FUNCTIONAL EFFICIENCY OF ORGANIC MEAL IN GROUNDNUT PRODUCTION

By

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THESIS
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DECLARATION

I hereby declare that this thesis entitled **"Functional efficiency of organic meal in groundnut production"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Functional efficiency of organic meal in groundnut production"** is a record of research work done independently by Mr. **S. SENTHIL** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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DEDICATED TO MY BELOVED GRANDFATHER

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

1. INTRODUCTION

Groundnut is an important edible oil seed in Indian agriculture. India accounts for 40 per cent of the world area and 30 per cent of the world production of groundnut. Though, India leads in the world both in area (8.8 m ha.) and production (9.2 mt) of groundnut, the country ranks eighth in productivity (Ramesh *et al.*, 1998; Singhal, 1999 and GOI, 2000).

Kerala has only 10,032 ha under groundnut cultivation with the production of 7,458 t (GOK, 2000). The productivity is nearly 350 kg lesser than the national average of 1078 kg ha^{-1} (Ghosh *et al.*, 2000). This important crop which has to lead the Yellow Revolution in oil seeds is generally grown in summer rice fallows, which are starved of nutrients and water in Kerala. It has been estimated that one gram of glucose synthesized through photosynthesis produces 0.83 g starch, 0.40 g protein and only 0.32 g of lipid. Unless oil seeds are provided with extra input to produce more, it is difficult to realize higher yields as in the case of cereals. In order to cater to the growing needs of the state as well as nation, finding ways and means at least to improve or double the productivity is necessary, and as such management manipulations are the sole means to increase the production.

The reported potential yields are between 7,500 kg and 11,000 kg pods ha^{-1} in the experimental farms situated at Shadong province in China (Hunsigi and Krishna, 1998). Even in India, the normal yield of 4500 kg ha^{-1} was reported by Ramesh *et al,* (1998) with average management. So, there are further chances to improve the productivity of the crop through horizontal expansion of cropping based on adaptability and management practices. However, many scientists all over the world described groundnut as an unpredictable legume based on varying response with nutrition, seasons, variety and soil etc. (Loganathan *et al.*, 1996).

Groundnut, though being a legume, is considered as a heavy feeder of nutrients and often gives response to applied nutrients (organics and inorganics) especially phosphorus (Prasad *et al.*, 1996). The essential plant nutrient, P is the costliest fertilizer nutrient. This resulted in the renewal of interest of researchers and farmers to fully exploit the potential alternative sources of plant nutrients (especially P) along with growing concern for environmental quality and ecological sustainability.

A sustainable food production system would envisage, progressive improvement in quantitative yields in tune with increasing demands and maintaining quality of the produce as well as the environment on the one side and the economic viability on the other. Integrated nutrient supply through judicious combinations of organic and biological sources along with inorganic fertilizers can be a part of organic production system (Swaminathan, 1987).

In the way of returning to organic and sustainable agriculture, non-availability of sufficient quantity of FYM diverted the attention of researchers towards identification and utilization of various alternative organic sources including industrial waste. One of the study conducted (Gopinathan, 1996) revealed that Kerala Chemicals and Proteins Ltd. (KCPL) slurry on proper bioprocessing can be a good organic fertilizer or soil enrichner which resulted in the development of organic meal from KCPL sludge waste. This process also tackled the environmental pollution caused by the slurry around the factory area.

The organic meal thus produced is processed material from the industrial waste of KCPL using crushed animal bones as its raw material for manufacturing ossein. The meal is rich in calcium, phosphorus, nitrogen, magnesium and sulphur etc. The utilization of this cheaper and locally available enriched organic manure has a lot of scope in groundnut nutrition in Kerala. So, a through understanding of the nutritional efficiency of this material is essential. In this context, an investigation was undertaken with the following objectives:

- to investigate the efficiency of fortified concentrated organic manure (organic meal from KCPL) on productivity improvement of groundnut,
- to investigate its potential as a liming material and its mechanism of influence in relation to other mineral sources,
- to study the effect of S in groundnut production and modifying the availability of P and Ca component of organic meal,
- to elucidate the influence of organic meal in rhizosphere characteristics of a leguminous oil seed (groundnut).

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Judicious nutrient management plays an important role in increasing crop production and to maintain soil fertility. At the present rate of escalation in price of chemical fertilizers, combining inorganics with locally available organic sources of nutrient will help to sustain high productivity and soil health. Though information on the inorganic and organic sources of nutrients in groundnut production is available, the literature on combined application of fertilizers with locally available organic nutrient sources are limited. The available literature on the influence of organic and inorganic sources of nutrients on groundnut production and soil fertility is reviewed in this chapter.

2.1. Effect of organic manuring on groundnut

Groundnut removes large amount of plant nutrients and maintaining optimum level of plant nutrients in soil with application of organic manures like FYM becomes imperative (Nair *et al.*, 1982, Chawale *et al.*, 1995 and Mudalagiriyappa *et al.*, 1997). The highest sustainability in yields of oilseed crops like groundnut could be achieved through combined use of plant nutrients (Singh *et al.*, 1990). The beneficial effect of organic manuring in groundnut production was reported by Cooke (1970), Chellamuthu *et al*, (1988) and Jeyabal *et al.* (1999).

2.1.1. Growth characters

Application of organic manures like FYM, press mud, groundnut shell and rice husk improved the germination percentage of groundnut in red lateritic soils (Shanmugam and Rathnasamy, 1995).

The significant increase in length of main shoot and branches, number of branches, gynophores and dry matter in roots was reported with FYM application (Agasimani and Hosmani, 1989 and Chawale *et al.*, 1993). But, Metha and Rao (1996) reported a non-significant increase in growth characters with FYM application.

Loganathan (1990) reported that application of cow dung and / or sunhemp resulted in increased dry matter production. Application of FYM @ 5-10 t ha^{-1}

resulted with increased dry matter production (Nandhagopalan, 1985 and Intodia *et al.*, 1989) and the increase was approximately 60 per cent (Cisse, 1988).

The growth parameters like LAI, LAD, CGR and NAR were favourably improved with organic manuring (Balasubramanian, 1993).

2.1.2. Yield and yield attributes

Cattle manure applied plots had better flowering and fruiting (GOM, 1966). Application of coir dust at 500 kg ha $^{-1}$ gave 19 per cent increase in yield of groundnut (Loganathan *et al.*, 1979). Similarly, Shanmugam and Rathnasamy (1995) obtained higher pod yield with FYM, press mud, groundnut shell and rice husk.

FYM application (10-12.5 t ha^{-1}) resulted in improved number of mature pods, 100 kernel weight, shelling percentage, sound mature kernel percentage and reduction in immature pods (Williams, 1979; Chittapur, 1982; Agasimani and Hosmani, 1989 and Ghosh, 1997).

A low level of application of FYM (5-6.25 t ha^{-1}) resulted in higher production of pods and haulms (Jeyachandran *et al.*, 1975; Loganathan and Krishnamoorthy, 1980; TNAU, 1990 and Loganathan *et al.*, 1996), and Agasimani and Hosmani (1989) reported the highest pod and haulm yield with 7.5 t ha^{-1} FYM.

However, Kumaresan *et al.* (1984) observed that application of FYM at the rate of 10 t ha^{-1} had no significant effect compared to 5 t ha^{-1}, but superior to control. However, Balasubramanian (1993), Chawale *et al.* (1993), Lourduraj and Rajagopal (1996), Tausif and Sudarvano (1998) and Malawia *et al.* (1998) have reported that organic manuring was not having any effect on haulm yield. The combined application of organic sources like FYM, press mud, wheat straw, paddy straw, water hyacinth compost and enriched FYM with NPK fertilizers, gypsum and lime resulted in the highest pod yield (Yaduvanshi, 1980; Singh and Dhar, 1986; Yadav *et al.*, 1991; Geethalakshmi *et al.*, 1993; Ghosh, 1997 and Lourduraj *et al.*, 1998).

2.1.3. Nutrient concentration and nutrient uptake

Generally, application of organics resulted with increased uptake of nutrients because of better availability for longer period and this was favourably observed in groundnut (Patil *et al.*, 1998). The N concentration in shells, kernels and total uptake of N was significantly increased with FYM application, but N concentration in shoot decreased (Wey and Obatom, 1980 and Chawale *et al.*, 1995). Combination of inorganic N with organic sources resulted in higher N uptake and soil N (Ghosh, 1997). The high nitrogen uptake observed with FYM application might be probably due to increase in Mo availability (Rosolem and Caires, 1998).

Phosphorus concentration and uptake were increased significantly with increasing levels of FYM which was due to better P solubilization, mineralization and availability (Dahiya and Singh, 1980 and Bhujpal,1989). But, the P uptake was decreased when lime was applied with FYM, because of reduction in solubilization effect of FYM by lime (Dahiya and Singh, 1980).

Application of FYM @ 10 t ha^{-1} showed significantly higher uptake of K (Asha *et al.*, 1995). Dahiya and Singh (1980) reported decrease in Ca uptake with higher level of applied FYM and increased Ca uptake with increasing rate of lime with FYM. Similarly, the decrease in uptake of Mg and increase in uptake of Mn with increasing FYM level were also noticed. Poultry manure application increased Zn, Cu, Mn and Fe uptake (Patel and Thakur, 1998).

2.1.4. Quality parameters

Application of FYM favourably increased the crude protein and oil content and their respective yields (Wey and Obatom, 1980; Chittapur, 1982 and Balasubramaniyan, 1997a), where as, Asha *et al.*, (1996) reported that FYM application did not exert any significant effect on oil and protein contents in kernel. Combination of organic and inorganic nutrient sources resulted with increased oil and protein content and yield (Lourduraj *et al.*, 1998 and Ramesh *et al.*, 1998).

2.2. Effect of fertilizer application on groundnut

2.2.1. Nitrogen

Nitrogen is the major structural constituent of the plant cell and plays an important role in plant metabolism (Mahapatra *et al.*, 1985). Groundnut is a leguminous crop, which fixes atmospheric nitrogen in the root nodule and reduces the demand for applied nitrogen. Groundnut may respond to N fertilizer additions though it fixes around 200-260 kg N ha^{-1} (York and Colwell, 1951; Williams, 1979 and Dart and Krantz, 1977).

