NITROGEN AND SULPHUR INTERACTION ON THEIR RELEASE PATTERN AND USE EFFICIENCY IN FERRALITIC SOILS

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THESIS

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Dedicated to

My

Parents and Dain

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LIST OF ABREVIATIONS

%	per cent
µg	microgram
μm^2	micro square metre
B: C	Benefit: Cost
B	Boron
Ca	Calcium
CD	Critical Difference
CEC	Cation Exchange Capacity
cm	centimeter
DAS	Days After Sowing
DOI	Days of Incubation
dS	Deci Siemens
et al	And others
Fe	Iron
Fig.	Figure
FYM	Farn Yard Manure
g	gram
h	hour
ha^{-1}	Per hectare
K	Potassium
KAU	Kerala Agricultural University
kg	Kilogram
Mg	Magnesium
m	metre
mg	milligram

min	minutes
ml	millilitre
mm	millimeter
N	Nitrogen
NRA	Nitrate Reductase Activity
NUE	Nitrogen Use Efficiency
°C	Degree Celcius
P	Phosphorus
PDI	Percentage Disease Incidence
POP	Package of Practices
RDF	Recommended Dose of Fertilizers
S	Sulphur
s	seconds
t	tonnes
TDM	Total Drymatter Production
Var.	variety
Zn	Zinc

Introduction

1. INTRODUCTION

India will have to produce more and better food from limited land area to feed its growing population. Sustainability of Indian agriculture to maintain food self sufficiency will depend on proper plant nutrition measures along with best management practices. Vegetable crops can play a very important role in alleviating the alarming demand for food and fibre as they can serve as protective foods and these are integral part of balanced diet. Even among non vegetarians, vegetables have a significant role in the diet, being a rich source of vitamins, minerals, dietary fibre etc. The requirement of vegetables is 300-350 g person^{-1} day^{-1} (100-120 kg annum^{-1}). The current production can supply only 125-150 g person^{-1} day^{-1}(50 kg year^{-1}).

India is the second largest producer of vegetables in the world, after China. Currently, India occupies 7.8 m ha of area of vegetable cultivation with an annual production of 128.45 m t (NHB database). With increasing population, it is estimated that by 2020, the production has to be increased to at least 135 m t year^{-1}. Hence, it is imperative to increase production to meet the daily requirement and for attaining food security.

Bhindi, or Ladies finger, which is also known as okra (*Abelmoschus esculentus* L. Moench), is one of the important vegetables cultivated in India. It is grown throughout the tropical and sub-tropical regions and also in the warmer parts of the temperate regions. The importance of bhindi in our diet cannot be under-emphasized as they serve as an important source of dietary fiber, vitamin A, B and C as well as calcium, phosphorous, iron and iodine. The nutritional value of 100g of edible okra is characterized as 1.9 g protein, 0.2 g fat, 6.4 g carbohydrate, 0.7 g minerals and 1.2 g fibers. The pods contain an ascorbic acid content of 20 g 100g $^{-1}$ and the mature seeds contain 20-24 per cent protein as well as 13-22 per cent edible oil. The essential and nonessential amino acids that okra contains are comparable to that of soybean. It is used for the treatment of goiter. The fruit is useful against genito- urinary disorders, spermatorrhoea and chronic dysentery. Its mucilage is suitable for medicinal and industrial applications. It has medically found application as a plasma replacement or blood volume expander. World wide production of bhindi as fruit vegetable is estimated to be six million tonnes per year. Okra has a good potential as a foreign exchanger crop and accounts for 60 per centof the export of fresh vegetables. In Kerala, it is cultivated in 1134 ha area and production is about 11000 tonnes. The vegetable is very popular in Kerala and is also exported to foreign countries.

To maximize the production of vegetables, it is necessary to apply balanced fertilizers as nutrient source. The NUE (NUE) is very low in ferralitic soils, often necessitating the application of huge quantities of nitrogen (N) fertilizer. This will increase the cost of cultivation when vegetables are cultivated in large scale. It has been reported that S, a major secondary nutrient, helps in N metabolism in plants which leads to increase in use efficiency of N. But sulphur (S) also is deficient in most of the ferralitic soils. The two nutrients which are major constituents of proteins are synergistically related and of vital importance for plants. Deficiency of S adversely affects N metabolism and causes accumulation of non-protein N compounds in plants. N-S interaction affects the yield and composition of protein-N, non protein-N and soluble carbohydrates in crops. N and S nutrition plays a crucial role in determining the photosynthetic capacity of plants. S deficiencies are frequently encountered in the tropics and subtropics because of intense weathering. Most of our soils are extremely deficient in S due to the fertilizer use pattern at present, which is dominated by S free fertilizers like urea, DAP, MOP and NPK complexes. Crops can yield to their full potential only by adding S along with NPK fertilizers. All these factors underline the significance of N and S application and its interaction in improving the yield and quality of most crops. Not only the yield but also the quality of produce is impaired by S deficiency. Hence, it is imperative to test the interactive effect of N and S on their release pattern and use efficiency in the field. The present study was undertaken with the following objectives:

1. To investigate the interactive effect of N and S application on their release pattern in ferralitic soil.
2. To study the interactive effect of these nutrients and use efficiency in plant using bhindi as test crop.
3. To find out the interactive effect of N and S application with other major nutrients.

Review of literature

2. REVIEW OF LITERATURE

With the improvement of crop productivity through the adoption of high yielding varieties and multiple cropping systems, fertilizer use has become more and more important to increase crop yields and quality. The nutrient elements nitrogen and sulphur are essential to many plant metabolic processes and it is evident that out of all the major plant nutrients found in Indian soils, N and S are the most deficient elements (Arekery *et al.*, 1956). The Nitrogen Use Efficiency (NUE) is very low in ferralitic soils, often necessitating the application of huge quantities of N fertilizer. While N directly affects the photosynthetic efficiency of plants, S affects photosynthetic efficiency indirectly by influencing the NUE of crops (Ahmad and Abdin, 2000). S, recognized as the forth major nutrient after N, P and K helps in N metabolism in plants that leads to increase in NUE. Since both N and S are vital constituents of plant proteins and are closely associated in their synthesis, they are synergistically related and are of vital importance in plants. The importance of S in agriculture is being increasingly emphasized and its role in crop production is well recognized (Jamal *et al.*, 2010; Scherer, 2009). S is best known for its role in the formation of aminoacids methionine (21 per cent S) and cysteine (27 per cent S), synthesis of proteins and chlorophyll and oil content in oilseeds and nutritive quality of forages (Tandon, 1986; Jamal *et al.*, 2005; Jamal *et al.*, 2006a and Jamal *et al.*, 2009).

Although S is similar to N in terms of functions and similar to phosphorus in terms of uptake, this element received little attention for many years, because fertilizers and atmospheric inputs supplied the soil with adequate amounts of S. Now, areas of S deficiency are becoming widespread throughout the world due to the use of high analysis low S fertilizers, low S returns with FYM, high yielding varieties and intensive agriculture, declining use of S containing fungicides and reduced atmospheric input caused by stricter emission regulation. In the early 1990's, S deficiencies in Indian soils were estimated to occur in about 130 districts (Tandon, 1991). Now, 40 per cent soils in our country are found to be S deficient. An insufficient supply of S can affect yield and quality of crops.

Shortage of S adversely affects the N metabolism and causes accumulation of non protein compounds in plants. Crops can yield to their full potential only by applying S along with NPK fertilizers. To overcome the problems associated with S deficiency, a number of S containing fertilizers as well as other S containing by- products from industrial processes are available (Jamal *et al.*, 2010). This chapter gives a brief review of the work done on N and S interaction on different crops.

3. 1. EFFECT OF N AND S APPLICATION ON SOIL CHEMICAL PROPERTIES

3. 1. 1. pH

According to Pasha *et al.* (2007), different S treatments had moderating effect on soil pH towards neutrality especially with 50 kg S ha^{-1} followed by 25 kg S ha^{-1} in the form of gypsum. Phosphogypsum was found to be an effective material for the correction of subsoil acidity (Sumner, 1970; Reeve and Sumner, 1972). Later, several scientists such as Sumner (1990) and Alcordo and Recheigl (1993) also reported the same. An increase in the soil pH to the extent of 0.80 units in dark red latosol after gypsum application was reported by Ritchery *et al.* (1980). Mathew (2003) reported that phosphogypsum along with lime is effective in reducing exchangeable acidity in laterite soils. Similar results of increase in pH were also reported by Keng and Uehera (1974) and Bolan *et al.* (1992). Jacob (1992) suggested that soil pH increased by 0.05 units by the application of lime and gypsum in red and laterite soil of Kerala. The variations in response among different S treatments could also be attributed to the levels of S and presence of calcium in case of gypsum.

Contrary to the above reports, a decrease in pH after gypsum application was noticed by Black and Cameroon (1984). Soil pH decreased to the extent of 0.5 to 0.9 units after gypsum application in non allophanic Andosol (Toma and Saigusa, 1997). In highly weathered Palexerult soils also the decrease in pH was noticed by Arias and Fernandez (2001). No change in pH due to phosphogypsum application was reported by Hammel *et al.* (1985) and Sumner *et al.* (1986). Ramdevputra *et al.* (2010) conducted an experiment to study the effect of S application on yield of groundnut and soil fertility under rainfed condition and reported that there was no change in pH by the application of S.

3. 1. 2 Available nutrient status of soil

Gypsum application checked the volatilization loss of ammonia and improved N use efficiency in soil (Tripathi *et al.*, 1997). An increase in N content in soil due to the application of S was reported by Tisdale *et al.* (1985). Souza and Ritchery (1986) reported that the recovery of nitrate from subsoil horizon was increased as an additional benefit of phosphogypsum application. Eriksen *et al.* (2001) suggested that the availability of soil S during grain-filling is important for an adequate S supply to the developing grains as the distribution of S to the ears considerably exceeded the amount exported from the leaves.

Mishra (1995) suggested that the application of phosphogypsum could correct S deficiency in red and laterite soil, black soil and alluvial soil. According to Beena (2000), the exchangeable Ca, Mg and available S were increased by the application of gypsum @ 30 kg ha^{-1} in red and laterite soil of Vellayani. Singh *et al* (2002) found that the addition of S up to 30 kg ha^{-1} significantly increased available soil S. Yunas *et al.* (2010) investigated the effect of S application on soil sulfur (Sulphate S) contents in different textured soils and concluded that the application of gypsum and ammonium sulphate @ 30 kg ha^{-1} increased sulphate S contents by 8.5 and 7.60 per cent over control, respectively.

Jakubus and Toboa (2006) studied the influence of fertilization of winter oilseed rape with increasing doses of gypsum on S content in soil and reported that the mean content of sulfate-S amounted from 11.03 mg kg^{-1} in absolute control to 32.26 mg kg^{-1} at 80 kg S ha^{-1} and the content of available sulfur ranged from 16.0 mg kg^{-1} in control soil to 40.94 mg kg^{-1} in samples fertilized with gypsum @ 80 kg S ha^{-1}. Singh and Mann (2007) reported that the application of S significantly increased the available S status at the harvest stage of groundnut.

Jyothi *et al.* (2001) reported that application of different sources of S as gypsum in sunflower increased the available N, P, K and S in alfisol and was 33.8 per cent and 57.9 per cent for N and P over control and for S it was 95.56

per cent over control. Mora *et al.* (2002) reported that combined application of limestone, dolomite and gypsum increased concentration of plant available P, K, Ca, Mg and S in soil. Mathew (2003) reported that organic carbon content and available N, P, K, Ca and S status of the soil increased by application of S @ 30 kg ha^{-1}.Chaurasiya *et al.* (2009) reported that the available nutrients were significantly influenced by the rate of S application. Available N, P, K and S were significantly increased by the increasing rate of S form 0 to 40 kg S ha^{-1}.

Ramdevputra *et al.* (2010) reported that the available N and K status after harvesting of crop were significantly affected by the application of S @18.75 kg ha^{-1} as Sulphate of Potash in addition to the recommended dose of fertilizer (12:5:25 kg ha^{-1}) in groundnut. The maximum value for available S (19.93 ppm) was recorded under N, P K and S @ 12: 5: 25 and 18.75 kg ha^{-1}. Jayaram *et al.* (2010) reported that S at 200 kg ha^{-1} (104 kg through N and P source + 96 kg through elemental source) recorded the highest post harvest soil S status of 8.08 mg kg^{-1} of soil and concluded that it is quite expected that the soil with low S would be enhanced by the external addition of S.

3. 2. EFFECT OF N AND S APPLICATION ON BIOMETRIC CHARACTERS

S, the forth nutrient in crop nutrition has a favourable effect on enhancing the growth characters of crops which is reflected in attributes like height, number of primary and secondary branches plant^{-1}, internodal length, dry matter production, leaf area index and finally the harvest index.

There was an increase in plant height in bhindi by the application of N fertilizer to the soil. (Syriac and Rajan, 1992; Sajitharani, 1993). Application of 25 kg S ha^{-1} caused an increase in plant height in rice (Sudha, 1999). Resurreccion *et al.* (2001) found that an increase in the sulfate concentration in the medium up to 0.03 m*M* resulted in a significant increase in the relative growth rate due to the increase in the net assimilation rate when rice plants are grown hydroponically. Nair (1995) reported progressive and significant increase in plant height and leaf area index by the application of S @ 30kg ha^{-1} in rice variety Jyothi in Kerala.

Sajitharani (1993) concluded that nutrient application significantly influenced the days for fifty per cent flowering and reported a delay in flowering due to increased levels of N fertilizer. Beena (2000) reported that S application @ 30 kg ha-1 increased the plant height, number of branches and leaf area index, and decreased the number of days for first flowering in cowpea. Ram *et al.* (2003) observed that days to 50 per cent silking reduced by the application of 60 kg S ha^{-1} in maize. The number of days to fifty per cent flowering was reduced by the application of S. (Krishanamoorthy and Mathan, 1996; Beena, 2000 and Mathew, 2009).

According to Nasreen *et al.* (2007) addition of N and S fertilizers exerted significant influence on the number of leaves $plant^{-1}$, plant height and diameter of bulb in onion. Ahmad (2009) showed that increasing N and S application rates up to 200 kg N ha^{-1} and 100 kg S ha^{-1} significantly enhanced the plant height, number of green leaves per plant weight in onion. Farooqui *et al.* (2009) concluded that the application of 200 kg N ha^{-1} along with 60 kg S ha^{-1} significantly increased the growth attributes like plant height @ 38.16, 42.35 and 55.12 cm at 30, 60 and 90 DAP respectively, number of leaves per plant @ 5.86, 6.22 and 8.83 at 30, 60 and 90 DAP respectively in comparison to 50 kg N ha^{-1} and 100 kg N ha^{-1} in garlic.

S application improved nodule weight, nodule number, and root weight and root growth parameters when vegetable pea was additionally treated with S @ 20 and 40 kg ha^{-1}along with N @ 30, P @ 60 and K @ 80 kg ha^{-1}. (Singh *et al* ., 2006).

Hocking *et al.* (2003) found that S and N deficiencies reduced the plant height and leaf area of sunflower. Timely application of S increases the plant growth by increasing the assimilating surface area. Abbas *et al.* (1995) reported that increasing levels of S up to 40 kg S ha^{-1} increased the plant height and number of branches per plant in safflower. Ravi *et al.* (2008) reported that application of S @ 30kg ha^{-1} in sunflower registered the maximum plant height and number of leaves in sunflower.

Shelke *et al.* (2007) reported that the plant height was significantly increased by S application up to 30 mg kg^{-1} S over control in soybean under laboratory conditions. Malik and Sofi (2007) reported that the plant height increased significantly by the use of *Rhizobium* along with sulfur @ 30 kg S ha^{-1} in soybean. Singh *et al.* (2006) concluded that P at 60 kg ha^{-1} and S at 40 kg ha^{-1} alone gave maximum plant height and branches per plant in blackgram.

Mathew (2003) observed that S @ 30 kg ha^{-1} increased the plant height, number of primary and secondary branches, root spread and root volume in *Sesamum*. Chaubey *et al.* (2000) found that plant height and primary branches plant-1 in groundnut were significantly influenced by the application of S @ 45 kg ha^{-1}. Sulfur fertilizer application at 50 and 25 kg ha^{-1} were found equally effective and increased growth, root volume and plant height in groundnut over control in groundnut (Vaghasia *et al.*, 2007).

Tomar and Singh (2007) found that N application up to 80 kg ha^{-1} and S application up to 30kg ha^{-1} significantly increased the plant height, branches per plant and leaf area index in Indian mustard. Sharma and Arora (2008) studied the effect of gypsum and pyrite as different source of S and confirmed that 25 kg S ha^{-1} as the optimum dose, preferably of ground gypsum, under rainfed condition in reducing the duration of Indian mustard. Makeen *et al.* (2008) concluded that the numbers of leaves, plant height as well as fresh and dry weight of leaves were significantly influenced by the application of S @ 60 kg ha^{-1} in mustard.

3. 3. EFFECT OF N AND S APPLICATION ON YIELD AND YIELD ATTRIBUTES

Singh and Singh (1965) reported that number of fruits per plant increased with increasing levels of N up to 75-90 kg ha^{-1} in bhindi (Syriac and Rajan, 1992). Gupta and Rao (1979) reported that N application above 100 kg ha^{-1} did not increase the number of fruits per plant.

S application @ 30 kg ha^{-1} as gypsum increased the number of nodules, weight of nodules, grain yield of cowpea by 46 per cent and protein by 25 per cent in Rhodic Haplustox soil (Beena, 2000). Increased number of pods as a result of S fertilization was reported by Ramamurthy *et al.* (1997) and Sharma and Singh (1997) in cowpea.

According to Nasreen et al. (2007), the highest diameter of bulb, single bulb weight and yield of onion and the maximum uptake of N and S were recorded by the combined application of 120 kg N ha^{-1} and 40 kg S ha^{-1}. Ahmad (2009) showed that increasing N and S application rates significantly enhanced the bulb weight in onion. Total yield (13.90 per cent), marketable yield (11.81 per cent), culls yield (2.13 per cent), per cent of marketable doubles and bolters also increased with increase in the rates of N and S up to 200 kg N ha^{-1} and 100 kg S ha^{-1}.

Losak *et al.* (2009) by combined application of N (1.2 and 2.4 g N pot^{-1}) and S (25, 35 and 45 ppm S-SO_4^{2-}), found that the yield of kale increased as 64.3-74.2 per cent regardless of S fertilization. In connection with a higher dose of N, the highest dose of S in the soil increased yields by 5.8 per cent. Farooqui *et al.* (2009) concluded that application of 200 kg N ha^{-1} and 60 kg S ha^{-1} significantly increased the yield parameters like neck thickness (0.7492 cm), bulb diameter (95.03 cm), number of cloves per bulb (23.51), fresh weight of 20 cloves (36.76 g), dry weight of 20 cloves (13.78 g), fresh weight of bulb (48.67 g), dry weight of bulb (24.09 g) and bulb yield (165.18 q ha^{-1}) in garlic. Jaggi and Raina (2008) concluded that weight of cloves per 5 bulbs and weight per 100 cloves at 30 kg S ha^{-1} significantly increased over control from 10.5 to 11.9, 98.3 to 141.2 g and from 159 to 217 g in respective manner in garlic.

Rice requires 100 kg N ha^{-1} and 20 kg S ha^{-1} for increased productivity (Oo *et al.,* 2007). Sheela (2007) reported that S application @ 15 kg ha^{-1} is sufficient for enhancing the productivity of rice and in most of the crops the critical limit of S deficiency is 0.20-0.25 per cent . Srivastava and Singh (2007), in a greenhouse experiment, involving factorial combinations of N (0, 15, 30, 45, and 60 mg kg^{-1} soil) and sulfur (0, 7.5, 15.0, 22.5, 30.0 mg kg^{-1} soil) found that the highest grain yield was recorded from the treatment combinations of 60 mg N + 15 mg S kg^{-1} or 45 mg N + 30 mg S kg^{-1}. According to Manivannan *et al.* (2008), growth and yield increased significantly with graded dose of sulfur and addition of 40 kg S ha^{-1} where on an average 15 per cent increase in rice yield over control was seen.

Rice yield and S, N, P and K uptake increased with increasing S rate up to 40 kg ha^{-1}, then decreased or remained the same. (Wani and Refique, 2000). Singh *et al.* (2002) concluded that significant increase in panicles m^{-1} row length, panicle length and grains $panicle^{-1}$ was obtained in rice with increasing levels of N and sulfur up to 150 kg N ha^{-1} and 40 kg S ha^{-1} respectively. The use of S coated urea per m^2 resulted in higher yield than the urea super granules and prilled urea in low land rice (Sankaran and Balasubramanian, 1985). Gypsum coated urea treatment in rice IR 20 registered the highest grain and straw yield. (Jayaramamurthy *et al.*, 1985). Availability, uptake and yield of rice were increased due to application of gypsum in proportion with added levels of urea. (Kandasamy and Arulmozhiselvum, 1985).

Scherer (2001) suggested that additional 250 mg N pot^{-1} were fixed as a result of an optimum S supply @ 200 kg S ha^{-1} in pea. Prasad and Prasad (2003) reported that grain yield, number of pods per plant, number of grains per plant and grain weight per plant increased with increasing S as gypsum up to 30 kg ha^{-1} in pea. S at 30 kg ha^{-1} treated plants had higher grain yield (8.4 q ha^{-1}), pods $plant^{-1}$ (5.52), number of grains per plant (16.12) grain weight per plant (7.79 g) and 1000 grain weight (7.01 g), which were 41.08, 25.31, 24.18, 33.36 and 3.45 per cent higher, respectively, compared to the control. Chaubey and Singh (2004) observed a linear increase in growth and yield attributes with increasing rates of sulfur and the highest yield was achieved at 30 kg S ha^{-1} in pea. A significant increase in grain yield was observed in plants treated with 20 kg S ha^{-1}. Singh *et al.* (2006) reported that the number of pods per plant and fresh vegetable pod yield were significantly higher when vegetable pea was additionally treated with S.

Anwar *et al.* (2002) found that the content of menthol in Japanese mint (*Mentha arvensis*) was highest (84 per cent) with the application of S and N at 25 kg ha^1 and 100 kg ha^{-1} respectively. Kumar *et al.* (2010) concluded that addition of S increased the herb, oil and menthol yield in mint, but combined application of Zn and S with all three NPK levels resulted in higher herb, oil and menthol yield. Total oil yield and total menthol yield was highest due to the application of recommended dose of NPK (150: 60: 40) + Zn + S.

Shinde (2005) concluded that cane yield and single cane weight were highest at 80 kg S ha^{-1} (154.66 t ha^{-1} and 1.66 kg ha^{-1} respectively) and was on par with 60 kg S ha^{-1}. The quality and yield of sugarcane remained unaffected due to both sources of S. Jayaram *et al.* (2010) and reported that S @ 200 kg ha^{-1} (104 kg through N and P source and 96 kg through elemental source) recorded higher cane yield of 182.45 t ha^{-1} under sandy loam soil condition. According to Singh *et al.* (2007), application of S up to 80 kg ha^{-1} increased sugarcane yield significantly from 3.7 to 13.47 t ha^{-1} and 5.03 to 13.32 t ha$^{-1.}$ Navnit and Sinha (2008) reported that the response of S was pronounced at 80 kg ha^{-1} as evident from significant increase in mean cane length (219 cm), number of millable canes (1, 31, 000 ha^{-1}), single cane weight (566.0 g) and cane yield (73.17 t ha^{-1}) in sugarcane. S @ 45 kg ha^{-1} increased the tuber yield and dry matter yield in potato (Sharma *et al.,* 2011).

Jamal *et al.* (2006 a) found that sulfur @ 0 and 20 kg ha^{-1} and N @ 23.5 and 43.5 kg ha^{-1} was applied and the results indicated significant enhancement of the seed yield (90 per cent) and oil yield (103 per cent) in groundnut. Ramdevputra *et al.* (2010) reported that maximum pod yield (1914 kg ha^{-1}) was recorded with the application of S @ 18.5 kg ha^{-1} in addition to the recommended dose of fertilizer as N P K @12.5:25 kg ha^{-1} in groundnut. Chandini (1992) in the red sandy clay loam of Kerala revealed that 25 kg S ha^{-1} increased the number of pods plant^{-1}, weight of pods plant^{-1}, weight of kernals per plant, shelling per cent , oil content and protein content of groundnut kernals.

Vyas *et al.* (2006) suggested that basal application of S @ 40 kg ha^{-1} increased the soybean yield by 21.8 per cent over basal application of N @ 20 kg ha^{-1}. Shelke *et al.* (2007) reported that the average dry matter yield varied from 4.47 to 5.92 g plant^{-1} by application of S up to 45 mg kg^{-1} soil.

Grzebisz *et al.* (2007) suggested that S application @ 25 kg ha^{-1} significantly increased yield of barley grain. Togay *et al.* (2008) observed that the highest grain yield (2, 253-3, 424 kg ha^{-1}) , spike length (6.4-7.9 cm), number of seed per spike (16.4–20), biological yield (7, 325-11, 368 kg ha^{-1}), 1000 seed weight (46.0-51.4 g) were obtained from 160 kg S ha^{-1}, whereas the highest harvest index (27.3 per cent - 36.7 per cent) was obtained by S @ 80 kg ha^{-1} in barley.

Ram *et al.* (2003) reported that seed and stover yields increased significantly up to 180 kg N ha^{-1}, whereas marked beneficial effects on barrenness percentage and days to 50 per cent silking were noticed only up to 120 kg N ha^{-1} in maize cultivars. But barrenness percentage was reduced significantly only up to 20 kg S ha^{-1}, days to 50 per cent silking reduced up to 60 kg S ha^{-1} and the significant increase in yield was observed up to 20 kg S ha^{-1}. Rasheed *et al.* (2004) found that application of fertilizers at the rate of 150+30 and 150+20 kg of N and S ha^{-1} respectively greatly increased dry weight per plant, grains number per ear and grain weight per ear in maize over other treatments. Similarly, the highest grain yield of 8.59 t ha^{-1} and maximum grain oil content was recorded from the plot fertilized at the rate of 150 kg N ha^{-1} and 30 kg S ha^{-1}.

Pasha *et al.* (2007) in an experiment on medium black soil found that, application of 50 kg S ha^{-1} through gypsum can significantly increase the number of productive tillers (77.66 m^{-1}) and grain yield (4.74 t ha^{-1}) of maize. Syed *et al.* (2006) found that stalk yield was maximum (40.07 q ha^{-1}) at 120 kg N ha^{-1} and 60 kg S ha^{-1} and seed yield was maximum (16.73 q ha^{-1}) at 80 kg N and 60 kg S ha^{-1} in sunflower. The optimum dose of N and S was worked out to be 109.51 kg ha^{-1} and 57.80 kg ha^{-1}respectively. Maragatham *et al.* (2007) reported that application of 60 kg S ha^{-1} obtained from Cochin Refinery produced significantly high seed yield (18.7q ha^{-1}) and oil yield (7.4 q ha^{-1}) in sunflower.

Piri and Sharma (2006) concluded that application of 15, 30 and 45 kg S ha^{-1}increased the seed yield by 9, 16 and 23 per cent and oil yield by 13, 22 and 33 per cent respectively in Indian mustard.

S requirement and metabolism are closely related to N nutrition and a positive interaction between these nutrients results in higher yield, higher biomass and protein levels in *Brassica sp* (Bhupinder *et al.*, 2002). Application of 60 kg N ha^{-1} resulted in a significantly higher seed yield (22.12 q ha^{-1}), biological yield (18.7 per cent) and 1000 seed weight. Khan (2004) found that S application @ 40 kg S ha^{-1} in the form of gypsum significantly improved the N accumulation as well as the seed and oil yield in rapeseed-mustard. Makeen *et al.*, (2008) concluded that sulfur application at 60 kg ha^{-1} caused percent increase in yield over the control in mustard and the increase in seed yield was mainly due to increase in siliqua number per plant and number of seeds per siliqua were significantly influenced by the different levels of sulfur.

Sharma *et al.* (2005) noticed that S application significantly increased the number of primary branches, number of siliquae per plant, length of siliqua, and 1000 seed weight of mustard. Kumar *et al.* (2001) found that the optimum seed yield (14.9 q ha^{-1}) was obtained with the application of 65 kg S ha^{-1}. S application up to 32.5 kg S ha^{-1} can increase the stover and total dry matter yields and oil content of seeds.

N application up to 80 kg ha^{-1} significantly increased the yield attributes and seed yield, while stover yield increased up to 120 kg N ha^{-1} in Indian mustard. Oil yield and protein yield also registered higher values with the application of 80 kg N ha^{-1} over 0 and 40 kg N ha^{-1}. Similarly, application of 30 kg S ha^{-1}significantly improved the yield attributes, seed and stover yields. Sulfur application increased both oil content and oil yield (Tomar and Singh, 2007).

According to Salroo *et al.* (2007) increased N levels of up to 60 kg ha^{-1} significantly improved seed and oil yield as well as N and S uptake, whereas the protein yield showed significant improvement with N fertilizer application only up to 30 kg N ha^{-1} in brown sarson. It was also observed that S application at 20 kg ha^{-1} significantly improved seed yield, oil yield, N and S uptake and protein yield compared to the control.

Jackson (2000) reported that higher yield was obtained for Canola (*Brassica napus* L.) when 22 kg S ha^{-1} was applied along with 250 kg N ha^{-1} than that obtained by application of N alone. Bahmanyar and Poshtmasari (2010) reported that the levels of 150 and 225 kg N ha^{-1} resulted in the maximum protein content and the interaction effect between S and N levels showed the highest N content in seed was obtained with 300 kg S ha^{-1} and 225 kg N ha^{-1}.

According to Kumar *et al.* (2002), application of 25 kg S ha^{-1} significantly increased the yield attributes (siliquae per plant, seeds per siliquae and 1000 seed weight) and seed and oil yields of *Brassica species*. The seed and oil yields of *Brassica species* were significantly increased with S application up to 50 kg ha^{-1}.

Singh *et al.* (2002) reported that, among the sources of sulfur, gypsum proved significantly superior with respect to yield attributes (pods per plant and 1000 grain weight), harvest index, and grain (19.04 q ha^{-1}) and straw yields (35.52 q ha^{-1}) in lentil. The yield and yield attributes, protein content in grain and total protein production increased significantly with increasing levels of sulfur up to 40 kg ha^{-1}. Yadav *et al.* (2008) noticed that the seed yield (17.69 q ha^{-1}) of lentil was significantly increased by the application of 40 kg S ha^{-1}.

The yields of cotton fibre and seeds were significantly reduced by S deficiency, as were the quality of cotton seeds, which was reflected in low contents of oil, sugars, starch and proteins and a high concentration of phenols (Chatterjee *et al.*, 2000). N application up to 120 kg ha^{-1} increased the yield significantly and S application at 40 and 80 kg ha^{-1} resulted in significantly higher yield over 120 and 160 kg S ha^{-1}. N and S content at 4.47 per cent and 0.18 per cent respectively were found critical for obtaining optimum yield of tea (Sharma *et al.*, 2002).

Panda and Srivastava (2004) reported that application of 120 ppm N as enriched digested sludge (N enriched to 10 per cent) with 30 ppm S as K_2SO_4 in split doses recorded the highest values for dry matter content (96.38 g pot $^{-1}$), grain yield (66.3 g pot $^{-1}$) and straw yield (73.9 g pot $^{-1}$) in rice. S @ 45 kg ha^{-1} increased dry matter content in potato (Sharma *et al.*, 2011).

Influence of different levels of S on the growth and yield of soybean indicates maximum dry matter accumulation @ 30 kg S ha^{-1} (Singh and Singh, 1996). The enhanced synthesis of chlorophyll facilitated by the addition of S enables the plant to capture greater insolation and thereby result in increased dry matter production. Malik and Sofi (2007) reported that dry matter accumulation increased significantly by the use of *Rhizobium* along with sulfur @ 30 kg S ha^{-1} in soybean.

In order to understand the effect of gypsum application on the performance of groundnut, Geethalakshmi and Lourdraj (1998) conducted field trials and concluded that application of gypsum @ 500 kg ha^{-1} enhanced the dry matter yield in groundnut. Singh *et al.* (2006) concluded that P at 60 kg ha^{-1} and S at 40 kg ha^{-1}, alone, gave maximum dry matter accumulation per plant, pods per plant in blackgram. S nutrition @ 50 and 25 kg ha^{-1} being on par significantly enhanced the yield attributes *viz.,* mature pods, immature pods, peg to pod ratio, pod weight per plant, test weight, shelling and increased dry matter in groundnut over control (Vaghasia *et al.*, 2007).

Seran *et al.* (2004) studied the effect of different levels of S on the growth and productivity of summer sesame and reported that the dry matter production was favourably influenced by the increasing levels of S from 0 to 45 kg ha^{-1}. The increased growth components of the plant due to the application of S attributes itself to the increased chlorophyll synthesis and enhanced photosynthetic activity which finally results in increased dry matter yield. Bharti *et al.* (2001) observed significant increase due to sulfur application was observed up to 15 kg S ha^{-1} in *Brassica juncea.* This was statistically on par with 30 and 45 kg S ha^{-1}. Higher values of seed and stalk yields were recorded at higher doses but it could not show its superiority over 15 kg S ha^{-1} (13.59 q seed and 61.33 q stalk ha^{-1}).

Poonkodi and Poomurugesan (2004) while studying the effect of S on the growth and yield of sunflower found that application of S at increasing rate from 0 to 60 kg ha^{-1} increased the dry matter content and significant response was recorded at 40 kg ha^{-1}. Ravi *et al.* (2008) reported that application of S @ 30 kg ha^{-1} recorded the maximum dry matter production in sunflower. Cyna and Grzebisz (2006) reported that S sufficient barley plants were able to produce higher dry matter yield and decrease N concentration in grains. This phenomenon known as "N dilution effect" stresses the effect of S supply during grain filling on C economy of barley plants. Shelke *et al.* (2007) reported that the average dry matter yield varied from 4.47 to 5.92 g plant^{-1} and there was significant increase in dry matter yield by application of S upto 45 mg kg^{-1} soil in maize.

Ruiter and Martin (2001) observed that N fertilizer strongly increased the N uptake in vegetative parts, but there was little effect of S fertilizer on yield in wheat. Farabhakhsh *et al.* (2006) reported that N and S application did not affect grain weight in oilseed rape. Antagonistic effect of N and S on yield components was observed by Nasreen *et al.* (2007), when they are applied together at higher rates of N (150 kg ha^{-1}) and S (40 kg ha^{-1}). Griffiths *et al.* (2009) concluded that yield was not significantly increased by N and S application in winter wheat cultivars.

3. 4. EFFECT OF N AND S APPLICATION ON CROP QUALITY

The deficiency of S causes accumulation of nitrates, amides and carbohydrates which retard formation of proteins (Tandon, 1989). According to Marschner (1995), the inhibition of protein synthesis with decreasing S supply leads to an accumulation of organic N as the total concentration of N increases. Beena (2000) reported that S application @ 30 kg ha^{-1} increased the protein content (25.39 per cent) compared to POP (19 per cent) in cowpea.

Mathew (2009) found that the acid value (2.00) and saponification value (177.86) was decreased by the application of S @ 30 kg ha^{-1} and iodine value was increased (125) in seasame. The content of unsaturated fattyacid increased and that of saturated fattyacid decreased. The N adsorbed in excess of protein synthesis requirement accumulates as nitrates, amides and free amino acids in wheat and corn (Friedrich and Schrader, 1978). According to Singh and Singh (2002), straw and grain protein yields of rice were significantly improved with increasing levels of N and S application being maximum at 150 kg N ha^{-1} and 40 kg S ha^{-1}. Panda and Srivastava (2004) reported that application of 120 ppm N as enriched digested sludge (N enriched to 10 per cent) with 30 ppm S as K_2SO_4 in split doses recorded the highest values for amylose content (23.55 per cent), protein content (7.20 per cent) in rice. Pasha *et al.* (2007) concluded that application of 50 kg ha^{-1} S through gypsum recorded higher protein content (12.51 per cent) over control (11.70 per cent) in wheat. Togay *et al.* (2008)

reported that application of 160 kg S ha^{-1} increased the protein ratio (9.2 per cent - 11.0 per cent) in barley grain.

In a pot culture experiment Scherer *et al.* (2006) noticed that the amounts of glucose and sucrose in shoots and nodules of pea were significantly reduced under S deficiency conditions. Abbey *et al.* (2002) found that S application differentially influenced Total Soluble Solids in spring onion and it was correlated with increasing per cent dry matter. Ahmad (2009) showed that total soluble salts (14.37 per cent) increased with increase in the rates of N and S up to 200 kg N $ha^{-1}$and 100 kg S ha^{-1} in onion. Ahmad *et al.* (2007) reported that protein content increased from 22.4 per cent to 23.2 per cent as S rate was increased from 0 to 20 kg ha^{-1} in canola. Oil content responded negatively to increasing N levels.

Liu *et al.* (2009) reported that low S supply decreased the pungency of onion. With increasing N supply up to (24.0 mmol L^{-1}), plant growth was significantly inhibited, assimilation of S was retarded, and pungency was decreased. Sutherland *et al.* (2004) suggested that application of sulfur to the soil can increase the sulfur content of leaves in the spring onion and can increase the levels of the amino acid cysteine and its derivatives.

