. Spencer (1959) reported that the percentage of protein N and total N increased as S supply increased, protein nitrogen forming a greater proportion of the total N at higher S levels. In contrast, protein sulphur formed the bulk of the total sulphur in deficient plants, but as S supply approached an adequate level for growth there was a marked increase in the non protein S and a smaller increase in organic sulphur.

In the present experiment, protein N and protein S of selected treatments in the second year are estimated by Lowry's method and presented in Table 4.50 & 4.51. A comparison of the total protein N and S (Table 4.50 & 4.51) between the true protein N and protein S as influenced by treatments is presented in the Table 5.2.

The N estimated from the extracted grain (Lowry's method) protein was less than that of kjeldhal N method indicating that 0.08 to 0.29 % N is present as

Table 5.2 Non protein N and S in the rice grain

Treatments	Nitrogen content (%)	Crude protein (%)	Protein nitrogen (%)	True protein (%)	Estimated conc. (%)	Non protein N (%)	Sulphur content (%)	Protein sulphur (%)	Non protein S (%)
No organics + N_0 + S_0	0.93	5.81	0.79	4.92	5.29	0.14	0.33	0.28	0.05
No organics + N_0 + S_{30}	0.98	6.12	0.83	5.22	5.33	0.15	0.34	0.31	0.03
No organics + N_{90} + S_0	1.05	6.56	0.85	5.34	5.08	0.20	0.34	0.31	0.03
No organics + N_{90} + S_{30}	1.09	6.81	0.93	5.83	5.35	0.16	0.45	0.37	0.08
Cow dung + N_0 + S_0	1.05	6.56	0.83	5.17	4.92	0.22	0.39	0.32	0.07
Cow dung + N_0 + S_{30}	0.98	6.12	0.90	5.64	5.75	0.08	0.38	0.35	0.03
Cow dung + N_{90} + S_0	1.23	7.69	1.00	6.29	5.11	0.23	0.37	0.34	0.03
Cow dung + N_{90} + S_{30}	1.32	8.25	1.03	6.47	4.90	0.29	0.47	0.39	0.08
Mean	**1.08**	**6.74**	**0.89**	**5.61**	**5.21**	**0.18**	**0.38**	**0.33**	**0.05**

Treatments	Means of non protein nitrogen (%)	Means of non protein sulphur (%)
No organic manures	0.16	0.05
Cow dung application	0.20	0.05
No nitrogen	0.15	0.04
N @ 90 kg ha^{-1}	0.22	0.05
No sulphur	0.19	0.04
S @ 30 kg ha^{-1}	0.17	0.05

non protein N. The comparison of mean show that cow dung increased non protein N, S_{30} slightly reduced or maintained it and N_{90} increased the non protein N in rice grain. The study also indicate that the true protein content is over estimated if N content is multiplied by the factor 6.25. Conversion factor varying from 4.90 to 5.75 with a mean of 5.22 was observed in the experiment. Fujihara *et al*. (2008) reported conversion factor 5.75 for rice instead of 6.25. However, it seems more detailed experimentation is needed towards the fixing of conversion factors for nitrogen to protein of rice growth in various environment and management sectors. The Table 5.2 shows a range of 0.03 to 0.08 % of non protein S present in rice grain. Both S and N application has slightly improved the non protein S. Spencer (1959) has reported marked increase in non protein S and small increase in sulphate sulphur under adequate sulphur fertilizer in white clover crop.

Summary and Conclusion

Summary and Conclusion

VI. Summary and Conclusion

The present study entitled "Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction" was carried at the Farmers' field, Pudhunagaram, Palakkad during the rabi seasons (*Mundakan*) Sep 2006 – Feb 07 and Sep 2007 – Feb 08 and the pot culture studies were conducted in the College of Horticulture, Vellanikkara, Thrissur during the same season of Sep 2007 – Feb 08. The salient research findings obtained are summarized here.