2.2.1.1. Effect on growth characters

Groundnut showed a significant increase in plant height with increasing levels of nitrogen and attained maximum with 40 kg N ha^{-1}(Jakhro, 1984, Reddy *et al.*, 1984; Hemasundar *et al.*, 1990 and Barik *et al.*, 1994). It is because of rapid meristematic activity in plants. But, Saradhi *et al.* (1990) reported significant increase in plant height up to 20 kg N ha^{-1} only, after that it was not significant.

The increase in the production of branches in groundnut with increasing levels and up to 40 kg N ha^{-1} was observed by Reddy *et al.* (1984) where as Chawale *et al.* (1993) and Surajbhan and Mishra (1972) found the highest number of branches with 30 and 50 kg N ha^{-1} respectively.

LAI was significantly increased in groundnut by N rates (Selamet and Gardener, 1985) and the increase was up to 90 DAS with 30 kg N ha^{-1}(Reddy, 1984). Mahakulkar *et al.* (1992) reported increase in leaf area up to 50 kg N ha^{-1}, but the increase in LAI was up to 25 kg N ha^{-1} only.

Selamet and Gardner (1985) reported increase in CGR up to 240 kg N ha^{-1}. Barik *et al.* (1994) observed higher CGR with 20 and 40 kg N ha^{-1}, whereas RGR is markedly reduced by the application of 40 kg N ha^{-1}. Mahakulkar *et al.* (1992) reported that AGR was increasing with increase in N level but not RGR.

2.2.1.2. Effect on yield and yield attributes

Nitrogen had significant influence on the number of pods per plant and number of filled pods per plant (Jadhar and Narkhede, 1980) which was because of production of more number of flowers and pegs at higher doses of nitrogen (Saradhi *et al.*, 1990). The increase in number of pods with 40-60 kg N ha^{-1} was reported by Reddy *et al.* (1984); Yakadri *et al.* (1992) and Patra *et al.* (1995). However Chawale *et al.* (1993) reported that application of N did not influence the number of mature pods in silty clay loam soils.

Patel and Patel (1985) observed that application of N showed marginal influence on pod weight per plant. Chowdary *et al.* (1977) and Dohatonde (1978) found that N application did not affect the shelling percentage and test weight significantly. But Reddy *et al.* (1984), Saradhi *et al.* (1990), Reddy *et al.* (1992), Yakadri *et al.* (1992) and Patra *et al.* (1995) found pronounced effect on the test weight up to 40 kg N ha^{-1}. Shelling percentage was not improved by N application (Patra *et al.*, 1995), where as Saradhi *et al.* (1990) observed significant increase in shelling percentage upto 20 kg N ha^{-1}.

Haulm yield consistently increased with increase in N rate up to 30-40 kg N ha^{-1} (Lombin *et al.*, 1985; Pradham *et al.*, 1992 and Bhatol *et al.*, 1994). However, there were reports that lower level of N up to 10-20 kg N ha $^{-1}$ was sufficient (Saradhi *et al.*, 1990 and Chawale *et al.*, 1995).

Application of moderate level of N (10-30 kg N ha^{-1}) produced higher pod yield and after that there was a decrease in pod yield (Tripathi and Moolani, 1971; Saini and Tripathi, 1975; Chowdary *et al.*, 1977; Mahakulkar *et al.*, 1992 and Rao, 1992). Application of 25 kg N ha^{-1} in the form of ammonium sulphate gave higher yield than other sources (Negi and Dalal, 1957). But, the increasing yield was obtained with 40 kg N ha^{-1} also (Saradhi *et al.*, 1990; Reddy *et al.*, 1992; Barik *et al.*, 1994 and Bhatol *et al.*, 1994).

2.2.1.3. Nutrient concentration and uptake

Naphade (1970) reported that uptake of N by haulms was more than pods, where as Muralidharan and George (1971) reported that 75 per cent of the plant N was in kernels. The uptake of N was increased with successive increase in N application and maximum with 40 kg N ha $^{-1}$ (Sathyanarayana and Rao, 1962 and Reddy *et al.*, 1992). Generally application of P and K fertilizers improved the N uptake with or without FYM (Chevalior, 1976; Devarajan, 1976; Rathee and

Chalal, 1977; Balasubramaniyan *et al.*, 1980, Sharma *et al.*, 1983; Kulkarni *et al.*, 1986 and Patel and Thakur, 1997b). Increased uptake of N with addition of S fertilizers was reported by Naphade (1970), Yadav and Singh (1970) and Pathak and Pathak (1972) which might be due to balancing action of N-S ratio (Parvathamma *et al.*, 1988; Reddy *et al.*, 1988 and Sailaja *et al.*, 1996).

2.2.1.4. Effect on quality parameters

The highest oil content in groundnut was obtained at higher levels of N, but oil recovery was significantly influenced by 20 kg N ha^{-1} beyond which there was reduction in oil out turn. The decrease in oil recovery with increase in nitrogen level could be attributed due to lower pod yield at higher doses of nitrogen. Increased protein level was also observed with increase in level of N (Chowdary *et al.*, 1977 and Reddy *et al.*, 1991). The seeds from the plants receiving nitrogen at the time of flowering had higher amount of proteins than those receiving complete N at sowing (Reddy *et al.*, 1991). Similarly, Chawale *et al.* (1995) also observed increase in oil content and protein content of kernels with increase in level of nitrogen.

2.2.2. Phosphorus

Being rich in protein and oil, it may need relatively more phosphorus (Rajendran and Lourduraj, 1998). P is also important for root formation, root growth and nitrogen fixation (Lakshmamma and Raj, 1997). The magnitude of response to applied P depends on initial available soil P (Budhar *et al.*, 1986). Agasimani and Hosmani (1989) reported that the response to P could be obtained when the available P status in soil is less than 35 kg P_2O_5 ha^{-1}.

2.2.2.1. Effect on growth characters

A significant increase in plant height was observed when the level of application was up to 40 kg P_2O_5 ha^{-1} (Chauhan *et al.*, 1987 and Barik *et al.*, 1994), and up to 60-80 kg P_2O_5 ha^{-1} (Saradhi *et al.*, 1990 and Choudhery *et al.*, 1991), where as P levels up to 80 kg P_2O_5 ha^{-1} had no significant effect on plant height in clay loam soils with medium available P (Thanzuala and Dahiphale, 1988).

The P application significantly increased the growth characters (Tomar *et al.*, 1983). The highest number of branches was reported with 40 kg P_2O_5 ha^{-1} (Chauhan *et al.*, 1987) and above that the trend was negative (Prasad *et al.*, 1996). But increased number of branches with application of 60 kg P_2O_5 ha^{-1} as single super phosphate was reported by Lakshmamma and Raj (1997).

Increase in LAI was reported with increase in level of P (Shankar *et al.*, 1984 and Raju *et al.*, 1985) and it was more up to 50 kg P_2O_5 ha^{-1} (Mahakulkar *et al.*, 1992) and even up to 60-80 kg P_2O_5 ha^{-1} (Barik *et al.*, 1994). Leaf area also increased with increasing P level upto 100 kg P_2O_5 ha^{-1} (Mahakulkar *et al.*, 1992). Combination of MRP with SSP at 50:50 and 75:25 ratio produced higher leaf area and 50:50 ratio produced higher LAD, where as NAR was higher with 100:0 ratio and CGR was not significant with source combinations (Mudalagiriyappa *et al.*, 1997). The highest RGR and CGR were obtained with 40 and 80 kg P_2O_5 ha^{-1} respectively (Angadi *et al.*, 1990 and Barik *et al.*, 1994).

Application of graded level of P_2O_5 increased the dry matter production and it was also influenced by soil fertility status (Rathee and Chalal, 1977). The P application increased the DMP at different levels viz., 40 kg P_2O_5 ha^{-1} (Thanzuala and Dahiphale 1988, Saradhi *et al.*, 1990 and Prasad *et al.*, 1996), 50 kg P_2O_5 ha^{-1} (Kulkarni *et al.*, 1986), 60 kg P_2O_5 ha^{-1} as SSP (Patil *et al.*, 1983) and 80 kg P_2O_5 ha^{-1} (Saradhi *et al.*, 1990 and Barik *et al.*, 1994).

2.2.2.2. Effect on yield and yield attributes

Number of pods and number of filled pods per plant were increased significantly with increasing P dose upto moderate level only (Singh *et al.*, 1994). Application of 40-60 kg P_2O_5 ha^{-1} produced higher number of pods (Shinde *et al.*, 1981; Sagare *et al.*, 1986; Vishnumurthy and Rao, 1986; Thanzuala and Dahiphale, 1988; Saradhi *et al.*, 1990; Metha and Rao, 1996 and Patel and Thakur, 1997a). However, application of P above 60 kg P_2O_5 ha^{-1} did or did not decrease the number of pods depending on soil fertility status (Rao *et al.*, 1984 and Singh *et al.*, 1994).

Application of moderate to high level of P fertilizers resulted in an increase in shelling percentage and 100 kernel weight (Rao *et al.*, 1984; Chauhan *et al.*, 1987; Patel and Patel, 1987; Metha and Rao, 1996 and Patel and Thakur, 1997a), where as Choudhery *et al.* (1991); Reddy *et al.* (1992) and Ramesh *et al.* (1998) reported lack of response of P_2O_5 application with respect to shelling percentage and 100 kernel weight.