Losak *et al.* (2008) opined that increasing the S level in the soil can significantly reduce the nitrate (NO_3^-) concentrations in the tubers of kohl rabi by 42.2 per cent –53.6 per cent and in the leaves by 8.80 per cent– 21.70 per cent and the histidine concentration increased with increase in S fertilization. Fertilization with ammonium sulfate produced high yield with low nitrate content in broccoli (Elwan *et al.*, 2011). Investigations from Schnung (1990) on lettuce and kale revealed high nitrate concentration at low S supply.

Bhosale *et al.* (2005) suggested that good juice quality and growth characteristics were obtained with 60 and 80 kg S ha^{-1} in sugarcane. Singh *et al.* (2007) studied the effect of sources of S on yield and quality of sugarcane and concluded that sucrose content in cane juice increased from 14.66 per cent to 15.68 per cent and 16.04 per cent to 16.86 per cent at 10^{th} and 12^{th} month crop age in different sources and levels of S.

Srivastava and Singh (2007) in a greenhouse experiment with rice, involving factorial combinations of N and S (60 mg N+15 mg S kg^{-1} or 45 mg N + 30 mg S kg^{-1}) the interaction of N and S influenced the milling (per cent) and other quality parameters significantly. Milling (per cent) and hulling (per cent), cooked grain breadth, and aroma score were found to be significantly and positively correlated with the N: S ratio of rice grain.

S @ 45 kg ha^{-1} increased the sugar content and starch content in potato. (Sharma *et al.*, 2011). S application improves the starch content of potato (Ramamurthy and Susheeladevi, 1981). S application reduces HCN concentration in cassava (Mohankumar *et al.*, 1984).

Singh and Pareek (2003) found that addition of S up to 30 kg ha^{-1} significantly increased grain, straw and protein yield in blackgram. Gypsum increased tryptophan and methionine percentage in chickpea. (Hairam and Dwivedi, 1992). Application of 40 kg S ha^{-1} increased the seed protein content in green gram (Shrikrishna, 1995). Gum content in cluster bean was increased by S application (Bhadoria *et al.*, 1997).

Habtegebrial and Singh (2009) while studying the response of wheat cultivars to N and sulfur for crop yield, NUE, and protein quality in the semiarid region found that sulfur fertilization increased the concentration of cysteine and methionine by 27 per cent and 14 per cent in wheat cultivars. Increasing the amount of N applied significantly increased loaf volume and grain protein in wheat. McGrath *et al.* (2002) reported that loaf volume correlated more closely with grain S concentration than with grain protein and it was associated with a grain N: S ratio of greater than 16: 1.

Zhao *et al.* (1999) reported that bread making quality correlated more closely with grain S concentration than with N concentration and, limiting S availability has been shown to favour the synthesis and accumulation of low-S storage proteins such as ω-gliadin and high molecular weight subunits of glutenin at the expense of S- rich proteins in wheat. Significant responses of bread making quality to the addition of S fertilizers have been established under field conditions. Singh (2007) reported that N and S fertilization improved considerably the protein quality. The concentration of cysteine and methionine was increased by 27 per cent and 14 per cent, respectively with N and S fertilization as compared to N alone in wheat cultivars. Baking quality of wheat is related to disulphide bridging as it is responsible for the polymerization of glutellin (Ewart, 1978).

Lacroux *et al.* (2008) concluded that foliar N and S fertilization (10 kg ha^{1} of N and 5 kg ha^{-1} of S) increased vine N status, yeast available N content in grape vine and enhance aroma expression in grape wines without the negative impact on vigour and Botrytis susceptibility. The wines produced from N+S vines contained more volatile thiols and glutathione. As foliar N as well as foliar N and S applications increases glutathione content in wines, it can be expected that these treatments improve ageing potential of the wines.

Protein content was highest @ 45 kg S ha^{-1} and 60 kg S ha^{-1} and oil content was highest with S @ 45 kg ha^{-1} in sesame (Raja *et al.*, 2007a). S is essential in the biosynthesis of secondary metabolites with high nutritional value that typically accumulate in *Brassica species*. S application significantly improved the content of chlorophyll, flavanols, phenolic acids, glucosinolate and antioxidant activity in *Brassica* (Pascale *et al.*, 2007). Increases in the oleic acid and linoleic acid contents and decreases in the eicosenoic acid and erucic acid contents were recorded in *Brassica* with the application of S with N, when compared with N alone. Protein, N and S contents were maximum from 40 kg S ha^{-1} and 100 kg N ha^{-1} (Ahmad and Abdin, 2000).

Ahmad *et al.* (1999) concluded that the highest nitrate reductase activity, ATP- Sylase activity and yield were achieved with 40 kg S ha^{-1} and 100 kg N ha^{-1} in rapeseed and mustard. According to Ahmad and Abdin (2000), S application increased the oleic acid (18: 1) content and decreased the erucic acid (22: 1) content in rapeseed which led to a reduced 22: 1 or 18: 1 ratio and thus improved the quality of oil. This ratio is closely related to the N: S ratio in mustard seeds. Majumdar *et al.* (2001) concluded that the protein content of soybean grown in a

Typic Hapludalf soil showed an increase of 11.26 per cent over control by the application of 40 kg S ha^{-1}.

Govahi and Saffari (2006) reported that significant increase in protein content (32.8 per cent) of spring canola was obtained with 120 kg S ha^{-1}. Hocking *et al* (2003) suggested that cysteine and methionine decreased by 30 per cent in seeds of S deficient, but N sufficient sunflower plants. Singh *et al.* (2002) reported that protein content in grain and total protein production increased significantly with increasing levels of sulfur up to 40 kg ha^{-1} in lentil.

Munshi and Juneja (2001) observed that application of S significantly enhanced the total lipid content and the proportion of triacylglycerols and correspondingly decreased that of membrane lipids during developmental phases of groundnut kernels. Migge *et al.* (2000) reported that the basic amino acids glutamine, asparagine and arginine accumulated in the leaves of sulfur-deprived tobacco plants which may deteriorate the crop quality.

Sharma and Arora (2008) studied the N and S interactions affecting yield and quality of tea (*Camellia chinensis*) grown on acid soils of Himachal Pradesh and suggested that quality parameters were found positively and significantly affected due to graded application of N and S ranging from 60 to 90 and 40 to 80 kg ha^{-1} respectively. With higher application of these nutrients deterioration in quality was witnessed. Synergistic effects of N and S were seen at N @ 90 kg ha^{-1} and S @ 80 kg ha^{-1}.

3. 5. EFFECT OF N AND S APPLICATION ON CHLOROPHYLL CONTENT

Chaubey *et al.* (2000) reported that S can favourably enhance the chlorophyll synthesis and increase the photosynthetic activity of plants which in turn are evidenced in the growth characters of the plant.

Nanavati *et al.* (1973) observed that chlorophyll content of rice was significantly reduced under conditions of S deficiency. A deficiency of S in rice makes it chlorotic at tillering (Suzuki, 1978).

Qui (1989) found that leaf chlorophyll was increased by S application in wheat and maize. According to Deng *et al.* (1990), application of phosphogypsum to paddy crop increased the chlorophyll content. Beena (2000) found that chlorophyll content in cowpea leaves increased (3.6 mg $100g^{-1}$) by the application of S @ 30 kg ha^{-1} compared to that of POP (1.8 mg $100g^{-1}$).

Singh *et al.* (2006) reported that S application improved the assimilation of photosynthates per unit leaf area due to higher chlorophyll content and enzyme activity in vegetable pea. Karibasappa *et al.* (2007) reported that RDF (Recommended Dose of Fertilizers) + $MgSO_4$ @ 50 kg ha^{-1} increased the chlorophyll content in okra leaves. Tisdale *et al.* (1985) reported that application of S to S deficient soil at 80 kg ha^{-1} improved chlorophyll content from 0. 49 per cent to 1.18 per cent .

To study the effect of sulfur nutrition on the growth and photosynthesis of rice, rice plants (*Oryza sativa* cv. IR72) were grown hydroponically and found that S-deficiency strongly decreased the leaf photosynthesis, which was caused by large decreases in the contents of chlorophyll and ribulose-1, 5-bisphosphate carboxylase/oxygenase (Rubisco) below 0.1 m*M* SO_4^{2-} in the growth solution. (Resurreccion *et al.*, 2001). Sudha (1999) during her work on rice at Cropping System Research Centre, Karamana found out an improvement in growth, chlorophyll content and yield in variety Kanchana by the application of S @ 25kg ha^{-1}.

Khanpara *et al.* (1993) suggested that total chlorophyll content and peroxidase activity increased up to 150 kg S ha^{-1} and leaf-sap pH decreased with application of S in mustard. Vaghasia *et al.* (2007) concluded that S nutrition @ 50 and 25 kg ha^{-1} being on par significantly enhanced the growth in terms of chlorophyll content at 60 DAS in groundnut over control. S fertilization, with a direct effect and an indirect effect through N_2 fixation, increases white clover performances particularly as regards to photosynthesis and potential vegetative reproduction. (Varin *et al.*, 2006)

Mobin (2010) found that the content of total chlorophyll was significantly lower in sulfur-deprived plants at pre-anthesis (44.1 per cent) and at anthesis

(52.4 per cent) in comparison to the sulfur supplied plants in Indian mustard. The rate of photosynthesis in the sulfur supplemented plants was 59.2 per cent and 68.3 per cent more than sulfur deprived *Brassica* plants.

3. 6. EFFECT OF N AND S APPLICATION ON NITRATE REDUCTASE ACTIVITY

Qui (1989) observed an increase in NRA in wheat and maize by S application. Beena (2000) found that NRA in cowpea leaves increased (3.6 NO_2^- $g^{-1}h^{-1}$) by the application of S @ 30 kg ha^{-1} compared to that of POP (1.8 NO_2 $g^{-1}h^{-1}$). Karibasappa *et al.* (2007) reported that RDF and MgSO4 @ 50 kg ha^{-1} increased the Nitrate Reductase Activity in okra leaves. Losak *et al.*, (2009) showed that the nitrate content in kale increased with the applied N, i.e. by 477.4-938.2 per cent . With every increase in N level, there was corresponding increase in the chlorophyll content of leaves as reported by several workers in bhindi (Chauhan and Gupta, 1963); Balasubramoni (1988); Arora *et al.* (1991).

Even though S is not a constituent of chlorophyll, it has been identified as essential for chlorophyll biosynthesis (Tisdale *et al.*, 1985). Similar increase in chlorophyll content of rice by S application was reported by Sudha (1999).

Khan (2004) found that S application @ 40 kg S ha^{-1} in the form of gypsum significantly improved due to the improvement in nitrate reductase activity in the leaves of rapeseed-mustard. Nitrate Reductase (NR) and ATP-Sylase activities in the leaves were strongly correlated with seed yield. The higher seed, oil and protein yields were achieved with the treatment 20 + 20 kg S ha^{-1} combined with 23.5 + 20 kg N ha^{-1} in both the cultivars due to optimization of nitrate reductase activity and ATP-sulfurylase activity, as these parameters were influenced by N and S assimilation.

Any variation from this combination was observed to decrease the activity of these enzymes resulting in reductions in the seed, oil and protein yield of soyabean (Jamal *et al.*, 2006 b). Munshi and Juneja (2001) observed that the nitrate reductase activity is increased by 43 per cent in the nodules and 16 per cent in the leaves of groundnut, coinciding with a significant decrease in the nitrate content in the nodules and leaves, and increase in the nitrite content in both the tissues with the supplementation of S in peanut. S supplementation enhanced Nase activity compared to the control and resulted in the mobilization of starch into soluble sugars, mainly non-reducing sugars in the root nodules.

Migge *et al.* (2000) reported that maximum extractable Nitrate Reductase Activity decreased strongly in response to sulfur- deprivation in tobacco leaves. S fertilization significantly reduced the content of undesirable nitrates by 18.1-44.4 per cent, depending on the dose of N. Sairam *et al.* (1995) conducted an experiment with *Phalaris aquatica* under hydroponic conditions in the glasshouse and concluded that there was increased nitrate-reductase activity at all levels of sulfur and 1.68 μ L^{-1} molybdenum.

Ruiz *et al.* (2005) showed that S deficiency translated as decreased assimilation of NO_3^-, with the lowest activities of the enzymes involved in this processes *viz.* nitrate reductase, nitrite reductase, glutamine synthase, and glutamate synthase and a notable decline in biomass production in mustard. Mobin (2010) concluded that sulfur- deprivation triggers a complex modulation in both N and sulfur assimilation in Indian mustard. Starvation of S reduced the NR activity by 43.7 per cent and 127 per cent at pre-anthesis and anthesis. The reduction in Nitrate Reductase Activity under sulfur deprivation is due to the inhibition of protein synthesis, inactivation of enzyme, and reduced flux of nitrate to the leaf. S application resulted in significant reduction of leaf nitrate content in *Brassica* (Pascale *et al.*, 2007).

Ahmad *et al.* (2010) reported that S application significantly enhanced NRA and physiological changes which resulted in higher seed yield ($P<0.05$) when compared with the S deficient plant. (*Ammi majus* L.).

3. 7. EFFECT OF N AND S APPLICATION ON CONTENT AND UPTAKE OF NUTRIENTS

Singh *et al.* (2002) concluded that significant increase in plant height, tillers m^{-1} row length, dry matter production, panicles m^{-1} row length, panicle length and grains $panicle^{-1}$ was obtained in rice with increasing levels of N and sulfur up to 150 kg N ha^{-1} and 40 kg S ha^{-1} respectively. The total N uptake, grain, straw, and grain protein yields significantly improved with increasing levels of N and sulfur application, being maximum at 150 kg N ha^{-1} and 40 kg S ha^{-1} respectively. Sulfur uptake was also augmented by N and S application.

According to Kumpavat and Jain (2007), S uptake is generally 9-15 per cent of N uptake though it can range from 5-30 per cent and the crops absorb nearly as much S as they absorb P. The usual S content in plant dry matter is 0.1-0.4 per cent (Kharub and Dhillion, 2007).

Sajitharani (1993) reported that there was progressive and significant increase in the uptake of N and P by plant and fruit of bhindi by the application of increased N levels. Beena (2000) reported that application of S @ 30 kg ha^{-1} increased the uptake of all the nutrients in cowpea. Mahmoud (2000) reported that the application of S @1000 kg $feddan^{-1}$ in combination with 0.2 per cent P gave the best results for mineral content (N, K and Fe) in eggplant.

According to Singh *et al.* (2006) the application of S up to 45 kg ha^{-1} significantly increased grain and straw S uptake in blackgram. Arunageetha *et al.* (2006) conducted an experiment to study the effects of S application on nutrient uptake by black gram grown on Typic Ustropept and Vertic Ustropept. The main plot treatments consisted of the control (no amendment), elemental S + *Thiobacillus sp.*, naturally oxidized elemental S, and elemental S + farmyard manure (12.5 t ha^{-1}) + *Thiobacillus sp.*, whereas the subplot treatments consisted of various levels of elemental S (0, 20, 40, 60 and 80 kg ha^{-1}). In experiments I and II, elemental S + FYM + *Thiobacillus sp.* resulted in the greatest uptake of N (47.53 and 64.14 kg ha^{-1} on average, respectively), P (5.03 and 6.05 kg ha^{-1}) and K (18.20 and 24.78 kg ha^{-1}). This treatment also increased the mean S uptake by 20.7 and 41.8 per cent over the control, respectively.

Eriksen *et al.* (2001) suggested that N and S had a clear interactive effect on the uptake of nutrients by all the plant parts with little or no effect of S at low N application rates and similar low effect of N without S application. The sulphate concentration in the different plant parts was markedly affected by the S application rate. About 70 per cent of leaf N was redistributed to the ears in plants growing at adequate S supply compared with about 35 per cent of leaf N in

S-deficient plants. The results suggested that the availability of soil or root S during grain-filling is important for an adequate S supply to the developing grains as the distribution of S to the ears considerably exceeded the amount exported from the leaves.

Piri and Sharma (2006) concluded that content and uptake in both seed and straw increased significantly with increasing level of S up to the highest level of 45 kg ha^{-1}. Application of 15, 30 and 45 kg S ha^{-1} increased uptake by 25, 48 and 65 per cent respectively. Losak *et al.* (2009) showed that the contents of both N and S in the plants increased with the applied dose of these elements (1.2 and 2.4 g N pot^{-1} and 25, 35 and 45 g SO_4^{2-}- S) in the soil, at the same time narrowing the N: S ratio. Kumar *et al.* (2011) reported that application of 80 kg N ha^{-1}significantly improved uptake of N and S @ 54.26 and 57.52 kg ha^{-1}). Among the S level, 45 kg S ha^{-1} being at par with 30 kg S ha^{-1} gave significantly higher S uptake (20.07 and 21.27 kg ha^{-1}).

Oo *et al.* (2007) conducted a field experiment to study the productivity and nutrient uptake in aromatic rice. Various N levels (0, 50,100,150 kg ha^{-1}) and S levels (0, 20, 40, and 60 kg ha^{-1}) had a significant effect on N, P, K and S uptake by grain, straw. Based on the total N uptake (grain + straw), there was 49.9, 63.9 and 70.4 per cent increase in the N uptake over the control with 50, 100 and 150 kg N kg ha^{-1} respectively. He concluded that aromatic rice requires 100 kg N and 20 kg S for increased productivity and uptake of N, P, K and S, under transplanted puddled condition. Singh *et al.* (2007) reported that the content and uptake of N, P and S increased in linear order with increasing levels of external S application up to 40 kg ha^{-1} in sugarcane. Rahman *et al.* (2007) reported that N, P, and K uptake in rice 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}.

Rice plants were grown hydroponically in 1.0 m*M* SO_4^{2-} for one week and transferred to 0, 0.01, 0.03, 0.1, 0.3, or 3 m*M* SO_4^{2-} . An increase in the sulfate concentration in the medium up to 0.03 m*M* resulted in a significant increase in the relative growth rate due to the increase in the net assimilation rate. The leaf blade and leaf sheath showed a linear increase in the total S content at 0 to 0.1 m*M* SO_4^{2-} in the growth solution. Total S content in the roots continued to increase with increased S supply. Changes in the soluble S content followed the same pattern as the total S content but increased proportionally in the leaf sheath and roots (Resurreccion *et al.*, 2001). Srivastava and Singh (2007) in a greenhouse experiment, involving factorial combinations of N and S (60 mg N +15 mg S kg $^{-1}$ or 45 mg N +30 mg S kg $^{-1}$) indicated that the interaction of N and S influenced the N and S content in rice grain, N content in straw and N: S ratio both in grain and straw.

Fernando *et al.* (2009) reported that Sulfur addition showed no effect at the lowest N fertilizer rate, but N uptake was increased when S was applied at the highest N rate, revealing a synergism between both nutrients in wheat. Singh (2007) concluded that N concentration increased significantly from N0 to N2 in wheat cultivars. There was also a marked N-S interaction on the S concentration of grains. Pasha *et al.* (2007) opined that application of 50 kg ha^{-1} S through gypsum recorded significantly higher N, P, K and S uptake (154, 28.70, 104 and 18.57 kg ha^{-1} respectively) in wheat.

S fertilization had a more pronounced effect on the S concentration in leaf tissues of kohlrabi where it increased from 0.50 to 0.58 or to 0.76 per cent and S concentration in the tubers ranged between 0.59 and 0.64 per cent by the application of S @ 25–35–45 mg kg^{-1} in a greenhouse experiment (Losak *et al.*, 2008). S levels significantly improved the uptake of P and S up to 80 kg S ha^{-1} and the increase was 21.4 and 22.2 per cent over the control respectively in sugarcane. (Navnit and Sinha, 2008).

Shelke *et al.* (2007) reported that the mean P uptake value varied from 19.97 to 32.79 mg plant $^{-1}$ that indicated the significant response to S up to 45 mg kg^{-1} in soils containing low available S. The K uptake was significantly increased by S application up to 60 mg kg^{-1} in all soils. The mean K uptake value ranged between 59.84 to 138.31 mg $plant^{-1}$. The mean value of S concentration in soybean plants varied from 0.23 to 0.42 per cent. There was significant increase in the concentration of S in soybean plants due to application of S over control. There was significant increase in S uptake by soybean due to S application up to

60 mg kg^{-1}. The critical concentration of S in plants under Inceptisol soil was found to be 0.23 per cent and the critical level of S in Inceptisol soil for soybean was found to be 13.33 mg kg^{-1}.

Sharma *et al.* (2005) suggested that application of S up to 97.5 kg ha^{-1} increased the S uptake by mustard seeds. Bhati *et al.* (2005) reported that the incorporation of treatments like 100 per cent N and 25 per cent FYM N+ 75 per cent N +100 per cent S significantly enhanced the uptake of N and S in seed and stover of mustard. Highest use efficiency of N and S was noticed in 25 per cent FYM N+ 75 per cent N+ 100 per cent S, followed by the treatments 100 per cent NS and 50 per cent FYM N + 50 per cent N + 100 per cent S respectively. Togay *et al.,* (2008) concluded that P, Cu, Mn, Ca, Mg, Fe and Zn content in grain and shoot were significantly affected by the S applications upto 160 kg S ha^{-1} in mustard. Piri and Sharma (2006) studied the S uptake pattern in Indian mustard with increasing levels of S and found that content and uptake in seed increased up to 15 kg S ha^{-1} and in the next year, it was up to 30 kg S ha^{-1}. Fazili *et al.* (2008) reported that the N content in the plant was increased by 29-148 per cent in rapeseed and 38-166 per cent in taramira with +S+N treatment.

According to Syed *et al.* (2006), uptake of N significantly increased the N uptake by sunflower plants at flowering and by stalk at harvest from 38.31 to 85.99 and 14.95 to 42.41 kg ha^{-1} respectively. The increase in N uptake may be contributed to increase in N concentration and dry matter yield. The uptake of N also increased significantly from 51.28 to 73.69 and 22.32 to 35.81 kg ha^{-1} respectively by S application. It could be due to the profuse vegetative root growth resulting in high absorption of N. Successive increase in S level from 0 to 60 kg ha^{-1} significantly increased S uptake from 3.42 to 7.21 and 1.64 to 5.57 kg ha^{-1} respectively. Nasreen and Ismael (2002) reported that the uptake of N, P, K and S in sunflower was synergistically affected by the application of 60- 80 kg S ha^{-1} in an Albaquept soil. Hocking *et al.* (2003) also noticed that concentration of S and N in plant organs increased with increase in S and N supply in sunflower.

Addition of S significantly increased the nutrient uptake of N, P, K and S in groundnut and the maximum uptake was recorded by gypsum @ 45 kg S ha^{-1}

(Kalaiyarasan *et al.*, 2003). The highest uptake of N, P and K in groundnut was obtained by the application of 125 per cent RDF along with gypsum (Dutta and Mondal, 2006). The enhanced uptake of S with increase in S dose up to 60 kg S ha^{-1} in groundnut (Singh and Mann, 2007) and *Brassica* oil seed crops with 30 kg S ha^{-1} (Malhi *et al*, 2007) and mustard with 45 kg S ha^{-1} (Kumar and Yadav, 2007) was also documented. Mathew (2009) found that application of S improved the uptake of nutrients by *Sesamum*.

The K and S uptake in *Sesamum* was positively influenced by the application of S @ up to 20 kg S ha^{-1} in a light textured Inceptisol. (Thakur and Patil, 2004). Pandiyan and Annadurai (2005) conducted an investigation to understand the interaction effect of P and S on sesame in a Typic Ustochrept soil and found positive response with regard to S applied @ 40 kg ha^{-1} in combination with P @ 100 kg ha^{-1}.

The increase in concentration of N, K, Ca and S in grain and bhusa with increase in level of S was reported in sunflower (Agarwal *et al.*, 2000), groundnut (Bandopadhyay and Samui, 2000) and soybean (Majumdar *et al.*, 2001).

The uptake of N, P, K and S were increased by the application of S @ 30 kg ha^{-1} in rape seed (Sarangthem, 2002), Safflower (Ravi *et al.*, 2008), mustard (Sharma and Arora, 2008) and sunflower (Shekhawat and Shivay, 2008). The synergistic effect of N, P, K and S in soybean up to 40 kg S ha^{-1} was reported by Chaurasiya *et al.* (2009).

Scherer (2001) suggested that in many regions in the world, S deficiency has been recognized as a limiting factor for crop production. To achieve higher yields and to minimize S leaching, rates of S should be recommended on the basis of available soil S and crop requirement. In a pot culture experiment Scherer *et al.* (2006) reported that S and N concentrations in shoots and nodules were significantly decreased under S deficiency conditions.

3. 8. EFFECT OF N AND S APPLICATION ON DISEASE RESISTANCE

S-containing compounds *viz.* thionins, defensins, glucosinolates, crucifer phytoalexins, alliin, and glutathione play some role in the defence mechanism of plants against microbial pathogens (Hell and Bergmann, 1997). Kruse *et al.*

(2007) revealed that contents of cysteine and glutathione increased which serve as markers of primary sulfate assimilation and stress response, in *Arabidopsis thaliana* upon infection, coinciding with the synthesis of sulfur-containing defence compounds.

Haneklaus *et al.* (2004) concluded that application of sulphate fertilizers to soil proved to be significantly reduce infection rate and severity of crops by fungal diseases. The potential efficacy of so called S Induced Resistance (SIR) expressed as a reduction of the disease index ranged from 5–50 per cent and 17–35 per cent in greenhouse and field experiments respectively. This is because of the improved synthesis of S containing phytoalexins, glutathione, glucosinolates and the release of S-containing volatiles.

Sadowski *et al.* (2006) revealed that higher rates of N resulted in an increase in black spot (*Alternaria sp.*) severity in winter oilseed rape. However, simultaneous application with N and S resulted in lower intensity of symptoms of black spot and stem canker. The effects of S on plant health were not clear, but the use of this element together with higher rates of N protected the plants against fungal infection.

Application of sulfur to the soil increased the sulfur content of leaves in the spring onion and increased the levels of the amino acid cysteine and its derivatives, suggesting the breakdown of cysteine and release of H_2S. Application of sulfur to the soil, thus, increased the levels of all the chemicals *viz.*, glutamylcysteine, glutathione and glucosinolates associated with disease resistance. (Sutherland *et al.*, 2004)

Krumbein *et al.* (2001) suggested that arising level of S supply up to 600 mg S plant^{-1} increased the content of the alkyl glucosinolate glucoraphanin and, to a lesser extent, the indole glucosinolate glucobrassicin in broccoli which imparts disease resistance. The content of the alkenyl glucosinolate glucoraphasatin in radish increased up to 150 mg S per container.

Gypsum helps to prevent blossom end rot of water melon and tomatos and bitter pit in apples. Gypsum is preferred over lime for potatoes grown in acid soils so that scab may be controlled. Root rot of avocado trees cased by *Phytophthora* is partially corrected by gypsum and organics (http: //www.diamondkgypsum.com.).

Without S fertilization, application of 150 kg N ha^{-1} caused the decrease of glucosinolates by 11.72 μ mol g^{-1}. Yet, by the application of 150 kg N ha^{-1}, S fertilization significantly increased the amount of accumulated glucosinolates up to 14.58 μ mol g ha^{-1} (Siaudinis, 2010).

Li *et al.* (2007) found that total glucosinolate concentration varied widely from 9.7 ($N_{320}S_{10}$) to 91.6 ($N_{160}S_{60}$) mg 100 g^{-1} root fresh weight and individual glucosinolate concentrations were increased with increasing S supply regardless of the N treatment in turnip. N-containing tryptophan-derived indole glucosinolate was highest with increased N supply, whereas S-containing methionine-derived aromatic and aliphatic glucosinolates decreased with increasing N supply combined at low S level @ 10-20 kg ha^{-1} in turnip. Glucosinolate concentration increased up to 250 kg N ha^{-1} and 150 kg S ha^{-1} in broccoli. (Omirou *et al.*, 2009)

Glucosinolates that are produced in *Brassica species* as a result of optimum S fertilization have been effective in inhibiting soil- borne fungal pathogens, such as " take- all infection" in wheat crop (Angus *et al.* , 1994). Ahmad *et al.* (2007) reported that glucosinolate content in *Brassica* increased from 13.6 to 24.6 μ mol g^{-1} as S rate was increased from 0 to 30 kg ha^{-1} in onion. The highest N level also resulted in the highest value for glucosinolate (19.9 μmol g^{-1}) content.

Significant increases of 2–3 fold were detected in concentrations of sulphate, glutathione and cysteine in inoculated vascular tissues from stems of resistant but not susceptible lines of tomato after infection by *V. dahliae* (Williams *et al.*, 2002). S application in the form of sodium sulphate showed resistance to aphids in barley and sugarbeet (Zelena *et al.*, 2004). Elemental S and many S containing compounds such as cysteine rich antifungal proteins, glucosinolates(GSL) and phytoalexins play important role in plant disease resistance(Dubuis *et al.*, 2005). Compared to fertilized oilseed rape, healthy looking S deficient plants showed increased susceptibility to black leg fungus. S fertilization increase the content of stress-related S-containing metabolites such as cysteine, GSH and H_2S (Salac *et al.*, 2005). Elemental S has been used efficiently against infections of grapes by powdery mildew (*Uncinula necator*) ever since.

3. 9. EFFECT OF N AND S APPLICATION ON USE EFFICIENCY OF N AND S

N directly affects the photosynthetic efficiency of plants, while S affects it indirectly by improving NUE, which was evident from the relationship between N content and photosynthetic rate in the leaves of *Brassica* plants treated with and without S (Ahmed and Abdin, 2000).

Fernando *et al.* (2009) reported that S addition in wheat increased N use efficiency by increasing the N recovery from soil. The concurrent management of N and S is important for reducing the potential pollution of residual soil nitrate. Habtegebrial and Singh (2009) while studying the response of wheat cultivars to N and S for crop yield, NUE, and protein quality in the semiarid region, found that S fertilization with N improved the NUE by 28 per cent in wheat.

Singh (2007) suggested that significant interaction between N and S in wheat cultivars markedly improved the NUE of wheat cultivars (28 per cent). Bhati *et al.* (2005) reported that the highest use efficiency of N and S was noticed in mustard with the application of 25 per cent FYM N+ 75 per cent N+ 100 per cent S. Agronomic efficiency and apparent recovery was maximum at 60 kg N ha^{-1} and 15 kg S ha^{-1}, and it declined with further increases in the levels of N and S in Indian mustard. According to Sharma *et al.* (2005) the agronomic efficiency of applied S decreased with increasing level of the fertilizer. Mean agronomic efficiency of S application was 8.1, 6.1 and 4.3 with the application of 32.5, 65.0 and 97.5 kg S ha^{-1}, respectively and the mean value of recovery on added S (32.5 kg ha^{-1}) varied from 13.8 to 21.6 per cent in mustard. S use efficiency was higher with the lower rate of S. Sachdev and Deb (1990) observed

25 per cent increase in oil yield of mustard due to N+ S application and had a marked increase in the recovery of N and S by the crop resulting in higher NUE and S use efficiency (SUE).

Application of 120 kg S ha^{-1} recorded maximum P-use efficiency (361.6 kg cane kg^{-1} S applied) and apparent P recovery (8.75 per cent) in sugarcane, but it recorded S-use efficiency (121.6 kg cane kg^{-1} S applied) up to 80 kg ha^{-1} level only. There was decrease in apparent S recovery with successive increase in S level from 40 to 120 kg S ha^{-1} (Navnit and Sinha, 2008)

Fismes *et al.* (2000) have shown using field-grown oilseed rape that S deficiency can reduce N use efficiency and that N deficiency can also reduce S use efficiency (SUE).

S was the element that modulated the most important traits for the N fixing lines NNU (Normal Nitrate Uptake) and LNU (Low Nitrate Uptake). N_2 fixation was enhanced when S was added along with N fertilization. S fertilization increased nodule length as well as the proportion of nodules containing leg haemoglobin. S fertilization, with a direct effect and an indirect effect through N_2 fixation, increases white clover performances particularly as regards to photosynthesis and potential vegetative reproduction (Varin *et al.*, 2006). Tallec *et al.* (2009) found that N recovery of *Lolium perenne* grown in mixture was greatly improved by S supply. For *Trifolium repens*, S enhanced its ability to fix N_2 and improved the accumulation of soluble proteins in its stolons.

3. 9. EFFECT OF N AND S APPLICATION ON N: S RATIO

Beena (2000) found that NRA in cowpea leaves increased (3.6 g NO_2 $litre^{-1}h^{-1}$) by the application of S @ 30 kg ha^{-1} compared to that of POP (1.8 g NO_2 $litre^{-1}$ h^{-1}). A number of studies on requirement of the crop in relation to N have been reported (Jamal *et al.*, 2010). There is significant positive N X S interaction in relation to the oil content and yield. Adequate N: S ratio has been found to be 7.5: 1, above which the deficiency of S can be observed (Aulakh *et al.*, 1980). There is a strong relationship between N and S content in plants. The ratio of total N to total S and protein S determine the degree of availability or deficiency of protein.

Experiments with rapeseed showed that N: S ratio of the rapeseed tops sampled at the rosette stage was very sensitive and changes due to change in site, year and seed varieties and these changes were sometimes greater than differences between S sufficient and S deficient rapeseed (Maynard *et al.*, 1983). Dev and Saggar (1974) observed that S application lowered total N: total S ratios in soybean. It was also shown that at the S levels where consistency in total N and S ratios was obtained, one part of S was required for every 14 and 16 parts of N in protein formation in different varieties of soybean.

Dev *et al.* (1981) reported that application of 20 kg S ha^{-1} lowered the N: S ratio in seeds from a range of 14:1-16: 1 to 11: 1-12: 1 and it was further reduced to 10: 1, when S was applied at 40 kg ha^{-1}. The total S content in plants varies with the plant species. In greenhouse trial with subterranean clover, N: S ratio was shown to be less variable with plant age (Freney *et al.*, 1977). Aulakh *et al.* (1977) found an N: S ratio of 15.5: 1 in plant tissue of mustard to be critical, above which the inadequacy of S may cause drastic reduction in grain yield.

Losak *et al.* (2009) concluded that the combined application of N (1.2 and 2.4 g N pot^{-1}) and S (25, 35 and 45 ppm S-SO_4^{2-}) narrowed the N: S ratio. Cyna and Grzebisz (2007) suggested that the threshold values for N and S in leaves in order to achieve the maximum total grain yield is 8.0 for the N: S ratio in barley. Decrease in N: S ratio of grain from 13.17–9.68 by increasing the levels of S fertilization was reported by Sakal *et al.* (1999).

Materials and methods

3. MATERIALS AND METHODS

A field experiment to investigate the interactive effect of nitrogen and sulphur application on their relese pattern and use efficiency in ferralitic soils , was carried out during July-October 2010, at the Instructional farm, College of Agriculture, Vellayani. The details of the experimental site, season, weather conditions, materials used and the methods adopted are presented in this chapter.

3. 1. LOCATION

The experiment was carried out at College of Agriculture,Vellayani. The site is situated at 8^0 30 N latitude and 76^0 54 E longitude and at an altitude of 29 m above MSL.

3. 2. SEASON

The experiment was conducted during the period July 2010 to October 2010.

3. 3. WEATHER

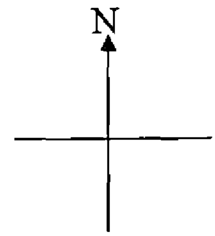
Data on weekly averages of temperature, evaporation, realative humidity and weekly totals of rainfall during the cropping period were collected from the Agro-meteorological observatory attached to the Department of Agronomy, College of Agriculture, Vellayani and are presented in Appendix I.

3. 4. SOIL

The soil of the experimental site belongs to the family of Loamy Skeletal Kaolinitic Isohyperthermic Rhodic Haplustult. The physical and chemical characteristics of the soil where the experiment was conducted are given in Table 1.