1. The mineralization of nitrogen and sulphur from the organic materials was influenced by time. The N mineralization from cow dung reached at its peak on 20 days after incorporation which readily decreased to a lower level by 40th day, which continued upto 110th day. But, N mineralization from straw reached its peak on 50 days after incorporation which gradually reduced but continued till 110 days relatively at higher level compared to cow dung.
2. The split application of nitrogen on 11th, 31st and 51st day and split application of sulphur on 11th day enhanced the ammoniacal N, nitrate N and available sulphur in straw incorporated treatments after 30 days and maintained long term sustainability.
3. The early growth characters of rice such as height, tiller production and dry matter production were significantly lower in straw incorporated treatments. The lower plant height observed in straw incorporated treatments at vegetative stage was increased at PI stage and reached at a significantly increased height by harvest stage than cow dung applied ones.
4. Straw incorporation followed by nitrogen, sulphur or both, did not make any significant change in growth pattern probably due to inadequacy or improper timing.
5. Increasing levels of nitrogen and sulphur positively influenced the vegetative growth and yield.

6. Beneficial effects of higher nitrogen and sulphur with straw incorporation was less evident in the early stages and was pronounced in the later stages.

7. Nitrogen application with cow dung showed better performance during vegetative stage, but declined towards harvest.

8. The tiller decline was lower in the straw incorporated than cow dung and increasing nitrogen doses increased the percent tiller decline.

9. Chlorophyll 'a' and 'b' contents of rice leaves at tillering and PI stage were increased by cow dung application than straw incorporation. Chlorophyll 'a' to 'b' ratio increased with sulphur doses but decreased with N doses and soil incorporation of organics.

10. At vegetative stage, cow dung application resulted in higher plant N in both the years, however, at PI stage straw incorporation increased the plant N, indicating that straw incorporation can maintain a long term sustainable effect.

11. The plant N content was increased with the application of S and the plant S content was increased with the application of N, showed the complementary effect of N and S among them.

12. The Ca contents in the plant was not influenced by organic manure sources or N or S application in general, but the plant Mg content at tillering was significantly increased by sulphur application.

13. The plant Fe content was 2 – 3 times higher in the PI stage than tillering stage and the increasing N rates and the organic matter addition either cow dung or straw reduced the Fe content of plant.

14. Yield attributing characters like productive tillers, spikelets/panicle, test weight and fertility percentage were significantly influenced by incorporation of straw and cow dung along with nitrogen and sulphur. These yield attributing characters were positively correlated with each other and positively correlated with grain yield also.

15. Grain yield increased from 3432 kg ha^{-1} in the absolute control to 7085 kg in the straw + N_{90} + S_{30} treatment in the first year and from 3657 kg to 7116 kg in the cow dung + N_{90} + S_{30} treatment in the second year.
16. The plant elemental composition with in the plant has been significantly correlated with grain yield except for Fe and Mn.
17. The interactive effect of manures × nitrogen and manures × sulphur were significant for several characters. Effects of manures × N and manures × S were more pronounced than N × S.
18. The protein content of rice was higher with cow dung application than straw incorporated treatments and the increasing levels of N and S increased the protein content of grain.
19. This study indicated that the true protein content of grain will be over estimated if the N content is multiplied with the conversion factor 6.25. A factor of 5.22 was observed from the nitrogen estimation from the extracted grain protein.
20. Application of cow dung @ 10 t ha^{-1} and N @ 90 kg ha^{-1} considerably increased the non protein nitrogen and non protein sulphur content of rice grain. S @ 30 kg ha^{-1} and N @ 90 kg ha^{-1} increased non protein sulphur in grain than no application of the same.
21. Agronomic efficiency (AE) of nitrogen or sulphur (kg grain/kg nutrient applied) was not influenced by organic manure application. AE and uptake efficiency (UE) were higher with lower dose of nitrogen (N_{45}) and the higher AE was observed with N_{45} + S_{30} treatment revealed that the role of S in enhancing the use efficiency of nitrogen.
22. Physiological efficiency (PE) of N was also higher with the above combination however N_{90} + S_{30} resulted in a similar PE with N_{45} + S_{30}. When organic sources were interacted with nitrogen, PE of N was higher with N_{45} than N_{90}.

23. AE and UE of sulphur were higher with lower dose of S (S_{15}) and the highest efficiencies were observed with N_{90} + S_{15}. PE of sulphur was similar to that of nitrogen.

24. In sulphur deficient soil, sulphur fertilization at 15 – 30 kg ha^{-1} could increase the rice yield and the use efficiency of nitrogen.

25. Soil organic matter loss is fast under increasing temperature due to the change in climate. Rice straw left in the field after harvesting with combine harvesters is a blessing in disguise.