The effect of P fertilization is generally seen in pod yield than haulm yield. Pod and haulm yields were appreciably influenced by successive increase in P levels (Kulkarni *et al.*, 1986 and Chauhan *et al.*, 1987). Moderate level of P application generally resulted in higher pod and haulm yield. Application of 20-50 kg P_2O_5 ha^{-1} resulted in higher pod and haulm yield (Vishnumurthy and Rao, 1986; Shinde *et al.*, 1989; Lomte and Khuspe, 1990; Reddy *et al.*, 1992; Singh *et al.*, 1994; Metha and Rao, 1996; Patel and Thakur, 1997b; Shekle *et al.*, 1997; Akbari *et al.*, 1998 and Patel and Thakur, 1998). When the level was increased there was a decrease in pod yield and haulm yield too (Bhatol *et al.*, 1994; Metha and Rao, 1996 and Prasad *et al.*, 1996). Among the sources, SSP out yielded TSP and DAP at 60 kg P_2O_5 ha^{-1} in respect of pod and haulm yield (Singh *et al.*, 1993).

Rabafka *et al.*, (1993) reported that application of SSP was not advantageous in terms of pod yield of groundnut in acid soil. Asha *et al.* (1996) reported that fertilising with P did not influence the pod and haulm yield even in soil with low available P.

2.2.2.3. Effect on nutrient concentration and nutrient uptake

Concentration of P in shoot was higher at mid flowering than at maturity stage, and kernel accumulated a higher amount of P and S compared to shoot portion (Rathee and Chalal, 1977). Jeyadevan and Shridharan (1975) and Rathee and Chalal (1977) reported an increase in P content with P application. With respect to P uptake, SSP was superior to TSP and DAP (Singh *et al.*, 1993). Similarly, acidulation of rock phosphate resulted with higher uptake, but lower than SSP application (De *et al.*, 1994) and different combinations of MRP and SSP also increased the P uptake (Mudalagiriyappa *et al.*, 1995).

Irrespective of sources of P, increased uptake of P was observed with NPK + gypsum application (Patamkr and Bathkal, 1967 and Soundararajan *et al.*, 1984 a.). P uptake was higher in pods and haulms with SSP + ammonium sulphate additions (Maliwal and Tank, 1988). Moderate to high levels of K application decreased the P content (Miller *et al.*, 1961 and Walker, 1973), whereas absence of K fertilization influencing P uptake favourably was also reported by Hanway and Weber (1971).

Nitrogen, phosphorus and sulphur fertilization also resulted in an increased uptake of P (Patamkar and Bathkal, 1967; Yadav and Singh, 1970 and Pathak and Pathak, 1972). Increasing levels of P and K application, resulted in increased P content in all stages of growth and in kernel (Jain and Dikshit, 1987).

2.2.2.4. Effect on quality paramerters

Maliwal (1987) concluded that SSP was superior to other sources of P in increasing the oil and protein content. The protein content of haulm and kernel increased with increasing levels of phosphorus (Chowdary *et al.*, 1977 and Kumar and Venkatachari, 1971) and maximum was obtained with application of 90 kg P_2O_5 ha^{-1} (Patel and Thakur, 1997a.), even though Patel and Thakur (1998) reported the highest protein yields with 17 kg P_2O_5 ha^{-1} application. Oil content increased with increased levels of P and the highest oil content (50.9 per cent) was obtained with 60 kg P_2O_5 ha^{-1} (Choudhery *et al.*, 1991). Prasad *et al.*, (1996) reported an increase in oil and protein percentage with 40 kg P_2O_5 ha^{-1}, but application of 50 kg P_2O_5 ha^{-1} did not show significant effect on oil and protein contents in kernel (Asha *et al.*, 1996).

2.2.3. Potassium

It is well recognized that groundnut is a heavy feeder of K and adequate supply of this nutrient is indispensable to obtain a better yield (Geethalakshimi *et al.*, 1993). But groundnut makes satisfactory growth even in K deficient soils where other crops would fail (York and Colwel, 1951).

K nutrition had favourable impact on the photosynthesis and translocation of leaf reserves to developing pods (Koch and Mengal, 1977). The general trends of K fertilisation showed that 40-60 kg K_2O ha^{-1} was optimum for groundnut beyond which deleterious effect was noticed (Naidu, 1968 and Putankar and Poathkel, 1967).

2.2.3.1. Effect on growth characters

An investigation conducted in red loam soil with low available K revealed that K application at 50 kg and 75 kg K_2O ha^{-1} increased the plant height and number of leaves per plant which resulted in increased dry matter of groundnut (Nair *et al.*, 1982). The potassium application had the least effect on plant dry matter weight except at 30 days growth stage (Kulkarni *et al.*, 1986).

The dry matter production at mid flowering stage increased significantly due to graded levels of potassium application; 75 kg K_2O ha^{-1} showing the highest DMP (Lakshminarayana and Subbiah, 1996).

Application of K enhanced the leaf area (LA) and leaf area duration (LAD) and hence resulted in higher net assimilation rate (NAR) (Nair *et al.*, 1981).

2.2.3.2. Effect on yield and yield attributes

Potassium application increased all the yield contributing characters and pod yield of groundnut with an increase in K level (Loganathan and Krishnamoorthy, 1980 and Singh *et al.*, 1994), where as absence of response to K fertilization in yield attributes and yield was also reported (Chowdary *et al.*, 1977).

Increased peg formation, number of pods per plant and pod yield per plant were observed with K fertilization (Eweida *et al.*, 1981 and Singh *et al.*, 1994). Application of K at higher level up to 75 kg K_2O ha^{-1} decreased the time taken for flowering and increased the number of pegs formed per plant (Nair *et al.*, 1982).

Soil dressing of 80 kg K_2O ha^{-1} increased the number of pods per plant (Gopalswamy *et al.*, 1978 and Nair *et al.*, 1981). Similarly, at 40 and 60 kg K_2O ha^{-1} levels, number of pods per plant and test weight of seeds increased (Ramanathan *et al.*, 1982 and Dubey *et al.*, 1986), and the maximum was attained with 50 kg K_2O ha^{-1}. The response was quadratic and also influenced the K content in seeds (Jana *et al.*, 1990).

Increase in shelling percentage with K fertilization was reported by Ramanathan *et al.* (1982) and Chavan and Kalra (1983), whereas AICORPO (1979) and Seopardi (1979) reported that shelling percentage and test weight of seeds were not influenced by K application.

2.2.3.3. Effect on nutrient concentration and uptake

Generally, groundnut takes up much more K than required if the nutrient is available in plenty (Reid and cox, 1973). Uptake of K was higher in initial stages of growth and later it was decreased with age (Soundararajan *et al.*, 1976). At ripening stage, seed K content was increased while stem K content was decreased (Chevalior, 1976).

Generally application of K increased the total K uptake in plants (Singh and Agarwal, 1976), where as Reddy and Krishnamurthy (1984) reported that application of K had no appreciable effect on uptake of nutrients by groundnut.

Application of P and K and NPK increased the K content of the plant (Soundararajan *et al.*, 1984b; Jain and Dikshit, 1987 and Patel and Patel, 1988b).

When the level of P application increased the K content was declined (Patel and Patel,1988a). Application of Ca and S or gypsum resulted in higher uptake of K (Soundararajan *et al.*, 1984b.). The uptake of K was also influenced by the level of K and S (Badiger *et al.*, 1988). The application of K decreased the K content in kernels but increased in haulm (Habeebullah *et al.*, 1977).

2.2.3.4. Effect on quality parameters

As the rate of K fertilisation increased, there was a general decrease in the free amino acid content and increase in the protein content (Mishra, 1967, and Bosewell and Anderson, 1976). However, Bhuiya and Chowdhury (1974) reported that K application did not increase the protein content, and Bilteanu *et al.* (1976) and Dubey *et al.* (1986) observed a reduction in the protein content of the seed due to K application. Potassium application to groundnut increased the oil content of kernels (Satyanarayana and Rao, 1962 and Varade and Urkude, 1982).

Application of K fertilizers @ 60 kg K_2O ha^{-1} to groundnut significantly increased oil content over control from 43 to 46 per cent (Devarajan, 1976). Nair and Sadanandan (1981) reported increase in oil content with increase in K_2O from 25 to 75 kg ha^{-1}, but application of 50 kg K_2O ha^{-1} had given higher oil content in many experiments (Chavan and Kalra, 1983; Babu *et al.*, 1984 and Patra *et al.*, 1996).

2.2.4. Calcium

Groundnut requires high amount of Ca for the developing pods. As calcium is relatively immobile in the plant tissues, which is not translocated in the plant in sufficient quantities from the root to meet the needs of developing pods. Calcium has to be available in adequate quantities near the fruiting zone (root zone and pod zone) *i.e.*, in the soil solution to produce good quality kernels (Nijhawan and Maini, 1966 and Geethalakshmi and Lourduraj, 1998).

Calcium application to the pod zone of groundnut reduces sterility and increases the number of pods per plant resulting in higher pod yields (Nijhawan and Maini, 1966). The groundnut plant showed preference to applied Ca rather than native calcium (Loganathan and Krishnamoorthy, 1977).

2.2.4.1. Effect on growth characters

The calcium application through gypsum alone improved germination, seedling survival, seedling vigour and root growth, when groundnut was grown on soils of different pH (Sullivan *et al.*, 1974).

Application of lime to groundnut resulted with significant increase in plant height (Geethalakshmi and Lourduraj, 1998), while LAI was not affected by liming. Similarly, the groundnut had shown increase in vegetative growth due to lime application but without increase in yield (Caires and Rosolem, 1996).

In a pot culture experiment, chlorophyll content in groundnut decreased as lime level increased from 5 to 20 per cent (Raut *et al.*, 1999).

2.2.4.2. Effect on yield and yield attributes

Application of gypsum in the pegging zone after 30 days of planting increased the number of developed pods per plant (Reddy, 1984) and decreased the number of immature pods. Application of gypsum (500 kg ha^{-1}) as basal produced higher pod and haulm yield, 100 kernel weight, sound mature kernel percentage and test weight of groundnut than application at pegging (Geethalakshmi and Lourduraj, 1998). Significant increase in sound mature kernels, extra large kernels and calcium content of kernels of groundnut due to top dressing with graded levels of gypsum was observed by Walker and Cosinos (1980).