Table 1. Physico-chemical properties of the soil at the experiment site

Sl. No.	Parameter	Content
A. Mechanical composition		
	Coarse sand	49.15 %
	Fine sand	14. 4 %
	Silt	6.25 %
	Clay	27.5 %
	Texture	Sandy clay loam
B. Physical properties		
	Particle density	2.38 g / cc
	Bulk density	1.24 g /cc
	Porosity	47.8%
	Water holding capacity	23.4%
C. Chemical properties		
	pH	5. 69
	CEC	3.2 c mol kg^{-1}
	Organic carbon	0.75% (medium)
	Available nitrogen	320.49 kg ha^{-1}
	Available phosphorus	13.50 kg ha^{-1} (medium)
	Available potassium	112.00 kg ha^{-1}(low)
	Exchangeable calcium	2.25 c mol kg^{-1}
	Exchangeable magnesium	1.50 c mol kg^{-1}
	Available sulphur	7.45 kg ha^{-1} (low)



R_1	R_2	R_3
$M_1N_1S_1$	$M_0N_0S_0$	$M_2N_3S_3$
$M_1N_1S_2$	$M_2N_1S_1$	$M_2N_3S_1$
$M_1N_1S_3$	$M_2N_1S_2$	$M_1N_2S_2$
$M_1N_2S_1$	$M_2N_1S_3$	$M_1N_2S_1$
$M_1N_2S_2$	$M_2N_2S_1$	$M_0N_0S_0$
$M_1N_2S_3$	$M_2N_2S_2$	$M_1N_2S_3$
$M_1N_3S_1$	$M_2N_2S_3$	$M_1N_1S_1$
$M_1N_3S_2$	$M_2N_3S_1$	$M_2N_1S_2$
$M_1N_3S_3$	$M_2N_3S_2$	$M_1N_1S_3$
$M_2N_1S_1$	$M_2N_3S_3$	$M_2N_2S_1$
$M_2N_1S_2$	$M_1N_3S_3$	$M_2N_2S_3$
$M_2N_1S_3$	$M_1N_3S_2$	$M_1N_1S_2$
$M_2N_2S_1$	$M_1N_3S_1$	$M_2N_2S_2$
$M_2N_2S_2$	$M_1N_2S_3$	$M_2N_1S_1$
$M_2N_2S_3$	$M_1N_2S_2$	$M_2N_1S_3$
$M_2N_3S_1$	$M_1N_2S_1$	$M_2N_3S_2$
$M_2N_3S_2$	$M_1N_1S_3$	$M_1N_3S_3$
$M_2N_3S_3$	$M_1N_1S_2$	$M_1N_3S_1$
$M_0N_0S_0$	$M_1N_1S_1$	$M_1N_2S_2$

Fig. 1. Layout plan of the experiment

Plate 1. A general view of the experimental plot

3. 5. MATERIALS

3. 5. 1. Planting material and variety

Seed of the okra variety 'Varsha Uphar' was obtained from Department of Olericulture, College of Agriculture, Vellayani. It is a green fruited variety with a duration of 105 days.

3. 5. 2. Manures and fertilizers

Fertilizers used were urea, Rajphos, muriate of potash and gypsum.

Urea	46%	N		
Rajphos	20%	P_2O_5		
Muriate of potash	60%	K_2O		
Gypsum	11.87%	S	and	20.6% Ca

3. 6. DESIGN AND LAYOUT OF THE EXPERIMENT

3. 6. 1. Field Experiment

Crop	: Bhindi
Variety	: Varsha Uphar
Design	: Factorial RBD
Treatments	: 19 (Levels of N-3, Levels of M-2 and levels of S-3 and an absolute control)

2×3×3+1 factorial RBD with the treatments as indicated below.

$M_1N_1S_1$	$M_2N_1S_1$
$M_1N_1S_2$	$M_2N_1S_2$
$M_1N_1S_3$	$M_2N_1S_3$
$M_1N_2S_1$	$M_2N_2S_1$
$M_1N_2S_2$	$M_2N_2S_2$
$M_1N_2S_3$	$M_2N_2S_3$
$M_1N_3S_1$	$M_2N_3S_1$
$M_1N_3S_2$	$M_2N_3S_2$
$M_1N_3S_3$	$M_2N_3S_3$
	$M_0N_0S_0$

M_1 - P_2O_5 @ 8 kg ha^{-1} + K_2O @ 25 kg ha^{-1} (current POP)

M_2 - P_2O_5 @ 35 kg ha^{-1} + K_2O @ 70 kg ha^{-1}(modified POP)

N_1 – N @ 50 kg ha^{-1} , N_2 - N @ 80 kg ha^{-1} , N_3 - N @ 110 kg ha^{-1}

S_1 – S @ 10 kg ha^{-1} , S_2 - S @15 kg ha^{-1} , S_3 - S @ 20 kg ha^{-1}

Current POP : FYM 12 t ha^{-1}+ N @ 50 kg ha^{-1}+ P_2O_5 @ 8 kg ha^{-1}+ K_2O @ 25 kg ha^{-1}.

Modified POP : FYM 12 t ha^{-1}+ N @ 110 kg ha^{-1}+ P_2O_5 @ 35 kg ha^{-1}+ K_2O @ 70 kg ha^{-1}.

Replications : 3

Gross plot size : 3 x 2 m

Spacing : 60 x 45 cm

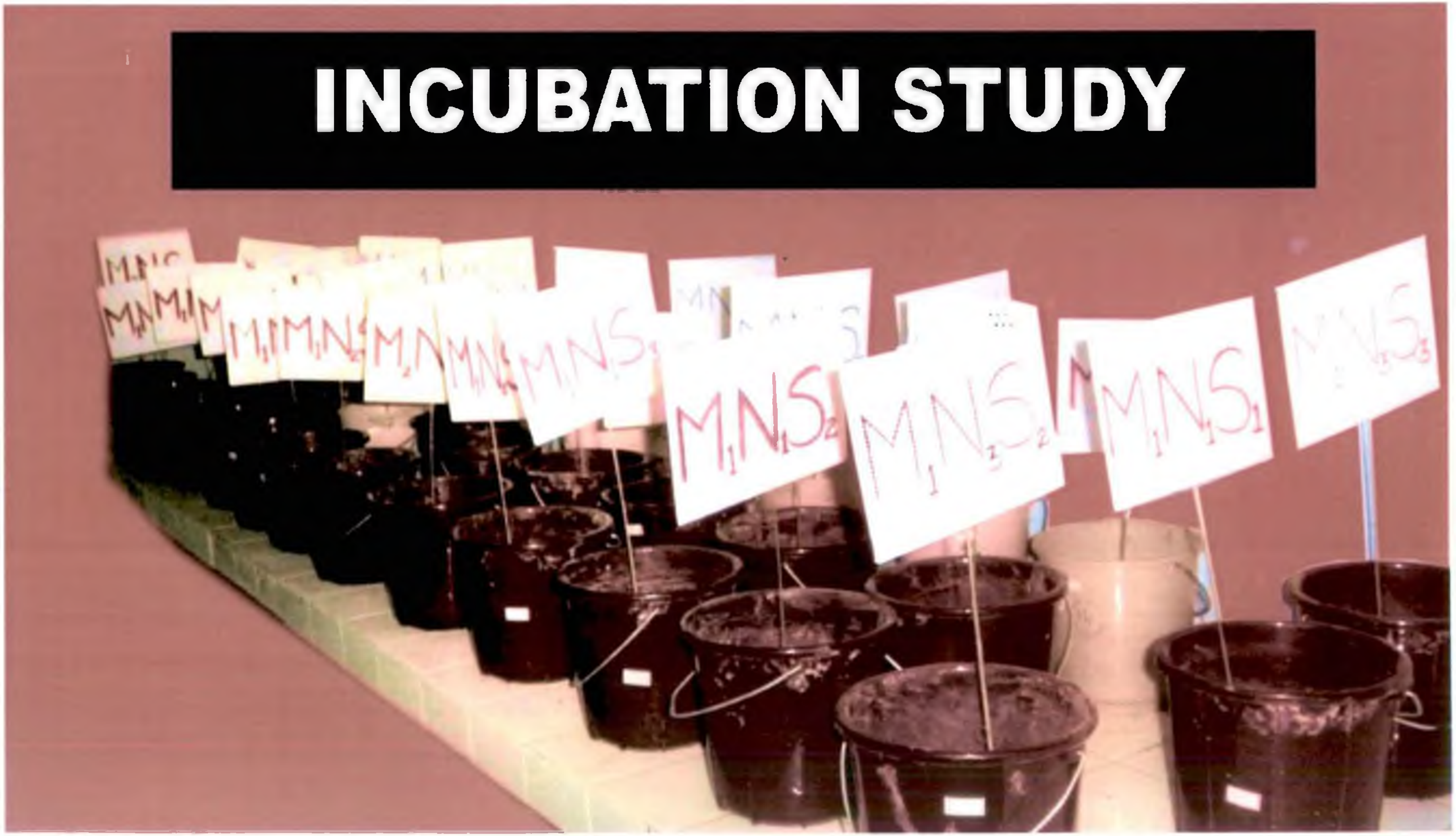


Plate 2. A view of the incubation study

3. 6. 2. Incubation study

An incubation study with the treatments of the field experiment was carried out simultaneously for studying the release pattern of N and S under application of gypsum and N fertilizer. In pots, 2 kilograms of ferralitic soil was kept at field capacity and incubated for a period as that of the field crop and samples were drawn at 50% flowering (30 DAS) and at final harvest of the crop in the field (100 DAS) for analyzing available N, available S and also to test the soil reaction.

Design : Factorial CRD

3. 7. DETAILS OF CULTIVATION

3. 7. 1. Land Preparation

The experimental field was ploughed thoroughly using power tiller, clods were broken and weeds were removed. The field was laid out into blocks and plots.

3. 7. 2. Manure and fertilizer application

The entire quantity of farm yard manure, gypsum, Rajphos, muriate of potash and half the quantity of urea were applied as basal dose. Second dose of urea (25%) was applied at 30 DAS and the other half (25%) at 60 DAS.

3. 7. 3. Sowing

Pits were taken and seeds were dibbled at the rate of three seeds per hole at a spacing of 60 cm between rows and 45 cm between plants.

3. 7. 4. After cultivation

Uniform germination was observed in the field. Gap filling was done four days after sowing. The crop was thinned to one plant per pit one week after emergence. The crop was given regular weeding throughout the cropping period.

Irrigation was given once in two days. Earthing up was also given along with top dressing of nitrogen.

3. 7. 5. Plant protection

For controlling leaf hoppers and white flies, neem oil - garlic emulsion (2%) was applied. Carbaryl 0.15% was sprayed against shoot and fruit borers.

3. 7. 6. Harvesting

Fruits were harvested for vegetable purpose from fifty days after sowing onwards. Subsequent harvests of green, immature fruits were done on alternate days from all the treatments up to 90 days after sowing and the fresh weight were recorded. After the crop period, when the vegetable yield was fallen below the economic level, the plants were pulled out, oven dried and dry weight was recorded.

3. 8. OBSERVATIONS RECORDED

3.8. 1. Biometric observations

3. 8. 1. 1. Days to first flowering

Numbers of days to reach the first flowering were counted from the date of dibbling to the date at which first flowering in a plot was observed.

3. 8. 1. 2. Days to fifty per cent flowering

Number of days to reach fifty percent flowering were counted from the date of dibbling to the date on which flowering was noticed in nearly fifty percent of the population in a plot.

3. 8. 1. 3. Height of the plant

Height of the plant was measured from base of the plant to the terminal leaf bud at 30, 60 and 90 days after dibbling and expressed in centimeters.

3. 8. 1. 4. Length of internode (cm)

The internodal length measured as the vertical distance between two adjacent leaf axils.

3. 8. 1. 5. Fruit length (cm)

The length of the fruits harvested from the observation plants was measured and the mean was worked out and expressed in centimeters.

3. 8. 1. 6. Fruit girth (cm)

The same fruits used for measuring the length were used for finding the girth. Girth was measured by winding a thread around individual fruits at the centre, longitudinally of the fruit.

3. 8. 1. 7. Weight of fruits per plant

Weight of fruits from the observation plants was recorded. Total weight of fruits from observation plants of each plot at different harvests were worked out and expressed as fruit yield per plant.

3. 8. 1. 8. Duration

Duration is the number of days from flowering to final harvest of the plant.

3. 8. 1. 9. Number of fruits per plant

The number of fruits harvested from two observation plants was counted and the average was worked out.

3. 8. 2. Yield characters

Two representative plants selected for recording the shoot characters were used for recording yield and yield attributes.

3. 8. 2. 1. Total dry matter production (shoot)

Total dry matter productions was calculated by adding fruit yield and shoot weight and expressed in kg ha^{-1}.

3. 8. 2. 2. Harvest Index

Harvest Index was calculated using the formula:

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

Where biological yield is the total weight of all the plant parts including fruits and economic yield is the weight of fruits.

3. 8. 2. 3. B: C ratio

B: C ratio was calculated using the formula:

$$\text{B: C ratio} = \frac{\text{Gross Income}}{\text{Cost of cultivation}}$$

3. 8. 2. 4. Scoring for Incidence of Disease

For Yellow vein mosaic virus disease, Percentage Disease Incidence was calculated using the formula:

$$\text{PDI (\%)} = \frac{\text{Number of affected plants}}{\text{Total number of plants}} \times 100$$

3. 8. 2. 5. Nitrogen Use Efficiency (NUE)

NUE was calculated using the formula:

$$\text{NUE (\%)} = \frac{\text{Yield in treated plot (kg ha}^{-1}\text{) - yield in control plot (kg ha}^{-1}\text{)}}{\text{Applied dose of nutrient (kg ha}^{-1}\text{)}} \times 100$$

3. 9. ANALYTICAL PROCEDURES

3. 9. 1. Soil Analysis

Soil samples were taken from the experimental area before the start of the experiment, at fifty percent flowering time and after the experiment. The air dried samples passed through 2mm sieve were used for the analysis of physical, chemical parameters using standard procedures as described in Table 2.

3. 9. 2. Plant analysis

Plant samples were collected at fifty per cent flowering and at final harvest stage of the crop. The samples were oven dried at 70^0 C and powdered and used for the estimation of N, P, K, Ca, Mg and S. Standard procedures adopted are given in Table 3.

3. 9. 2. 1. Chlorophyll content

Chlorophyll content of the leaf was measured at fifty per cent flowering using SPAD Chlorophyll meter and expressed as SPAD value.

3.9. 2. 2. Nitrate Reductase Activity

Nitrate Reductase Activity of the leaf was determined at fifty percent flowering stage [illegible] leaf using the method suggested by Nason and Evans (1955) and is expressed as g NO_2 $litre^{-1}$ h^{-1}.

3. 9. 3. Fruit analysis

Fruits from the sample plants were collected, dried and powdered. Chemical analysis was carried out for the estimation of N, P, K, Ca, Mg and S. Procedures adopted were same as that for plant analysis.

3. 10. STATISTICAL ANALYSIS

Statistical analysis of the data from incubation study and field experiment was carried out using factorial RBD described by Cochran and Cox (1965).

Table 2. Analytical methods followed in soil analysis

	Character	Method	Reference
..	Physical properties		
	Mechanical composition	International pipette method	Piper, (1967)
	Bulk density	Undisturbed core sample	Black *et al.*, (1965)
	Water holding capacity	Undisturbed core sample	Black *et al.*, (1965)
	Porosity	Undisturbed core sample	Black *et al.*, (1965)
II.	Chemical properties		
	pH	pH meter	Jackson, (1973)
	Organic carbon	Walkley and Black's chromic acid wet digestion	Walkley and Black, (1934)
	CEC	Ammonium saturation using neutral normal ammonium acetate & distillation	Jackson, (1973)
	Available N	Alkaline permanganate method	Subbiah and Asija, (1956)
	Available P	Bray No.1 extraction and ascorbic acid reduced molybdo-phosphoric blue colour method	Bray and Kurtz, (1945)
	Available K	Neutral normal ammonium acetate extraction and flame photometry	Jackson, (1973)
	Exchangeable Ca and Mg	Neutral normal ammonium acetate extraction and titration with EDTA	Hesse, (1971)
	Available S	Extraction by $CaHPO_4$ & Turbidimetry	Chesnin and Yein (1950)

Table 3. Analytical methods followed in plant analysis

Sl. No.	Nutrient	Method	Reference
1	N	Microkjeldahl distillation after digestion in H_2SO_4	Jackson, (1973)
2	P	Nitric–perchloric (9:4) acid digestion and colorimetry using vanado-molybdo phosphoric yellow colour method	Jackson, (1973)
3	K	Nitric–perchloric (9:4) acid digestion and flame photometry	Jackson, (1973)
4	Ca and Mg	Nitric–perchloric (9:4) acid digestion and versanate titration with standard EDTA	Piper, (1967)
5	S	Nitric–perchloric (9:4) acid digestion and turbidimetry	Tabatabai and Bremner, (1970)

Results

4. RESULTS

Investigations were carried out at College of Agriculture, Vellayani to study the interactive effect of nitrogen and sulphur application on their release pattern and use efficiency in ferralitic soils using bhindi as a test crop. The experiment consisted of an incubation study and field experiment, which were conducted simultaneously. The results of the study are presented in this section.

4. 1. INCUBATION STUDY

Incubation study was conducted to study the release pattern of N and S from their sources namely urea and gypsum in a ferralitic soil. The effect of levels of N and S and the interaction effect of these nutrients at fifty per cent flowering and at final harvest stage of the crop are presented in Table 4. The soil under incubation study was maintained at field capacity. Soil samples were collected at 30 days and 100 days after incubation which coincides with 50 per cent flowering and final harvest stage of the crop in the field and analyzed for changes in pH, available N and available S.

4. 1. 1. Release pattern of N in soil

Changes in the availability of N by the application of treatments at different stages are given in Table 4.

At 30 DOI, the interaction between M, N and S was found to be non significant. The initial available N status was 320 kg $ha^{-1.}$ By the application of different treatments, the available N status was found to be increased when the samples were analyzed at fifty per cent flowering. The highest available N status of 431.15 kg ha^{-1} was recorded under the treatment which received 110 kg N ha^{-1}, 8 kg ha^{-1} P_2O_5, 25 kg K_2O ha^{-1} and 20 kg S ha^{-1} ($M_1N_3S_3$) followed by 429.87 kg ha^{-1} which was recorded by $M_2N_3S_3$ (110 kg N ha^{-1}, 35 kg ha^{-1} P_2O_5, 70 kg K_2O ha^{-1} and 20 kg S ha^{-1}). The lowest available N status of 329.00 kg ha^{-1} was shown by the control treatment. Interaction between N and S was also in significant. N_3S_2

Table 4. Effect of treatments on release pattern of available nitrogen, available sulphur and changes in pH of the soil (kg ha[-1])

Treatments	Av. N at 50 % flowering	Av. N at final harvest	S at 50 % flowering	S at final harvest	pH at 50 % flowering	pH at final harvest
$M_1N_1S_1$	378.40	335.60	20.78	15.65	7.01	6.34
$M_1N_1S_2$	379.65	337.89	25.05	21.43	7.01	6.35
$M_1N_1S_3$	379.84	336.00	30.46	25.78	7.01	6.40
$M_1N_2S_1$	401.05	359.54	21.65	17.98	7.02	7.00
$M_1N_2S_2$	404.30	363.46	26.78	22.78	7.12	7.04
$M_1N_2S_3$	405.11	365.09	31.23	26.20	7.36	7.23
$M_1N_3S_1$	427.67	382.67	20.67	14.67	7.35	7.29
$M_1N_3S_2$	429.00	385.05	24.89	18.89	7.36	7.27
$M_1N_3S_3$	431.15	387.45	30.09	24.76	7.32	7.27
$M_2N_1S_1$	380.12	334.67	20.67	16.98	7.00	6.81
$M_2N_1S_2$	382.34	336.55	24.43	22.36	7.01	6.84
$M_2N_1S_3$	382.67	335.80	31.54	26.68	7.12	6.82
$M_2N_2S_1$	403.30	360.34	21.64	16.56	7.30	7.18
$M_2N_2S_2$	405.15	361.45	25.35	20.87	7.18	7.04
$M_2N_2S_3$	406.28	363.32	31.32	25.76	7.20	7.14
$M_2N_3S_1$	428.00	383.24	21.90	16.10	7.00	6.86
$M_2N_3S_2$	428.98	384.45	26.75	20.75	7.01	6.89
$M_2N_3S_3$	429.87	384.87	31.56	26.20	7.10	7.01
$M_0N_0S_0$	329.00	283.59	6.45	6.39	7.00	6.20
N_1S_1	379.26	335.13	20.72	16.31	7.01	6.58
N_1S_2	381.00	337.22	24.74	21.90	7.01	6.50
N_1S_3	381.26	335.90	31.00	26.23	7.07	6.43
N_2S_1	402.18	359.94	21.65	17.27	7.16	7.09
N_2S_2	404.73	362.46	26.06	21.83	7.15	7.04
N_2S_3	405.70	364.21	31.28	25.98	7.28	7.19
N_3S_1	427.84	382.96	21.29	15.38	7.18	7.08
N_3S_2	428.99	384.75	25.82	19.82	7.19	7.08
N_3S_3	430.51	386.16	30.83	21.48	7.21	7.14
N_1	380.50	336.09	25.49	21.69	7.03	6.50
N_2	404.20	362.20	26.33	20.23	7.20	7.11
N_3	429.11	384.62	25.98	16.32	7.19	7.10
S_1	403.09	359.34	21.22	21.18	7.11	6.91
S_2	404.90	361.48	25.54	25.90	7.11	6.87
S_3	405.82	362.09	31.03	25.48	7.19	6.92
F-MNS	0.02	0.01	0.02	0.04	0.78	0.20
F-NS	0.01	0.02	0.02	0.16	0.09	0.16
F-N	100.14 **	25.89 **	0.11	1.08	3.27	11.83 **
F-S	0.34	0.09	14.90 **	39.55 **	0.59	0.06
CD-MNS	17.68	34.75	9.27	5.54	0.39	0.74
CD-NS	12.50	24.57	6.56	3.92	0.28	0.52
CD-N& S	7.22	14.19	3.79	2.26	0.16	0.30

(110 kg N ha^{-1} and 15 kg S ha^{-1}) recorded the highest value of 428.99 kg ha^{-1} followed by N_3S_1 (427. 84 kg ha^{-1}). It is clear from the data that there was significant difference between the N levels. The significantly superior available N status of 429.11 kg ha^{-1} was recorded by N_3 (110 kg ha^{-1}) followed by N_2 (404.20 kg ha^{-1}). Coming to the individual effect of S on available N status, there was no significant difference between the S levels. However, application of S @ 20 kg ha^{-1} (S_3) recorded the highest available N status of 405.82 kg ha^{-1} followed by S_2 (404. 90 kg ha^{-1}).

At 100 DOI, there observed a slight decrease in the available N status of the soil and there was no significant difference between the treatments. The highest value of 387.45 kg ha^{-1} was recorded by $M_1N_3S_3$ followed by $M_1N_3S_2$ (385.05 kg ha^{-1}). The lowest value of 283.59 kg ha^{-1} was shown by $M_0N_0S_0$. The interaction between N and S was also non significant. N_3S_3 (110 kg N ha^{-1} and 20 kg S ha^{-1}) recorded the highest value of 386.16 kg ha^{-1} followed by N_3S_2 (384.75 kg ha^{-1}). Regarding the main effect of N, there was significant difference between the N levels. The significantly superior available N status of 384.62 kg ha^{-1} was recorded by the highest dose of N (110 kg ha^{-1}) followed by N_2 (362.20 kg ha^{-1}). Coming to the individual effect of S, there was no significant difference between the S levels. S_3 (20 kg S ha^{-1}) recorded the highest value of 362.09 kg ha^{-1} followed by S_2 (361.48 kg ha^{-1}).

4. 1. 2. Release pattern of available S in soil

The release pattern of available S due to application of treatments is presented in table 4.

The initial S status of the soil was 7.45 kg ha^{-1}. At 30 DOI, the available S status of the soil showed an increasing trend by the application of N as urea and S as gypsum. The interaction between M, N and S was not significant as regard to the available S status in soil. The highest available S status of 31.56 kg ha^{-1} was recorded by $M_2N_3S_3$ followed by $M_2N_1S_3$ (31.54 kg ha^{-1}). The lowest value of 6.45 kg ha^{-1} was shown by $M_0N_0S_0$. The interaction between N and S was also not significant. However, N_2S_3 (80 kg N ha^{-1} and 20 kg S ha^{-1}) recorded the highest value of 31.28 kg ha^{-1} followed by N_1S_3 (31.00 kg ha^{-1}). As regard to the individual effect, there was no significant difference between the N levels. However, N_2 recorded the highest available S status of 26.33 kg ha^{-1} followed by N_3 (25.98 kg ha^{-1}). Coming to the main effect of S, there was significant difference between S levels, S_3 recorded significantly superior value of 31.03 kg ha^{-1} followed by S_2 (25. 54 kg ha^{-1}) and S_1 recorded the lowest value of 21.22 kg ha^{-1}.

A perusal of the data revealed that the interaction between M, N and S was not significant at 100 DOI and there was slight decrease in the available S status of the soil towards the end of incubation (100 DOI). The highest available S status of 26.68 kg ha^{-1} was recorded by $M_2N_1S_3$ followed by $M_1N_2S_3$ and $M_2N_3S_3$ (26.20 kg ha^{-1}) which received the highest dose of S. Even though the interaction between N and S was not significant, N_1S_3 (50 kg N ha^{-1} and 20 kg S ha^{-1}) recorded the highest available N status of 21.69 kg ha^{-1} followed by N_2S_3 (25.98 kg ha^{-1}). Considering the individual effect, there was no significant difference between the N levels. There was significant difference between the levels of S. S_2 which received S @ 15 kg ha^{-1} recorded the significantly superior value of 25.90 kg ha^{-1} and it was on par with S_3 (25.48 kg ha^{-1}) and S_1 recorded the lowest value of 21.18 kg ha^{-1}.

4. 1. 3. Changes in pH

The data on changes in pH by the application of treatments is presented in Table 4.

The initial pH of the soil taken for incubation was 5.69. By the application of N as urea and S as gypsum, there was increase in the pH value to the neutral range. At fifty per cent flowering stage, the highest value of 7.36 was recorded by $M_1N_2S_3$ (80 kg N ha^{-1}, 8 kg ha^{-1} P_2O_5, 25 kg K_2O ha^{-1} and 20 kg S ha^{-1}). All interactions involving M, N and S and their individual effects were found to be non significant. However, the highest value of 7.28 was recorded by N_2S_3 that received 80 kg N and 20 kg S ha^{-1}. As regard to the individual effect of N and S, there was no significant difference between different levels of N and S.

At final harvest stage, there observed a slight decrease in the values and the highest pH value of 7.29 was recorded by $M_1N_3S_1$. It is evident from the data presented in the table that, application of N and S had no significant influence on soil pH. Interaction between N and S was also not significant. The highest value of 7.19 was recorded by N_2S_3 followed by N_3S_3 (7.14). Regarding the individual effect of N, there was significant difference between different N levels. Among the N levels, N_2 (80 kg N ha^{-1}) recorded significantly superior value of 7.11 and it was on par with N_3 (7.10). The lowest value of 6.50 was shown by N_1. Among the S levels, the highest value of 6.92 was shown by S_3 followed by S_1 (6.91) and the lowest value of 6.87 was shown by S_2.

4. 2. FIELD EXPERIMENT

4. 2. 1. Effect of different treatments on biometric characters at different sampling stages

4. 2. 1. 1. *Days to first flowering*

Regarding this parameter, there was no significant difference between the treatments (Table 5). The interaction between N and S was also not significant. However, N_2S_2 which received 80 kg N and 15 kg S ha^{-1} took comparatively shorter duration of 21.25 days for first flowering. Considering the main effect of N and S, there was no significant difference between the different levels of N and S on days to first flowering.

4. 2. 1. 2. *Days to fifty per cent flowering*

Perusal of the data revealed that there was no significant difference between the treatments which involved M, N and S factors, regarding this parameter (Table 5). Among the treatments, $M_0N_0S_0$ took comparatively longer duration 31.00 days for fifty per cent flowering. The interaction between N and S

Table 5. Effect of treatments on days to first flowering, days to fifty per cent flowering and duration from flowering to final harvest stage of the crop

Treatments	Days to first flowering	Days to 50 % flowering	Duration from flowering to final harvest (days)
$M_1N_1S_1$	21.00	26.50	74.00
$M_1N_1S_2$	23.00	28.50	72.00
$M_1N_1S_3$	20.50	29.50	74.50
$M_1N_2S_1$	23.50	30.50	71.50
$M_1N_2S_2$	21.50	28.50	73.50
$M_1N_2S_3$	23.50	30.50	71.50
$M_1N_3S_1$	21.00	31.00	74.00
$M_1N_3S_2$	21.00	29.50	74.00
$M_1N_3S_3$	24.00	31.00	71.00
$M_2N_1S_1$	22.00	30.00	73.00
$M_2N_1S_2$	22.50	30.00	72.50
$M_2N_1S_3$	25.00	31.00	70.00
$M_2N_2S_1$	24.00	30.00	71.00
$M_2N_2S_2$	21.00	32.00	74.00
$M_2N_2S_3$	23.00	29.50	72.00
$M_2N_3S_1$	23.00	28.50	72.00
$M_2N_3S_2$	23.00	31.00	72.50
$M_2N_3S_3$	21.50	30.50	73.50
$M_0N_0S_0$	26.5	31.5	68.5
N_1S_1	21.50	28.25	73.50
N_1S_2	22.75	29.25	72.25
N_1S_3	22.75	30.25	72.25
N_2S_1	23.75	30.25	71.25
N_2S_2	21.25	30.25	73.75
N_2S_3	23.25	30.00	71.75
N_3S_1	22.00	30.00	73.00
N_3S_2	22.00	30.50	73.25
N_3S_3	22.75	30.75	72.25
N_1	22.33	29.25	72.67
N_2	22.75	30.17	72.25
N_3	22.25	30.42	72.83
S_1	22.42	29.50	72.58
S_2	22.00	30.00	73.08
S_3	22.92	30.33	72.08
F-MNS	2.49	0.64	2.54
F-NS	1.39	0.20	1.49
F-N	0.33	0.70	0.45
F-S	0.96	0.33	1.25
CD-MNS	3.41	5.33	3.26
CD-NS	2.41	3.78	2.31
CD-N & S	1.40	2.18	1.33

was also not significant. Regarding the main effect of N and S also, there was no significant difference between the levels of these factors.

4. 2. 1. 3. ***Duration from flowering to final harvest***

It had been statistically observed that the interaction between M, N and S was not significant (Table 5). The longer duration of 74.50 was observed for the treatment which received 80 kg N, 8 kg P_2O_5, 25 kg K_2O and 20 kg S and the lowest value of 68.50 was observed for the control plot. It is clear from the data that the interaction between N and S was also not significant. But, the longest duration from flowering to final harvest was recorded by N_2S_2 recorded (73.75) followed by N_2S_3 (71.75). The data analysis revealed that the main effect of N and S was also non significant.

4. 2. 1. 4. ***Plant height at different growth stages***

Plant height at 30 days, 60 days and 90 days after sowing is presented in Table 6.

Perusal of the data indicated that there was no significant difference between the treatments (Table 6) for plant height at 30 days, 60 days and 90 days after sowing. However, the highest plant height at 30 DAS (62.25 cm) and 90 DAS (159.75 cm) was shown by the treatment which received $M_1N_2S_3$. There was significant difference between the M levels and M_2 (35 kg P_2O_5 and 70 kg K_2O ha^{-1}) recorded the highest plant height of 49.36 cm at 30 DAS. It is obvious from the data that the interaction between N and S was also non significant for plant height at 30 days, 60 days and 90 days after sowing. But, N_2S_2 recorded the highest plant height of 56.63 cm at 30DAS, N_2S_3 at 60 DAS and 90 DAS. Individual effect of N and S was non significant.

Table 6. Effect of treatments on plant height (cm) at different growth stages

Treatments	30 DAS	60 DAS	90DAS
$M_1N_1S_1$	60.50	94.00	120.75
$M_1N_1S_2$	55.00	91.25	121.25
$M_1N_1S_3$	56.00	63.50	70.50
$M_1N_2S_1$	62.25	108.00	127.75
$M_1N_2S_2$	61.75	91.50	112.25
$M_1N_2S_3$	62.25	114.00	159.75
$M_1N_3S_1$	49.25	88.50	116.75
$M_1N_3S_2$	49.50	97.50	125.00
$M_1N_3S_3$	52.50	75.50	120.25
$M_2N_1S_1$	41.25	86.25	116.25
$M_2N_1S_2$	55.25	84.00	111.50
$M_2N_1S_3$	56.50	82.50	107.50
$M_2N_2S_1$	45.25	88.00	113.00
$M_2N_2S_2$	51.50	83.00	124.25
$M_2N_2S_3$	44.25	118.75	143.25
$M_2N_3S_1$	48.25	84.00	101.25
$M_2N_3S_2$	44.25	72.50	101.00
$M_2N_3S_3$	57.75	94.50	118.75
$M_0N_0S_0$	40.25	70.75	99.00
N_1S_1	56.25	73.00	89.00
N_1S_2	53.75	98.00	120.38
N_1S_3	56.63	87.25	118.25
N_2S_1	53.25	116.38	151.50
N_2S_2	48.75	86.25	109.00
N_2S_3	46.88	85.00	113.00
N_3S_1	55.13	85.00	119.50
N_3S_2	54.08	83.58	107.96
N_3S_3	54.54	100.54	130.04
N_1	50.25	85.42	113.83
N_2	51.13	91.46	115.96
N_3	52.88	86.63	115.88
S_1	54.88	91.46	120.00
S_2	1.05	0.21	0.50
S_3	0.73	1.38	1.62
M_1	56.56	91.53	119.36
M_2	49.36	88.17	115.19
F-MNS	50.88	90.13	118.50
F-N	0.79	0.23	0.09
F-S	15.37	42.33	58.50
F-M	8.71 **	2.56	2.02
CD-MNS	55.13	87.63	116.38
CD-NS	10.87	29.93	41.37
CD-N & S	6.27	17.28	23.88
CD-M	5.12	17.28	23.88

4. 2. 1. 5. *Length of internode*

Statistical analysis of the data indicated that there was no significant interaction between M, N and S with regard to this parameter (Table 7) at 30 DAS. The NS interaction also showed the same trend. But, the individual effect of S application had got significance with respect to length of internode. The lowest length of internode was shown by the treatment which received 15 kg S ha^{-1}. At 60 DAS, all the interactions between M, N and S as well as individual effects except M were significant with regard to this parameter. At 90 DAS, there observed no significant difference between treatments, NS interaction and the individual effects, for the length of internodes.

Application of P and K (M) had significant influence on length of internodes at 30 DAS and M_2 which received 35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1} registered the significantly superior value of 7.31 cm compared to M_1 (8.44 cm) where P and K was applied @ 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}.

4. 2. 1. 6. *Fruit length at different growth stages*

Perusal of the data on fruit length at 30 DAS revealed that the interaction between M, N and S was found to be not significant (Table 8). The interaction between N and S was also non significant. It is found from the data that the individual effect of N and S was also not significant but M application had significant influence on fruit length.

At 60 DAS and at 90 DAS, N and S interaction showed significant influence on fruit length. At 90 DAS, N_2S_1 (N @ 80 kg ha^{-1} and S @ 10 kg ha^{-1}) showed the superior value of 23.38 cm. N application also showed significant influence on fruit length at 60 DAS. The highest fruit length was observed in N_1 treatment which was on par with N_2. Towards final harvest, there was no significant difference between the treatments for fruit length. But, the NS interaction effect and individual effect of S were found to be significant. The

Table 7. Effect of treatments on length of internode (cm) at different growth stages

Treatments	30DAS	60DAS	90DAS
$M_1N_1S_1$	8.75	10.50	12.25
$M_1N_1S_2$	7.00	8.50	11.25
$M_1N_1S_3$	10.50	11.00	11.75
$M_1N_2S_1$	9.00	10.00	11.00
$M_1N_2S_2$	7.50	9.50	10.88
$M_1N_2S_3$	9.00	10.25	11.50
$M_1N_3S_1$	7.75	9.13	10.38
$M_1N_3S_2$	7.50	9.75	11.25
$M_1N_3S_3$	9.00	8.95	10.50
$M_2N_1S_1$	7.50	8.00	8.75
$M_2N_1S_2$	7.50	8.75	9.75
$M_2N_1S_3$	8.75	11.00	12.50
$M_2N_2S_1$	7.50	10.75	12.75
$M_2N_2S_2$	7.50	9.25	11.00
$M_2N_2S_3$	7.00	9.25	10.50
$M_2N_3S_1$	5.50	7.00	8.50
$M_2N_3S_2$	6.50	7.75	8.50
$M_2N_3S_3$	8.00	10.25	11.50
$M_0N_0S_0$	4.75	6.75	8.25
N_1S_1	8.13	9.25	10.50
N_1S_2	7.25	8.63	10.50
N_1S_3	9.63	11.00	12.13
N_2S_1	8.25	10.38	11.88
N_2S_2	7.50	9.38	10.94
N_2S_3	8.00	9.75	11.00
N_3S_1	6.63	8.06	9.44
N_3S_2	7.00	8.75	9.88
N_3S_3	8.50	9.60	11.00
N_1	8.33	9.63	11.04
N_2	7.92	9.83	11.27
N_3	7.38	8.80	10.10
S_1	7.67	9.23	10.60
S_2	7.25	8.92	10.44
S_3	8.71	10.12	11.38
M_1	8.44	9.73	11.19
M_2	7.31	9.11	10.42
F-MNS	0.43	3.34 *	2.70
F-NS	1.73	2.98 *	1.45
F-N	2.72	4.40*	3.15
F-S	6.64*	5.76*	2.06
F-M	11.46 **	4.28	3.73
CD-MNS	2.12	1.88	10.50
CD-NS	1.50	1.33	1.79
CD-N & S	0.87	0.77	1.04
CD-M	0.71	0.77	0.84

Table 8. Effect of treatments on fruit length (cm) at different growth stages

Treatments	30 DAS	60 DAS	90 DAS
$M_1N_1S_1$	16.30	17.75	19.00
$M_1N_1S_2$	15.35	17.00	18.25
$M_1N_1S_3$	16.00	20.00	21.25
$M_1N_2S_1$	15.63	21.75	23.00
$M_1N_2S_2$	15.98	22.75	23.50
$M_1N_2S_3$	16.15	15.88	16.75
$M_1N_3S_1$	14.98	17.25	18.25
$M_1N_3S_2$	15.00	20.50	21.25
$M_1N_3S_3$	16.05	21.25	22.25
$M_2N_1S_1$	15.13	23.50	24.50
$M_2N_1S_2$	16.40	22.75	24.00
$M_2N_1S_3$	16.08	24.50	25.25
$M_2N_2S_1$	18.40	22.25	23.75
$M_2N_2S_2$	16.25	17.20	18.00
$M_2N_2S_3$	17.00	16.63	17.50
$M_2N_3S_1$	18.50	18.25	19.00
$M_2N_3S_2$	18.70	18.42	19.75
$M_2N_3S_3$	16.00	15.88	17.00
$M_0N_0S_0$	12.75	13.00	14.00
N_1S_1	15.71	20.63	21.75
N_1S_2	15.88	19.88	21.13
N_1S_3	16.04	22.25	23.25
N_2S_1	17.01	22.00	23.38
N_2S_2	16.11	19.98	20.75
N_2S_3	16.58	16.25	17.13
N_3S_1	16.74	17.75	18.63
N_3S_2	16.85	19.46	20.50
N_3S_3	16.03	18.56	19.63
N_1	15.88	20.92	21.25
N_2	16.57	19.41	20.79
N_3	16.54	18.59	20.00
S_1	16.49	20.13	22.04
S_2	16.28	19.77	20.42
S_3	16.21	19.02	19.58
M_1	15.71	19.35	20.39
M_2	16.94	19.93	20.97
F-MNS	1.05	2.51	2.37
F-NS	0.28	6.28 **	6.30 **
F-N	0.70	5.37*	1.41
F-S	0.09	1.23	5.51 *
F-M	5.16 *	5.37 *	5.51 *
CD-MNS	3.40	3.70	3.88
CD-NS	2.40	2.62	2.74
CD-N & S	1.39	1.51	1.58
CD-M	1.13	1.51	1.58

levels of M showed significant influence on fruit length at 30 DAS and significantly superior fruit length of 16.94 cm was observed with M_2 which received 35 kg P_2O_5 and 70 kg K_2O ha^{-1}.