26. Straw incorporation sustained the fertility on long term basis than cow dung. However, 37 to 52 kg ha^{-1} less mineral N was observed in the straw incorporated soil during the 30 days after incorporation and 20 days after rice planting compared to cow dung, both incorporated at 10 t ha^{-1}. If this deficit could be compensated by N added at appropriate time, the straw will be a better and cheaper source of organic matter than cow dung.

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* Originals not seen

Appendix

Appendix I

Composition of buffer and reagent used for protein extraction

1. Phosphate buffer

Solution A : 0.2 M solution of monobasic sodium phosphate – 31.202 g NaH_2PO_4/1000 ml of water

Solution B : 0.2 M solution of dibasic sodium phosphate – 28.392 g Na_2HPO_4/1000 ml of water

39 ml of solution A and 61 ml of solution B was mixed, pH was adjusted to 7.0 and volume was made up to a total of 200 ml.

2. Alkaline copper solution

Solution A : 2 % Na_2CO_3 in 0.1 N NaOH

Solution B : 0.5 % $CuSO_4$. $5H_2O$ in 1 % potassium sodium tartarate

Solution C : 50 ml of solution A and 1 ml of solution B were mixed and the solution had to be prepared afresh.

Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction

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ABSTRACT OF THE THESIS
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Abstract

The research programme entitled "Productivity of rice in laterite soil in relation to nitrogen - sulphur interaction" was conducted mainly to study the nitrogen and sulphur availability and their interaction as influenced by organic manure sources, particularly straw incorporation in rice cultivation. The "Mineralization pattern of nitrogen and sulphur" was studied in pot culture experiment at College of Horticulture, Vellanikkara during the rabi season (*Mundakan*) Sep 2007 – Feb 08. "Response of rice to nitrogen and sulphur mineralization from organic matter with varying C:N ratios" was studied in farmers field, Pudhunagaram, Palakkad during the rabi seasons (*Mundakan*) Sep 2006 – Feb 07 and Sep 2007 – Feb 08.

The mineralization of nitrogen and sulphur from the organic materials was influenced by time after application. The straw incorporated treatment released noticeably lower amount of nitrogen and sulphur in the initial stages than no manure application. The early growth characters of rice such as plant height, tiller production and dry matter production were significantly lower in straw incorporated treatments. Straw incorporation followed by application of nitrogen and sulphur or both, did not make any significant change in growth pattern probably due to inadequacy or improper timing.

Increasing levels of nitrogen and sulphur positively influenced the vegetative growth and yield. The interactive effects of manures × N/S were significant for several characters. Beneficial effects of higher nitrogen and sulphur with straw incorporation were less evident in the early stages and was pronounced in the later stages. Nitrogen application with cow dung showed better performance during vegetative stage, but declined towards harvest. The tiller decline was lower in the straw incorporated treatments than either cow dung applied or unmanured treatments. Yield attributing characters were significantly influenced by incorporation of straw and cow dung along with nitrogen and sulphur.

Grain yield increased from 3432 kg ha^{-1} in the absolute control to 7085 kg in the straw + N_{90} + S_{30} treatment in first year and from 3657 kg to

7116 kg in the cow dung + N_{90} + S_{30} treatment in second year. The interaction effects of manures × N/S were more pronounced than N × S. Combined application of organic manures and nitrogen noticeably increased protein nitrogen and protein sulphur content. Most of the plant nutrients were positively correlated with each other and positively correlated with grain yield. N × Fe and S × Fe have showed significant negative correlation.

Agronomic efficiency of nitrogen or sulphur (kg grain/kg nutrient applied) was not influenced by organic manure application. Apparent recovery of nitrogen as well as physiological efficiency of nitrogen was the highest in combination of organic manures with 45 kg nitrogen and 30 kg sulphur. The utilization or physiological efficiency was also highest (kg grain/kg nutrient taken up) for the above combination.

Straw incorporation resulted in long term maintenance of soil fertility as evidenced by higher mineral nitrogen and sulphur in soil upto a period of 110 days. In sulphur deficient soil, sulphur fertilizers could increase the rice yield and the use efficiency of nitrogen. The finding of the study points to beneficial effects of rice straw left in the field after harvesting using combine harvesters. However 37 to 52 kg ha^{-1} less mineral N was observed in the straw incorporated soil during the 30 days after incorporation and 20 days after rice planting compared to cow dung, both incorporated at 10 t ha^{-1}. If this deficit could be compensated by N added at appropriate time, the straw will be a better and cheaper source of organic matter than cow dung.