Baynes *et al.* (1982) and Krishna *et al.* (1989) stated that, the yield of groundnut was not improved by addition of fertilizers containing N, P, K, Ca, Mg and/or S, but by the use of ground limestone (100 kg Ca ha^{-1}) at sowing.

Calcium application increased the shelling percentage and there was reduction in empty and poorly developed pods (Seoparadi, 1981 and Shanmugam and Rathnaswamy, 1995).

Hallock and Allison (1980) obtained increased groundnut yields from 360 to 1200 kg ha^{-1} in which kernel size was greatly improved by calcium application, and significantly higher productivity was obtained with calcium nutrition, irrespective of the sources applied at early flowering stage.

Supply of calcium to the groundnut plant through CaO (lime) has been observed to increase yield by 300 per cent (Puri, 1969). But Sanjeevaiah, (1969) reported 12 per cent increase in pod yield with 1200 kg ha^{-1} lime over control. Similarly, incorporation of 900 kg lime prior to sowing or top dressing of 675 kg ha^{-1} gypsum at maximum flowering stage improved the yield of kernel (Laurence, 1973).

2.2.4.3. Effect on nutrient concentration and uptake

The relative proportion of Ca was the highest in the leaves, followed by stem, shell and kernels (Chalal and Singh, 1979) and the calcium content of shell was twice that of kernels (Pillai *et al.*, 1984). A steady and linear increase in Ca accumulation in the seed took place from 30 to 80 days after the entry of peg into the soil and more than 80 per cent of the transported Ca was observed during this stage (Geethalakshmi and Lourduraj, 1998).

Calcium uptake was more when gypsum (S containing fertilizer) was applied than lime (non S containing fertilizers) (Pathak and Pathak, 1972 and Shankaran *et al.*, 1977). Similarly application of SSP resulted in more calcium uptake than DAP and also with increased levels of K and Ca (Rao, 1979). The heavy supply of Calcium alters the Ca and Mg ratio, which is critical for the uptake of many nutrients (Rajashekar and Deshpande, 1979). The Ca uptake was also depressed by Mg (Rao, 1979)

2.2.4.4. Effect on quality parameters

Application of 600 kg Ca ha^{-1} as lime to groundnut resulted in significantly higher pod yield, protein and oil yield over control. But, application of 400 and 500 kg ha^{-1} of calcium were on par (Thakare *et al.*, 1998). Application of gypsum resulted with increase in crude protein and oil yield (Devakumar and Giri, 1998).

2.2.5. Sulphur

Amongst the field crops groundnut has the highest requirement of sulphur per unit yield (Tiwari *et al.*, 1994). S is a constituent of amino acids like methionine and cystine, which are the building blocks of proteins, and part of important oil compounds. So, S application results in increased contents of proteins, phospholipids and FFA (free fatty acids) while glycolipids and sterols decreased and the accumulation of triglycerides in kernels increased (Kaur *et al.*, 1994). S is also known to promote nodulation in legumes thereby promoting nitrogen fixation (Tandon, 1991a).

Verma and Bajpai (1964) and Sagare *et al.* (1986) stated that sulphur is essential for the formation of chlorophyll and abundant supply of sulphur is necessary to develop dark green leaves. Sulphur application resulted in accumulation of starch, increase in activity of enzymes and mobilisation of photosynthates along with other nutrients from the leaves to the developing pods. It also enhances the availability of the energy (ATP) and reducing potential (NADPH) for the synthesis of lipids (Simcox *et al.*, 1979; Munshi *et al.*, 1983 and Shukhija *et al.*, 1983).

2.1.5.1. Effect on growth characters

Plants having an abundant supply of sulphur developed extensive root system with increase in nodular activity (Verma and Bajpai, 1964), and 20- 40 kg S ha^{-1} resulted with greater length of roots than control (Vishwakarma *et al.*, 1998). Sulphur application at 60 kg S ha^{-1} had increased the plant height and dry matter per plant (Balasubramanian, 1993)

Application of S at 20 and 40 ppm in the form of sulphate of potash increased significantly the mean dry matter produced by the plant to 28 and 33 g per pot over control (Sailaja *et al.*, 1996).

Sagare *et al.* (1986) and Reddy *et al.* (1988) reported 16.3 per cent increase in dry matter with 100 kg S ha^{-1} caused by increased number of branches, pod weight, seed index and dry matter accumulation per plant with each increment of S upto the level of 100 kg S ha^{-1} applied as elemental sulphur (Tiwari *et al.*, 1994).

Soil application of S at the rate of 37.5 kg S ha^{-1} through single super phosphate significantly increased plant height by 12 per cent, dry matter production per plant by 16 per cent and leaf area by 34 per cent (Sontakey *et al.*, 1999).

2.1.5.2. Effect on yield and yield attributes

Application of S showed positive influence on growth and yield of groundnut irrespective of sources (Panda *et al.*, 1997). The maximum pod yield was obtained with 30-40 kg S ha^{-1} (KAU, 1993 and Patil *et al.*, 1998), whereas Balasubramanian, (1993) did not obtain significantly higher yield even with 60 kg S ha^{-1}.

Application of gypsum had no bearing on flower production and flower to pod percentage and peg to pod percentage (Naidu, 1982). Application of 30-40 kg S ha^{-1} through gypsum increased the pod yield and net profit also (Mishra, 1996 and Thakare *et al.*, 1998)

Application of 20 to 40 kg S ha^{-1} as ammonium sulphate had shown significant increase in pod yield of groundnut (Singh *et al.*, 1970).

Application of S as elemental sulphur alone or in combination with other fertilizers resulted with higher pod yield, haulm yield and yield attributing characters (Laurence, 1973; Dungarwal *et al.*, 1974; Rathee and Chalal , 1977; Geethalakshmi and Lourduraj, 1998 and Thakare *et al.*, 1998), whereas, Devakumar and Giri (1998) reported that application of elemental sulphur at 36 kg S ha^{-1} did not bring any significant change in yield attributes and yield of groundnut.

2.2.5.3. Effect on nutrient concentration and nutrient uptake

Sulphur is one of the essential nutrients for groundnut production and groundnut requires as much S as P. Addition of S through various sources generally increased the S content in kernels, shells and haulm (Rathee and Chalal, 1977; Parvathamma *et al.,* 1988; Reddy, 1988 and Panda *et al.*, 1997). Similarly, Devi *et al.*, 1999) reported that 60 kg S ha^{-1} application recorded the highest uptake of plants.

When S was applied in combination with N and P, the uptake of S was increased (Pathak and Pathak, 1972). Generally, application of P was associated with significant increase in S contents of plants, and the highest dose depressed the S content, because of antagonistic relationship between S and P at higher concentrations (Rathee and Chalal, 1977).

Application of S also resulted with increase in S uptake but not K, and P application enhances the availability of S in soil (Pathak and Pathak, 1972). Generally, S uptake increased with increasing S rate, while S use efficiency decreased and the N:S, Ca:S and Mg:S ratio also decreased (Devi *et al.*, 1999).

2.2.5.4. Effect on quality characters

The protein and oil content were increased significantly with application of sulphur (Devakumar and Giri, 1998).

Killinger and Stokes (1951) obtained two to three percent increase in oil content by dusting sulphur at 20 kg S ha^{-1} at first bloom stage. Chopra and Kanwar, (1966) reported increased oil content of kernels and S containing amino acids in groundnut with application of 224 kg S ha^{-1}. Yadav and Singh (1970) reported increase in oil content and methionine percentage with application of 44.8 kg S ha^{-1}.

Naphade (1970) concluded that application of S @ 112 kg ha^{-1} particularly with nitrogen (22.4 kg ha^{-1}) significantly increased the protein content but not oil content. The application of S @ 20 kg ha^{-1} irrespective of sources in combination with NPK significantly increased oil and protein content of groundnut kernels

(Verma *et al.*, 1973). However insignificant effect on oil content was reported by Thakare *et al.* (1998).

2.3. Effect of integrated nutrient management

2.3.1. Groundnut production

Patel and Patel (1984), ICAR (1986) Kang and Balasubramaniyan (1990); Rao (1994) and Tilak and Singh (1996) reported that high and sustained crop yields especially from groundnut can be obtained with judicious and balanced NPK fertilization, combined with organic manures.

Integration of all sources of nutrients *ie.*, 10-10-45 kg N, P_2O_5, K_2O ha^{-1} + FYM (12.5 t ha^{-1}) + *Rhizobium* + enriched FYM (740 kg ha^{-1})+ gypsum (400 kg ha^{-1}) registered the highest groundnut pod yield which was 52 per cent higher than NPK treatment (Geethalakshmi *et al.*, 1993).

Application of 12.5 t ha^{-1} FYM and NPK (17-34-54 kg ha^{-1}) resulted in higher production (Balasubramaniyan, 1997a). It has been reported that FYM at 10-15 t ha^{-1} every year along with the recommended doses of NPK produced the highest groundnut yield than NPK alone (Khiabi and More, 1984 and Anonymous, 1986).

The application of N and P (1: 2) ratio with FYM had resulted in increased plant height, number of branches per plant, number of developed pods per plant, haulm yield, 100 kernel weight, shelling percentage, sound mature kernel percentage and harvest index which ultimately resulted in a higher pod yield (Agasimani and Hosmani, 1989).

Similarly, Lourduraj and Rajagopal (1996) reported that groundnut responded to higher level of fertilization and organic manure application. The yield attributes, yield and net return were higher at 125 per cent NPK with 12.5 t FYM. Pod, seed, oil and protein yields were the highest when P was applied as 75 per cent MRP and 25 per cent super phosphate along with 9 t FYM ha^{-1} and seed inoculation with *Aspergillus awamori* (Ramesh *et al.*, 1998).

For better growth and higher yield, application of NPK (17-34-54 kg ha^{-1}) + *Rhizobium* seed inoculation + phosphobacteria+ 12.5 t FYM ha^{-1} + 400 kg gypsum were recommended for Tamil Nadu (DA, 1994).