4. 2. 1. 7. *Fruit girth at different growth stages*

It had been statistically observed that the interaction between MNS, NS and individual effects were not significantly different at 30, 60 and 90 DAS (Table 9). Application of P and K significantly influenced the fruit girth and M_2 that received the maximum dose of P and K registered the superior fruit girth of 6.94 cm compared to M_1 (6.26 cm).

4. 2. 2. Yield and yield attributes

4. 2. 2. 1. *Number of fruits per plant*

It can be observed from the data that the interaction between M, N and S was found to be non significant (Table 10). The highest value of 20.75 was shown by $M_1N_2S_2$ (80 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1}, 25 kg K_2O ha^{-1} and 15 kg S ha^{-1}). The lowest number of fruits of 12.00 was shown by the control. It is evident from the data that the interaction between N and S was also non significant. N_2S_2 recorded the highest number of fruits (17.25).

Among the N levels, the highest value of 16.75 was recorded by N_2 followed by N_3 (14.46). The lowest value of 13.50 was shown by N_1. Among the S levels, application of 15 kg ha^{-1} recorded the highest number of fruits of 15.13 followed by S_3 (14.92) and the lowest value of 14.67 was recorded by S_1.

4. 2. 2. 2. *Yield per plant*

It had been statistically observed that the interaction between M, N and S was not significant (Table 10). The highest value of 10.13 t ha^{-1} was recorded by $M_1N_2S_2$ (80 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1}, 25 kg K_2O ha^{-1} and 15 kg S ha^{-1}) followed

Table 9. Effect of treatments on fruit girth (cm) at different growth stages

Treatments	30DAS	60DAS	90DAS
$M_1N_1S_1$	6.35	7.20	8.00
$M_1N_1S_2$	6.63	7.88	8.63
$M_1N_1S_3$	6.55	8.50	8.98
$M_1N_2S_1$	6.20	8.92	9.23
$M_1N_2S_2$	6.55	7.75	8.18
$M_1N_2S_3$	6.38	7.73	8.30
$M_1N_3S_1$	6.10	7.63	8.30
$M_1N_3S_2$	6.05	7.68	8.08
$M_1N_3S_3$	5.58	7.93	8.27
$M_2N_1S_1$	5.75	6.70	7.05
$M_2N_1S_2$	6.50	7.60	8.05
$M_2N_1S_3$	6.28	7.25	7.75
$M_2N_2S_1$	6.88	9.00	9.25
$M_2N_2S_2$	7.03	8.48	8.88
$M_2N_2S_3$	7.75	7.05	7.48
$M_2N_3S_1$	7.00	8.80	9.08
$M_2N_3S_2$	8.90	7.15	7.63
$M_2N_3S_3$	6.40	6.80	7.23
$M_0N_0S_0$	5.18	6.03	6.33
N_1S_1	6.05	6.95	7.52
N_1S_2	6.56	7.74	8.34
N_1S_3	6.41	7.88	8.36
N_2S_1	6.54	10.31	10.71
N_2S_2	6.79	8.11	8.52
N_2S_3	7.06	7.39	7.89
N_3S_1	6.55	8.21	8.69
N_3S_2	7.48	7.41	7.85
N_3S_3	5.99	7.36	7.75
N_1	6.34	7.52	8.97
N_2	6.80	8.60	8.24
N_3	6.67	7.66	8.00
S_1	6.38	8.49	8.08
S_2	6.94	7.75	9.04
S_3	6.49	7.54	8.10
M_1	6.26	7.91	8.44
M_2	6.94	7.95	8.37
F-MNS	0.86	0.22	0.32
F-NS	1.26	1.51	1.41
F-N	0.96	1.54	1.15
F-S	1.55	1.10	1.35
F-M	5.99 *	1.54	1.35
CD-MNS	1.75	3.46	3.46
CD-NS	1.23	2.45	2.44
CD-N & S	0.71	1.41	1.41
CD-M	0.58	1.41	1.41

Table 10. Effect of treatments on yield and yield attributes

Treatments	Number of fruits per plant	Yield (t ha^{-1})	TDM (shoot) (Kg ha^{-1})	Harvest Index	NUE (%)
$M_1N_1S_1$	13.00	6.92	1537.50	0.26	19.00
$M_1N_1S_2$	15.75	7.39	1537.50	0.31	28.40
$M_1N_1S_3$	13.25	6.05	1781.25	0.30	1.60
$M_1N_2S_1$	17.00	9.55	2043.75	0.41	44.75
$M_1N_2S_2$	20.75	10.13	2062.50	0.33	52.00
$M_1N_2S_3$	17.75	9.27	2268.75	0.31	41.25
$M_1N_3S_1$	20.50	6.85	2287.50	0.31	8.00
$M_1N_3S_2$	13.00	6.49	1650.00	0.31	4.72
$M_1N_3S_3$	13.25	7.82	2568.75	0.31	16.82
$M_2N_1S_1$	13.25	6.63	1781.25	0.30	13.20
$M_2N_1S_2$	13.50	7.23	1631.25	0.31	25.20
$M_2N_1S_3$	15.75	6.47	2006.25	0.34	10.00
$M_2N_2S_1$	15.75	7.46	1218.75	0.36	18.63
$M_2N_2S_2$	13.75	7.49	1425.00	0.27	19.00
$M_2N_2S_3$	15.50	9.89	1687.50	0.31	49.00
$M_2N_3S_1$	12.20	7.25	1837.50	0.36	11.64
$M_2N_3S_2$	14.00	6.08	1575.00	0.27	1.00
$M_2N_3S_3$	14.00	6.65	1518.75	0.34	6.18
$M_0N_0S_0$	12.00	5.97	1050.00	0.45	-
N_1S_1	11.38	6.77	1659.38	0.28	17.61
N_1S_2	14.63	7.31	1584.38	0.31	32.25
N_1S_3	14.50	6.15	1893.75	0.32	9.15
N_2S_1	16.38	8.50	1631.25	0.39	35.10
N_2S_2	17.25	8.81	1743.75	0.30	38.93
N_2S_3	16.63	9.58	1978.13	0.31	52.28
N_3S_1	16.25	7.05	2062.50	0.34	12.29
N_3S_2	13.50	5.91	1612.50	0.29	5.34
N_3S_3	13.63	7.23	2043.75	0.33	14.00
N_1	13.50	6.74	1712.50	0.30	21.67
N_2	16.75	8.97	1784.38	0.33	25.50
N_3	14.46	6.85	1906.25	0.32	25.14
S_1	14.67	7.44	1784.38	0.33	19.67
S_2	15.13	7.47	1646.88	0.30	42.10
S_3	14.92	7.66	1971.88	0.32	10.54
F-MNS	2.14	0.42	0.31	0.13	0.27
F-NS	1.22	0.48	0.24	1.14	0.87
F-N	3.50	5.30 *	0.33	0.59	0.10
F-S	0.07	0.05	0.92	0.82	6.11 **
CD-MNS	6.5	3.96	1234.96	0.13	16.09
CD-NS	4.60	2.80	873.25	0.10	11.38
CD-N & S	2.65	1.62	504.17	0.05	6.57

by $M_2N_2S_3$ (9.89 t ha^{-1}). The lowest value of 5.97 t ha^{-1} was shown by $M_0N_0S_0$. It is explicit from the data that the interaction between N and S was not significant. N_2S_3 recorded the highest value of 9.58 t ha^{-1} followed by N_2S_2 (8.81 t ha^{-1}) and N_1S_3 recorded the lowest value of 6.15 t ha^{1}.

Regarding the main effect of N, there was significant difference between the N levels. The significantly superior value of 8.97 t ha^{-1} was recorded by N_2 which received 80 kg N ha^{-1}, followed by N_3 (6.85 t ha^{-1}) and N_1 recorded the lowest value of 6.74 t ha^{-1}. Coming to the individual effect of S, there was no significant difference between the S levels. S_3 recorded the highest value of 7.66 t ha^{-1} followed by S_2 (7.47 t ha^{-1}). The lowest value of 7.44 t ha^{-1} was shown by S_1 (10 kg ha^{-1})

4. 2. 2. 3. *Total dry matter production (shoot)*

The data analysis showed that there was no significant difference between the treatments (Table 10). $M_1N_3S_3$ showed the highest dry matter production of 2568.75 kg ha^{-1} followed by $M_1N_2S_3$ (2268.75 kg ha^{-1}) and the lowest value of 1050 kg ha^{-1} was recorded by the control treatment. It can be observed from the data that the interaction between N and S was not significant. The individual effect of N and S was also not significant. However, application of N @ 110 kg ha^{-1} resulted in higher dry matter production of 1906.25 kg ha^{-1} followed by N_2 (1784.38 kg ha^{-1}) and application of 20 kg S ha^{-1} recorded the highest value of 1971.88 kg ha^{-1}.

4. 2. 2. 4. *Harvest Index*

The statistical analysis of the data revealed that there was no significant difference between the treatments, NS interaction and individual effects (Table 10). The individual effect of N and S was also not significant. Among the N levels, N_2 recorded the highest value of 0.33 followed by N_3 (0.32).

4. 2. 2. 5. *Nitrogen Use Efficiency*

A perusal of the data revealed that the interaction between M, N and S was not significant (Table 10). The highest NUE of 52.00 per cent was recorded by $M_1N_2S_2$ (80 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1}, 25 kg K_2O $ha^{-1}$and 15 kg S ha^{-1}) followed by $M_2N_2S_3$ (49.00 per cent). It is explicit from the data that the interaction between N and S was not significant. N_2S_3 recorded the highest value of 52.28 per cent followed by N_2S_2 (38.93 per cent). Among the N levels, N @ 80 kg ha^{-1} recorded the highest NUE of 25.50 per cent followed by N_3 (25.14 per cent). The lowest value of 21.67 per cent was shown by N_1. There was significant difference between the S levels. Among the S levels, S application @ 15 kg ha^{-1} recorded significantly superior NUE of 42.10 per cent followed by S_1 (19.67 per cent).

4. 2. 3 Soil analysis

Changes in pH due to application of treatments at different growth stages are presented in Table 11.

4. 2. 3. 1. *Changes in* p^H

By the application of treatments, at first, there was an increase in pH but towards harvest stage, it decreased to a lower value. Statistical analysis of the data indicated that there was no significant difference between the treatments at fifty per cent flowering and at final harvest. The NS interaction and individual effects also showed the same trend.

4. 2. 3. 2. *Organic carbon content*

The initial organic carbon content of the soil was 0.70 per cent and there observed an increase in the value by the application of treatments. It had been statistically verified that at fifty per cent flowering, there was no significant difference between the treatments (Table 11). The highest value of 0.90 per cent was shown by $M_1N_3S_3$ followed by $M_2N_2S_2$ and $M_2N_3S_2$ (0.88 per cent). The lowest value of 0.65 per cent was shown by the control treatment. It is obvious that

Table. 11. Effect of treatments on changes in pH and organic carbon content (%) at different growth stages

Treatments	PH at 50 % flowering	PH at final harvest	Organic Carbon at 50 % flowering	Organic Carbon at final harvest
$M_1N_1S_1$	5.94	5.48	0.70	0.65
$M_1N_1S_2$	6.37	5.95	0.75	0.71
$M_1N_1S_3$	6.56	6.13	0.73	0.67
$M_1N_2S_1$	5.97	5.52	0.78	0.73
$M_1N_2S_2$	5.98	5.57	0.82	0.78
$M_1N_2S_3$	6.31	6.03	0.80	0.76
$M_1N_3S_1$	6.88	6.43	0.85	0.81
$M_1N_3S_2$	6.11	5.70	0.87	0.83
$M_1N_3S_3$	6.38	5.97	0.90	0.86
$M_2N_1S_1$	6.52	6.20	0.73	0.69
$M_2N_1S_2$	6.80	6.62	0.75	0.72
$M_2N_1S_3$	6.07	5.67	0.74	0.60
$M_2N_2S_1$	6.48	6.02	0.83	0.79
$M_2N_2S_2$	6.85	6.55	0.88	0.85
$M_2N_2S_3$	6.50	6.18	0.85	0.81
$M_2N_3S_1$	6.55	6.15	0.86	0.83
$M_2N_3S_2$	6.03	5.76	0.72	0.69
$M_2N_3S_3$	6.08	5.75	0.88	0.85
$M_0N_0S_0$	5.65	5.28	0.65	0.62
N_1S_1	6.23	5.84	0.72	0.67
N_1S_2	6.59	6.29	0.75	0.72
N_1S_3	6.32	5.90	0.74	0.64
N_2S_1	6.23	5.77	0.80	0.76
N_2S_2	6.42	6.06	0.85	0.82
N_2S_3	6.40	6.11	0.83	0.78
N_3S_1	6.72	6.29	0.86	0.82
N_3S_2	6.07	5.73	0.80	0.81
N_3S_3	6.23	5.86	0.89	0.86
N_1	6.38	6.01	0.73	0.67
N_2	6.35	5.98	0.83	0.79
N_3	6.34	5.96	0.85	0.83
S_1	6.39	5.97	0.79	0.75
S_2	6.36	6.03	0.80	0.78
S_3	6.32	5.96	0.82	0.76
F-MNS	0.57	0.47	0.36	0.21
F-NS	2.06	1.47	0.81	0.77
F-N	0.03	0.03	6.81 **	13.47 **
F-S	0.11	0.07	0.31	0.50
CD-MNS	0.81	1.02	0.17	0.16
CD-NS	0.58	0.72	0.12	0.11
CD-N	0.33	0.42	0.07	0.07

the interaction between N and S was also non significant. N_3S_3 (110 kg N ha^{-1} and 20 kg S ha^{-1}) recorded the highest value of 0.89 per cent followed by N_3S_1 (0.86 per cent). As regards to the main effect of N, there was significant difference between the N levels. The highest value of 0.85 per cent was recorded by N_3 (110 kg N ha^{-1}) and it was on par with N_2 (0.83 per cent). The lowest value of 0.73 per cent was shown by N_1 (50 kg N ha^{-1}). There was no significant difference between the S levels. S_3 recorded the highest value of 0.82 per cent followed by S_2 (0.80 per cent). The lowest value of 0.79 per cent was shown by S_1.

At final harvest also, there was no significant difference between the treatments. The highest value of 0.86 per cent was shown by $M_1N_3S_3$ followed by $M_2N_2S_2$ and $M_2N_3S_3$ (0.85 per cent). The lowest value of 0.62 per cent was shown by the control treatment. The interaction between N and S was also non significant. But, the treatment which received highest dose of N and S (N_3S_3) recorded the highest value of 0.86 per cent followed by N_2S_2 and N_3S_1 (0.82 per cent). Considering the main effect of N, there was significant difference between the N levels. The highest value of 0.83 per cent was recorded by N_3 (110 kg ha^{-1}) and it was on par with N_2 (0.79 per cent) which received N @ 80 kg ha^{-1}. There was no significant difference between the S levels.

4. 2. 3. 3. *Available Nitrogen*

A perusal of the data revealed that by the application of Nous fertilizers, there was increase in the availability of N in soil followed by a decrease due to uptake of N by the plant. There was significant difference between the treatments in availability of N due to application of treatments (Table 12). The highest availability of N was recorded by $M_1N_3S_1$ (426.68 kg ha^{-1}) which was significantly higher from all other treatments followed by $M_2N_3S_1$ (407.46 kg ha^{-1}). The lowest value of 329.68 kg ha^{-1} was recorded by the control treatment. The data analysis showed that the interaction between N and S was also significant. Significantly superior value of 417.07 kg ha^{-1} was recorded by N_3S_1 (110 kg N ha^{-1} and 10 kg S ha^{-1}) followed by N_3S_2 (404.17 kg ha^{-1}). The lowest value of 358.48 kg ha^{-1} was

Table 12. Effect of treatments on available N, available P and available K (kg ha^{-1}) status of soil at different growth stages

Treatments	Av. N at 50 % flowering	Av. N at final harvest	Av. P at 50 % flowering	Av. P at final harvest	Av. K at 50 % flowering	Av. K at final harvest
$M_1N_1S_1$	368.50	336.31	23.34	19.00	119.00	117.89
$M_1N_1S_2$	365.69	335.98	24.89	20.00	122.40	120.98
$M_1N_1S_3$	355.25	336.37	27.20	22.52	122.34	120.67
$M_1N_2S_1$	378.68	338.96	24.86	20.52	126.89	124.68
$M_1N_2S_2$	384.23	343.27	25.67	21.86	125.65	123.98
$M_1N_2S_3$	385.73	345.95	24.87	20.87	129.89	127.45
$M_1N_3S_1$	426.68	386.51	27.34	23.63	126.57	125.30
$M_1N_3S_2$	402.00	362.19	23.98	19.89	125.32	124.23
$M_1N_3S_3$	398.16	359.80	26.78	24.02	127.11	125.89
$M_2N_1S_1$	348.45	313.72	42.48	31.50	157.20	153.90
$M_2N_1S_2$	357.56	319.98	46.42	38.86	151.67	149.97
$M_2N_1S_3$	369.10	329.27	44.56	33.07	149.35	147.80
$M_2N_2S_1$	399.12	358.32	46.54	35.34	147.98	144.97
$M_2N_2S_2$	384.83	346.82	45.23	34.98	149.59	146.59
$M_2N_2S_3$	386.56	348.60	45.67	35.20	151.37	149.10
$M_2N_3S_1$	407.46	369.89	41.48	30.98	155.45	153.93
$M_2N_3S_2$	406.34	368.80	43.65	32.45	154.87	152.89
$M_2N_3S_3$	403.69	366.79	45.31	34.89	154.45	152.83
$M_0N_0S_0$	329.68	326.87	18.20	15.40	118.78	116.00
N_1S_1	358.48	325.02	32.91	25.25	138.10	135.89
N_1S_2	361.63	327.98	35.66	29.43	137.04	135.48
N_1S_3	362.18	332.82	35.88	27.80	135.85	134.24
N_2S_1	388.90	348.64	35.70	27.93	137.44	134.83
N_2S_2	384.53	345.05	35.45	28.42	137.62	135.29
N_2S_3	386.15	347.28	35.27	28.04	140.63	138.28
N_3S_1	417.07	378.20	34.41	27.31	141.01	139.61
N_3S_2	404.17	365.50	33.82	26.17	140.10	138.56
N_3S_3	400.93	363.29	36.05	29.46	140.78	139.36
N_1	360.76	328.61	34.81	27.49	136.99	135.20
N_2	386.53	346.99	35.47	28.13	138.56	136.13
N_3	407.39	369.00	34.76	27.64	140.63	139.18
S_1	388.15	350.62	34.34	26.83	138.85	136.78
S_2	383.44	346.17	34.97	28.01	138.25	136.44
S_3	383.08	347.80	35.73	28.43	139.09	137.29
M_1	384.99	349.48	25.44	21.37	125.02	123.45
M_2	384.79	346.91	44.59	34.14	152.44	150.22
F-MNS	19.44 **	31.15 **	0.19	1.35	1.65	1.56
F-NS	9.15 **	29.48 **	0.19	1.66	1.05	1.44
F-N	518.04 **	1057.96 **	0.07	0.21	5.07 *	9.38 **
F-S	7.60 **	13.15 **	5.82	1.31	0.29	0.41
F-M	0.08	12.83 **	115.69 **	233.47 **	859.13 **	116.94 **
CD-MNS	7.47	4.53	11.23	5.27	5.90	4.95
CD-NS	5.28	3.20	7.94	3.73	4.17	3.50
CD-N & S	3.05	1.85	4.58	2.15	2.41	2.02
CD-M	2.49	1.51	3.74	1.76	1.97	1.6492

shown by N_1S_1.As regard to the individual effect of N and S, there was significant difference between different levels of N and S. Among the N levels, application of 110 kg N ha^{-1} recorded significantly superior value of 407.39 kg ha^{-1} followed by N_2 (386.53 kg ha^{-1}).

At final harvest also the same trend was observed. The highest value of 386.51 kg ha^{-1} recorded by $M_1N_3S_1$ followed by $M_2N_3S_2$ (368.80 kg ha^{-1}). The lowest value of 326.87 kg ha^{-1} was recorded by the control treatment. Regarding the NS interaction effects, significantly superior value of 378.20 kg ha^{-1} was recorded by N_3S_1 (110 kg N ha^{-1} and 10 kg S ha^{-1}) followed by N_3S_2 (365.50 kg ha^{-1}). The lowest value of 325.02 kg ha^{-1} was shown by N_1S_1. It is clear that the individual effect of N and S, there was significant difference between different levels of N and S. Among the N levels, 110 kg N recorded significantly superior value of 369 kg ha^{-1} followed by N_2 (346.99 kg ha^{-1}). Among the S levels, the significantly superior value of 350.62 kg ha^{-1} was shown by S_1, followed by S_3 (347.80 kg ha^{-1}) and then S_2 (346.17 kg ha^{-1}).

4. 2. 3. 4. *Available phosphorus*

By the application of treatments, at first there was an increase in available P status when compared to initial value (13 kg ha^{-1}) but towards harvest stage, there occurred a decrease. Statistical analysis of the data at fifty per cent flowering revealed that there was no significant difference between the treatments (Table 12). However $M_2N_2S_1$ (80 kg N, 35 kg P_2O_5, 70 kg K_2O and 10 kg S) recorded the highest value of 46.54 kg ha^{-1} followed by $M_2N_1S_2$ (46.42 kg ha^{-1}) which received higher dose of P_2O_5 and the lowest value of 18.20 kg ha^{-1} was recorded by the control plot. It can be observed from the data that the interaction between N and S was non significant. N_3S_3 recorded the highest value of 36.05 kg ha^{-1} followed by N_1S_3 (35.88 kg ha^{-1}) and N_1S_1 recorded the lowest value of 32.91 kg ha^{-1}. With regard to the main effect of N, there was no significant difference between the different N levels. Among the N levels, N application @ 80 kg ha^{-1} recorded the highest value of 35.47 kg ha^{-1} followed by N_1 (34.81 kg ha^{-1}). The lowest value of 34.76 kg ha^{-1} was recorded by N_3. There was no significant difference between the S levels applied. Among the S levels, S_3 recorded the highest value of 35.73 kg ha^{-1} followed by S_2 (34.97 kg ha^{-1}) and the lowest value of 34.34 kg ha^{-1} was recorded by S_1.

At final harvest also, there was no significant difference between the treatments. But, $M_2N_1S_2$ (50 kg N, 35 kg P_2O_5, 70 kg K_2O and 15 kg S) recorded the highest value of 38.86 kg ha^{-1} followed by $M_2N_2S_1$ (35.34 kg ha^{-1}) and the lowest value of 15.40 kg ha^{-1} was recorded by $M_0N_0S_0$. It can be observed from the data that the interaction between N and S was non significant. Application of highest doses of N and S resulted in highest available P status of 29.46 kg ha^{-1} followed by N_1S_2 (29.43 kg ha^{-1}) and N_1S_1 recorded the lowest value of 25.25 kg ha^{-1}. The main effect of N and S was also non significant. Among the N levels, N_2 recorded the highest value of 28.13 kg ha^{-1}, followed by N_3 (27.64 kg ha^{-1}). The lowest value of 27.49 kg ha^{-1} was recorded by N_1. Among the S levels, highest dose of S (S_3) recorded the highest value of 28.43 kg ha^{-1} followed by S_2 (28.01 kg ha^{-1}) and the lowest value of 26.83 kg ha^{-1} was recorded by S_1.

The data showed that the different M levels had significant influence on available P content in soil and M_2 registered significantly superior value of 44.59 kg ha^{-1} and 34.14 kg ha^{-1} compared to M_1(25.44 and 21.37 kg ha^{-1}) respectively at fifty per cent flowering and at final harvest stage.

4. 2. 3. 5. *Available potassium*

Statistical analysis of the data indicated that there was no significant difference between the treatments (Table 12) at fifty per cent flowering. The highest value of 157.20 kg ha^{-1} was recorded by $M_2N_1S_1$ followed by $M_2N_3S_1$ (155.45 kg ha^{-1}). It was observed that the interaction between N and S was also non significant. It is explicit from the data that there was significant difference between the N levels. The significantly superior value of 140.63 kg ha^{-1} was recorded by N_3 followed by N_2 (138.56 kg ha^{-1}) which were in turn on par. There was no significant difference between the S levels. However, the treatment which received maximum quantity of S as gypsum (S_3) gave the highest available potassium (139.09 kg ha^{-1}).

At final harvest, the highest availability of potassium was recorded by $M_2N_3S_1$ (153.93 kg ha^{-1}) followed by $M_2N_1S_1$ (153.90 kg ha^{-1}) even though there was no significant difference between the treatments. The interaction between N and S was also non significant. Considering the main effect, there was significant difference between the N levels. The significantly superior value of 139.18 kg ha^{-1} was recorded by N_3 followed by N_2 (136.13 kg ha^{-1}). There was no significant difference between the S levels. But, S_3 recorded the highest value of 137.29 kg ha^{-1}.

There was significant difference between the M levels as regard to available K status of soil. M_2 (35 kg P_2O_5 and 70 kg K_2O) registered highest available potassium in soil which received highest dose of K at fifty per cent flowering (152.44 kg ha^{-1}) and at final harvest (150.22 kg ha^{-1}) when compared to M_1 (125.02 kg ha^{-1} and 123.45 kg ha^{-1}).

4. 2. 3. 6. ***Exchangeable calcium***

It can be observed from the data that application of treatments had no significant influence on exchangeable calcium in soil (Table 13). However, the highest value of 3.30 c mol kg^{-1} was recorded by $M_2N_3S_3$ followed by $M_2N_2S_3$ (3.25 c mol kg^{-1}) which received maximum quantity of gypsum. The lowest value of 2.01 was shown by $M_0N_0S_0$. It is explicit from the data that the interaction between N and S was not significant. N_3S_3 recorded the highest value of 3.03 c mol kg^{-1} followed by N_2S_3 (2.90 c mol kg^{-1}) and N_1S_1 recorded the lowest value of 2.75 c mol kg^{-1}. As regard to the individual effect, there was no significant difference between the N levels and S levels. Among the levels of N, N_3 recorded the highest value of 2.89 c mol kg^{-1} followed by N_2 (2.77 c mol kg^{-1}). The lowest value of 2.94 c mol kg^{-1} was shown by N_1. Among the S levels, S_3 recorded the highest value of 2.93 c mol kg^{-1} followed by S_2 (2.80 c mol kg^{-1}).

Table 13. Effect of treatments on exchangeable Ca, Mg (c mol kg^{-1}) & available S (kg ha^{-1}) in soil

Treatments	Ca at 50 % flowering	Ca at final harvest	Mg at 50 % flowering	Mg at final harvest	S at 50 % flowering	S at final harvest
$M_1N_1S_1$	2.25	2.15	1.00	0.25	11.68	9.79
$M_1N_1S_2$	2.50	2.25	1.00	0.25	14.4	11.65
$M_1N_1S_3$	2.75	2.50	0.75	0.20	16.81	13.32
$M_1N_2S_1$	2.55	2.25	0.75	0.30	13.23	10.56
$M_1N_2S_2$	2.75	2.45	1.25	0.25	13.92	11.92
$M_1N_2S_3$	2.95	2.55	0.75	0.25	15.26	12.78
$M_1N_3S_1$	2.65	2.40	0.75	0.20	12.79	10.06
$M_1N_3S_2$	2.85	2.65	0.75	0.20	15.88	13.76
$M_1N_3S_3$	3.00	2.75	1.00	0.20	19.03	16.56
$M_2N_1S_1$	3.25	3.00	1.25	0.25	10.67	8.49
$M_2N_1S_2$	3.35	3.15	0.75	0.25	15.38	11.99
$M_2N_1S_3$	3.55	3.25	0.75	0.25	16.99	13.86
$M_2N_2S_1$	3.15	3.00	1.75	0.35	9.35	8.69
$M_2N_2S_2$	3.35	3.15	0.75	0.20	14.64	12.89
$M_2N_2S_3$	3.45	3.25	0.75	0.25	18.98	16.66
$M_2N_3S_1$	3.25	3.10	1.00	0.30	9.82	8.10
$M_2N_3S_2$	3.35	3.15	1.25	0.25	10.93	10.90
$M_2N_3S_3$	3.55	3.30	0.75	0.20	14.45	14.05
$M_0N_0S_0$	2.00	2.00	0.50	0.15	5.32	4.96
N_1S_1	2.75	2.58	1.13	0.25	11.18	9.14
N_1S_2	2.93	2.70	0.88	0.25	14. 89	11.82
N_1S_3	3.15	2.88	0.75	0.18	16.90	13.59
N_2S_1	2.85	2.63	1.25	0.33	11.29	9.63
N_2S_2	3.05	2.80	1.00	0.18	14.28	12.41
N_2S_3	3.20	2.90	0.63	0.20	17.12	14.72
N_3S_1	2.95	2.75	0.88	0.25	11.31	9.08
N_3S_2	3.10	2.90	1.00	0.18	13.41	12.33
N_3S_3	3.28	3.03	0.88	0.20	16.74	15.30
N_1	2.94	2.72	0.92	0.22	14.32	11.52
N_2	3.03	2.77	0.96	0.23	14.23	12.25
N_3	3.11	2.89	0.92	0.21	13.82	12.24
S_1	2.85	2.65	1.08	0.28	11.26	9.28
S_2	3.02	2.80	0.96	0.20	14.19	12.19
S_3	3.21	2.93	0.75	0.19	16.92	14.54
M_1	2.69	2.44	0.86	0.21	14.78	12.27
M_2	3.36	3.15	1.00	0.23	13.47	11.74
F-MNS	0.01	0.02	0.73	0.37	0.94	0.91
F-NS	0.01	0.01	0.34	0.92	0.12	0.28
F-N	0.33	0.44	0.02	0.26	0.13	0.72
F-S	1.50	1.12	1.05	3.35	14.67 **	28.12 **
F-M	15.55 **	21.12 **	0.54	0.59	2.35	0.85
CD-MNS	1.07	0.98	1.20	0.18	5.38	3.61
CD-NS	0.75	0.69	0.85	0.13	3.81	2.56
CD-N & S	0.44	0.40	0.49	0.07	2.20	1.48
CD-M	0.36	0.33	0.40	0.06	1.79	1.20

At final harvest also, the interaction between M, N and S was not significant. The highest value of 3.55 c mol kg^{-1} was recorded by $M_2N_1S_3$ followed by $M_2N_2S_3$ (3.45 c mol kg^{-1}). It is explicit from the data that the interaction between N and S was not significant. N_3S_3 recorded the highest value of 3.28 c mol kg^{-1} followed by N_2S_3 (3.20 c mol kg^{-1}). As regard to the individual effects, there was no significant difference between the N levels and S levels. Among the levels of N, N_3 recorded the highest value of 3.11 c mol kg^{-1} followed by N_2 (3.03 c mol kg^{-1}). Among the S levels, S_3 recorded the highest value of 3.21 c mol kg^{-1} which received maximum quantity of S as gypsum, followed by S_2 (3.02 c mol kg^{-1}).

The individual effect of M had significant influence on exchangeable Ca status in the soil and M_2 registered the significantly superior Ca status of 3.36 c mol kg^{-1} and 3.15 c mol kg^{-1} compared to M_1 (2.69 c mol kg^{-1} and 2.44 c mol kg^{-1}) at fifty per cent flowering and at final harvest stage respectively.

4. 2. 3. 7. *Exchangeable magnesium*

The data showed that there was decrease in the exchangeable magnesium at flowering and at harvest since there was no addition of Mg during the application of treatments. No significant difference was observed between the treatments at flowering and at harvest stage (Table13).

4. 2. 3. 8. *Available Sulphur*

By the application of treatments, there was an increase in the available S content at flowering and towards harvest stage there was decrease in available S status. A perusal of the data revealed that the interaction between M, N and S was not significant at fifty per cent flowering (Table 13). However, the highest value of 19.03 kg ha^{-1} was recorded by the treatment which received 110 kg N, 8 kg P_2O_5, 25 kg K_2O and 20 kg S ($M_1N_3S_3$) followed by $M_2N_2S_3$ (18.98 kg ha^{-1}). It is explicit from the data that the interaction between N and S was not significant.

N_2S_3 recorded the highest value of 17.12 kg ha^{-1} followed by N_1S_3 (16.90 kg ha^{-1}). Considering the individual effect, there was no significant difference between the N levels. The data analysis showed that there was significant difference between the S levels. Among the S levels, S application @ 20 kg ha^{-1} recorded significantly higher value of 16.92 kg ha^{-1} followed by S_2 (14.19 kg ha^{-1}).

At final harvest stage, the interaction between M, N and S was not significant. The highest value of 16.66 kg ha^{-1} was recorded by $M_2N_2S_3$ followed by $M_1N_3S_3$ (16.56 kg ha^{-1}). The lowest value of 4.96 kg ha^{-1} was shown by $M_0N_0S_0$. It is explicit from the data that the interaction between N and S was not significant. However, application of 80 kg N ha^{-1} and 20 kg S ha^{-1}(N_2S_3) resulted in highest available S status of 15.30 kg ha^{-1} followed by N_2S_3 (14.72 kg ha^{-1}) and N_3S_1 recorded the lowest value of 9.08 kg ha^{-1}. Coming to the individual effects, there was no significant difference between the N levels. But, application of S (S_3 @ 20 kg ha^{-1}) showed significant influence on available S status of soil. Among the S levels, the highest dose of S (S_3) recorded significantly superior value of 14.54 kg ha^{-1} followed by S_2 (12.19 kg ha^{-1}) and S_1 recorded the lowest value of 9.28 kg ha^{-1}.

4. 2. 4. Plant analysis

Plant was analyzed at fifty per cent flowering and at final harvest stage and the data is presented in Tables 14 and 15.