2.3.2. Soil fertility management

Management of nutrients is an important aspect of maintaining soil productivity and maximising yield (Abrol, 1988; Goswami and Rattan 1992; Mishra and Kapoor, 1992). Supplementing the chemical fertilizers with organic manures can arrest deteoriation in soil health (Rao, 1994). Under tropical climatic conditions prevailing in southern part of India, organic matter is quickly decomposed and fresh applications are necessary to obtain increased yields and maintain soil fertility (Guar *et al.*, 1984).

Organic manure application in combination with or without chemical fertilizers significantly increased the bulk density of soil, where as soil pH was not affected (Lourduraj *et al.*, 1998). Appreciable increase in organic carbon level was noticed with organic manure with or without mineral fertilizer application (Nambiar *et al.*, 1987; Chellamuthu *et al.*, 1988 and Das and Singh, 1988).

Optimum dose of lime for acid soils was quite low under FYM application because of prevention of leaching of Ca^{2+} complex and stabilization of soil pH (Yaduvanshi, 1980).

Organic manure supply improved the nutrient availability and soil structure and reduced compaction and crusting which might have ensured better peg penetration and pod development of groundnut (Agasimani and Babalad, 1991 and Chawale *et al.*, 1995). Organic matter addition to soil improves chemical, physical and biological properties of soil contributing to better plant growth (Greenland, 1986).

2.4. Effect of organics, inorganics and liming on nodulation and soil microbial population

Nitrogen nutrition of legumes by means of symbiotic nitrogen fixation has many advantages over nitrogen fertilizer application from the physiological angle. Inoculation of legumes, with efficient N_2 fixing *Rhizobium* strains, apparently contributes physiologically active compounds like vitamins B complex, cytokinins and gibberellins and auxins which have a favourable effect on plant development (Ratner *et al.*, 1979 and Hemasundar *et al.*, 1990).

Lakshmamma and Raj (1997) reported increase of nodule weight and leghaemoglobin content up to 80 DAS. Maximum nitrogenase activity in nodules was observed during the pod filling stage, and after that activity was very low (Ratner *et al.*, 1979).

Application of enriched FYM to groundnut crop increased the number of nodules and weight. Due to lower quantity of application, enriched FYM did not bring about as much effect as FYM application (Balasubramanian, 1993). FYM application increased the nodulation in groundnut (Balasubramanian, 1993 and Ram *et al.*, 1993), where as nitrogen and phosphorus application decreased it (Rayer, 1986). Use of mineral nutrients at higher level of NPK limited nodule development and function (Punnose and George, 1975; Robson, 1983 and Ratner *et al.*, 1979; ICRISAT, 1984 and Yoneyama *et al.*, 1990).

The application of ammoniacal nitrogen at 30 kg ha^{-1} combined with rhizobial inoculation increased the nodule number, root and shoot growth and total dry matter production in groundnut.

Rao (1979) observed that, P application increased the nitrogen content in the nodules of groundnut at different stages of crop growth and reached maximum at harvest. This could be due to the influence of available P on the nitrogen fixation by the bacteria (Vyas and Desai, 1953). Increased nodulation and nitrogen fixation by groundnut was noticed when inoculated with VAM fungi, which is due to mobilization of P to groundnut crop from the areas of non-rooting zone (Draft and El-Giahmi, 1976). The positive effect of P on nodule volume and number in groundnut was observed by Punnose and George, (1975), Draft and El-Giahmi

(1976), Shukla and Yadav (1982), Singh and Ahuja (1985), Kulkarni *et al.* (1986), McLaughlin *et al.*, (1990) and Krishna (1997).

Munns (1977) and Patel and Patel (1988b) reported that application of K had little or no influence on the nodulation on cultivated legumes. Kulkarni *et al.* (1986) reported that K application on nodulation was not consistent. Application of 50 kg K_2O ha^{-1} had increased the number and weight of nodules and nitrogen content of plant.

Horner (1939) reported that nodulation was improved by calcium application in groundnut crop. Similarly, McCalla (1937) demonstrated that calcium was required for the growth and normal behaviour of *Rhizobium* bacteria as well as for effective nodulation. De Mooy and Pesak (1966) reported that calcium had a strong negative effect on leg-haemoglobin content. Application of sulphur irrespective of the source, increased the nodule number and weight in groundnut (Reddy, 1984; Patil *et al.*, 1998 and Vishwakarma *et al.*, 1998).

Recent research indicated that Al was more toxic to rhizobia of cowpea group than low pH, high Mn levels or low levels of Ca and P. It was concluded that depressed nodulation at high Al concentrations resulted in nitrogen deficiency which reduced the growth to a greater extent than the limitation imposed by Al on the host species (Keyser and Munns, 1979a and 1979b).

The incidence of *Bradyrhizobium japonicum* strains was higher in acid soil than in neutral soil (Asanuma and Ayanaba, 1990). It is appropriate to include strains that are isolated from acid soils for cultivation under acid soil situation (Rossum *et al.*, 1994).

The bacterial population was more favoured in the rhizosphere of groundnut till the time of flowering after which they declined in number while fungal population gradually increased. It is known that the highest rhizosphere effect is exerted by plants at the time of maximum vegetative growth (Katznelson, 1965).

Rao *et al.*, (1972) and Balasubramaniyan (1993) found that high doses of nitrogen fertilizer had increased the actinomycetes population while *Azotobacter* counts were decreased.

Mandal (1976) reported that liming of acid soils generally improved the microbial activity. He observed that liming raised the pH from 5.4 to 6.7 at the same time increased the population of bacteria from 1.6 to 6.6 x 10^{6} g^{-1} and that of actinomycetes from 1.0 to 2.5x10^{6} g^{-1} of soil.

Addition of sulphur decreased the population of bacteria and actinomycetes by 5-9 and 3-4 times respectively over control and the fungi and nitrogen fixers also decreased (Jadhav *et al.*, 1979). According to Turner *et al.*, (1985) addition of N or P alone had little effect on total bacteria in root zone soils. But, Ponsombat *et al.* (1997) and Singh *et al.* (1998) reported tremendous increase in population of bacteria, fungi and actinomycetes with combined application of N and P. Multiplication of rhizobia in soil and nodule formation are energy demanding process calling for readily available source of ATP which is furnished by addition of organic matter. It is well known that soil organic matter serves as a storehouse of food for soil microbes (Rovira and Davay, 1974). Sharma (1983) reported that addition of FYM with chemical fertilizers had greatly increased the bacterial population.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The field experiment was conducted at College of Horticulture, Vellanikkara during 1999. The details of the materials used and methods followed in the conduct of experiments are presented below:

3.1. Details of the experiment

3.1.1. Experimental site

The experiment was conducted in the field attached to the department of Agronomy, College of Horticulture, Vellanikkara. The site is located at 10° 31' N latitude and 76° 3' E longitude and at an altitude of 22.25 m above MSL.

3.1.2. Weather and climate

This area enjoys a typical tropical climate with an average rainfall of 3400 mm per year. The important weather parameters observed during the experimental period are presented in Appendix-1.

3.1.3. Soil

The soil of the experimental field was lateritic, gravelly sandy clay loam in texture of the Oxisol group. The physical and chemical properties of the soil are presented in the Table-1.

3.1.4. Cropping history of the experimental site

The area was under cultivation of cereals and kept fallow during previous cropping seasons.

3.1.5. Crop and variety

The groundnut cv. VRI 4, Spanish bunch, bold seeded variety of 105 days duration was used for the experiment. The variety is suitable for both rainfed and irrigated cultivation and for the three seasons of the year. This variety is having field tolerance to rust and leaf spot disease and capable of producing higher dry pod yield under favourable situations and moderately better yield under farmers field conditions (Varman *et al.*, 1996). The morphological and quality characters of VRI 4 groundnut are given in Appendix-2.

Table : 1 Physico chemical properties of the experimental field .

Particulars	Value	Method	Reference
A. PHYSICAL PROPERTIES			
Mechanical Analysis (%)			
Coarse sand	26.0		
Fine sand	23.1	Robinson International pipette method	Piper, 1942
Silt	21.2		
Clay	29.7		
Texture	Gravelly lateritic sandy clay loam soil		
Available N (kg ha^{-1})	327.0-351.6	Alkaline permanganate method	Subbiah and Asija, 1956
Available P_2O_5 (kg ha^{-1})	22.57-30.19	Ascorbic acid reduced molybdophosphoric blue colour method	Watnabe and Olsen, 1965
Available K_2O (kg ha^{-1})	411.6-472.7	NN NH_4 Ac extract using Flame photometer	Jackson, 1958
Organic carbon (%)	1.07-1.41	Walkely – Black method	Jackson, 1958
pH	5.44-5.66	Soil water suspension 1:2.5 and read in pH meter – Elico	Hesse, 1971
EC	0.34-0.68	Soil water suspension 1:2.5 and read in digital conductivity bridge	Jackson, 1958

3.2. Experimental methods

3.2.1. Layout and design

The experiment, which consisted of twelve treatments, was conducted during Sep. - Dec. 1999 in Randomized Complete Block Design with four replication. The plot size was 5x4 m and the spacing adopted was 20x20 cm. The treatment combinations and level of nutrients applied are given in Table 2. The layout of experimental plan is given in fig.2

3.2.3. Seed material

Seeds of VRI 4 groundnut were obtained from Agricultural Research Station, Tamil Nadu Agricultural University, Aliyar nagar, Pollachi, Tamil Nadu.

3.2.4. Manures and fertilisers

Farmyard manure (FYM), organic meal (OM), urea, single super phosphate (SSP), Musoorie rock phosphate (MRP), muriate of potash (MOP), elemental sulphur and burnt lime were used for experiment. The chemical composition of fertilisers and manures used for experiment is given in Table 3.

Table 3. Composition of various nutrient sources used for the experiment

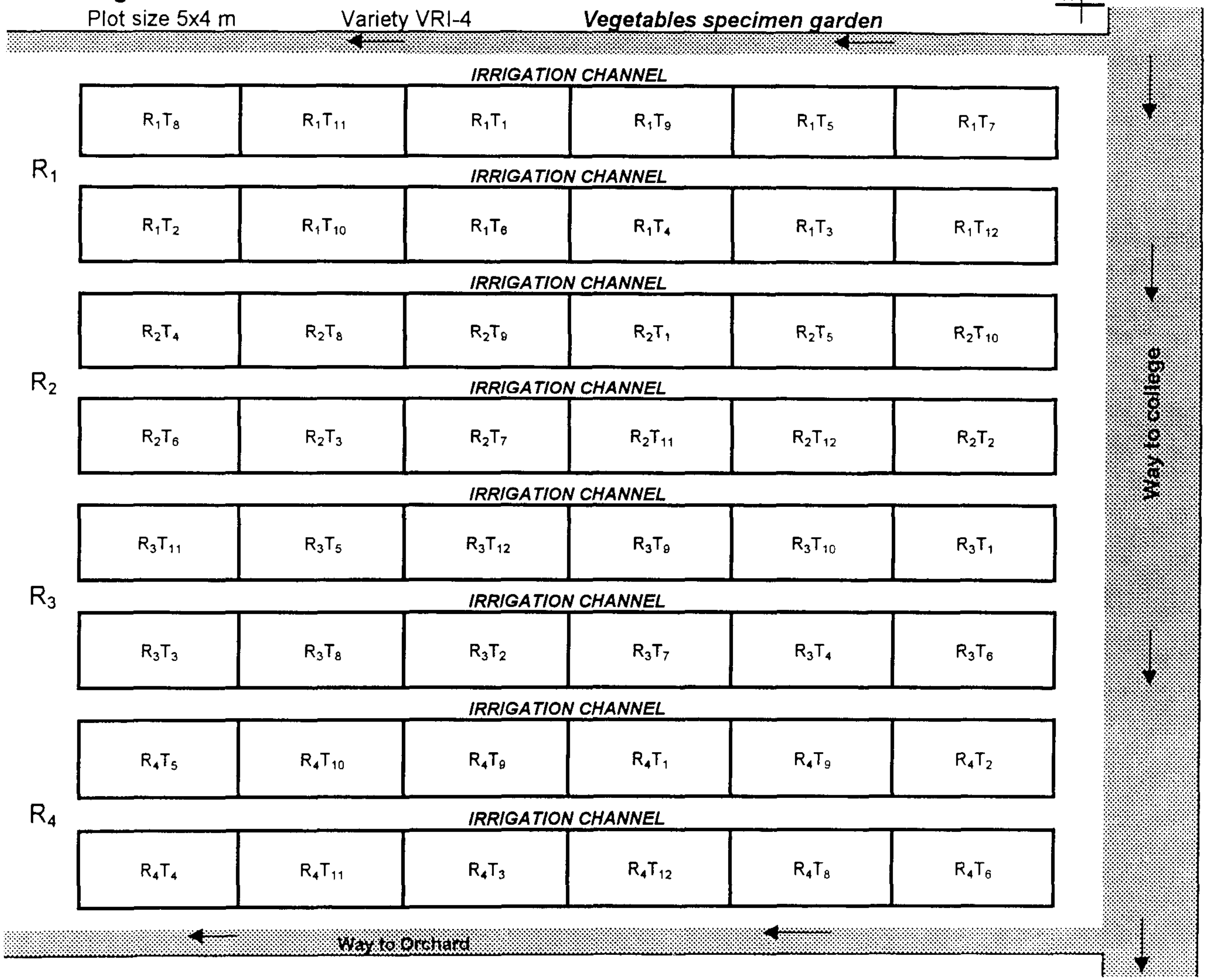
S.No	Nutrient source	Nutrient content in percentage				
		N	P_2O_5	K_2O	Ca	S
1	OM (Organic meal)	1.0	15.0	0.6	20.0	0.4
2	FYM	0.5	0.4	0.5	-	-
3	Urea	46.0	-	-	-	-
4	Rock phosphate (Musoorie phosphate)	-	18.0	-	30.0	4.0
5	Single super phosphate	-	16.0	-	19.5	12.0
6	Muriate of potash (MOP)	-	-	60.0	-	-
7	Lime	-	-	-	71.4	-

Table: 2 Treatment combinations and level of nutrients applied (kg ha^{-1}).

No.		Treatments	N	P_2O_5	K_2O	Ca	S
T_1	**R** (P as MP)	FYM 2 t + 10-75-75 kg N, P_2O_5, K_2O + lime 1000 kg ha^{-1} (P as mussoriephos)	20	83	85	840	17
T_2	**R** (P as SSP)	FYM 2 t + 10-75-75 kg N, P_2O_5, K_2O + lime 1000 kg ha^{-1} (P as SSP)	20	83	85	806	56
T_3	**R** (P as OM)	FYM 2 t + 10-75-75 kg N, P_2O_5, K_2O + lime 1000 kg ha^{-1} (P as organic meal, 500 kg)	20	83	88	814	2
T_4	R **(P as OM)**S_{56}	FYM 2 t + 10-75-75 kg N, P_2O_5, K_2O + lime 1000 kg + S as elemental S @ 56 kg ha^{-1} (P as organic meal)	20	83	88	790	58
T_5	$OM_{500}N_{15}K_{75}$	Org. meal 500 kg + 15 kg N + 75 kg K_2O ha^{-1} (N as urea)	20	75	78	100	2
T_6	$OM_{1000}N_{10}K_{75}$	Org. meal 1000 kg + 10 kg N + 75 kg K_2O ha^{-1} (N as urea)	20	150	81	200	4
T_7	$OM_{1500}N_5K_{75}$	Org. meal 1500 kg + 5 kg N + 75 kg K_2O ha^{-1} (N as urea)	20	225	84	300	6
T_8	$OM_{2000}K_{75}$	Org. meal 2000 kg + 75 kg K_2O ha^{-1}	20	300	87	400	8
T_9	$OM_{500}N_{15}K_{75}L_{860}$	Org. meal 500 kg + 15 kg N + 75 kg K_2O + lime 860 kg ha^{-1}	20	75	78	714	2
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	Org. meal 1000 kg + 10 kg N + 75 kg K_2O + lime 720 kg ha^{-1}	20	150	81	714	4
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	Org. meal 1500 kg + 5 kg N + 75 kg K_2O + lime 580 kg ha^{-1}	20	225	84	714	6
T_{12}	$OM_{2000}K_{75}L_{440}$	Org. meal 2000 kg + 75 kg K_2O + lime 440 kg ha^{-1}	20	300	87	714	8

(**R**- Package of Practices Recommendations of KAU. **MP**- Musoorie rock Phosphate. **SSP**- Single Super Phosphate. **OM**- Organic Meal. N-Nitrogen. P- Phosphorus. K- Potassium, S- Sulphur and L-Lime)

Fig.1 LAYOUT OF THE EXPERIMENTAL FIELD



3.2.5. Organic meal

The composted KCPL (The Kerala Chemicals and Proteins Ltd.) sludge popularly known as organic meal, was obtained from KCPL factory situated at Kathikudam near Koratty in Thrissur district of Kerala state. This is a joint sector company promoted by the Kerala State Industrial Development Corporation Ltd. in technical and financial collaboration with two leading Japanese companies *viz.*, M/S Mitsubishi Corporation and Nitta Gelatin Inc. The company produces ossein, an intermediate product from the manufacture of gelatin and dicalcium phosphate (DCP) from crushed animal bones. The combined effluent from various sections of the factory (bone charging and washing section, ossein washing section, DCP filtration system, laboratory etc.) are collected and subjected to different treatment like equalisation, flash mixing, flocculation, clarification, filtration etc., to seperate the sediment sludge and clear over flow. The over flow is left out into Chalakudy River with pH 7 - 7.2 and the sediment sludge is left in open. About 7-10 tones of filtered sludge is accumulating daily for which no effective disposal method is available causing environmental problems also (Plate 1). Due to uncontrolled putrefaction processes, the sludge emits nauseating and asphyxiant smell to surrounding atmosphere and restricts clean and pleasant air to the company staff and near by inhabitants. The sludge was then subjected for composting by K.A.U under a collaberative project, which resulted to organic meal devoid of foul smell. The physico-chemical properties of KCPL sludge / organic meal presented in the Table 4.

3.3. *Rhizobium* culture

It is better to use the native strains of *Rhizobium* for the better adaptation and functions, which ultimately leads to better crop growth by way of increased nodulation and nitrogen fixation. The *Rhizobium* culture used for the experiment was obtained from experiment plots. The nodules of big size and pink colour were collected from groundnut plants, which were grown in the experimental plots. The *Rhizobium* was isolated and purified as described by Vincent (1970) on YEMA medium (Appendix-4). The most effective and fast growing COHAG-5 strain was selected among the six isolates, for the mass multiplication (Vincent, 1970) and application to the crop. The final population of bacteria in lignite based culture was 4×10^{8} cfu g^{-1} of carrier material at the time of seed pelleting (Plate 2).

Plate: 1 Source of organic meal under study

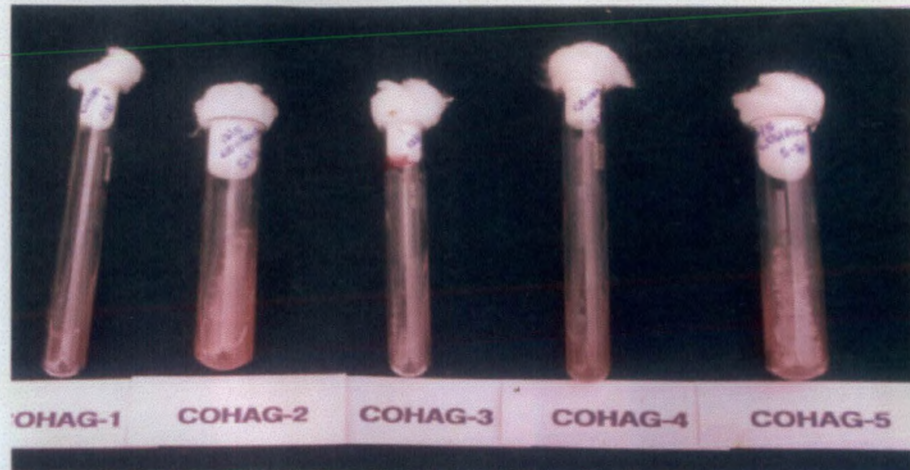
A general view of KCPL factory - Kathikudam

Slurry source point

Accumulation of filtered sludge- 7 to 10 t/day

Processed organic meal ready for use

Plate: 2 Preparation of rhizobial culture for seed treatment



Rhizobial isolates (COHAG-1 to COHAG-5) from groundnut on YEMA media

Lignite based rhizobial inoculant (COHAG-5)

A close view on root nodules

Table: 4. Physico-chemical properties of KCPL effluent sludge/ organic meal.