4. 2. 4. 1. *Nitrogen*

It had been statistically observed that the interaction between M, N and S was not significant (Table 14) at fifty per cent flowering stage. The highest value of 2.53 per cent was recorded by $M_1N_3S_2$ and $M_2N_3S_2$. The lowest value of 1.85 per cent was shown by the control treatment. It is revealed from the data that the interaction between N and S was also not significant. However, N_3S_2 (110 kg N ha^{-1} and 15 kg S ha^{-1}) recorded the highest N content in the plant (2.53 per cent)

Table 14. Effect of treatments on N, P and K content (%) of plant at different growth stages

Treatments	N at 50% flowering	N at final harvest	P at 50% flowering	P at final harvest	K at 50% flowering	K at final harvest
$M_1N_1S_1$	2.30	2.19	0.26	0.23	2.34	2.10
$M_1N_1S_2$	2.32	2.26	0.27	0.24	2.58	2.33
$M_1N_1S_3$	2.31	2.22	0.29	0.23	2.40	2.29
$M_1N_2S_1$	2.44	2.31	0.26	0.25	2.38	2.18
$M_1N_2S_2$	2.47	2.36	0.28	0.25	2.59	2.38
$M_1N_2S_3$	2.46	2.33	0.28	0.26	2.47	2.26
$M_1N_3S_1$	2.50	2.38	0.27	0.25	2.32	2.15
$M_1N_3S_2$	2.53	2.41	0.28	0.26	2.56	2.36
$M_1N_3S_3$	2.51	2.40	0.27	0.25	2.49	2.24
$M_2N_1S_1$	2.32	2.20	0.36	0.32	3.32	3.19
$M_2N_1S_2$	2.35	2.23	0.39	0.35	3.56	3.32
$M_2N_1S_3$	2.33	2.21	0.36	0.33	3.43	3.28
$M_2N_2S_1$	2.43	2.32	0.39	0.36	3.36	3.19
$M_2N_2S_2$	2.46	2.35	0.36	0.33	3.50	3.37
$M_2N_2S_3$	2.45	2.33	0.39	0.37	3.41	3.24
$M_2N_3S_1$	2.50	2.41	0.37	0.35	3.39	3.16
$M_2N_3S_2$	2.53	2.44	0.37	0.35	3.56	3.38
$M_2N_3S_3$	2.52	2.43	0.38	0.31	3.47	3.27
$M_0N_0S_0$	1.85	1.81	0.20	0.18	1.21	1.10
N_1S_1	2.31	2.20	0.31	0.27	2.83	2.65
N_1S_2	2.34	2.25	0.33	0.30	3.07	2.82
N_1S_3	2.32	2.22	0.33	0.28	2.92	2.78
N_2S_1	2.44	2.32	0.33	0.31	2.87	2.69
N_2S_2	2.47	2.36	0.32	0.29	3.05	2.88
N_2S_3	2.46	2.33	0.33	0.32	2.94	2.75
N_3S_1	2.50	2.40	0.32	0.30	2.86	2.66
N_3S_2	2.53	2.43	0.33	0.31	3.06	2.87
N_3S_3	2.51	2.42	0.33	0.28	2.98	2.76
N_1	2.32	2.22	0.32	0.28	2.94	2.75
N_2	2.45	2.33	0.33	0.30	2.95	2.77
N_3	2.52	2.41	0.32	0.29	2.97	2.76
S_1	2.42	2.30	0.32	0.29	2.85	2.66
S_2	2.44	2.34	0.33	0.30	3.06	2.86
S_3	2.43	2.32	0.33	0.29	2.95	2.76
M_1	2.43	2.32	0.27	0.25	2.46	2.25
M_2	2.43	2.32	0.37	0.34	3.44	3.27
F-MNS	0.002	0.001	0.49	0.18	0.02	0.06
F-NS	0.004	0.003	0.16	0.40	0.04	0.13
F-N	3.38	1.32	0.06	0.58	0.04	0.05
F-S	0.07	0.06	0.26	0.04	2.11	5.52 *
F-M	0.01	0.01	76.38 **	38.35 **	143.69 **	445.93 **
CD-MNS	0.39	0.62	0.07	0.10	0.52	0.30
CD-NS	0.28	0.44	0.05	0.07	0.37	0.21
CD-N & S	0.16	0.25	0.03	0.04	0.21	0.12
CD-M	0.13	0.21	0.02	0.03	0.17	0.10

followed by N_3S_3 (2.51 per cent). As regard to the individual effect, there was no significant difference between the N levels and S levels. Among the levels of N, the treatment which received the highest value of N recorded the highest value of 2.52 per cent followed by N_2 (2.45 per cent). Among the S levels, application of S @ 15 kg ha^{-1} resulted in highest value (2.44 per cent) for N content in the plant.

At final harvest stage, there was slight reduction in the content of N from that at fifty per cent flowering stage. It had been verified that at final harvest stage, MNS, NS interaction effects and the individual effects of N and S was found to be insignificant. The highest value of 2.44 per cent was recorded by $M_2N_3S_2$ followed by $M_2N_3S_3$ (2.43 per cent). Among the NS interaction effects, treatment which received N @ 110 kg ha^{-1} and S @ 15 kg ha^{-1} recorded the highest value of 2.43 per cent followed by N_3S_3 (2.42 per cent). Among the levels of N, the highest dose of N (110 kg ha^{-1}) resulted in highest N content (2.41 per cent) in the plant at final harvest, followed by N_2 (2.33 per cent). Among the S levels, S_2 (15 kg ha^{-1}) recorded the highest value of 2.34 per cent followed by S_3 (2.32 per cent).

4. 2. 4. 2. *Phosphorus*

It had been statistically verified that there was no significant difference between the treatments. Even though there was no significant difference between the treatments, the levels of M shows significance at fifty per cent flowering stage. It can be observed from the data that the NS interaction and their individual effects were insignificant. Among the N levels, N_2 (80 kg ha^{-1}) recorded the highest plant content of 0.33 per cent. Among the S levels, S_2 and S_3 recorded the highest value of 0.33 per cent.

At final harvest stage, it can be observed that there was no significant difference between the treatments. However, the treatment which received 80kg N, 35 kg P_2O_5, 70 kg K_2O and 20 kg S ($M_2N_2S_3$) recorded the highest value of 0.37 per cent followed by $M_2N_2S_1$(0.36 per cent) and the lowest value of 0.18 per cent was recorded by the control. It can be observed from the data that the interaction between N and S was non significant. N_2S_3 recorded the highest plant P of 0.32 per cent followed by N_2S_1 and N_3S_2 (0.31 per cent). Considering the main effect of N and S, there was no significant difference between the different N levels and S levels. Among the N levels, N_2 (80 kg ha^{-1}) recorded the highest content of 0.30 per cent followed by N_3 (0.29 per cent) and the lowest value of 0.28 per cent was shown by N_1. Among the S levels, S_2 (15 kg ha^{-1}) recorded the highest value of 0.30 per cent.

At fifty per cent flowering and at final harvest stage, the plant P content was significantly influenced by the different levels of M. M_2 that received 35 kg P_2O_5 and 70 kg K_2O ha^{-1} recorded the maximum P content of 0.37 per cent and 0.34 per cent respectively at fifty per cent flowering and at final harvest stage.

4. 2. 4. 3. *Potassium*

The content of K in plant was highest for the treatments $M_2N_1S_2$ and $M_2N_3S_2$, followed by $M_2N_2S_2$ which received highest dose of K (Table 14) at fifty per cent flowering stage. A perusal of the data revealed that there was no significant difference between the treatments. It can be observed from the data that the interaction between N and S and the main effect of N and S were also non significant.

At final harvest stage, the interaction between M, N and S was not significant. But, the treatment which received 110 kg N, 35 kg P_2O_5, 70 kg K_2O and 15 kg S ha^{-1} ($M_2N_3S_2$) recorded the highest K content (3.38 per cent) of plant followed by $M_2N_2S_2$ (3.37 per cent). The interaction between N and S also was non significant. However, N_2S_2 recorded the highest plant K of 2.88 per cent followed by N_3S_2 (2.87 per cent). Even though, the individual effect of N was not significant, N_2 recorded the highest value of 2.77 per cent followed by N_3 (2.76 per cent). Coming to the main effect of S, there was significant difference between the S levels. S application @ 15 kg ha^{-1} (S_2) recorded significantly higher value of 2.86 per cent which was on par with S_3 (2.76 per cent).The lowest value of 2.66 per cent was shown by S_1.

There observed significant difference among the M levels, M_2 (35 kg P_2O_5 and 70 kg K_2O) which received highest dose of K registered highest plant potassium content of 3.44 per cent and 3.27 per cent respectively ay fifty per cent flowering and at final harvest stage of the crop when compared to M_1 that received 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}.

4.2.4. 4. *Calcium*

At fifty per cent flowering, the application of M, N and S factors registered no significant difference between treatments (Table 15). However, $M_2N_2S_3$ (80 kg N, 35 kg P_2O_5, 70 kg K_2O and 20 kg S) recorded the highest value of 1.75 per cent, followed by $M_2N_3S_3$ (1.74 per cent). The lowest Ca content of 1.20 per cent was shown by the control treatment. It is observed that even though the interaction between N and S was not significant, N_3S_3 which received the higher dose of N and S recorded the highest content of Ca (1.60 per cent) followed by N_1S_3 (1.59 per cent). The main effect of N and S also registered a non significant value. Among the N levels, N_3 recorded the highest value of 1.52 per cent followed by N_2 (1.51 per cent). Coming to the main effect of S, S_3 (20 kg S ha^{-1}) recorded the highest value of 1.59 per cent followed by S_2 (1.50 per cent).

At final harvest stage also, the combined application of M, N and S factors together recorded a non significant value. But, from the data, it can be observed that $M_2N_2S_3$ recorded the highest value of 1.67 per cent followed by $M_2N_3S_3$ (1.65 per cent). The lowest value of 1.12 per cent was shown by $M_0N_0S_0$. The interaction between N and S factors was also not significant. However, N_3S_3 recorded the highest content of Ca (1.52 per cent) followed by N_2S_3 (1.51 per cent). It is clear that the main effect of N and S was also non significant. Among the N levels, N_3 (110 kg ha^{-1}) recorded the highest value of 1.43 per cent followed by N_2 (1.41 per cent) and the lowest value of 1.36 per cent was shown by N_1.

Table 15. Effect of treatments on Ca, Mg and S content (%) of plant at different growth stages

Treatments	Ca at 50% flowering	Ca at final harvest	Mg at 50% flowering	Mg at final harvest	S at 50% flowering	S at final harvest
$M_1N_1S_1$	1.28	1.16	0.18	0.16	0.23	0.20
$M_1N_1S_2$	1.32	1.23	0.22	0.21	0.24	0.23
$M_1N_1S_3$	1.44	1.33	0.24	0.22	0.26	0.24
$M_1N_2S_1$	1.26	1.15	0.23	0.21	0.25	0.23
$M_1N_2S_2$	1.37	1.26	0.25	0.24	0.27	0.26
$M_1N_2S_3$	1.44	1.34	0.28	0.27	0.30	0.29
$M_1N_3S_1$	1.32	1.25	0.20	0.18	0.22	0.20
$M_1N_3S_2$	1.39	1.29	0.23	0.21	0.25	0.23
$M_1N_3S_3$	1.46	1.38	0.25	0.22	0.27	0.24
$M_2N_1S_1$	1.50	1.42	0.31	0.28	0.33	0.30
$M_2N_1S_2$	1.64	1.45	0.33	0.30	0.35	0.32
$M_2N_1S_3$	1.73	1.64	0.37	0.34	0.37	0.36
$M_2N_2S_1$	1.56	1.49	0.32	0.30	0.34	0.32
$M_2N_2S_2$	1.65	1.53	0.34	0.33	0.36	0.35
$M_2N_2S_3$	1.75	1.67	0.37	0.35	0.39	0.37
$M_2N_3S_1$	1.56	1.48	0.30	0.28	0.32	0.30
$M_2N_3S_2$	1.63	1.54	0.32	0.31	0.34	0.33
$M_2N_3S_3$	1.74	1.65	0.35	0.33	0.37	0.35
$M_0N_0S_0$	1.20	1.12	0.16	0.11	0.20	0.16
N_1S_1	1.39	1.26	0.25	0.22	0.28	0.25
N_1S_2	1.48	1.34	0.27	0.26	0.30	0.27
N_1S_3	1.59	1.48	0.31	0.28	0.32	0.30
N_2S_1	1.41	1.32	0.27	0.26	0.30	0.28
N_2S_2	1.51	1.40	0.30	0.29	0.32	0.31
N_2S_3	1.60	1.51	0.33	0.31	0.35	0.33
N_3S_1	1.44	1.37	0.25	0.23	0.27	0.25
N_3S_2	1.51	1.42	0.28	0.26	0.30	0.28
N_3S_3	1.60	1.52	0.30	0.27	0.32	0.30
N_1	1.49	1.36	0.27	0.25	0.30	0.27
N_2	1.51	1.41	0.30	0.28	0.32	0.30
N_3	1.52	1.43	0.28	0.26	0.29	0.28
S_1	1.41	1.32	0.26	0.24	0.28	0.26
S_2	1.50	1.38	0.28	0.27	0.30	0.29
S_3	1.59	1.50	0.31	0.29	0.33	0.31
M_1	1.36	1.26	0.23	0.21	0.25	0.24
M_2	1.64	1.54	0.33	0.31	0.35	0.33
F-MNS	0.01	0.02	0.01	0.05	0.01	0.03
F-NS	0.00	0.03	0.01	0.03	0.03	0.01
F-N	0.03	0.27	0.59	1.43	0.65	0.83
F-S	0.81	1.94	2.33	3.40	1.95	1.95
F-M	5.68 *	12.96 **	26.16 **	35.44 **	27.45 **	22.21 **
CD-MNS	0.73	0.49	0.13	0.11	0.12	0.13
CD-NS	0.52	0.35	0.09	0.08	0.08	0.09
CD-N & S	0.30	0.20	0.05	0.04	0.05	0.05
CD-M	0.24	0.16	0.04	0.04	0.04	0.04

Coming to the main effect of S, S_3 recorded the highest Ca content of 1.50 per cent followed by S_2 (1.38 per cent).

There was significant difference between the M levels and M_2 (35 kg P_2O_5 and 70 kg K_2O) recorded the highest Ca content of 1.64 per cent at 50 per cent flowering and 1.54 per cent at final harvest stage.

4. 2. 4. 5. *Magnesium*

The Mg content of the plant was high at fifty per cent flowering when compared to final harvest (Table 15). At fifty per cent flowering, it was found that there was no significant difference between the treatments. However, $M_2N_2S_3$ and $M_2N_1S_3$ recorded the content of 0.37 per cent followed by $M_2N_3S_2$ (0.35 per cent) and the lowest content of 0.16 per cent was shown by the control treatment. Even though the interaction between N and S was also not significant, N_2S_3 recorded the highest value of 0.33 per cent .As regards to the main effect of N and S, there was no significant difference between the different N levels and S levels. Among the N levels, N_2 @ 80 kg ha^{-1} recorded the highest Mg content of 0.30 per cent followed by N_3 (0.28 per cent) and among the S levels, S_3 recorded the highest Mg content (0.31 per cent) followed by S_2 (0.28 per cent).

The data analysis showed that at final harvest stage, there was no significant difference between the treatments. $M_2N_2S_3$ recorded the highest Mg content of 0.35 per cent followed by $M_2N_1S_3$ (0.34 per cent) and the lowest value of 0.11 per cent was recorded by $M_0N_0S_0$. It can be observed from the data that the interaction between N and S was non significant. N_2S_3 recorded the highest Mg content of 0.31 per cent followed by N_2S_2 (0.29 per cent). For the main effect of N and S also, there was no significant difference between the different N levels and S levels. Among the N levels, N_2 recorded the highest Mg content of 0.28 per cent followed by N_3 (0.26 per cent). Among the S levels, S_3 @ 20 kg ha ha^{-1} recorded the highest value of 0.29 per cent followed by S_2 (0.27 per cent). At fifty per cent flowering and at final harvest stage, the plant Mg content was significantly influenced by the different levels of M. M_2 that received 35 kg P_2O_5 and 70 kg K_2O ha^{-1} recorded the highest Mg content of 0.33 per cent and 0.31 per cent respectively at fifty per cent flowering and at final harvest stage.

4. 2. 4. 6. *Sulphur*

The content of S was high at fifty per cent flowering of the crop when compared to harvest stage. At fifty per cent flowering, it can be observed that the interactive effect of M, N and S factors was not significant (Table 15). The highest S content of 0.39 per cent was recorded by $M_2N_2S_3$ .The lowest content of S (0.20 per cent) was shown by the control treatment. The interaction between N and S was also not significant. But, N_2S_3 (80 kg N ha^{-1} and 20 kg S ha^{-1}) recorded the highest value of 0.35 per cent followed by N_1S_3 and N_2S_2 (0.32 per cent) and N_3S_1 recorded the lowest value of 0.27 per cent. The main effect of N and S was also non significant. Among the N levels, application of N @ 80 kg ha^{-1} (N_2) recorded the highest S content of 0.32 per cent followed by N_1 (0.30 per cent) and the lowest value of 0.29 per cent was shown by N_3. Coming to the main effect of S, S_3 recorded the highest value of 0.33 per cent followed by S_2 (0.30 per cent). The lowest content of S (0.28 per cent) was shown by S_1.

At final harvest stage, the data revealed that the interaction between M, N and S was not significant. The highest S content (0.37 per cent) was recorded by $M_2N_2S_3$ (80 kg N ha^{-1}, 35 kg P_2O_5 ha^{-1}, 70 kg K_2O ha^{-1} and 20 kg S ha^{-1}) followed by $M_2N_1S_3$ (0.36 per cent). The interactive effect of N and S was also not significant. N_2S_3 recorded the highest plant S of 0.33 per cent followed by N_2S_2 (0.31 per cent) and N_3S_1 recorded the lowest value of 0.25 per cent. The main effect of N and S was also non significant. Among the N levels, N_2 recorded the highest value of 0.30 per cent followed by N_3 (0.28 per cent) and the lowest value of 0.27 per cent was shown by N_1. Coming to the main effect of S, application of 20 kg S ha^{-1} (S_3) recorded the highest plant content of 0.31 per cent followed by S_2 (0.29 per cent). The lowest value of 0.26 per cent was shown by S_1. There observed a significant difference among the M levels and M_2 (35 kg P_2O_5 and 70 kg K_2O) which received highest dose of P and K registered highest plant S content of 0.35 per cent and 0.33 per cent respectively at fifty per cent flowering and at final harvest stage of the crop when compared to M_1 that received 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}.

4. 2. 4. 7. *Chlorophyll content*

At fifty per cent flowering the chlorophyll content of leaf was measured and the data analysis revealed that the interaction between M, N and S factors was significant (Table 16). The highest chlorophyll content of 52.40 SPAD value was recorded by $M_2N_2S_3$ which received 80 kg N ha^{-1}, 35 kg P_2O_5 ha^{-1}, 70 kg K_2O ha^{-1} and 20 kg S ha^{-1} and it was on par with $M_2N_3S_2$ (50.60 SPAD value). The value of 33.00 SPAD was recorded by the control treatment. The interaction between N and S was also significant. Significantly superior value of 52.40 SPAD value was recorded by N_2S_3 which received 80 kg N ha^{-1} and the highest dose of S (20 kg ha^{-1}) followed by N_3S_2 (44.7 SPAD value). Regarding the individual effect of N and S, there was significant difference between different levels of N and S. Among the N levels, N_2 recorded significantly superior value of 45.99 SPAD followed by N_3 (42.6 SPAD units) and the lowest value of 39.65 SPAD was shown by N_1. Among the S levels, the highest chlorophyll content of 44.25 SPAD value was shown by S_2 which was on par with S_1 (42.73 SPAD value). Application of M also had significant influence on chlorophyll content of leaves and the significantly superior value of 44.77 SPAD was registered by M_2 (35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}).

4. 2. 4. 8. *Nitrate Reductase Activity*

Statistical analysis of the data revealed that there was significant difference between the treatments (Table 16). $M_2N_2S_3$ recorded a significantly higher NRA of 3.75 g NO_2 $litre^{-1}$ h^{-1} and the lowest value of 1.60 g NO_2 $litre^{-1}$ h^{-1} was recorded by $M_0N_0S_0$. The data analysis showed that the interaction between N and S was also significant. Significantly superior value of 3.49 g NO_2 $litre^{-1}$ h^{-1} was recorded by N_2S_3 which received 80 kg N and 20 kg S ha^{-1} followed by N_2S_2 (3.21 g NO_2 $litre^{-1}$ h^{-1}) and the NRA was shown by N_1S_1. Considering the 'able 16. Effect of M, N, and S application on chlorophyll content and NRA of leaf at 50 % flowering

Treatments	Chlorophyll content (SPAD units)	Nitrate Reductase Activity ($g\ NO_2\ litre^{-1}\ h^{-1}$)
$M_1N_1S_1$	36.95	2.56
$M_1N_1S_2$	43.05	2.77
$M_1N_1S_3$	33.75	2.85
$M_1N_2S_1$	44.65	3.09
$M_1N_2S_2$	46.25	3.16
$M_1N_2S_3$	45.20	3.22
$M_1N_3S_1$	41.25	2.36
$M_1N_3S_2$	38.90	2.35
$M_1N_3S_3$	37.10	2.97
$M_2N_1S_1$	41.05	2.46
$M_2N_1S_2$	43.80	2.79
$M_2N_1S_3$	39.30	2.95
$M_2N_2S_1$	44.55	3.16
$M_2N_2S_2$	42.90	3.26
$M_2N_2S_3$	52.40	3.75
$M_2N_3S_1$	47.90	3.53
$M_2N_3S_2$	50.60	3.16
$M_2N_3S_3$	40.40	3.16
$M_0N_0S_0$	33.00	1.60
F-MNS	6.43 **	15.59 **
CD-MNS	4.09	0.21
N_1S_1	39.00	2.51
N_1S_2	43.43	2.78
N_1S_3	36.53	2.90
N_2S_1	44.60	3.12
N_2S_2	44.58	3.21
N_2S_3	48.80	3.49
N_3S_1	44.58	2.95
N_3S_2	44.75	2.76
N_3S_3	38.75	3.06
N_1	39.65	2.86
N_2	45.99	2.92
N_3	42.69	3.15
S_1	42.73	2.73
S_2	44.25	3.27
S_3	41.36	2.92
M	40.79	2.81
M	44.77	3.14
F-NS	12.43 **	5.79 **
F-N	31.89 **	28.59 **
F-S	6.63 **	91.47 **
F-M	37.62 **	94.05 **
CD-NS	2.89	0.15
CD-N & S	1.67	0.09
CD-M	1.36	0.07

individual effect of N and S, there was significant difference between the different levels of N and S. Among the N levels, N_3 recorded significantly superior value of 3.15 g NO_2 litre^{-1} h^{-1} followed by N_2 (2.92 g NO_2 litre^{-1} h^{-1}). Among the S levels, the NRA of 3.27 g NO_2 litre^{-1} h^{-1} was shown by S_2 followed by S_3 (2.92 g NO_2 litre^{-1} h^{-1}) and the lowest value of 2.73 g NO_2 litre^{-1} h^{-1} was shown by S_1.

Application of P and K significantly influenced NRA in leaf at fifty per cent flowering and M_2 that received 35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}, recorded significantly higher value of 3.14 g NO_2 litre^{-1} h^{-1} compared to M_1 (2.81 g NO_2 litre^{-1} h^{-1}) where P and K was applied @ 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}.

4. 2. 5. Fruit analysis

Fruit was analyzed at fifty per cent flowering and at final harvest stage for its nutrient composition and the data is presented in Tables 17, 18 and 19. Content of all the nutrients analyzed were high at fifty per cent flowering stage when compared to harvest stage.

4. 2. 5. 1. *Nitrogen*

Data showed a similar trend as that of N content in plant. There was no significant difference between the treatments for N content of the fruit (Table 17). At fifty per cent flowering stage, the highest value of 2.08 per cent was recorded by $M_1N_3S_2$ that received highest dose of N, followed by $M_1N_3S_3$ and $M_2N_3S_2$ (2.06 per cent). Considering the NS interaction effects, N_3S_2 (110 kg N ha^{-1} and 15 kg S ha^{-1}) recorded the highest N content of 2.07 per cent followed by N_3S_3 (2.05 per cent). Among the levels of N, N_3 (110 kg ha^{-1}) recorded the highest value of 2.05 per cent followed by N_2 (1.93 per cent). Among the S levels, S_2 (15 kg ha^{-1}) recorded the highest N content of 1.96 per cent followed by S_3 (1.95 per cent).

At final harvest, there observed a slight reduction in the N content in fruit from that at fifty per cent flowering stage. It had been statistically observed that the interaction between M, N and S was not significant. The highest fruit N

Table 17. Effect of M, N, and S application on N, P and K content (%) of fruit at fifty per cent flowering and at final harvest

Treatments	N at 50 % flowering	N at final harvest	P at 50 % flowering	P at final harvest	K at 50 % flowering	K at final harvest
$M_1N_1S_1$	1.83	1.80	0.21	0.19	1.68	1.43
$M_1N_1S_2$	1.86	1.85	0.23	0.21	1.83	1.68
$M_1N_1S_3$	1.85	1.83	0.22	0.20	1.78	1.59
$M_1N_2S_1$	1.90	1.89	0.25	0.23	1.57	1.38
$M_1N_2S_2$	1.94	1.92	0.24	0.22	1.68	1.46
$M_1N_2S_3$	1.93	1.90	0.24	0.22	1.63	1.40
$M_1N_3S_1$	2.00	1.97	0.25	0.23	1.55	1.33
$M_1N_3S_2$	2.08	2.02	0.26	0.24	1.67	1.42
$M_1N_3S_3$	2.06	2.00	0.24	0.22	1.59	1.37
$M_2N_1S_1$	1.84	1.82	0.32	0.28	2.26	2.08
$M_2N_1S_2$	1.87	1.84	0.35	0.33	2.42	2.31
$M_2N_1S_3$	1.85	1.83	0.34	0.32	2.37	2.13
$M_2N_2S_1$	1.92	1.89	0.33	0.29	2.28	2.03
$M_2N_2S_2$	1.96	1.92	0.30	0.28	2.40	2.32
$M_2N_2S_3$	1.94	1.90	0.37	0.35	2.34	2.12
$M_2N_3S_1$	2.03	2.00	0.34	0.32	2.35	2.16
$M_2N_3S_2$	2.06	2.04	0.33	0.29	2.58	2.34
$M_2N_3S_3$	2.05	2.03	0.33	0.30	2.43	2.28
$M_0N_0S_0$	1.39	1.30	0.19	0.17	1.07	1.02
N_1S_1	1.83	1.81	0.26	0.24	1.97	1.76
N_1S_2	1.87	1.84	0.29	0.27	2.13	2.00
N_1S_3	1.85	1.83	0.28	0.26	2.07	1.86
N_2S_1	1.91	1.89	0.29	0.26	1.92	1.70
N_2S_2	1.95	1.92	0.27	0.25	2.04	1.89
N_2S_3	1.94	1.90	0.31	0.29	1.99	1.76
N_3S_1	2.01	1.99	0.30	0.27	1.95	1.75
N_3S_2	2.07	2.03	0.30	0.27	2.13	1.88
N_3S_3	2.05	2.01	0.29	0.26	2.01	1.82
N_1	1.85	1.83	0.28	0.26	2.06	1.87
N_2	1.93	1.90	0.29	0.26	1.98	1.79
N_3	2.05	2.01	0.29	0.27	2.03	1.82
S_1	1.92	1.90	0.28	0.26	1.95	1.74
S_2	1.96	1.93	0.29	0.26	2.10	1.92
S_3	1.95	1.92	0.29	0.27	2.02	1.82
M_1	1.94	1.91	0.24	0.22	1.66	1.45
M_2	1.95	1.92	0.33	0.31	2.38	2.20
F-MNS	0.002	0.001	0.23	0.44	0.03	0.03
F-NS	0.003	0.002	0.55	0.79	0.07	0.02
F-N	2.13	0.68	0.34	0.31	0.58	0.14
F-S	0.10	0.03	0.09	0.27	2.35	0.65
F-M	0.01	0.01	49.56 **	46.45 **	164.26 **	30.98 **
CD-MNS	0.50	0.80	0.09	0.08	0.35	0.84
CD-NS	0.35	0.57	0.06	0.06	0.25	0.60
CD-N & S	0.20	0.33	0.04	0.03	0.14	0.34
CD-M	0.16	0.27	0.03	0.02	0.12	0.28

content of 2.04 per cent was recorded by $M_1N_3S_2$ followed by $M_2N_3S_3$ (2.03 per cent). Regarding the NS interaction, N_3S_2 recorded the highest content of 2.03 per cent followed by N_3S_3 (2.01 per cent). Among the levels of N, N_3 @ 110 kg ha^{-1} recorded the highest value of 2.01 per cent followed by N_2 (1.90 per cent). The lowest value of 1.83 per cent was shown by N_1. Among the S levels, S_2 recorded the highest value of 1.93 per cent followed by S_3 (1.92 per cent).

4. 2. 5. 2. *Phosphorus*

At fifty per cent flowering stage, the interaction between M, N and S was not significant. However, $M_2N_2S_3$ which received 80 kg N, 35 kg P_2O_5, 70 kg K_2O and 20 kg S registered the highest P content of 0.37 per cent in fruit. The interaction between N and S was also found to be non significant. The highest value of 0.31 per cent was recorded by N_2S_3. There was no significant difference between the different N levels and S levels as regard to P content in the fruit.

At final harvest stage also, there was no significant difference between the treatments. But, the highest P content in fruit (0.35 per cent) was shown by $M_2N_2S_3$. The lowest value of was shown by the control treatment. Even though the interaction between N and S was not significant, N_2S_3 recorded the highest content of P in fruit (0.29 per cent) and N_1S_1 recorded the lowest value of 0.24 per cent. As regard to the individual effect, there was no significant difference between the N levels and S levels.

Application of P and K had significant influence on P content in the fruit and M_2 which received the highest dose of P (35 kg P_2O_5) recorded the significantly higher value of 0.33 per cent and 0.31 per cent respectively at fifty per cent flowering and at final harvest stage.

4. 2. 5. 3. *Potassium*

A perusal of the data revealed that there was no significant difference between the treatments at fifty per cent flowering (Table 19). $M_2N_3S_2$ recorded the highest K content in fruit (2.58 per cent) followed by $M_2N_1S_2$ (2.42 per cent). The main effect of N and S as well as their interaction effect were also non significant.

At final harvest stage also, the interaction between M, N and S was found to be insignificant. $M_2N_3S_2$ recorded the highest value of 2.34 per cent and the lowest value was recorded by the control treatment. The interaction between N and S and their individual effect were also non significant.

At fifty per cent flowering and at final harvest stage, application of P and K (M) showed significant influence on K content in fruit and significantly higher values of 2.38 per cent and 2.20 per cent were registered by M_2 (35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}) at fifty per cent flowering stage and at final harvest compared to M_1.

4. 2. 5. 4. *Calcium*

At fifty per cent flowering, the interaction between M, N and S was not significant. $M_1N_3S_3$ recorded the highest Ca content of 1.16 per cent, followed by $M_1N_2S_3$ (1.12 per cent). The lowest Ca content of 0.53 per cent was shown by the control treatment. Even though the interaction between N and S was also non significant, N_2S_2 which received 80 kg N ha^{-1} and 15 kg S ha^{-1} recorded the highest content of Ca in fruit (1.04 per cent) followed by N_3S_3 (1.03 per cent). The main effect of N was also non significant. But, among the N levels, application of N @ 80 kg ha^{-1} recorded the highest value of 1.04 per cent followed by N_1 (0.97 per cent) and the lowest value of 0.96 per cent was shown by N_3. The main effect of S was found to be non significant and S_3 (20 kg ha^{-1}) recorded the highest value of 1.03 per cent for the content of Ca in fruit. Main effect of M showed significant influence on Ca content in fruit and M_2 which received 35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}, registered the significantly highest value of 1.08 per cent at fifty per cent flowering compared to M_1 (0.90 per cent) that received 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}.

Table 18. Effect of M, N, and S application on Ca, Mg and S content (%) of fruit at fifty per cent flowering and at final harvest

Treatments	Ca at 50% flowering	Ca at final harvest	Mg at 50% flowering	Mg at final harvest	S at 50% flowering	S at final harvest
$M_1N_1S_1$	1.00	0.72	0.12	0.10	0.14	0.13
$M_1N_1S_2$	1.04	0.72	0.14	0.11	0.16	0.14
$M_1N_1S_3$	1.09	0.92	0.16	0.14	0.18	0.16
$M_1N_2S_1$	1.05	0.88	0.14	0.12	0.16	0.15
$M_1N_2S_2$	1.09	0.94	0.16	0.14	0.18	0.16
$M_1N_2S_3$	1.12	0.84	0.17	0.15	0.19	0.17
$M_1N_3S_1$	1.07	0.92	0.11	0.10	0.13	0.11
$M_1N_3S_2$	1.10	0.84	0.13	0.11	0.15	0.14
$M_1N_3S_3$	1.16	1.00	0.14	0.12	0.16	0.15
$M_2N_1S_1$	1.00	0.68	0.18	0.16	0.20	0.18
$M_2N_1S_2$	0.85	0.88	0.19	0.17	0.21	0.19
$M_2N_1S_3$	0.85	0.92	0.21	0.19	0.23	0.21
$M_2N_2S_1$	0.92	0.84	0.18	0.16	0.20	0.18
$M_2N_2S_2$	1.00	0.88	0.21	0.19	0.23	0.21
$M_2N_2S_3$	1.04	0.78	0.23	0.21	0.25	0.23
$M_2N_3S_1$	0.77	0.88	0.20	0.18	0.22	0.20
$M_2N_3S_2$	0.77	0.68	0.22	0.20	0.24	0.22
$M_2N_3S_3$	0.89	0.92	0.23	0.21	0.25	0.23
$M_0N_0S_0$	0.53	0.48	0.08	0.04	0.12	0.10
N_1S_1	1.00	0.70	0.15	0.13	0.17	0.16
N_1S_2	0.95	0.80	0.16	0.14	0.19	0.16
N_1S_3	0.97	0.92	0.19	0.16	0.21	0.19
N_2S_1	0.98	0.86	0.16	0.14	0.18	0.17
N_2S_2	1.04	0.80	0.19	0.16	0.21	0.19
N_2S_3	1.08	0.94	0.20	0.18	0.22	0.20
N_3S_1	0.92	0.90	0.16	0.14	0.18	0.16
N_3S_2	0.94	0.76	0.18	0.16	0.19	0.18
N_3S_3	1.03	0.96	0.19	0.17	0.21	0.19
N_1	0.97	0.81	0.17	0.15	0.19	0.17
N_2	1.04	0.87	0.18	0.16	0.20	0.18
N_3	0.96	0.87	0.17	0.15	0.19	0.18
S_1	0.97	0.82	0.16	0.14	0.18	0.16
S_2	0.97	0.79	0.18	0.15	0.20	0.18
S_3	1.03	0.94	0.19	0.17	0.21	0.19
M_1	1.08	0.84	0.14	0.12	0.16	0.15
M_2	0.90	0.86	0.21	0.19	0.23	0.21
F-MNS	0.22	0.89	0.05	0.08	0.02	0.04
F-NS	0.21	1.21	0.04	0.15	0.02	0.02
F-N	0.62	1.21	0.59	1.07	0.26	0.24
F-S	0.35	5.84 *	3.11	4.26 *	1.37	1.20
F-M	9.01 **	0.21	31.45 **	47.77 **	13.80 **	11.67 **
CD-MNS	0.38	0.24	0.07	0.06	0.11	0.11
CD-NS	0.27	0.17	0.05	0.04	0.08	0.08
CD-N & S	0.16	0.10	0.03	0.02	0.04	0.05
CD-M	0.12	0.08	0.02	0.02	0.04	0.04

At final harvest stage also, the interaction between M, N and S was found to be not significant. $M_1N_3S_3$ recorded the highest Ca content of 1.00 per cent, followed by $M_1N_2S_3$ (0.94 per cent). The interaction between N and S was also non significant. However, N_3S_3 which received the highest dose of N and S, recorded the highest value of 0.96 per cent followed by N_2S_3 (0.94 per cent). There was no significant difference between the N levels. It is clear from the data that the main effect of S was significant. S_3 recorded significantly higher Ca content of 0.94 per cent followed by S_1 (0.82 per cent) and the lowest value of 0.79 per cent was shown by S_2.

4. 2. 5. 5. *Magnesium*

At fifty per cent flowering, MNS and NS interactions were found to be non significant. However, $M_2N_2S_3$ and $M_2N_3S_3$ recorded the highest Mg content of 0.23 per cent followed by $M_2N_3S_2$ (0.22 per cent). Among the N and S interaction effects, N_2S_3 recorded the highest value of 0.20 per cent. The main effect of N and S, there was no significant difference between the different N levels and S levels. Among the N levels, application of N @ 80 kg ha^{-1} recorded the highest value for Mg content in fruit (0.18 per cent). Among the S levels, S_3 recorded the highest value of 0.19 per cent followed by S_2 (0.18 per cent).

The data analysis showed that there was no significant difference between the treatments at final harvest stage of the crop. $M_2N_2S_3$ and $M_2N_3S_3$ recorded the highest value of 0.21 per cent. It can be observed from the data that the interaction between N and S was non significant. N_2S_3 recorded the highest value of 0.18 per cent followed by N_3S_3 (0.17 per cent). There was no significant difference between the N levels. Among the N levels, N_2 recorded the highest content of Mg in fruit (0.16 per cent). Coming to the main effect of S, there was significant difference between the S levels. S_3 (20 kg ha^{-1}) recorded the significantly higher Mg content of 0.17 per cent followed by S_2 (0.15 per cent) and the lowest value of 0.14 per cent was recorded by S_1. Application of P and K also showed significant influence of the content of Mg in fruit and M_2 registered the significantly higher values of 0.21 per cent and 0.19 per cent respectively at fifty per cent flowering and at final harvest stage of the crop.

4. 2. 5. 6. *Sulphur*

It can be observed from the data that the interaction between M, N and S was not significant at fifty per cent flowering stage. However, the highest S content of 0.25 per cent was recorded by $M_2N_2S_3$ and $M_2N_3S_3$. It is explicit from the data that the interaction between N and S as well as their individual effects were also not significant. But, N_2S_3 recorded the highest content of S in fruit (0.22 per cent). Application of N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1} recorded the highest values of 0.20 per cent and 0.21 per cent respectively for the content of S in fruit.

At final harvest stage also, the interaction between M, N and S was not significant. However, the highest S content of 0.23 per cent was recorded by $M_2N_2S_3$ and $M_2N_3S_3$. The lowest S content of 0.10 per cent was shown by the control treatment. The interaction between N and S was not significant. However, N_2S_3 recorded the highest content of S (0.20 per cent). The main effect of N and S was also non significant. Among the N levels, N_2 and N_3 recorded the highest value of 0.18 per cent. Among the S levels, S_3, which received the highest dose of S, recorded the highest value of 0.19 per cent followed by S_2 (0.18 per cent). There observed significant difference with regard to the content of S in fruit at fifty per cent flowering and at final harvest stage of the crop and the highest level of P and K registered the highest content of S in fruit.

4. 2. 5. 8. *N: S ratio*

At fifty per cent flowering stage, M, N and S interaction had no significant influence on N: S ratio of fruit (Table 19). However, $M_2N_2S_3$ (80 kg N, 35 kg P_2O_5, 70 kg K_2O and 20 kg S) registered the narrower N: S ratio of 7.76. Narrower the ratio better will be the crop quality. The interaction between N and S was non significant. However, ratio was narrower for N_2S_3(8.96) which received 80 kg N and 20 kg S ha^{-1} and N_3S_1 recorded the highest ratio of 12.30 followed by N_3S_2.

Table 19. Effect of treatments on N: S ratio of fruit

Treatments	N:S ratio fruit at 50 % flowering	N:S ratio fruit at final harvest
$M_1N_1S_1$	13.07	13.85
$M_1N_1S_2$	11.63	13.21
$M_1N_1S_3$	10.28	11.44
$M_1N_2S_1$	11.88	12.60
$M_1N_2S_2$	10.78	12.00
$M_1N_2S_3$	10.16	11.18
$M_1N_3S_1$	15.38	17.91
$M_1N_3S_2$	13.87	14.43
$M_1N_3S_3$	12.88	13.33
$M_2N_1S_1$	9.20	10.11
$M_2N_1S_2$	8.90	9.68
$M_2N_1S_3$	8.043	8.71
$M_2N_2S_1$	9.60	10.50
$M_2N_2S_2$	8.52	9.14
$M_2N_2S_3$	7.76	8.26
$M_2N_3S_1$	9.23	10.00
$M_2N_3S_2$	8.58	9.27
$M_2N_3S_3$	8.20	8.83
$M_0N_0S_0$	11.58	13.00
N_1S_1	11.14	11.98
N_1S_2	10.26	11.45
N_1S_3	9.16	10.08
N_2S_1	10.74	11.55
N_2S_2	9.65	10.57
N_2S_3	8.96	9.72
N_3S_1	12.30	13.96
N_3S_2	11.23	11.85
N_3S_3	10.54	11.08
N_1	10.19	11.17
N_2	9.78	10.61
N_3	11.36	12.30
S_1	11.39	12.50
S_2	10.38	11.29
S_3	9.55	10.29
M	12.21	13.33
M	8.67	9.39
F-MNS	0.11	0.14
F-NS	0.03	0.08
F-N	3.56*	0.91
F-S	4.47 *	1.51
F-M	49.66 **	14.48 **
CD-MNS	3.17	6.52
CD-NS	2.24	4.61
CD-N & S	1.29	2.67
CD-M	1.06	2.17

The main effect of N was significant. Among the N levels, N_2 registered the significantly narrower ratio of 9.78 followed by N_1 (10.19). The main effect of S was also found to be significant. Among the S levels, significantly narrower ratio of 9.55 was registered by S_3, followed by S_2 (10.38).

At final harvest stage, N: S ratio became widened. It had been statistically observed that the interaction between M, N and S was not significant. But, $M_2N_2S_3$ showed the narrower ratio of 8.26. The interaction between N and S was also non significant. However, N_2S_3 recorded the lowest ratio of 9.72. Considering the main effect of N and S, there was no significant difference between the N levels and S levels. Among the N levels, N_2 recorded the lowest N: S ratio of 10.61. Coming to the main effect of S, application of highest dose of S resulted in narrowing the N: S ratio to 10.29.

Application of P and K had significant influence on N: S ratio of fruit at fifty per cent flowering and at final harvest stage of the crop. Among the M levels, M_2 which received 35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1} recorded the significantly narrower ratio of 8.67 and 9.39 at fifty per cent flowering and final harvest respectively compared to that of M_1 (12.21 and 13.33) that received 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1} .

4. 2. 6. Uptake of nutrients

4. 2. 6. 1. *Nitrogen*

A perusal of the data revealed that there was no significant difference between the treatments. However, the highest uptake of 83.32 kg ha^{-1} was recorded by the treatment that received 80 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1}, 25 kg K_2O ha^{-1} and 20 kg S ha^{-1} ($M_1N_2S_3$) followed by $M_1N_3S_1$ (82.70 kg ha^{-1}). The lowest value of 23.30 kg ha^{-1} was recorded by the control treatment. The data analysis showed that the interaction between N and S was significant. Significantly higher value of 76.71 kg ha^{-1} was recorded by N_3S_1 which was on par with N_2S_3 (76.55 kg ha^{-1})

Table 20. Effect of treatments on uptake of nutrients (kg ha^{-1}) by the crop

Treatments	N	P	K	Ca	Mg	S
$M_1N_1S_1$	41.77	4.39	38.72	20.15	2.91	3.66
$M_1N_1S_2$	48.80	5.28	48.58	24.38	4.06	4.60
$M_1N_1S_3$	57.56	6.07	56.44	32.75	5.30	5.85
$M_1N_2S_1$	73.79	8.34	63.96	35.88	5.98	6.81
$M_1N_2S_2$	66.50	7.2	62.64	32.67	6.25	6.85
$M_1N_2S_3$	83.32	9.43	73.72	43.87	8.53	9.30
$M_1N_3S_1$	82.70	9.02	68.26	41.79	5.55	6.15
$M_1N_3S_2$	68.74	7.73	59.31	33.33	5.04	5.80
$M_1N_3S_3$	75.15	7.91	66.79	42.20	6.46	7.18
$M_2N_1S_1$	53.01	7.83	72.62	30.46	6.20	6.71
$M_2N_1S_2$	55.52	9.14	78.20	32.81	6.66	7.20
$M_2N_1S_3$	62.87	9.86	87.37	42.22	8.75	9.35
$M_2N_2S_1$	49.54	7.65	61.72	27.61	5.46	5.93
$M_2N_2S_2$	70.15	10.04	92.92	39.12	8.44	9.10
$M_2N_2S_3$	69.78	11.85	88.66	44.85	9.27	9.93
$M_2N_3S_1$	70.72	10.66	86.62	38.83	7.52	8.16
$M_2N_3S_2$	65.40	9.35	84.17	33.24	7.53	8.11
$M_2N_3S_3$	69.45	9.52	86.21	39.81	8.38	9.00
$M_0N_0S_0$	23.03	2.40	14.71	13.25	1.28	1.99
N_1S_1	47.39	6.11	55.67	25.31	4.56	5.19
N_1S_2	52.16	7.21	63.39	28.60	5.36	5.90
N_1S_3	60.21	7.96	71.91	37.49	7.03	7.60
N_2S_1	61.66	8.00	62.84	31.75	5.72	6.37
N_2S_2	68.33	8.62	77.78	35.90	7.35	7.98
N_2S_3	76.55	10.65	81.19	44.36	8.90	9.62
N_3S_1	76.71	9.84	77.44	40.31	6.54	7.15
N_3S_2	67.07	8.54	71.74	33.29	6.29	6.96
N_3S_3	72.30	8.72	76.50	41.01	7.42	8.09
N_1	53.25	7.10	63.66	30.46	5.65	6.23
N_2	68.85	9.09	73.94	37.33	7.32	7.99
N_3	72.03	9.03	75.23	38.20	6.75	7.40
S_1	61.92	7.98	65.32	32.45	5.60	6.24
S_2	62.52	8.12	70.97	32.59	6.33	6.94
S_3	69.69	9.11	76.53	40.95	7.78	8.44
M_1	66.48	7.26	59.82	34.11	5.56	6.24
M_2	62.94	9.55	82.05	36.55	7.58	8.17
F-MNS	2.14	0.69	4.46 *	2.64	0.82	0.53
F-NS	3.98 *	2.64	7.53 **	7.89 **	1.59	0.82
F-N	37.18 **	9.46 **	23.82 **	30.12 **	8.85 **	5.17 *
F-S	6.88 **	2.77	18.63 **	39.68 **	15.02 **	8.12 **
F-M	3.47	28.71 **	219.57 **	7.46 *	37.17 **	17.88 **
CD-MNS	11.99	2.68	9.46	5.62	2.08	2.87
CD-NS	8.48	1.90	6.67	3.98	1.47	2.03
CD-N	4.90	1.10	3.86	2.30	0.85	1.17
CD-M	4.00	0.89	3.15	1.87	0.69	0.96

and N_2S_2 (68.33 kg ha^{-1}). As regard to the individual effect of N and S, there was significant difference between different levels of N and S. Among the N levels, N @ 110 kg ha^1 (N_3) registered the significantly highest N uptake (72.03 kg ha^{-1}) which was on par with N_2 (68.85 kg ha^{-1}). The lowest value of 53.25 kg ha^{-1} was shown by N_1. Among the S levels, S_3 recorded the significantly higher value of 69.69 kg ha^{-1} for the uptake of N followed by S_2 (62.52 kg ha^{-1}). The lowest value of 61.92 kg ha^{-1} was shown by S_1 (10 kg ha^{-1}).

4. 2. 6. 2. *Phosphorus*

It had been statistically verified that the interaction between M, N and S was not significant. But, $M_2N_2S_3$ recorded the highest value of 11.85 kg ha^1 for the uptake of P, followed by $M_2N_3S_1$ (10.66 kg ha^{-1}) and the lowest value of 2.40 kg ha^{-1} was recorded by $M_0N_0S_0$. It can be observed from the data that the interaction between N and S was also non significant. However, N_2S_3 recorded the highest P uptake of 10.65 kg ha^{-1}. The main effect of N was found to be significant. Among the N levels, N_2 recorded a higher value of 9.09 kg ha^{-1} and it was on par with N_3 (9.03 kg ha^{-1}) for P uptake. The lowest value of 7.10 kg ha^{-1} was recorded by N_1. Among the S levels, S_3 (20 kg ha^{-1}) recorded the highest value of 9.11 kg ha^{-1} followed by S_2 (8.12 kg ha^{-1}) even though there was no significant difference between S levels. Application of P and K significantly influenced the uptake of N by the crop and M_2 showed the higher value of 9.55 kg ha^{-1} compared to M_1 (7.26 kg ha^{-1}).

4. 2. 6. 3. *Potassium*

Statistical analysis of the data indicated that there was significant difference between the treatments. $M_2N_2S_2$ that received 80 kg N ha^{-1}, 35 kg P_2O_5 ha^{-1}, 70 kg K_2O ha^{-1} and 15 kg S ha^{-1} registered the significantly highest value of 92.92 kg $ha^{-1}$and it was on par with $M_2N_1S_3$ (87.37 kg ha^{-1}), $M_2N_2S_3$ (88.66 kg ha^{-1}), $M_2N_3S_1$ (86.62 kg ha^{-1}), $M_2N_3S_2$ (84.17 kg ha^{-1}) and $M_2N_3S_3$ (86.21 kg ha^{-1}). The lowest value for the uptake of K (14.71 kg ha^{-1}) was shown by the control treatment. The interaction between N and S was also significant. N_2S_2 recorded the highest value of 77.78 and it was on par with N_1S_3 (71.91 kg ha^{-1}), N_2S_3 (77.44 kg ha^{-1}), N_3S_1 (71.74 kg ha^{-1}), N_3S_2 (76.50 kg ha^{-1}). The lowest uptake of 55.67 kg ha^{-1} was shown by N_1S_1. Considering the main effect, levels of N and S were found to be significant for the uptake of K. Among the N levels, the significantly highest value of 75.23 kg ha^{-1} for the uptake of K was recorded by N_3 followed by N_2 (73.94 kg ha^{-1}). The lowest value of 63.66 kg ha^{-1} was shown by N_1. Coming to the main effect of S, S_3 recorded the superior value of 76.53 kg ha^{-1}, which was significantly different from S_2 (70.97 kg ha^{-1}) and S_1 (65.32 kg ha^{-1}). The data showed that there was significant difference between the M levels and M_2 which received the maximum dose of P and K registered a significantly higher K uptake of 82.05 compared to M_1 (59.82 kg ha^{-1}) which received 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}.

4. 2. 6. 4. *Calcium*

For the uptake of Ca, the interaction between M, N and S was found to be non significant. However, $M_2N_2S_3$ recorded the maximum value of 44.85 kg ha^{-1} followed by $M_1N_2S_3$ (43.87 kg ha^{-1}). The lowest uptake of 13.25 kg ha^{-1} was shown by the control. It is clear from the data that the interaction between N and S was significant. N_2S_3 registered the highest uptake of 44.36 kg ha^{-1} and it was on par with N_3S_3 (41.01 kg ha^{-1}). The lowest value of 25.31 kg ha^{-1} was shown by N_1S_1. There was significant difference between the N levels and S levels for the uptake of Ca. Among the N levels, the significantly higher value of 38.20 kg ha^{-1} was recorded by N_3 (110 kg ha^{-1}) followed by N_2 (37.33 kg ha^{-1}). The lowest uptake of 30.46 kg ha^{-1} was shown by N_1. Coming to the main effect of S, S_3 registered the significantly superior value of 40.95 kg ha^{-1} followed by S_2 (32.59 kg ha^{-1}). The lowest uptake of 32.45 kg ha^{-1} was recorded by S_1. Application of P and K significantly influenced the uptake of Ca by the crop. Among the M levels, the maximum value of 36.55 kg ha^{-1} was recorded by M_2.

4. 2. 6. 5. *Magnesium*

The data showed that, there was no significant difference between the treatments for the uptake of Mg also. However, $M_2N_2S_3$ (80 kg N, 35 kg P_2O_5, 70 kg K_2O and 20 kg S) recorded the highest value for Mg uptake (9.27 kg ha^{-1}) followed by $M_2N_2S_2$ (8.44 kg ha^{-1}) and the lowest value of 1.28 kg ha^{-1} was recorded by the control treatment. It is evident from the data that interaction between N and S was non significant. But, N_2S_3 recorded the highest value of 8.90 kg ha^{-1}. Considering the main effect of N and S there was significant difference between the N levels and S levels. Among the N levels, the significantly higher value of 7.32 kg ha^{-1} was recorded by N_2 and it was on par with N_3 (6.75 kg ha^{-1}). The lowest value of 5.65 kg ha^{-1} was shown by N_1. Coming to the main effect of S, S_3 recorded significantly higher value of 7.78 kg ha^{-1} followed by S_2 (6.33 kg ha^{-1}). The lowest value of 5.60 kg ha^{-1} was shown by S_1. Different levels of M had significant influence on the uptake of Mg and M_2 (35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}) recorded the highest value of 7.58 kg ha^{-1} compared to M_1 (5.56 kg ha^{-1}).

4. 2. 6. 6. *Sulphur*

The interaction between M, N and S was non significant. However, $M_2N_2S_3$ recorded the highest value of 9.93 kg ha^{-1} followed by $M_2N_1S_3$ (9.35 kg ha^{-1}) and the lowest value of 1.99 kg ha^{-1} was recorded by $M_0N_0S_0$. It is evident from the data that interaction between N and S was also non significant. N_2S_3 (80 kg N ha^{-1} and 20 kg S ha^{-1}) recorded the highest value of 9.62 kg ha^{-1} followed by N_3S_3 (8.09 kg ha^{-1}). The lowest value of 5.19 kg ha^{-1} was shown by N_1S_1. Coming to the main effect of N and S, there was significant difference between the N levels and S levels. Among the N levels, the significantly higher value of 7.99 kg ha^{-1} was recorded by N_2 (80 kg ha^{-1}) and it was on par with N_3 (7.40 kg ha^{-1}). The lowest uptake of 6.23 kg ha^{-1} was shown by N_1. Coming to the main effect of S, S_3 recorded significantly superior value of 8.44 kg ha^{-1} followed by S_2 (6.94 kg ha^{-1}) for the uptake of S. The lowest value of 6.24 kg ha^{-1} was shown by S_1. Application of P and K also had significant influence on the uptake of S the M_2

Table 21. Effect of treatments on PDI (%) and B: C ratio

Treatments	PDI	B:C ratio
$M_1N_1S_1$	15.12	1.69
$M_1N_1S_2$	14.60	1.81
$M_1N_1S_3$	16.20	1.48
$M_1N_2S_1$	12.76	2.32
$M_1N_2S_2$	11.20	2.46
$M_1N_2S_3$	12.85	2.25
$M_1N_3S_1$	15.43	1.66
$M_1N_3S_2$	15.76	1.57
$M_2N_1S_1$	15.74	1.89
$M_2N_1S_2$	14.90	1.61
$M_2N_1S_3$	15.81	1.75
$M_2N_2S_1$	14.57	1.56
$M_2N_2S_2$	14.51	1.79
$M_2N_2S_3$	12.68	1.80
$M_2N_3S_1$	14.87	2.37
$M_2N_3S_2$	16.05	1.73
$M_2N_3S_3$	15.52	1.45
$M_0N_0S_0$	18.50	1.49
N_1S_1	15.43	1.65
N_1S_2	14.75	1.78
N_1S_3	16.01	1.52
N_2S_1	13.67	2.05
N_2S_2	12.86	2.13
N_2S_3	12.77	2.31
N_3S_1	15.15	1.69
N_3S_2	15.90	1.51
N_3S_3	14.92	1.74
N_1	15.40	1.65
N_2	13.09	2.17
N_3	15.33	1.65
S_1	14.75	1.80
S_2	14.50	1.81
S_3	14.56	1.86
M_1	14.25	1.90
M_2	14.96	1.74
F-MNS	0.27	1.80
F-NS	0.29	1.94
F-N	3.50	22.46 **
F-S	0.03	0.24
F-M	0.78	5.14 *
CD-MNS	5.09	0.46
CD-NS	3.60	0.32
CD-N & S	2.08	0.19
CD-M	1.70	0.15

(35 kg P_2O_5 ha^{-1}, 70 kg K_2O ha^{-1}) which received the highest dose of P and K registered the highest S uptake. It is evident that application of P and K significantly influenced the uptake of S by the crop.

4. 2. 7. B: C Ratio

It can be inferred that there was no significant difference between the treatments as regards to B: C ratio. The highest ratio of 2.46 was recorded by $M_1N_2S_2$ followed by $M_2N_3S_1$ (2.37). The interaction between N and S was also non significant. However, N_2S_3 recorded the highest B: C ratio of 2.31 followed by N_2S_2 (2.13). It was observed that there was significant difference between the N levels. The significantly maximum value of 2.17 was recorded by N_2 (15 kg ha^{-1}) followed by N_1 and N_3 (1.65). Coming to the individual effect of S, there was no significant difference between the S levels. S_3 recorded the highest value of 1.86 followed by S_2 (1.86). The lowest value of 1.80 was shown by S_1. Among the M levels, M_1 which received 8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1} recorded asignificantly higher B: C ratio (1.90) compared to M_2 (1.74).

4. 2. 8. Scoring for incidence of yellow vein mosaic virus disease (Percentage Disease Incidence)

Statistical analysis of the data revealed that there was no significant difference between the treatments. However, the lowest percentage disease incidence of 11.2 per cent was registered for $M_1N_2S_2$ which received 80 kg N, 8 kg P_2O_5, 25 kg K_2O and 15 kg S ha^{-1}, followed by $M_1N_2S_3$ and the highest value of 18.50 per cent was recorded by the control treatment. The interaction between N and S was also non significant. The lowest disease incidence of 12.77 per cent was shown by N_2S_3. Regarding the individual effect of N and S, there was no significant difference between different levels of N and S. Among the N levels, N_2 (80 kg ha^{-1}) recorded the lowest value of 13.09 per cent and among the S levels, the lowest value of 14.50 per cent was recorded by the application of 15 kg S ha^{-1}.

Discussion

5. DISCUSSION

The salient results of laboratory and field investigations carried out at College of Agriculture, Vellayani to investigate the interactive effect of nitrogen and sulphur application on their release pattern and use efficiency in ferralitic soil are discussed in this session. The treatments were $M_1N_1S_1$, $M_1N_1S_2$, $M_1N_1S_3$, $M_1N_2S_1$, $M_1N_2S_2$, $M_1N_2S_3$, $M_1N_3S_1$, $M_1N_3S_2$, $M_1N_3S_3$, $M_2N_1S_1$, $M_2N_1S_2$, $M_2N_1S_3$, $M_2N_2S_1$, $M_2N_2S_2$, $M_2N_2S_3$, $M_2N_3S_1$, $M_2N_3S_2$, $M_2N_3S_3$ and $M_0N_0S_0$. The different levels of N were N_1 (50kg ha^{-1}), N_2 (80kg N ha^{-1}) and N_3 (110kg N ha^{-1}). The levels of M include M_1 (8 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}) and M_2 (35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}) and the levels of S were S_1 (10 kg ha^{-1}), S_2 (15 kg ha^{-1}) and S_3 (20 kg ha^{-1}).

5. 1. INCUBATION STUDY

5. 1. 1. Release pattern of available N in soil

The available N status of the soil had been increased by the application of N and S. For the same level of N application as urea, with the increase in S levels there observed enhancement in the availability of N in soil (Table 4). From this, we can infer that both the nutrients have synergistic effect in increasing the availability. The highest available N content in the soil was obtained with $M_1N_3S_3$ (110 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1}, 25kg K_2O ha^{-1} and 20 kg S ha^{-1}). At 100 DOI, all the treatments showed a decreasing trend. It may be due to the loss of N as volatilization of ammonia from the soil incubated at field capacity or it may be immobilized by microorganisms. Considering the N and S interaction, N_3S_3 (110 kg N ha^{-1} and 20 kg S ha^{-1}) showed the highest value for available N. This may be due to increased application of N and positive influence of S in releasing N in soil. Among the N levels, N_3 showed the significantly higher value (Fig. 2). As N application increases, available N status also increased. (Tisdale *et al.*, 1985).

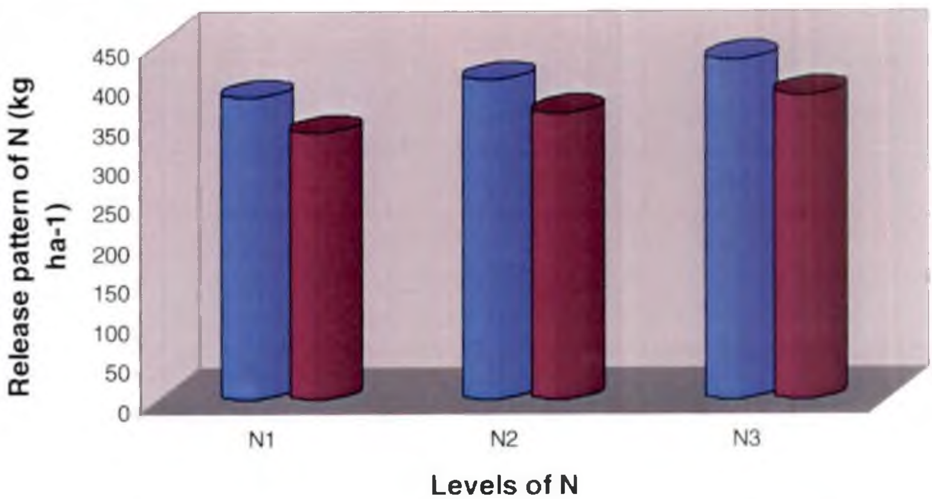


Fig. 2. Effect of nitrogen application on release pattern of N in soil

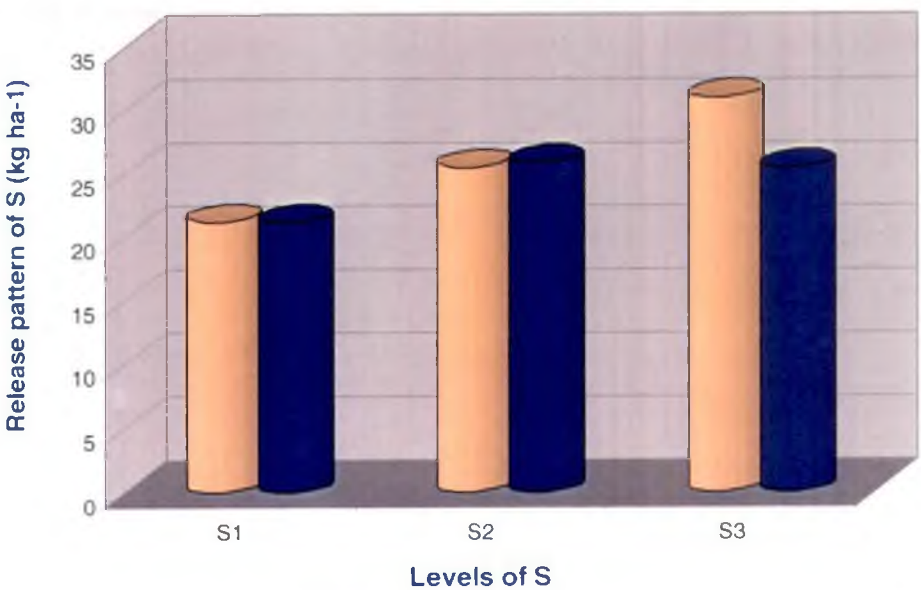


Fig. 3. Effect of sulphur application on release pattern of S in soil

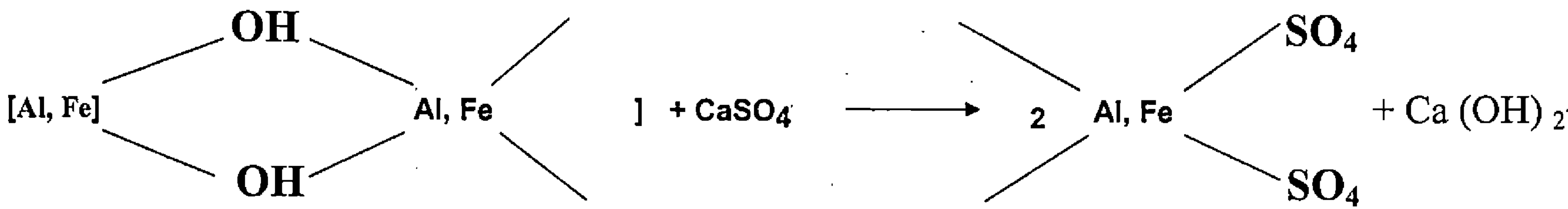
5. 1. 2. Release pattern of available S in soil

N and S application increased the available S status in soil (Table 4). For the same level of S application as gypsum, with increase in N application there was increase in availability of S. S and N when applied as gypsum and urea, there was synergistic effect in increasing the availability of both. N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) showed the highest values at 30 DOI. Among the S levels, application of 20 kg S ha^{-1} which is the highest dose of S was significantly superior and this may be due to the S content in gypsum (Fig. 3). Increased dose of application of gypsum increased the available S status of soil (Mathew, 2003). Mishra (1995) suggested that application of phosphogypsum could correct S deficiency in red and laterite soil. Beena (2000) reported that gypsum @ 30 kg S ha^{-1} increased the available S content in red and laterite soils of Vellayani. This will be very much useful in the management of laterite soil, where S deficiency is also a major problem. However, the S content showed a gradual decrease for all the treatments in the course of incubation. This may be due to microbial immobilization or the adsorption of S as sulphate in the exchange sites.

5. 1. 3. Changes in pH

The initial soil pH was 5.69. By the application of N as urea and S as gypsum, there was increase in pH value to the neutral range at fifty per cent flowering stage (30 Days of Incubation) and all the treatments showed a decreasing trend in the pH value at 100 Days of Incubation (Table 4). The increase in pH at 30 DOI might be due to the ligand exchange of hydroxyl group by sulphate in gypsum (Fig. 4) and due to the effect of cow dung application @ 12 t ha^{-1} as basal dose.

The decrease in pH at 100 DOI may be due to mineralization of ammoniacal form of N to nitrate form which releases H^+ ions to soil solution. Phosphogypsum was found to be an effective material for the correction of subsoil acidity (Sumner, 1970; Reeve and Sumner, 1972). Ritchery *et al.* (1980) suggested that soil pH increased by 0.8 units in dark red latosol after gypsum application. Phosphogypsum, a waste product from phosphoric acid plant was found to be effective in correcting soil acidity in laterite soil by reducing the



$$3Ca(OH)_2 + 2\,Al^{3+} \longrightarrow 2\,Al(OH)_3 + 3\,Ca^{2+}$$

$$3Ca(OH)_2 + 2\,Fe^{3+} \longrightarrow 2\,Fe(OH)_3 + 3\,Ca^{2+}$$

Fig. 4. Ligand exchange of hydroxyl group by sulphate in gypsum

exchangeable acidity, especially the exchangeable Al content (Sumner, 1970; Reeve and Sumner, 1972)). Since phosphogypsum is highly mobile in soil, it can correct subsoil acidity also. (Alcordo and Recheigl, 1993). Mathew (2003) reported that phosphogypsum along with lime was effective in reducing exchangeable acidity. Sumner (1970) suggested that the ameliorating effect of phosphogypsum is mainly due to the supply of calcium. The various mechanisms include ligand exchange of hydroxyl group by sulphate (Reeve and Sumner, 1972), precipitation as basic aluminium sulphate (Hue *et al*., 1985), co-sorption of sulphate and aluminium (Sumner *et al.*, 1986) and ion pair formation (Cameroon *et al.*, 1986). Whatever be the mechanism, the ability of phosphogypsum to reduce the acidity or to increase the pH of soil is clearly evident from the study and is in conformity with the results published by Liu and Hue (2001).

5. 2. FIELD EXPERIMENT

5. 2. 1. Biometric observations

5. 2. 1. 1. ***Days to first flowering***

Among the N and S interaction effects, N_2S_2 which received 80 kg N ha^{-1} and 15 kg S ha^{-1} took comparatively lesser number of days for first flowering (Table 5). This might be due to the fact that N and S application caused an increase in plant vigour and the metabolic partitioning might be better with the optimum dose of these nutrients. This might have helped in increased translocation of photosynthates thereby reaching the reproductive stage earlier. Treatments without N and S took more number of days for first flowering. Beena (2000) reported that lesser number of days was taken for flowering in the case of treatment which received 30 kg S ha^{-1} along with POP recommendation in Cowpea in a Rhodic Haplustult.

5. 2. 1. 2. ***Days to fifty per cent flowering***

N_1S_1 (N @ 50 kg ha^{-1} and S @ 10 kg ha^{-1}) took lesser number of days for fifty per cent flowering among the N and S interaction effects (Table 5). As the application of N increased, the plant took more number of days for fifty per cent flowering. Sajitharani (1993) opined that nutrient application significantly influenced the days for fifty per cent flowering and reported a delay in flowering due to the increased levels of N fertilizer. This may be due to the fact that N application helps in better vegetative growth of the plant. Compared to the control treatment, all the treatments which received N and S took lesser number of days for fifty per cent flowering. But, the application of treatments had no significant effect on days to fifty per cent flowering in bhindi.

5. 2. 1. 3. *Duration from flowering to final harvest*

Treatment received N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) showed maximum duration from flowering to final harvest (Table 5). Even though there was no significant difference between treatments for this character, the control plot took lesser duration from flowering to final harvest. This may be due to the fact that balanced nutrition especially N and S, might have helped in better partitioning of photosynthates to fruit for longer period.

5. 2. 1. 4. *Plant height*

Plant height at 30DAS and 90 DAS was highest for $M_1N_2S_3$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 20 kg S ha^{-1}) and at 60DAS the height was maximum for $M_2N_2S_3$ (80 kg N ha^{-1} + 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20 kg S ha^{-1}). But, there was no significant difference between the treatments (Table 6). The treatments which received higher levels of P and K along with N and S (M_2) showed significantly superior plant height because of increased plant vigour.

5. 2. 1. 5. *Length of internode*

At 30 DAS, $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}) recorded comparatively less internodal length (7.50 cm) (Table 7). As regards to main effect of S application, S @15 kg ha^{-1} had significant influence on internodal length at 30 DAS and 60 DAS. The shortest internodal length (7.25 cm) was recorded by this level. Individual effect of N as well as individual effect of S also influenced the length of internodes significantly. N @ 80 kg ha^{-1} and S @ 15 kg ha might be sufficient for a balanced availability of nutrients which favoured more leaf production and hence lesser internodal length.

5. 2. 1. 6. *Fruit length*

At 60 DAS and at 90 DAS, N and S interaction showed significant influence on fruit length. At 90 DAS, N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) showed the highest value (Table 8). N application up to 80 kg ha^{-1} also showed significant influence on fruit length at 60 DAS. Arora *et al.* (1991) found that maximum fruit length was seen in plots where N was applied @ 90 kg ha^{-1} in bhindi. Sharma *et al.* (2005) concluded that S application increased length of siliqua in mustard.

5. 2. 1. 7. *Number of fruits per plant*

The maximum number of fruits was obtained for the treatment which received $M_1N_2S_2$ (80 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1} , 25 kg K_2O ha^{-1} and 15 kg S ha^{-1}). All the treatments showed an increased number of fruits than the control (Table 10). Considering the N and S interaction effects, N_2 S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) recorded the highest number of fruits followed by N_2 S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}). The number of fruits per plant increased up to 80 kg N ha^{-1} there after a reduction occurred. Among the S levels, S_2 (15 kg ha^{-1}) resulted in maximum number of fruits.

The increase in number of fruits per plant by the application of N and S may be due to the highest uptake and efficient utilization of nutrients. N and S application increased the availability of these nutrients in soil. Greater number of fruits was produced due to balanced nutrition and efficient partitioning of metabolites there by adequate translocation of the nutrients to the developing reproductive structures. Increased number of pods in cowpea as a result of S fertilization was reported by Beena (2000) and Ramamurthy *et al.* (1997). Singh and Singh (1965) reported that number of fruits per plant increased with increasing levels of N up to 90 kg ha^{-1} in bhindi and up to S @ 75 kg ha^{-1} (Syriac and Rajan, 1992). Gupta and Rao (1979) reported that N application above 100 kg ha^{-1} did not increase the number of fruits per plant.

5. 2. 2. Yield and yield attributes

5. 2. 2. 1. *Yield per plant*

The highest yield of 10.13 t ha^{-1} was recorded by $M_1N_2S_2$ (80 kg N ha^{-1},8 kg P_2O_5 ha^{-1}, 25 kg K_2O and 15 kg S ha^{-1}), followed by $M_2N_2S_3$ (80 kg N ha^{-1}, 35 kg P_2O_5 ha^{-1}, 70 kg K_2O ha^{-1} and 20 kg S ha^{-1}) (Fig. 5). There was no significant difference between the treatments (Table 10). Among the NS interaction effects, N_2S_3 recorded the highest yield of 9.58 t ha^{-1} followed by N_2S_2 (Fig. 6). Griffiths *et al.* (2009) concluded that yield was not significantly increased by N and S interaction in winter wheat cultivars. Farabhakhsh *et al.* (2006) reported that interactive effect of N and S did not affect grain weight in oilseed rape.

Among the N levels, N_2 (80 kg N ha^{-1}) recorded significantly superior yield. But above 80 kg N ha^{-1} there was reduction in yield. There was no significant difference between the levels of S with respect to yield. This appears to be on account of beneficial effect of N nutrition in exploiting inherent potentials of the crop for vegetative and reproductive growth. The optimum availability of nutrients especially N, and photosynthates results in proper growth and development of both vegetative and reproductive development of the crop and finally leads to improved productivity. Syed *et al.* (2006) reported that application of 80 kg N ha^{-1} increased the yield of sunflower from 9.31- 14.6 q ha^{-1}. Experiments carried out at Coimbatore by Kamalanathan *et al.* (1970) showed that optimum level of N was 90 kg ha^{-1} to get maximum yield in bhindi. According to Syriac and Rajan (1992), 75 kg N ha^{-1} gave the maximum yield in bhindi in reclaimed soils of Kuttanad. (. Ahmed and Tulloch- Reid (1968) found that increase in the rates from 112- 336 kg ha^{-1} resulted in decrease in yield by 16.8 t ha^{-1} in bhindi. Antagonistic effect of N and S on yield components was observed by Nasreen *et al.* (2007) when they are applied together at higher rates of N (150 kg ha^{-1}) and S (40 kg ha^{-1}). Ruiter *et al.* (2001) observed that N fertilizer strongly increased the N uptake in vegetative parts, but there was little effect of S fertilizer on yield in wheat.