Sl.No.	Characteristics	Value
1.	Colour and appearance	Light to deep grey cobbled / flake form
2.	Bulk density (g cm^{-3})	0.61
3.	Particle density (g cm^{-3})	1.30
4.	pH	6.60
5.	Total N (%)	1.13
6.	Total P (%)	5.60
7.	Total K (%)	0.31
8.	Total Ca (%)	21.30
9.	Total Mg (%)	0.51
10.	Total S (%)	0.40
11.	Organic carbon (%)	14.30

Source : (Gopinathan, 1996)

3.4. Crop culture

The field was ploughed two times with tractor and one time by manual digging to bring the soil condition to optimum tilth for the cultivation of groundnut. The field was then levelled and plots were laid out as per the statistical design. Irrigation channels of width of 40 cm were laid out between each row of experimental plots.

FYM, organic meal and other recommended mineral fertilisers were applied as basal dressing. The elemental sulphur was applied 15 days before sowing to the respective treatment plots. The details of dates of important field operations are presented in the Appendix-3.

3.4.1. Sowing

The seedpods were shelled three days before sowing and mixed with fungicide mancozeb (2 g kg^{-1}) and prepared carrier based *Rhizobium* culture (250 g) was mixed with seeds on the day of sowing. Treated seeds were dibbled in the plots at a depth of 3-5 cm and at a spacing of 20 x 20 cm in the prepared flat beds. Gap filling was done at 7 DAS to ensure the better crop stand.

3.4.2. Cultural operations

First hand weeding was done at 7 DAS. The second hand weeding was combined with earthing up operation which was carried out at the time of flowering stage *ie.*35 DAS. Lime was applied as per the treatment dosage before earthing. Irrigation was given once in a week depending on climatic conditions. Plant protection measures were taken as and when required. Pod eating ants were observed during the pod filling stage. These were controlled by 0.05 % quinolphos as a soil drenching. During the initial stage of crop establishment, root rot was observed and for this, spot drenching with 0.05 % copperoxy chloride was done.

3.4.3. Harvesting

Harvesting was done at 108 DAS. The day before harvesting, a light irrigation was given for easy harvesting. Plants were uprooted using hand hoes and pods were separated on the same day. The weight of the wet haulms and pods were recorded for each plot separately. Pods and haulms were sun dried for a week and dry weights were recorded at minimum moisture level (6-8 %).

3.5. Observations

3.5.1. Biometric observations

Observations on growth characters were taken from twelve fixed plants from two locations in each plot once in 20 days from sowing and at harvest. Three plants were uprooted randomly from each plot once in 20 days as destructive sampling. These plant samples were used for taking observations regarding biomass accumulation, nodulation studies and chemical analysis.

3.5.1.1. Height of the plants

Height was measured from the ground level to the growing point of the plant and mean plant height was expressed in cm.

3.5.1.2. Number of branches per plant

Number of branches produced per plant was counted and the average was expressed once in 20 days.

3.5.1.3. Number of leaves per plant

The number of compound leaves (four-leafleted compound leaf) were recorded from the twelve tagged plants.

3.5.1.4. Dry matter production per plant

From each plot, three plants were uprooted as destructive sampling. The roots were washed thoroughly and the leaves, stem and roots were separated and dried at 80° C to a constant weight and the average weight was recorded in grams.

3.5.1.5. Shoot : root ratio

Shoot:root ratio was calculated from the oven dried samples at 20 days intervals and at harvest.

3.5.1.6. Leaf area per plant

The maximum leaf length and maximum width of all the leaflets of three plants were recorded and the mean leaf length and width were calculated. Leaf area of the plants were recorded at 20, 40, 60, 80 and at harvest using the formulae:

Leaf area per plant = Number of compound leaves x number of leaflets per compound leaf x average leaf length x average leaf width x 0.78

The factor 0.78 was calculated from the leaves collected from the field by graphical method.

3.5.1.7. Third leaf area and third leaf weight

Generally, third leaf is designated as recently matured leaf from the growing tip, and they were collected from the individual plots at the rate of 12 random leaf samples. The average leaf length and width were observed and the leaf area was calculated. The leaves were oven dried to a constant weight and dry weights were recorded.

3.5.1.8. Days to 50 % flowering

The number of days taken for 50 % of plant population for flowering was observed from the each plot and recorded.

3.5.1.9. Number of pegs per plant

The number of immature pods / pegs per plant were counted from destructive sampling plants at 20 days interval from 40 DAS.

3.5.2. Nodulation

3.5.2.1. Number of nodules

Observations on nodule number were taken at 20, 40, 60, 80 DAS and at harvest by separating the nodules from the roots of destructive sampling plants, and the mean of number of nodules per plant was calculated and recorded.

3.5.2.2. Dry weight of nodules

The separated nodules were oven dried to a constant weight and the mean weight of nodules per plant was recorded in milligrams.

3.5.3. Physiological parameters

3.5.3.1. Chlorophyll content

Chlorophyll content of index leaves *i.e.*, recently matured leaves (3^{rd} leaf from growing tip) were estimated colorimetrically using spectronic-20 spectrophotometer suggested by Hiscox and Israelstam (1979) at 20 days interval and at harvest. The formula used for calculation of chlorophyll was as follows.

$$\textbf{Chlorophyll 'a' content (mg g}^{-1}\textbf{)} = [12.7\ (A_{663}) - 2.69\ (A_{645})] \times V / (1000 \times W)$$

$$\textbf{Chlorophyll 'b' content (mg g}^{-1}\textbf{)} = [22.9\ (A_{645}) - 4.68\ (A_{663})] \times V / (1000 \times W)$$

$$\textbf{Total chlorophyll (mg g}^{-1}\textbf{)} = [20.2\ (A_{645}) + 8.02\ (A_{663})] \times V / (1000 \times W)$$

Where,

A_{645}, A_{663} – the absorptance value at wave length 645 and 663 ηm respectively

W – fresh weight of the sample (g)

V – the volume of the extract (ml)

3.5.3.2. Growth indices

From the observations on leaf area, total plant dry weight, the following growth parameters were computed at 20, 40, 60, 80 DAS and at harvest.

3.5.3.2.1. Leaf area index (LAI)

LAI is the ratio of the total leaf area of plant to the ground area covered by the plant. LAI was worked out as suggested by Watson (1952) for all treatments at all levels of observations.

$$\text{LAI} = \frac{\text{Leaf area per plant}}{\text{Land area occupied per plant}}$$

3.5.3.2.2. Leaf area ratio (LAR)

LAR is the ratio of leaf area to dry weight of plant expressed as cm^2g^{-1} (Whitehead and Mycersough, 1962).

$$\text{LAR} = \text{LA} / \text{W}$$

Where,

LA – Total leaf area per plant, W – Total plant dry weight

3.5.3.2.3. Relative growth rate (RGR)

RGR expresses the dry weight increase in a time interval in relation to the initial weight and is expressed as g g^{-1} day^{-1}. The RGR was calculated following the formulae given by Blackman (1919).

$$RGR = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

Where,

ln – logarithm to the base 'e' (Naperian constant)

W_2 and W_1 – total plant dry weights at time T_2 and T_1 respectively.

3.5.3.2.4. Net assimilation rate (NAR)

NAR is the net gain of assimilates (net photosynthesis) per unit of leaf area and time (Gregory, 1926).

$$NAR = \frac{(W_2 - W_1) \quad (\ln LA_2 - \ln LA_1)}{(T \ -T\ ) \quad (LA \ - LA1)} \quad g\ m^{-2}\ day^{-1}$$

Where,

ln – logarithm to the 'e' base (Naperian constant)

LA_2 and W_2 – leaf area and dry weight of the plant at time T_2

LA_1 and W_1 - leaf area and dry weight of the plant at time T_1

3.5.3.2.5. Crop growth rate (CGR)

The gain in weight of a community of plants on a unit land per unit time is called CGR. It was calculated by following formula given by Watson (1952).

$$CGR = \frac{(W_2 - W_1)}{P\,(T_2 - T_1)} \quad g\ cm^2\ day^{-1}$$

Where,

P – land area occupied by the plant

W_2 and W_1 - total plant dry matter at T_2 and T_1 respectively

3.5.3.2.6. Specific leaf area (SLA) and specific leaf weight (SLW)

SLA is the ratio between leaf area and leaf weight and expressed as $cm^2\ g^{-1}$ (Ondok and kvet, 1971). SLW is the ratio of leaf weight and leaf area and expressed as $g\ m^{-2}$ (Jackson, 1963).

$$SLA = LA \setminus LW$$

$$SLW = LW \setminus LA$$

Where,

LA and LW – leaf area and leaf weight respectively

3.5.3.2.7. Leaf area duration (LAD)

It expresses the magnitude and persistence of leaf or leafiness during the period of crop growth (Ondok and Kvet, 1971).

$$LAD = \frac{(L_1 + L_2)\ \ (T_2 - T_1)}{2} \text{ days}$$

Where ,

L_1 and L_2 – leaf area index at time T_1 and T_2

3.5.3.2.8. Harvest index (HI)

The proportion of biological yield represented by economic yield is called as harvest index (HI) or migration co-efficient. It is characterized by the movement of dry matter to economic part of the plant. The HI was calculated by the formulae given by Redford (1967).

$$HI = \frac{Y_{ECON}}{Y_{BIOL}} \times 100$$

Where,

Y_{ECON} and Y_{BIOL} - the economic and biological yield respectively

3.5.4. Yield attributes and yield

The details of the observations taken with regard to yield and related characters are given in Table 5.