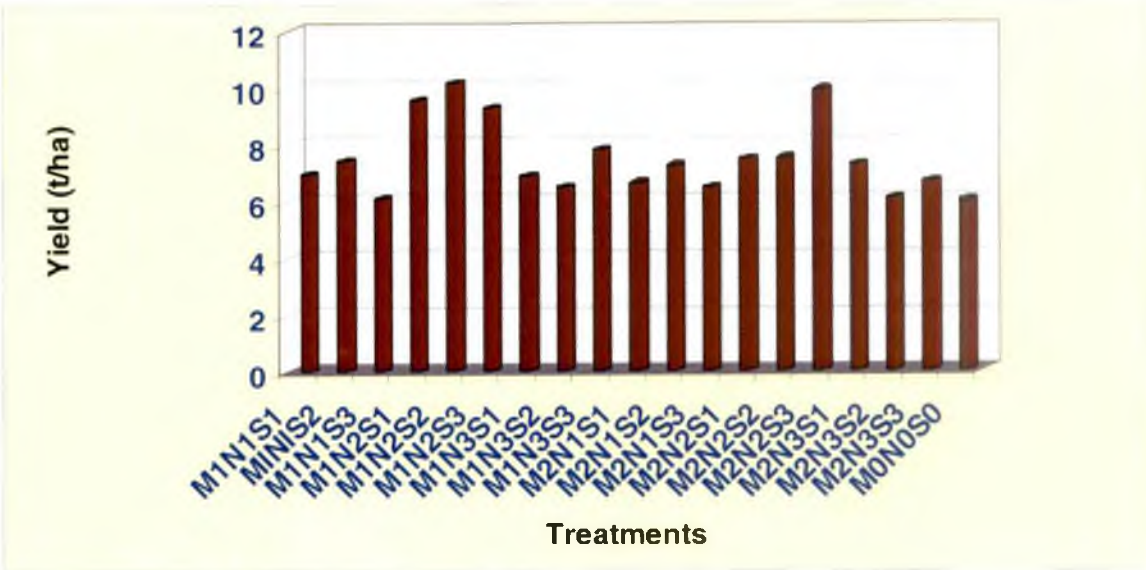


Fig. 5. Effect of treatments on yield (t ha^{-1})

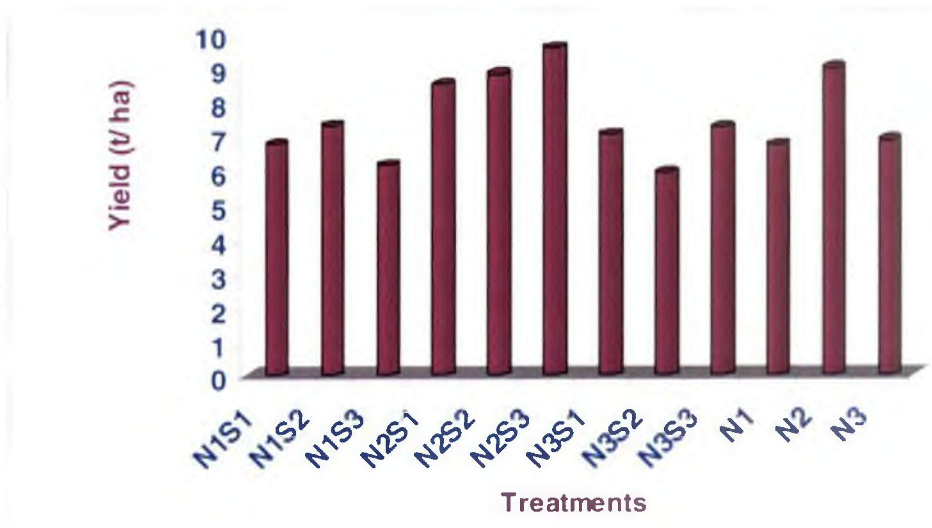


Fig. 6. Effect on N and S application on yield (t ha^{-1})

Plate 3. A view of the highest yielding treatment ($M_1N_2S_2$)

Plate 4. A view of the higher yielding treatment ($M_2N_2S_3$)

$M_0 N_0 S_0$

Plate 5. A view of the control treatment

5. 2. 2. 2. *Total Dry Matter Production*

The highest dry matter production (DMP) was recorded by $M_1N_3S_3$ (110 kg N ha^{-1}, 8 kg P_2O_5 ha^{-1}, 25 kg K_2O ha^{-1} and 20 kg S ha^{-1}). Among the N levels N_3 (110 kg N ha^{-1}) and among the S levels, S_3 (20 kg S ha^{-1}) recorded the highest dry matter content, even though there was no significant difference between the treatments (Table 10). At higher levels of N and S, the plant was not able to convert much of its photosynthates to fruit. Interactive effect of N and S had no significant influence on dry matter production. Similar result was obtained by Farabhakhsh *et al.* (2006). There was increased dry matter production than the control treatment. This may be due to increased plant height, number of leaves and increased vegetative growth.

N and S enhance cell multiplication, elongation and expansion and imparts deep green colour to the leaves due to increased chlorophyll synthesis resulting in increased dry matter production. Panda and Srivastava (2004) reported that application of 120 ppm N as enriched digested sludge with 30 ppm S in split doses recorded the highest values for dry matter content in rice. Medhi *et al.* (1990) obtained maximum dry matter production in chilli with 80 kg N ha^{-1}. John (1989) reported that DMP in chilli increased with N up to 125 kg ha^{-1}

5. 2. 2. 3. *Nitrogen Use Efficiency*

Among the treatments, the highest NUE of 52per cent was recorded by $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O+ 15 kg S ha^{-1}) and the results are presented in (Table 10). Even though the interaction between N and S was not significant, N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) recorded the highest NUE followed by N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}). S application @ 15 kg ha^{-1} showed significant influence on NUE in bhindi (Fig. 7). Habtegebrial and Singh (2009) found that S fertilization with N increased the NUE by 28 per cent in wheat. S deficiency can reduce NUE and N deficiency can reduce SUE (Fismes *et al.*, 2000).

S, a major secondary nutrient, helps in N metabolism in plants which leads to increased use efficiency of N. Fernando *et al.* (2009) reported that S application increased the NUE By increasing the N recovery from soil. S

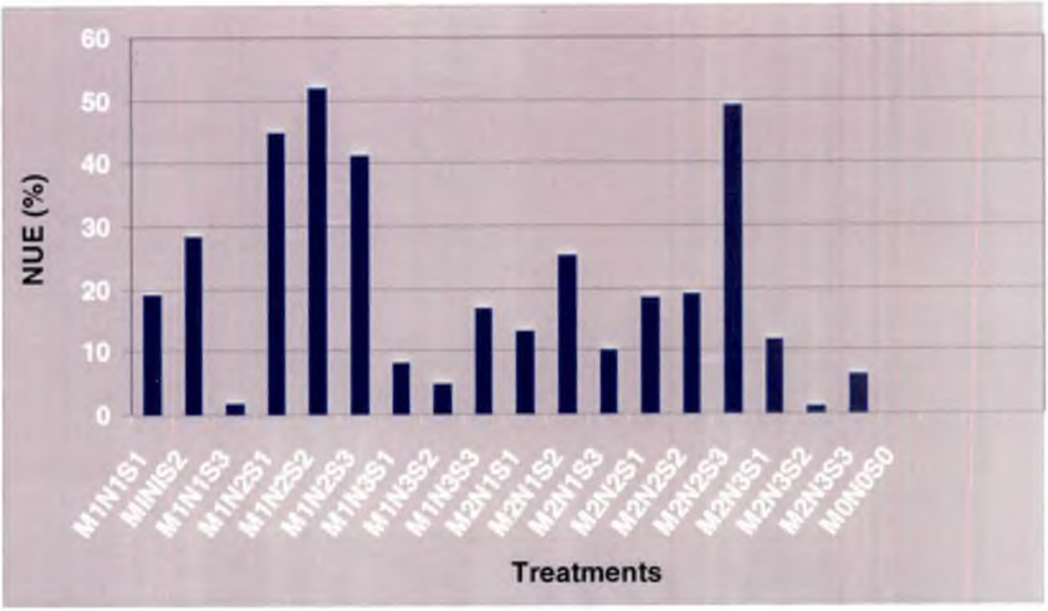


Fig. 7. Effect of treatments and individual effect of sulphur on NUE (%)

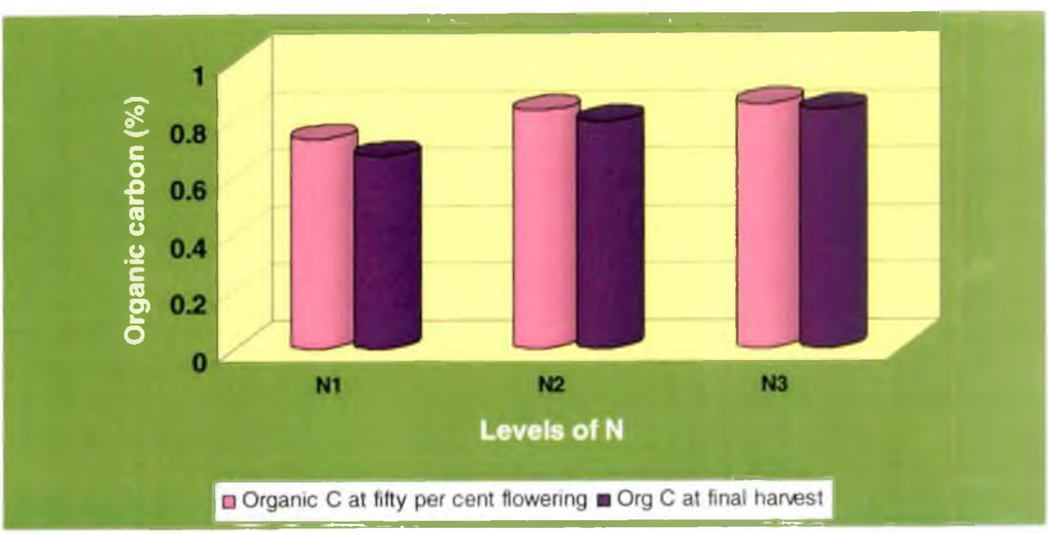


Fig. 8. Effect of N application on Organic C content (%)

application results in significant reduction of leaf nitrate content in Brassica. (Pascale *et al.*, 2007) and prevents the accumulation of non protein N compounds in the plant tissue. Losak *et al.* (2009) showed that nitrate content in kale increased with the applied N by 477per cent-938per cent. S fertilization significantly reduced the undesirable nitrates by 18per cent-44per cent.

5. 2. 3. Soil analysis

5. 2. 3.1. ***pH***

By the application of N as urea and S as gypsum, there was increase in pH value to the neutral range at fifty per cent flowering stage and all the treatments showed a decreasing trend in the pH value at final harvest (Table 11). The increase in pH at fifty per cent flowering stage might be due to the fact that gypsum inactivated Fe and Al (H^+ supplying cations) of laterite soil by ligand formation. Another reason for increased pH is the presence of Ca in gypsum and also application of cowdung. The decrease in pH at final harvest may be due to the leaching loss of Ca, the organic acid production during decomposition of plant litter and the release of H^+ ions during mineralization of N. The application of treatments had no significant influence on changes in pH.

5. 2. 3. 2. ***Organic Carbon***

N application had significant influence on the organic carbon content in the soil (Fig. 8). This might be due to the increased availability of N in soil and subsequent increase in population of soil microorganisms and its activity which in turn accelerated the decomposition of organic residues. Among the treatments $M_2N_3S_3$ (110 kg N ha^{-1}, 35kg P_2O5 ha^{-1},70 kg K_2O ha^{-1} and 20 kg S ha^{-1}) recorded the highest organic carbon content in the soil (0.90per cent) and among N levels N_3 (110 kg ha^{-1}) showed the significantly higher organic carbon content (0.85per cent) and it was on par with N_2 (80 kg ha^{-1}). Among the S levels, S_3 (20 kg ha^{-1}) showed the highest value for organic carbon content in soil.

5. 2. 3. 3. ***Available nitrogen***

At fifty per cent flowering all the nutrients showed an increase in availability from the initial values and there was a decrease at the final harvest stage because of crop uptake (Table 12).

N and S application significantly influenced available N status in the soil. Among the N levels, N_3 (110kg ha^{-1}) recorded the significantly higher value. As the N level increased, available N status also increased. The increase is due to the soluble N content in applied urea. Sajitharani (1993) in bhindi reported an increase in available N status by N application.

Among the levels of S application, S_1 (10 kg ha^{-1}) recorded the significantly highest value. As the S level increased available N status decreased. According to Raja *et al.* (2007b) the available N status was decreasing with increased levels of application of S up to 60 kg ha^{-1} due to enhanced crop uptake and growth. Considering the N and S interaction effects, N_3S_1 (N @ 110 kg ha^{-1} +S @10 kg ha^{-1}) recorded significantly higher available N in soil.

5. 2. 3. 4. ***Available phosphorus***

S application influenced the available P content in soil. S_3 (20 kg ha^{-1}) recorded the highest value of 46.54 kg ha^{-1} (Table 12). This may be due to the fact that gypsum decreased P adsorption by the replacement of phosphate held by Fe and Al, by the $SO_4^{\ 2-}$ present in gypsum (Frenkel and Fey, 1989). Mathew (2003) suggested that application of phosphogypsum helps to maintain higher levels of P in the soil that ensures enhanced availability. Due to higher levels of application of P (35 kg ha^{-1}), there was significant increase in the availability of P in soil (Table 12).

5. 2. 3. 5. ***Available potassium***

As the N level increased, there was significant increase in K content also (Table 12). Rajan (1991) found an increasing trend in available K status in soil with increasing levels of N from 50- 125 kg ha^{-1} in *Amaranthus*. As the S level increased, K status of the soil also increased. This may be due to the release of K^+ from the exchange sites by $Ca^{\ 2+}$ from gypsum (Beena, 2000). Between the M levels, application of K @ 70 kg ha^{-1} increased the K availability in soil.

5. 2. 3.6. ***Exchangeable calcium and magnesium***

Even though N and S application had no significant influence on Ca and Mg status in soil, as the levels of S increased, there was increase in the exchangeable calcium in soil (Table 13). A higher level of application of gypsum ensures higher Ca content in soil. These results are in conformity with the reports of Liu and Hue (2001) and Mathew (2003).

5. 2. 3. 7. Available sulphur

Phosphogypsum significantly influenced the available soil S status and S_3 (20 kg ha^{-1}) recorded the maximum value (Table 13). The increase is due to the S addition from gypsum. These results are in conformity with that of Mathew (2003). Beena (2000) reported that gypsum @ 30 kg ha^{-1} increased the available S content in red and laterite soils of Vellayani. Mishra (1995) suggested that application of phosphogypsum could correct S deficiency in red and laterite soils. The interaction between N and S was also non significant.

Thus the application of gypsum had a beneficial effect on increasing S availability. This will be very much useful in the management of laterite soil where S deficiency is also a major problem.

5. 2. 4. Plant and fruit analysis

The content of all the nutrients were higher at fifty per cent flowering stage and at final harvest there was slight decrease in the content. Also, the nutrient content in plant was slightly higher than that in fruit.

5. 2. 4. 1. ***Nitrogen***

Even though there was no significant difference between the N levels, N_3 (110 kg N ha^{-1}) showed the highest N content. At N_3 level of application, the available N status was maximum which coincides with the highest N content in plant as well as in fruit (Table 14 and 17).

5. 2. 4. 2. ***Phosphorus***

Application of P at M_2 level (35 kg ha^{-1}) registered significantly higher P content in plant as well as in fruit (Table 14 and 16). The highest soil available P was also observed for this level of application. Hence, higher level of application of P resulted in higher P content in plant parts.

5. 2. 4. 3. *Potassium*

The plant content of K was highest at M_2 level (70 kg ha^{-1}) of application when compared to M_1 (Table 14 and 17). This level of K as MOP resulted in highest availability of K in soil which led to higher content in plant as well as in fruit.

At final harvest stage of the crop, S application had a significant influence on K content in plant and fruit. S_2 (15 kg ha^{-1}) recorded the significantly higher value followed by S_3 (20 kg ha^{-1}). Beena (2000) reported that by the application of S @ 30 kg ha^{-1}along with NPK increased the K content in cowpea. Sudha (1999) reported similar increase in K content in rice by the application of 25 kg S ha^{-1}. Mathew (2003) also reported that phosphogypsum can increase the K content in cowpea. The increased K content in plant and fruit may be due to the presence of Ca in gypsum which might have displaced K from exchange sites.

5. 2. 4. 4. *Calcium*

Application of K significantly influenced the content of Ca in plant and fruit both at fifty per cent flowering and at final harvest stage of the crop (Table 15 and 18). Among the M levels, M_2 which received 35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1} registered the significantly highest Ca content. This may be due to the presence of Ca in super phosphate that resulted in increased availability of this nutrient in soil which in turn led to the higher content of Ca in plant and fruit. S application up to 20 kg ha^{-1} had significant influence on the fruit Ca concentration. The better mobility of Ca in gypsum had played its role. Increased availability of Ca in soil at flowering and final harvest resulted in enhanced uptake of calcium that led to higher content of Ca in fruit. These results are in conformity with that of Beena (2000), Mathew (2003) and Mathew (2009).

5. 2. 4. 5. *Magnesium*

Fruit Mg content was significantly influenced by S fertilization up to 20 kg S ha^{-1} at final harvest stage (Table 15 and 18). This might be due to the fact that S fertilization might have helped in producing a favourable environment for absorption of Mg by the plant. This would have resulted in increased uptake of Mg by the fruit and its content in fruit.

5. 2. 4. 6. *Sulphur*

Even though there was no significant interaction between N and S in the case of S content, N_2S_3 (N @ 80 kg ha^{-1} and S@ 20 kg ha^{-1}) recorded the highest content of 0.35per centS in plant and fruit (Table 15 and 18). Among the N levels, N_2 (80 kg ha^{-1}) and among the S levels, S_3 (20 kg ha^{-1}) recorded the higher values. This is due to the increased availability of S coupled with enhanced S uptake. The positive influence of phosphogypsum on S content and uptake was reported by Beena (2000) and Mathew (2003).

5. 2. 4. 7. *N: S ratio*

Narrower the N: S ratio, better will be the crop quality. At fifty per cent flowering stage, N and S fertilization significantly influenced the N: S ratio of the fruit. By progressive increase in S application up to 20 kg ha^{-1} and N application up to 80 kg ha^{-1} N: S ratio was found to be significantly decreased to 9.78 and 9.55 respectively (Fig. 9). Progressive decrease in N: S ratio was noticed with increase in the rate of S application which resulted in higher uptake and assimilation. Beena (2000) reported that decrease in N: S ratio from 42.93 to 15.86 was achieved in cowpea by S application @ 30 kg ha^{-1}. Decrease in N: S ratio of grain from 13.17–9.68 by increasing the levels of S fertilization was reported by Sakal *et al.* (1999).

5. 2. 4. 7. *Chlorophyll content*

N and S fertilization had significant influence on leaf chlorophyll content and $M_2N_2S_3$ (80 kg N ha^{-1} + 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20kg S ha^{-1}) showed a significantly higher value of 52.40 SPAD value for chlorophyll content (Fig. 10). Considering the N and S interaction effects, N_2S_3 (N @ 80 kg ha^{-1}and S @ 20 kg ha^{-1}) showed the significantly superior value of 52.40 SPAD value (Fig. 11). Content and uptake of N, P, S, Ca, and Mg (Table 14, 15) of P, K, Ca, Mg and S (Table 20) were also highest for this treatment. Increased uptake of Mg by

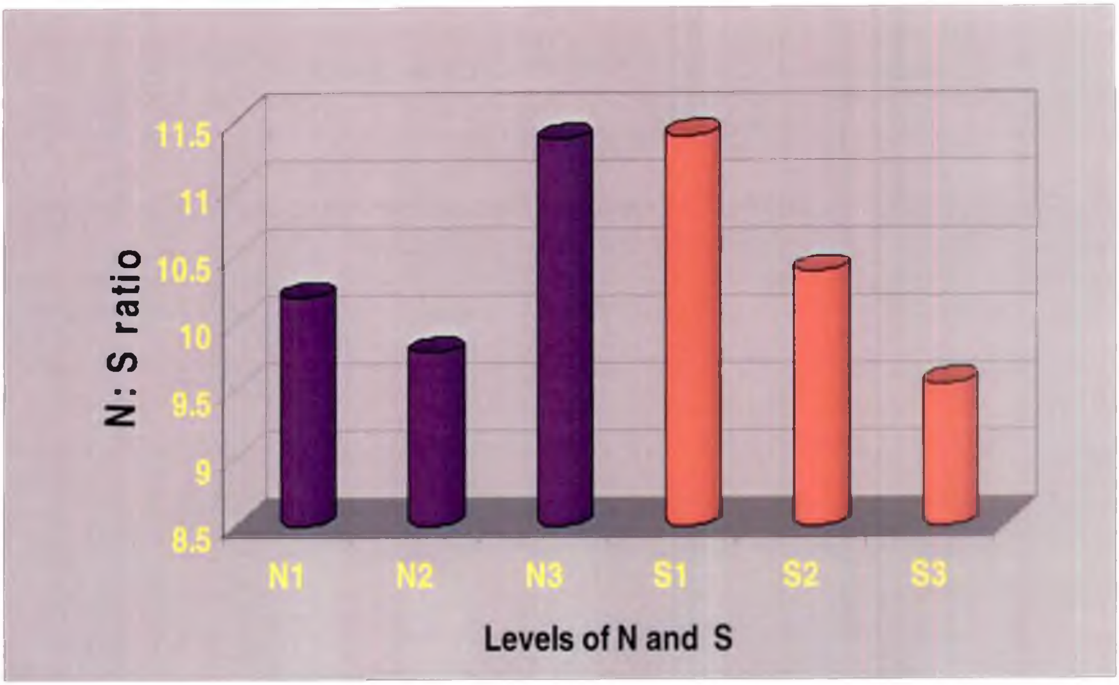


Fig. 9. Effect of N and S application on N: S ratio of fruit.

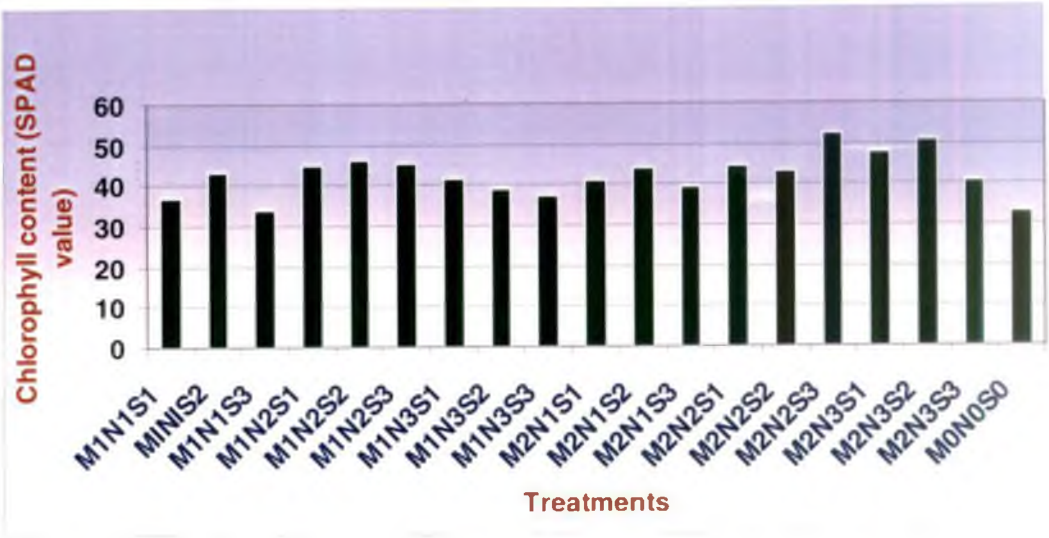


Fig. 10. Effect of treatments on chlorophyll content of leaf (SPAD value)

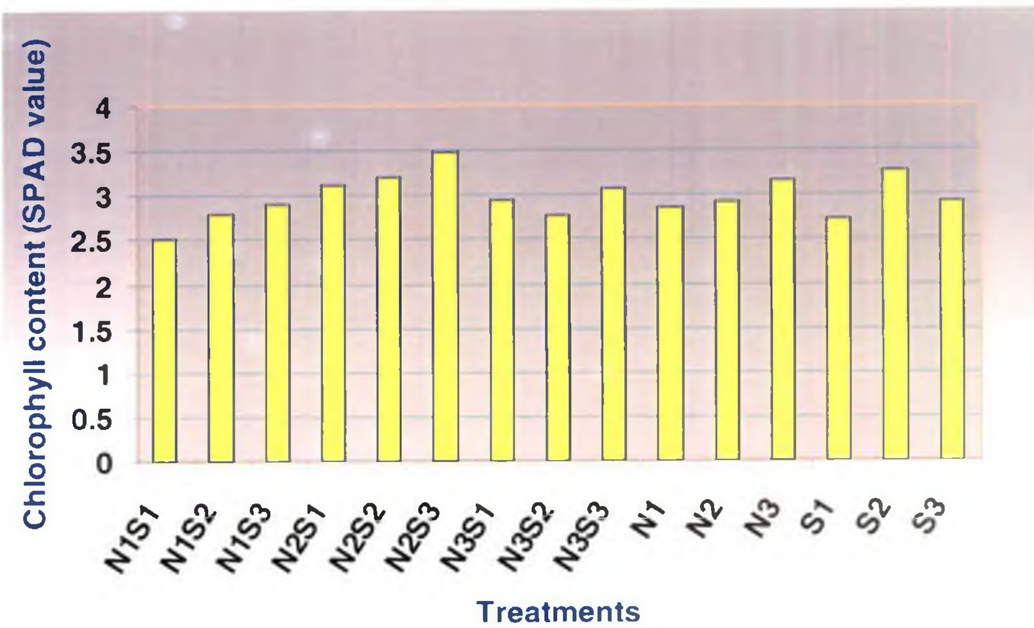


Fig. 11. Effect of N and S application and their individual effects on chlorophyll content of leaf (SPAD value)

the application of N and S also resulted in increased chlorophyll synthesis. Chlorophyll synthesis was accelerated with N supply. With every increase in N level, there was corresponding increase in the chlorophyll content of leaves as reported by several workers in bhindi (Arora *et a*l., 1991). This is due to the fact that N is an integral part of chlorophyll, which converts light energy into chemical energy needed for photosynthesis. The basic chlorophyll structure is a porphyrin ring, composed of 4 pyrrole rings, each containing 1 N and 4 C atoms. Even though S is not a constituent of chlorophyll, it has been identified as essential for chlorophyll biosynthesis (Tisdale *et al.*, 1985). Similar increase in chlorophyll content of rice by S application was reported by Sudha (1999). Confirmatory reports were recorded by Qui (1989); Beena (2000) in cowpea and Mathew (2009) in *Sesamum*. Mg is an important constituent of chlorophyll molecule and acts as co factor for many enzymes (Karibasappa *et al.*, 2007).

According to Pasha *et al.*, (2004) application of 120 ppm N as enriched digested sludge (N enriched to 10per cent) with 30 ppm S recorded the highest valued for chlorophyll content (33.9 SPAD value) in rice. Chaubey *et al.* (2000) reported that S can favourably enhance the chlorophyll synthesis and increases the photosynthetic activity in plants which in turn are evidenced in the growth characters of the plant. Application of M levels also had significant influence on the chlorophyll content of the leaf and M_2 that received the highest dose of P and K (35 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1}) registered the highest chlorophyll content of 44.77 SPAD value. This may be due to the increased uptake of P and K.

5. 2. 4. 8. ***Nitrate Reductase Activity (NRA)***

Nitrate Reductase Activity in leaves was significantly increased by N and S application (Fig. 12). An increasing trend was noticed with higher levels of N up to 80 kg ha^{-1} and S up to 20 kg ha^{-1}. This might be due to the influence of S on Nitrate Reductase Activity. Among the treatments $M_2N_2S_3$ (80 kg N ha^{-1}+ 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20 kg S ha^{-1}) recorded the significantly higher value of 3.75 g NO_2 litre^{-1} h^{-1} and among the interaction effects of N and

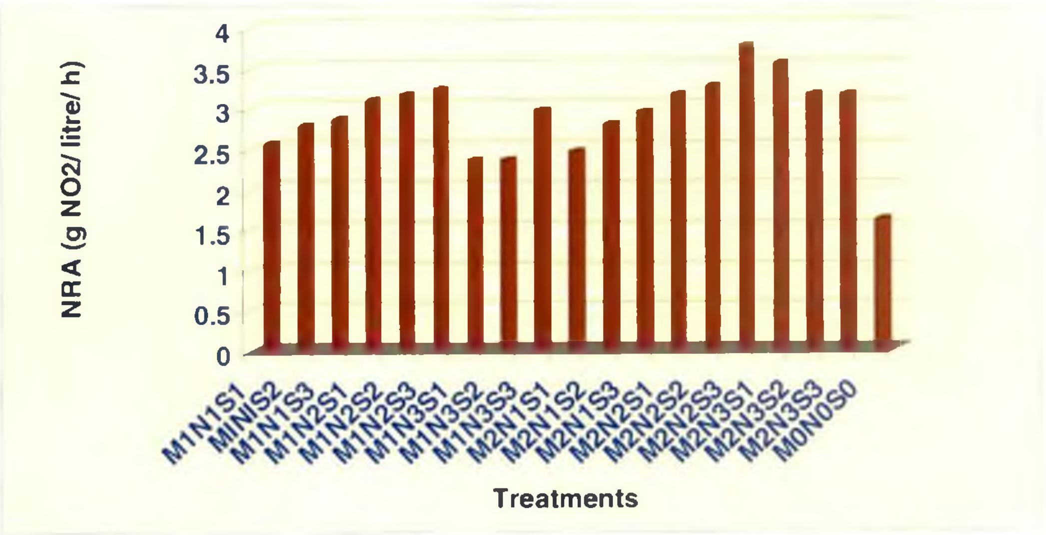


Fig. 12. Effect of treatments on NRA in leaf (g NO_2 litre^{-1} h^{-1})

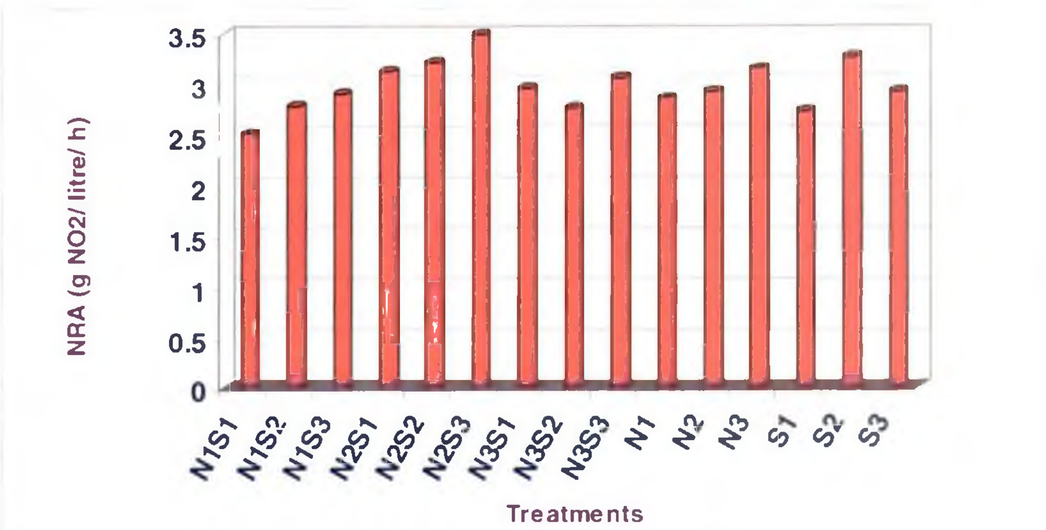


Fig. 13. Effect of N and S interaction and their individual effect on NRA in leaf (g NO_2 litre^{-1} h^{-1})

S, N_2S_3 recorded significantly superior NRA (3.49 g NO_2 litre^{-1} h^{-1}) followed by N_2S_2 (Fig. 13). Application of S resulted in increased uptake of this nutrient resulting in the synthesis of proteins. This is in agreement with increase in NRA reported by Qui (1989) and Beena (2000). Involvement of S in NRA can be attributed to the following reasons. Nitrate reductase is a soluble molybdo-flavo protein occurring in the envelope of chloroplast. One of the main functions of S in proteins is the formation of disulphide bonds between peptide chains. S is a vital part of ferredoxin, a type of non–haeme Fe-S protein occurring in chloroplasts. Ferredoxin participates in oxidation reduction process by transferring electrons and has significant role in nitrate reduction (Tisdale et al., 1985). Optimum NRA was observed with soybean leaves fertilized with 20 kg S ha^{-1} and 23.5 kg N ha^{-1} (Jamal *et al.*, 2005). Khan (2004) found that S application @ 40 kg ha^{-1} in the form of gypsum significantly improved the NRA in the leaves of rapeseed- mustard. Application of P and K also had significant influence on NRA and the highest NRA was recorded by the treatment that received the highest level of M (35 kg P_2O_5 ha^{-1} & 70 kg K_2O ha^{-1}).

5. 2. 5. Uptake of nutrients

5. 2. 5. 1. ***Nitrogen***

N uptake (shoot and fruit) increased significantly up to N_3 (110 kg N ha^{-1}). As the levels of S increased, N uptake also increased significantly (Table 20). Regarding the N and S interaction effects, N and S fertilization had significant influence on N uptake (Fig. 14). The increase in N uptake due to high levels of N and S application might be due to the increased N availability in soil which resulted in increased dry matter production. This synergistic relation between N and S is a well established fact. Confirmatory reports by Beena (2000); Mathew (2009) and Sakal *et al.* (1999) prove this relationship. N and S application improved the plant vigour. This also contributed to the enhanced N uptake. Sudha (1999) and Krishnamoorthy *et al.* (1996) observed similar enhancement of N uptake by S application. Fazili *et al.* (2008) found that uptake of N was considerably reduced under S deficiency in *Eruca sativa*.

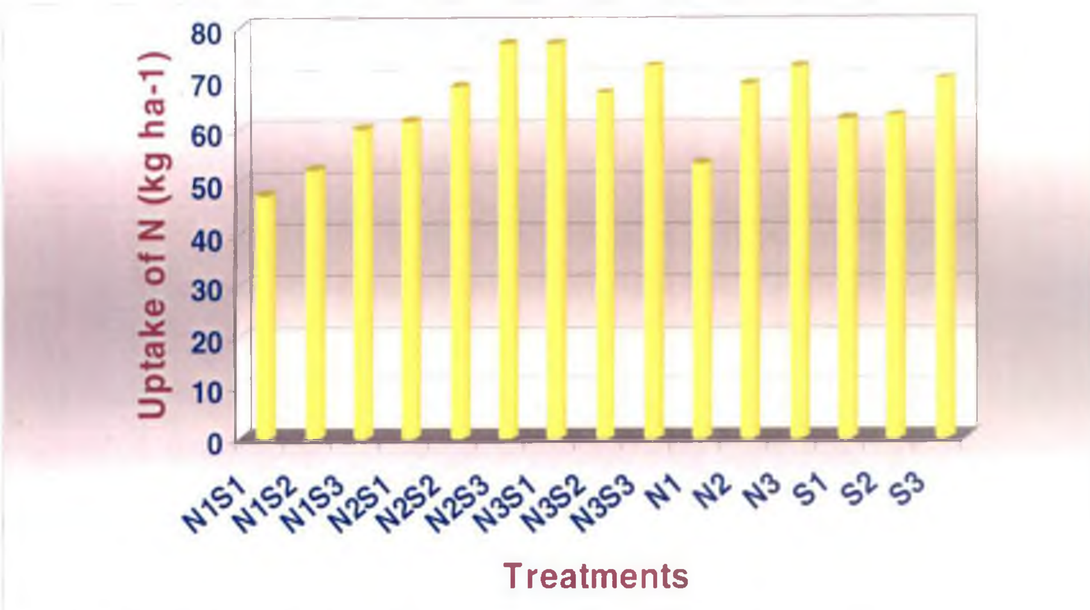


Fig. 14. Effect of N and S interaction and their individual effects on uptake of N (kg ha^{-1})

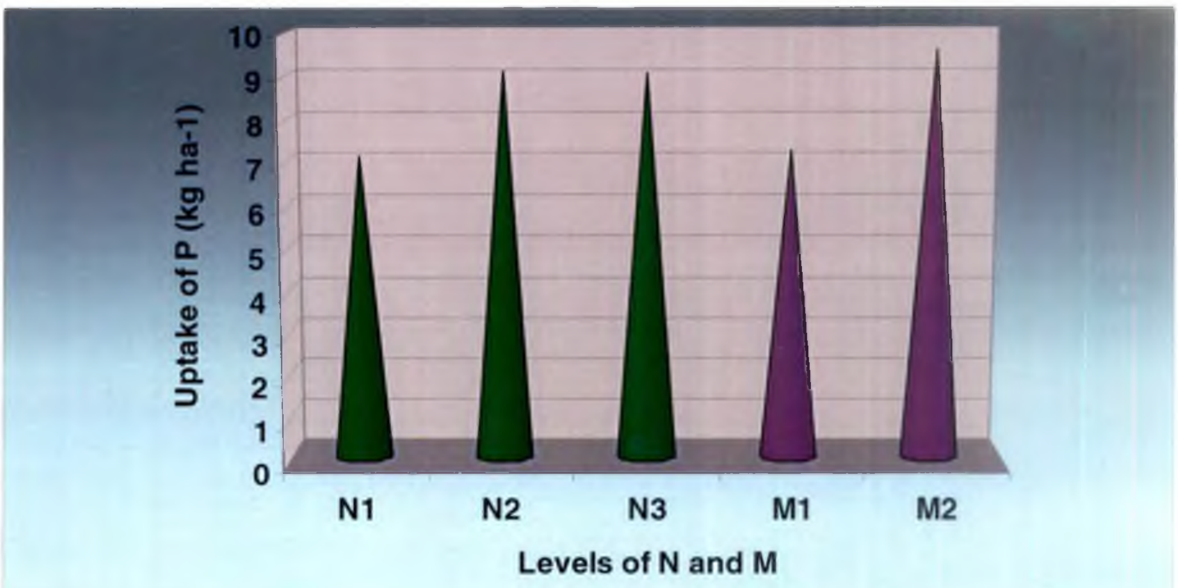


Fig. 15. Effect of N and M application on uptake of P (kg ha^{-1})

5. 2. 5. 2. *Phosphorus*

Among the treatments, $M_2N_2S_3$ (80 kg N ha^{-1}+ 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20 kg S ha^{-1}) recorded the highest value for the uptake of P and among the N and S interaction effects, N_2S_3 (80 kg N ha^{-1} + 20 kg S ha^{-1}) showed the highest P uptake of 10.65 kg ha^{-1}(Table 20). N application up to 80 kg N ha^{-1} had significant influence on P uptake (Fig. 15). Oo *et al.*, (2007) observed that the uptake of P was significantly affected by the application of N @ 100 kg ha^{-1} and S @ 20 kg ha^{-1} in aromatic rice. Sajitharani (1993) reported that there was progressive and significant increase in the uptake of N and P by plant and fruit of bhindi by the application of increased N levels. This may be due to the fact that application of N increases the N content in plant and fruit and increases the vigour of the crop resulting in a deep root system which will help to absorb more P from soil. Among the S levels, S_3 (20 kg S ha^{-1}) showed the highest uptake of P even though there was no significant difference between the S levels. S application as gypsum increased the P uptake in cowpea. (Beena, 2000; Mathew, 2003). Navnit and Sinha (2008) reported that S application improved the P uptake by 21.4 per cent in sugarcane.

Application of P at M_2 level (35 kg ha^{-1}) registered significantly higher P uptake (9.55 kg ha^{-1}). The highest soil available P was also observed for this level of application (Fig. 16). Hence, higher level of application of P resulted in higher P availability and uptake by the plant.

5. 2. 5. 3. *Potassium*

N and S fertilization significantly influenced the uptake of K in bhindi and $M_2N_2S_2$ (80kg N + 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1}+ 15 kg S ha^{-1}) showed a significantly higher K uptake of 92.92 kg ha^{-1}and among the N and S interaction effects, N_2S_2 (80 kg N ha^{-1} + 15 kg S ha^{-1}) and N_2S_3 (80 kg N ha^{-1} + 20 kg S ha^{-1}) recorded the highest uptake (Fig. 16). Oo *et al.* (2007) observed that K uptake was significantly affected by the application of N @ 100 kg ha^{-1} and S @ 20 kg ha^{-1} in aromatic rice. The uptake of K was significantly increased when rapeseed was fertilized with graded levels of N @ 39- 72 kg N ha^{-1} and S @ 40 kg ha^{-1} (Sarangthem, 2002).

Among the N levels N_3 (110 kg ha^{-1}) and among S levels S_3 (20 kg ha^{-1}) showed significant influence on K uptake (Table 20). Beena (2000) and Mathew (2003) reported an increase in K uptake by S application. This may be due to the enhanced availability of K in soil and also due to the increased dry matter production by balanced fertilization. Another reason for increased K uptake is the presence of Ca in gypsum and this might have displaced K from exchangeable sites (Mathew, 2003). Sakal *et al.* (1999) observed an enhanced K uptake in rice by the application of S @ 40 kg ha^{-1}. Similar results were obtained by Rao and Shaktawat (2002).

The plant uptake of K was highest at M_2 level (70 kg ha^{-1}) of application when compared to M_1 (Fig. 19). This level of K as MOP resulted in highest availability of K in soil and higher concentration in plant and fruit and which led to highest uptake of this nutrient.

5. 2. 5. 4. *Calcium and Magnesium*

N and S application significantly increased the Ca and Mg uptake (Fig. 17). Application of 80 kg N ha^{-1} and 20 kg S ha^{-1} gave the significantly higher uptake of Ca (44.36 kg ha^{-1}) and Mg (8.9 kg ha^{-1}). Among the N levels N_2 (80 kg ha^{-1}) and N_3 (110 kg ha^{-1}) were on par and among the S levels, S_3 (20 kg ha^{-1}) recorded the significantly superior values for Ca as well as Mg uptake. Beena (2000) also reported that S application significantly increased the Ca and Mg uptake in cowpea. This is due to the fact that increased application of gypsum which is a source of Ca resulted in increased availability of Ca in soil which resulted in higher uptake by the plant. The increased dry matter production also contributed to increased Ca uptake by fruit and plant. The increased uptake of Mg may be due to the improved soil properties and balanced fertilization which increased the availability of this nutrient in soil and also due to the significantly higher content in fruit. Application of P and K had significant influence on the uptake of Ca and Mg and M_2 (35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1}) registered the highest uptake because of higher plant vigour (Fig. 19).

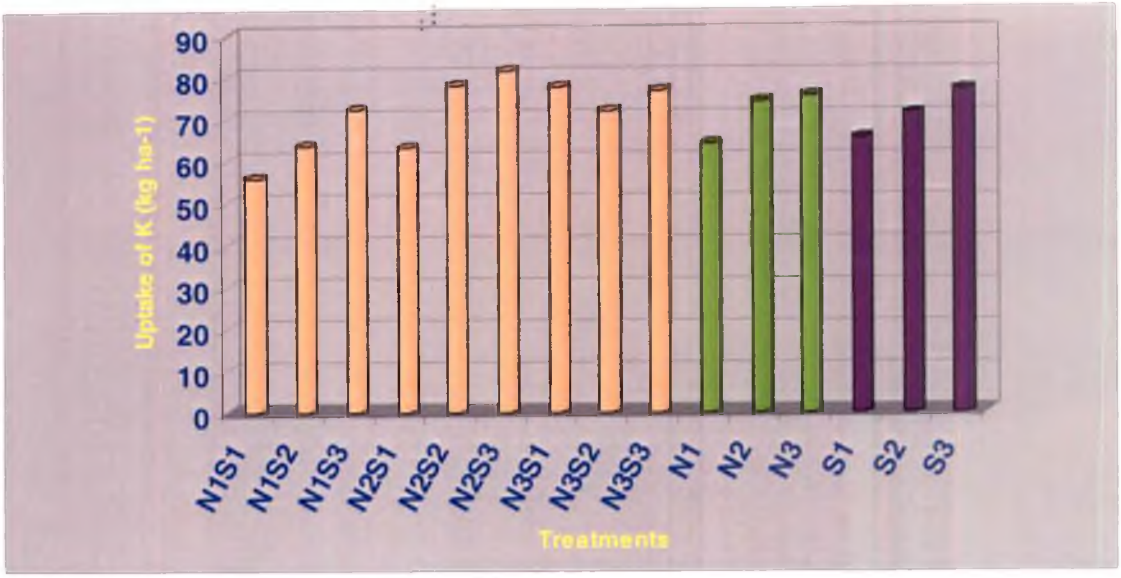


Fig. 16. Effect of N and S interaction and their individual effects on uptake of K (kg ha^{-1})

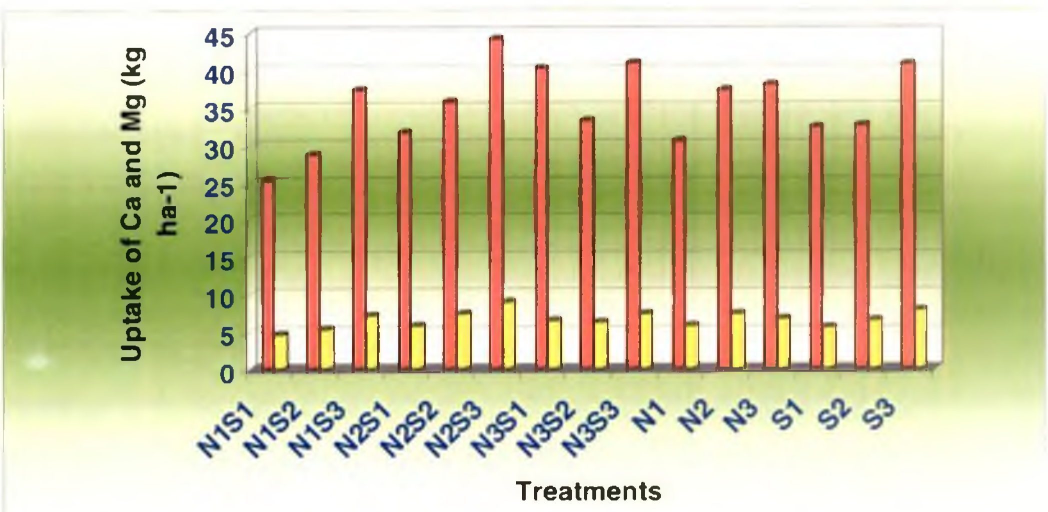


Fig. 17. Effect of N and S interaction and their individual effects on uptake of Ca and Mg (kg ha^{-1})

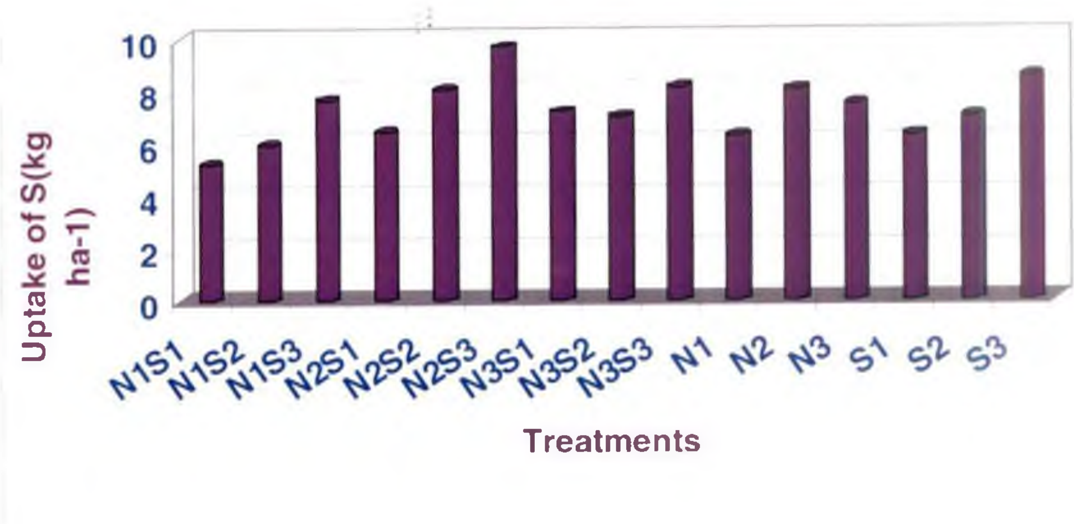


Fig. 18. Effect of N and S interaction and their individual effects on uptake of S (kg ha^{-1})

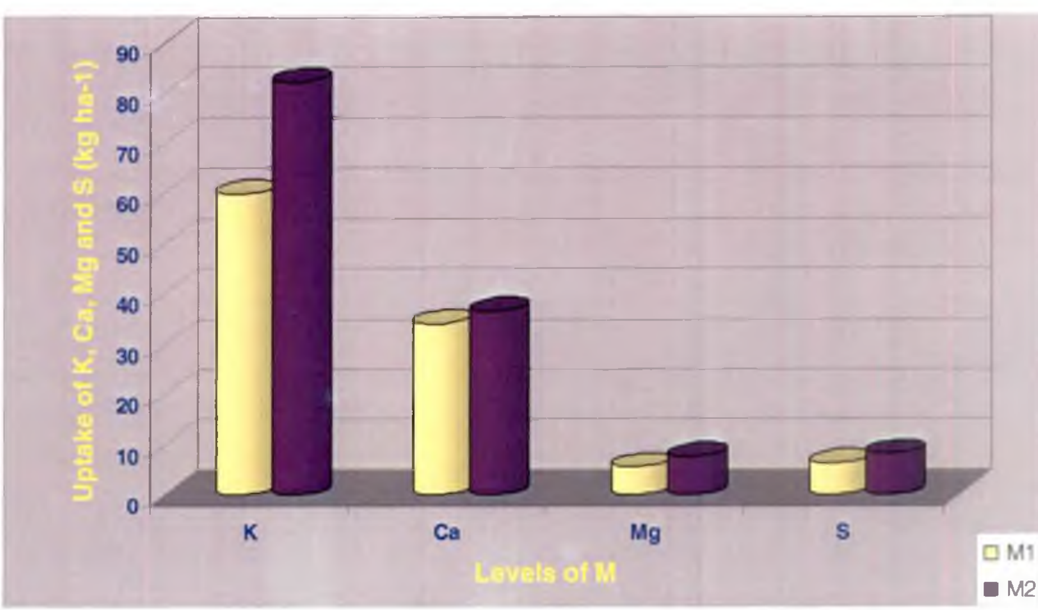


Fig. 19. Effect of M application on uptake of K, Ca, Mg and S (kg ha^{-1})

5. 2. 5. 5. *Sulphur*

Different levels of N and S significantly increased the uptake of S (Fig. 18). Among the N levels, N_2 (80 kg ha^{-1}) and N_3 (110 kg ha^{-1}) were on par and among the S levels, S_3 (20 kg ha^{-1}) recorded the significantly superior S uptake. Higher dose of S resulted in more availability of S in soil which led to higher uptake of S by the plant. Beena (2000) reported that S application @ 30 kg ha^{-1} increased the uptake of S in cowpea. The positive influence of S application on S content and uptake was reported by Mishra *et al.* (1995). Panda and Srivastava (2008) reported that S along with N increased the S uptake in rice. Thankur and Patil (2004) suggested that gypsum @ 20 kg ha^{-1} increased the S uptake in groundnut.

Application of P and K at M_2 level (35 kg ha^{-1} and 70 kg ha^{-1}) registered significantly higher uptake of S by the crop due to increased crop growth and higher dry matter production (Fig. 19).

5. 2. 6. *B: C ratio*

N application significantly influenced the B: C ratio (Fig. 20) and the highest B: C ratio (2.17) was obtained for the application of 80 kg N ha^{-1}. This may be due to the fact that N application up to 80 kg enhances the crop yield and provides better returns to the farmer. Among the treatments $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1}+ 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}) which registered better yield and highest NUE gave the highest B: C ratio of 2.46. Regarding the N and S interaction effects, N_2 S_3 (N @ 80 kg $ha^{-1}$and S @ 20 kg ha^{-1}) recorded the highest B: C ratio of 2.31. Among the S levels, the highest level of S (S_3 @ 20 kg ha^{-1}) was the best. Even though the S application had no significant influence on B: C ratio, as the application of S increased, the B: C ratio also increased. S fertilization @ 25 kg ha^{-1} and 50 kg ha^{-1} increased the B: C ratio in groundnut (Vaghasia *et al.*, 2007). Ramdevputra *et al.* (2010) reported that maximum pod yield and net realization were recorded with the application of S in groundnut. Yadav *et al.* (2008) found that B: C ratio of lentil was significantly increased (2.13) by the application of 40 kg S ha^{-1}.

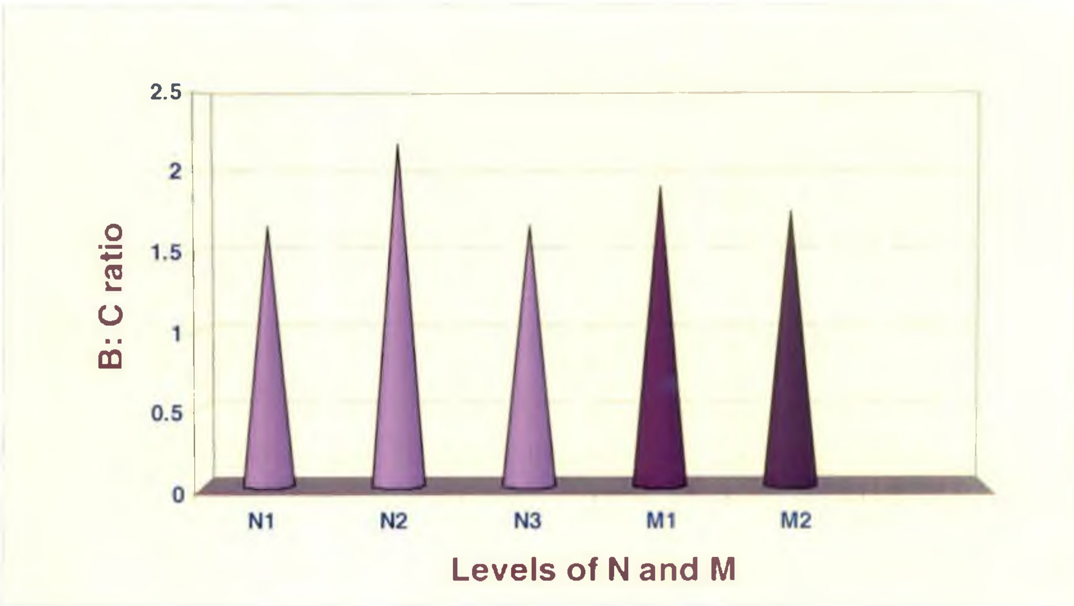


Fig. 20. Effect of N and M application on B: C ratio

5. 2. 7. *Percentage Disease Incidence*

Even though there was no significant difference between the treatments, N and S application showed decreased incidence of yellow vein mosaic virus disease (Table 21). Among the treatments, $M_1N_2S_2$ (80 kg N + 8 kg P_2O_5 + 25 kg K_2O+15 kg S) which recorded the maximum yield showed the minimum incidence of the disease and among the N and S interaction effects, N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) showed the minimum incidence. Among the N levels, N_1 (50 kg ha^{-1}) showed the maximum disease incidence followed by N_3 (110 kg ha^{-1}) and N_2 (80 kg ha^{-1}) showed the minimum percentage disease incidence. Reduction in the incidence of disease may be due to improved synthesis of S containing phytoalexins, glutathione, glucosinolates and the release of S-containing volatiles which provides resistance to the crop. Kruse *et al.* (2007) revealed that contents of cysteine and glutathione increased which serve as markers of primary sulfate assimilation and stress response, in *Arabidopsis thaliana* upon infection, coinciding with the synthesis of sulfur-containing defence compounds.

Haneklaus *et al.* (2004) concluded that soil-applied sulphate fertilization proved to significantly reduce infection rate and severity of crops by fungal diseases. The potential efficacy of so called S Induced Resistance (SIR) expressed as a reduction of the disease index ranged from 5–50per cent and 17–35per cent in greenhouse and field experiments, respectively.

From the investigations, it can be confirmed that the treatment $M_1N_2S_2$ (80 kg N + 8 kg P_2O_5 + 25 kg K_2O + 15 kg S) which gave the highest yield, highest NUE and highest B: C ratio could be taken as the best treatment as far as production is concerned. Application of S along with N can reduce the dose of N to 80 kg ha^{-1}, when compared to modified POP which advocates 110 kg ha^{-1}.

Summary

6. SUMMARY

Detailed investigations consisting of laboratory incubation study and field experiments were carried out at College of Agriculture, Vellayani to study the interactive effect of nitrogen and sulphur application on their relese pattern and use efficiency in ferralitic soils. The treatments consisted of $M_1N_1S_1$, $M_1N_1S_2$, $M_1N_1S_3$, $M_1N_2S_1$, $M_1N_2S_2$, $M_1N_2S_3$, $M_1N_3S_1$, $M_1N_3S_2$, $M_1N_3S_3$, $M_2N_1S_1$, $M_2N_1S_2$, $M_2N_1S_3$, $M_2N_2S_1$, $M_2N_2S_2$, $M_2N_2S_3$, $M_2N_3S_1$, $M_2N_3S_2$ and $M_2N_3S_3$ and $M_0N_0S_0$. Levels of N include N_1 (50 kg ha^{-1}), N_2 (80 kg ha^{-1}) and N_3 (110 kg ha^{-1}). M_1 include P_2O_5 @ 8 kg ha^{-1} + K_2O @ 25 kg ha^{-1} (current POP) and M_2 include P_2O_5 @ 35 kg ha^{-1} + K_2O @ 70 kg ha^{-1}(modified POP). Different levels of S are S_1 (10 kg ha^{-1}), S_2 (15 kg ha^{-1}) and S_3 (20 kg ha^{-1}). The results of the study are summarized below:

The incubation study was undertaken to analyze the release pattern of N and S from their sources viz. urea and gypsum in the soil at different sampling stages such as 30 and 100 days of incubation. It had been observed that by the application of N as urea and S as gypsum, there was increase in pH value to the neutral range at fifty per cent flowering stage (30 Days of Incubation) and all the treatments showed a decreasing trend in the pH value at 100 Days Of Incubation. The increase in pH at 30 DOI might be due to the ligand exchange of hydroxyl group by sulphate in gypsum and due to the effect of cow dung application @ 12 t ha^{-1} as basal dose. Another reason for increased pH is the presence of Ca in gypsum. The decrease in pH at 100 DOI may be due to mineralization of ammoniacal form of N to nitrate form which releases H^+ ions to soil solution.

The available N status of the soil had been increased by the application of N and S at 30 DOI. The highest available N content in the soil was obtained with $M_1N_3S_3$ (110 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 20 kg S ha^{-1}). At 100 DOI, all the treatments showed a decreasing trend. It may be due to the loss of N as volatilization of ammonia from the soil incubated at field capacity or N may be immobilized by microorganisms. Considering the N and S interaction effects,

N_3S_3 (110 kg N ha^{-1} and 20 kg S ha^{-1}) showed the highest value for available N. This is due to increased application of N and positive influence of S in releasing N in soil. Among the N levels, N_3 showed a significantly highest value.

N and S application increased the available soil S status at 30 DOI. N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) showed the highest values at 30 DOI. Among the S levels, S_3 was significantly superior and this may be due to the S content in gypsum, which is readily soluble. However, the S content showed a gradual decrease for all the treatments in the course of incubation. This may be due to the adsorption of S as sulphate in the exchange sites and immobilization by microorganisms.

In the field experiment, among the N and S interaction effects, N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) took comparatively lesser number of days for first flowering. Among the N levels, highest dose of N (110 kg N ha^{-1}) and among S levels, S_2 (15 kg S ha^{-1}) took lesser number of days than the other N and S levels. Treatments without N and S took more number of days for first flowering. As the application of N increased, the plant took more number of days for fifty per cent flowering. Compared to the control treatment, all the treatments which received N and S took lesser number of days for fifty per cent flowering. Treatment that received N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) showed maximum duration from flowering to final harvest.

Plant height at 30 DAS and 90 DAS was highest for $M_1N_2S_3$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 20 kg S ha^{-1}) and at 60 DAS the height was maximum for $M_2N_2S_3$ (80 kg N ha^{-1} + 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20 kg S ha^{-1}). Among the N levels and S levels, N_2 and S_3 respectively showed the maximum plant height. All the treatments showed increased plant height than that of the control treatment. Increased plant height by S nutrition might be due to the effects of S in metabolism of growing plants, increased photosynthetic rate, chlorophyll content and uptake of nutrients. N application also increased the plant height up to 80 kg ha^{-1}. This may be because of increased availability of N resulting in better dry matter production and translocation of photosynthates.

At 30 DAS, $M_2N_2S_3$ (80 kg N ha^{-1} + 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20 kg S ha^{-1}) recorded the shortest internodal length and it was followed by $M_2N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}). S application @15 kg ha^{-1} had significant influence on internodal lengh. Individual effect of N as well as individual effect of S also influenced the length of internodes significantly. Among the N levels, N_3 (110 kg N ha^{-1}) and among the S levels, S_2 (15 kg ha^{-1}) showed significantly shorter internode length.

At 60 DAS and at 90 DAS, N and S interaction showed significant influence on fruit length. At 90 DAS, N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) showed the higher value. N application up to 80 kg ha^{-1} also showed significant influence on fruit length at 60 DAS.

The maximum number of fruits was obtained for the treatment which received $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}). Considering the N and S interaction effects, N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}) recorded the highest number of fruits followed by N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}). The number of fruits per plant increased up to 80 kg N ha^{-1}. Among the S levels, S_2 (15 kg ha^{-1}) resulted in maximum number of fruits. The increase in number of fruits per plant by the application of N and S may be due to the highest uptake and efficient utilization of nutrients.

The highest yield was recorded by $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O+ 15 kg S ha^{-1}) followed by $M_2N_2S_3$ (80 kg N ha^{-1} + 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 20 kg S ha^{-1}). There was no significant difference between the treatments. Among the N levels, N_2 (80 kg N ha^{-1}) recorded significantly higher yield. But above 80 kg N ha^{-1} there was reduction in yield. The highest dry matter accumulation (shoot) was recorded by $M_1N_3S_3$ (110 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 20 kg S ha^{-1}). Among the N levels N_3 (110 kg N ha^{-1}) and among the S levels, S_3 (20 kg S ha^{-1}) recorded the highest dry matter content. There was no significant difference between the treatments.

S application showed significant influence on NUE in bhindi and application @ 15 kg ha^{-1} registered the highest NUE. Among the treatments, the highest NUE was recorded by $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg

K_2O + 15 kg S ha^{-1}). Even though the interaction between N and S was not significant, N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) recorded the highest NUE followed by N_2S_2 (N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1}).

By the application of N as urea and S as gypsum, there was increase in pH value to the neutral range at fifty per cent flowering stage and all the treatments showed a decreasing trend in the pH value at final harvest. Organic carbon content increased to some extent due to N and S application at fifty per cent flowering stage and at final harvest it decreased. N application had significant influence on the organic carbon content in the soil. Among N levels N_3 (110 kg ha^{-1}) showed a significantly higher value. Among the S levels, S_3 (20 kg ha^{-1}) showed the highest value for organic carbon content in soil.

At fifty per cent flowering, all the nutrients showed an increase in availability from the initial values and there was a decrease at the final harvest stage because of crop uptake.

Different levels of N significantly influenced the available N status in soil. Among the N levels, N_3 (110 kg ha^{-1}) recorded the significantly superior value. Considering the N and S interaction effects, N_3S_1 (N @ 110 kg ha^{-1}+S @10 kg ha^{-1}) recorded significantly higher value. S application significantly influenced the available P and K content in soil due to the fact that gypsum decreased P adsorption because of its high solubility and the release of K^+ from the exchange sites by Ca $^{2+}$ respectively. S_3 (20 kg ha^{-1}) recorded the highest value. Application of P and K at M_2 level significantly increased the availability of P and K in soil. As the levels of N as well as S increased, there was increase in the exchangeable calcium in soil. Better availability of Ca from gypsum ensured higher Ca content in soil. Phosphogypsum significantly influenced the available soil S status and S_3 (20 kg ha^{-1}) recorded the highest value. The increase is be due to the S content in gypsum, which is readily soluble even though there was no significant difference between the treatments.

Higher levels of application of N recorded higher N content in both plant and fruit. Application of P and K at M_2 (35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1}) level significantly increased the content of P, K and Ca in plant and fruit. Increased S application increased the Ca content in plant since gypsum was used as the source of S. S application up to 20 kg ha^{-1} had significant influence on the fruit Ca and Mg concentration. The interactive effect of N and S was not significant in the case of S content in plant. But, N_2S_3 (N @ 80 kg ha^{-1} and S@ 20 kg ha^{-1}) recorded the highest value. N application had got positive influence on the content of P, K, Ca, Mg and S in plant and fruit.

At fifty per cent flowering stage, N and S fertilization significantly influenced the N: S ratio of the fruit. By progressive increase in S application up to 20 kg ha^{-1} and N application up to 80 kg ha^{-1}, N: S ratio was found to be significantly decreased. These levels of N and S gave the highest yield, NRA, chlorophyll content, B: C ratio and lower PDI. Uptake of P, Ca, Mg and S also was higher for this interaction. Progressive decrease in N: S ratio was noticed with increase in the rate of S application.

N and S fertilization had significant influence on leaf chlorophyll content and $M_2N_2S_2$ (80 kg N ha^{-1}+ 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1} + 15 kg S ha^{-1}) showed the higher value for chlorophyll content. Considering the N and S interaction effects, N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) showed the significantly superior value. With every increase in N level, there was corresponding increase in the chlorophyll content of leaves. NRA in leaves was significantly increased by N and S application. An increasing trend was noticed with higher levels of N up to 80 kg ha^{-1} and S up to 20 kg ha^{-1}.

N and S application increased the uptake of N, P, K, Ca, Mg and S. N uptake increased significantly up to N_3 (110 kg N ha^{-1}) and S_3 (20 kg S ha^{-1}). Among the treatments $M_2N_2S_3$ (80 kg N ha^{-1}+ 35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1}+ 20 kg S ha^{-1}) recorded the highest uptake of P, K, Ca, Mg and S. The same trend was observed for interactive effect of N and S as well as individual effects of N and S.

N application @ 80 kg ha^{-1} significantly influenced the B: C ratio. Among the treatments $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1}+ 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}) which gave the maximum yield showed the highest B: C ratio. As the application of S increased, the B: C ratio also increased. S application along with N showed a decrease in the incidence of yellow vein mosaic virus disease. Among the treatments, $M_1N_2S_2$ (80 kg N + 8 kg P_2O_5 + 25 kg K_2O + 15 kg S) which recorded the maximum yield showed the minimum incidence of the disease.

FUTURE LINE OF WORK

From the investigations, it can be confirmed that the treatment $M_1N_2S_2$ (80 kg N + 8 kg P_2O_5 + 25 kg K_2O + 15 kg S) which gave the highest yield, highest NUE and highest B: C ratio could be taken as the best treatment as far as production is concerned. Application of S along with N can reduce the dose of N to 80 kg ha^{-1}, when compared to modified POP which advocates 110 kg ha^{-1}. The experiment has to be carried out at different locations in farmer's field in order to confirm the result.

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NITROGEN AND SULPHUR INTERACTION ON THEIR RELEASE PATTERN AND USE EFFICIENCY IN FERRALITIC SOILS

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ABSTRACT

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ABSTRACT

An experiment was carried out at College of Agriculture, Vellayani to investigate the interactive effect of nitrogen and sulphur on their release pattern and use efficiency in ferralitic soils with bhindi as the test crop. The experiment consisted of an incubation study and a field experiment.

The incubation study was carried out to understand the release pattern of N and S from their sources *viz.* urea and gypsum in the soil at different sampling stages (30 and 100 days of incubation) using ferralitic soil kept at field capacity. The treatments consisted of $M_1N_1S_1$, $M_1N_1S_2$, $M_1N_1S_3$, $M_1N_2S_1$, $M_1N_2S_2$, $M_1N_2S_3$, $M_1N_3S_1$, $M_1N_3S_2$, $M_1N_3S_3$, $M_2N_1S_1$, $M_2N_1S_2$, $M_2N_1S_3$, $M_2N_2S_1$, $M_2N_2S_2$, $M_2N_2S_3$, $M_2N_3S_1$, $M_2N_3S_2$ and $M_2N_3S_3$ and $M_0N_0S_0$. Levels of N include N_1 (50 kg ha^{-1}), N_2 (80 kg ha^{-1}) and N_3 (110 kg ha^{-1}). M_1 include P_2O_5 @ 8 kg ha^{-1}+ K_2O @ 25kg ha^{-1} (current POP) and M_2 include P_2O_5 @ 35 kgha^{-1} + K_2O @ 70 kg ha^{-1}(modified POP). Different levels of S are S_1 (10 kg ha^{-1}), S_2 (15 kg ha^{-1}) and S_3 (20 kg ha^{-1}). Soil samples were collected and analyzed for pH, available N and available S content. There was increase in pH value to the neutral range at fifty per cent flowering stage (30 Days of Incubation) and all the treatments showed a decreasing trend in the pH value at 100 Days of Incubation. Available N and available S content increased to some extent at fifty per cent flowering and decreased at the final harvest stage. Application of N up to 110 kg ha^{-1} significantly increased the available N status of soil and S application up to 20 kg ha^{-1} increased the soil S status during incubation.

The field experiment was laid out in 2×3×3+1 factorial RBD having three replications using bhindi variety Varsha Uphar as the test crop. The treatments were similar to that of the incubation study.

S application @15 kg ha^{-1} significantly reduced the internodal length. N and S interaction N @ 80 kg ha^{-1} and S @ 15 kg ha^{-1} showed significant influence on fruit length. The maximum number of fruits and highest yield was

obtained when the nutrients were applied @ 80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}. Considering the N and S interaction effects, combined application of N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1} increased the number of fruits and yield. Application of N up to 80 kg ha^{-1} increased the crop yield and above this level, there was reduction in yield. The increase in number of fruits per plant by the application of N and S may be due to the highest uptake and efficient utilization of nutrients. N @ 110 kg ha^{-1} and S @ 20 kg ha^{-1} recorded the highest dry matter content. S application @ 15 kg ha^{-1} showed significant influence on N Use Efficiency (NUE) in bhindi. Application of 80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1} resulted in highest NUE.

By the application of urea and gypsum, there was slight increase in the soil pH. After N and S application, there was increase in organic carbon content of the soil. At fifty per cent flowering all the nutrients showed an increase in availability and there was a decrease at the final harvest stage because of crop uptake and various losses. N application @ 110 kg ha^{-1} significantly increased the available N status in the soil. S application up to 20 kg ha^{-1} significantly increased the available P K and S content in soil. As the levels S increased, there was increase in the exchangeable calcium in soil.

Higher levels of application of N recorded higher N content in both plant and fruit. Application of P and K at M_2 (35 kg P_2O_5 ha^{-1} + 70 kg K_2O ha^{-1}) level significantly increased the content of P, K and Ca in plant and fruit. Increased S application increased the Ca content in plant since gypsum was used as the source of S. S application up to 20 kg ha-1 had significant influence on the fruit Ca and Mg concentration. The interactive effect of N and S was not significant in the case of S content in plant. But, N_2S_3 (N @ 80 kg ha^{-1} and S @ 20 kg ha^{-1}) recorded the superior value. N application had got positive influence on the content of P, K, Ca, Mg and S in plant and fruit. By progressive increase in S application up to 20 kg $ha^{-1}$and N application up to 80 kg ha^{-1}, there was significant reduction in N: S ratio. N and S fertilization had significant influence on leaf chlorophyll content and application of 80 kg N ha^{-1}, 35 kg P_2O_5 ha^{-1}, 70 kg K_2O ha^{-1} and 15 kg S ha^{-1} showed the superior value for chlorophyll content.

An increasing trend was noticed with higher levels of N up to 80 kg ha^{-1} and S up to 20 kg ha^{-1}. N and S application significantly enhanced the uptake of nutrients. Uptake of phosphorus, potassium, calcium, magnesium and S were highest when N, P, K and S were applied @ 80 kg N ha^{-1}+ 35 kg P_2O_5 ha^{-1}+ 70 kg K_2O ha^{-1}+ 20 kg S ha^{-1}.

N application @ 80 kg ha^{-1} significantly influenced the B: C ratio. Among the treatments $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}) which gave the highest yield showed the highest B: C ratio. Maximum B: C ratio was obtained when N and S were applied @ 80 kg ha^{-1} and 15 kg ha^{-1} respectively. As the levels of S increased, B: C ratio also increased. Fertilization of N, P, K and S @ 80 kg ha^{-1}, 35 kg ha^{-1}, 70 kg ha^{-1} and 15 kg ha^{-1} respectively recorded the minimum Percentage Disease Incidence (yellow vein mosaic).

Among the treatments, yield, number of fruits per plant, N Use Efficiency and B: C ratio were highest for $M_1N_2S_2$ (80 kg N ha^{-1} + 8 kg P_2O_5 ha^{-1} + 25 kg K_2O ha^{-1} + 15 kg S ha^{-1}) and it can be considered as the best treatment combination. Application of N significantly increased the yield and the yield was highest at N_2 level (80 kg N ha^{-1}). There was reduction in yield if we apply N @ 110 kg ha^{-1}. By the application of S along with N increased the NUE and we can reduce the dose of N to 80 kg ha^{-1} instead of 110 kg N ha^{-1} for bhindi.

Appendix

APPENDIX - I

Weather Data for the cropping period

(July 2010 to October 2010)

Standard week	Temperature (^0C) (maximum)	Rainfall (mm)	Relative Humidity (%)	Evaporation (mm/day)
29	30.17	14.07	84.14	3.4
30	30.34	4.73	85.07	3.42
31	30.34	2.6	86.29	3.46
32	30.46	3.8	85.86	3.51
33	30.2	6.69	84.36	3.29
34	30.37	0	83.79	3.51
35	30.46	0	84.5	3.51
36	30.6	3.83	83.49	3.49
37	30.43	3.03	82.86	3.4
38	30.8	3.37	82.43	3.51
39	30.66	8.97	82.36	3.11
40	29.63	53.03	84.43	2.6
41	29.69	17.74	84.79	2.8
42	30.8	0.46	82.29	3.6