3.5.5 Quality factors

3.5.5.1. Protein content of kernels

Protein content of kernels was worked out by multiplying nitrogen content of kernels with the constant 5.46 (Jones, 1931 and Sadasivam and Manickam, 1996).

3.5.5.2. Protein yield

This was calculated from protein content of kernels and kernel yield per ha.

3.5.5.3. Oil content of kernels

Oil content of kernels was determined using the instrument Oxford 4000 Nuclear Magnetic Resonance (NMR) as followed by Balasubramaniyan (1997 a).

3.5.5.4. Oil yield

This was calculated by multiplying kernel yield per ha and oil content of kernels.

Table:5. Observations on yield and related characters.

S.No.	Attributes	Descriptions
1.	Weight of pods per plant	Mean of 12 random plants per plot were taken
2.	Number of pods per plant	”
3.	Number of single seeded pods per plant	”
4.	Number of double seeded pods per plant	”
5.	Number of triple seeded pods per plant	”
6.	Number of four seeded pods per plant	”
7.	100 pod weight	Weight of randomly taken 100 pods per plot
8.	100 kernel weight	Weight of randomly taken 100 kernels per plot
9.	Shelling percentage	Found out by shelling of randomly selected, weighed 100 pods
10.	Pod yield per ha (kg)	At 10% moisture level
11.	Kernel yield per ha (kg)	”
12.	Haulm yield per ha (kg)	”
13.	Haulm kernel ratio	”
14.	Partitioning co-efficient (pod haulm ratio)	Computed from pod yield and total dry matter production

3.5.5.5. Carbohydrate content of kernels

Carbohydrate content of kernels was calculated colorimetrically using Spectronic 20 spectrophotometer suggested by Hedge and Hofreiter (1962).

3.5.5.6. Carbohydrate yield

This was computed from carbohydrate content of kernels, pod yield per ha and shelling percentage.

3.5.5.7. Ash content of kernels

The powdered weighed groundnut samples were burned at 600 $^{\circ}$ C for five hours in a muffle furnace and the ash content of kernels was calculated.

3.5.6. Uptake studies

Macro and micronutrients concentrations in plant were studied at 20, 40, 60, 80 DAS and at harvest. Shell and kernel were analysed for nutrient contents at harvesting stage. The uptake of nutrients at 20 days intervals and at harvest was calculated from the nutrient concentration at respective stages and dry matter production. The destructive samples collected from each plot were oven dried and powdered. Then, the estimations were done using the following procedures (Table-6).

3.5.7. Nutrient use efficiency

The nutrient use efficiencies in terms of protein and oil production were calculated by dividing the protein and oil yield with the level of nutrients applied.

3.6. Soil

3.6.1. Chemical characteristics

Soil samples were collected from the each plot before cropping and after cropping. It was dried, powdered and passed through 2 mm sieve and then used for analysing chemical characteristics of the soil. The methods used for the various analysis are given below in Table-7.

Table: 6 Methods used for plant nutrient analysis.

S.No.	Nutrient	Method	Reference
1.	Nitrogen	Microkjeldhal digestion and distillation method	Jackson, 1958
2.	Phosphorus	Vanadomolybdophosphoric yellow colour method – spectronic 20	,,
3.	Potassium	Diacid extract using a flame photometer	,,
4.	Calcium	Diacid extract using AAS	,,
5.	Magnesium	Diacid extract using AAS	,,
6.	Sulphur	Turbidimetric method using spectronic 20 spectrophotometer	Hart, 1961
7.	Iron	Diacid extract using AAS	Jackson, 1958
8.	Manganese	Diacid extract using AAS	,,
9.	Copper	Diacid extract using AAS	,,
10.	Zinc	Diacid extract using AAS	,,

AAS- Atomic Absorption Spectrophotometer

3.6.2. Microbial enumeration

The rhizosphere soils were collected at sowing, 20, 40, 60, 80 DAS and at harvest stage and were air dried. The soils were sieved using 2 mm sieve. For the sake of brevity and clarity, only six treatments were taken for microbial enumeration to study the microbial dynamics with source of phosphorus and organic manure. The selected treatments are T_1, T_2, T_3, T_5, T_6 and T_7 taken.

The soil population of bacteria, fungi, actinomycetes and rhizobia were estimated by serial dilution and pour plate method as suggested by Thronton (1922) and Jhonson (1940). The Nutient agar (NA) medium, Kenknight's agar (KA), Martin's rose bengal agar (RBA) and Yeast extract mannitol agar (YEMA) were used respectively for bacteria, actinomycetes, fungi and *Rhizobium*. The petridishes were incubated at 28^0 C (+2 or –2) for 3 to 14 days after inoculation. The microbial population was expressed cfu g^{-1} of soil. The compositions of media are given in Appendix-4.

Table: 7 Methods used for soil chemical analysis.

S.No.	Analysis	Method	Reference
1.	Soil reaction (pH)	Soil water suspension 1:2.5 and read in pH meter – Elico	Hesse, 1971
2.	Electrical conductivity (EC)	Soil water suspension 1:2.5 and read in digital conductivity bridge	Jackson, 1958
3.	Organic carbon	Walkely – Black method	”
4.	Available N	Alkaline permanganate method	Subbiah and Asija, 1956
5.	Available P_2O_5	Ascorbic acid reduced molybdophosphoric blue colour method	Watnabe and Olsen , 1965
6.	Available K_2O	NN NH_4 Ac extract using Flame photometer	Jackson, 1958
7.	Exchangeable Ca	NN NH_4 Ac extract using AAS	”
8.	Exchangeable Mg	NN NH_4 Ac extract using AAS	”
9.	Available S	$CaCl_2$ extract – turbidimetry method	Chesnin and Yien, 1951
10.	Available Fe	DTPA extract method using AAS	Lindsay and Norvell, 1978
11.	Available Mn	DTPA extract method using AAS	”
12.	Available Cu	DTPA extract method using AAS	”
13.	Available Zn	DTPA extract method using AAS	”

3.7. Statistical analysis

The data were subjected to statistical analysis of variance, as suggested by Panse *et al.*, (1985). The MSTATC, SPSS, Statistica and MS-Excel softwares were used for calculations and regression studies.

Path co-efficient and regression analysis (Singh and Choudhary, 1977) were also done to work out the relationship between yield and yield attributes, nutrient ratios and yield.

RESULTS

4. RESULTS

The results of the study conducted to elucidate the functional efficiency of organic meal in groundnut production are presented in this chapter. The results are showing the role of organics in modifying of nutrient availability and sustainable production in groundnut. Among twelve treatments, first three treatments were Packages of Practices Recommendations of Kerala Agricultural University Recommendations (POP) for groundnut with different sources of P (T_1 to T_3), the fourth treatment comprised of S application along with POP and the next eight treatments (T_5 to T_{12}) were of graded level of organic meal treatments without lime (T_5 to T_8) and with lime (T_9 to T_{12}).

4.1 Vegetative characters

4.1.1. Plant height

The data on plant height and number of branches per plant are presented in Table 8. Significant responses to various treatments with regard to plant height was observed only during 40 and 60 DAS, among the observations taken at 20 days intervals from planting to harvest. At 40 DAS, plant height was the highest with Packages of Practices Recommendations of KAU (POP) where P was applied as rock phosphate (T_1). This treatment was on par with all the treatments except the treatments which received the highest dose of P (T_8 and T_{12}), and the treatment where P was given as SSP (T_2).

At 60 DAS, organic meal 500 kg with lime (T_9) recorded the highest plant height, which was also on par with treatment, which received 2000 kg organic meal without lime (T_8).

At 80 DAS and at harvesting stage, plant height was increased, but the treatment effect was levelled off. However, T_9 [$OM_{500}N_{15}K_{75}L_{860}$] recorded the highest plant height at these stages also. At the final stage the plant height varied form 89.5 to 101.6 cm.

Table : 8 Effect of treatments on plant height and number of branches per plant of groundnut.

Treatment		Plant height (cm)					Number of branches per plant				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	16.96	44.14 [a]	66.81 [b]	86.38	96.06	4.46	9.00 [a]	9.31	9.78	9.75
T_2	R (P as SSP)	16.37	38.42 [bc]	62.46 [b]	75.05	85.71	4.12	8.73 [a]	9.21	9.59	9.73
T_3	R (P as OM)	16.01	39.46 [abc]	59.70 [b]	81.57	91.22	4.00	7.88 [ab]	8.67	8.84	8.88
T_4	R (P as OM) S_{56}	16.85	42.71 [abc]	64.15 [b]	83.27	92.78	3.73	8.17 [ab]	9.04	9.30	9.50
T_5	$OM_{500}N_{15}K_{75}$	18.35	42.83 [ab]	60.95 [b]	85.09	94.33	4.45	8.28 [ab]	9.04	9.20	9.40
T_6	$OM_{1000}N_{10}K_{75}$	15.07	40.32 [abc]	61.33 [b]	82.19	91.76	3.52	7.39 [b]	8.43	9.28	9.48
T_7	$OM_{1500}N_5K_{75}$	15.22	40.36 [abc]	60.29 [b]	82.12	92.36	4.63	7.40 [b]	7.83	8.06	8.36
T_8	$OM_{2000}K_{75}$	15.01	37.92 [c]	68.49 [ab]	83.51	92.85	3.58	7.84 [ab]	8.61	9.29	9.50
T_9	$OM_{500}N_{15}K_{75}L_{860}$	15.97	41.97 [abc]	76.10 [a]	92.44	101.62	3.86	8.97 [a]	9.16	9.63	9.80
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	15.73	43.03 [ab]	65.97 [b]	91.26	99.53	4.05	8.11 [ab]	9.23	9.74	9.97
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	15.61	41.43 [abc]	62.73 [b]	81.37	89.47	4.06	8.62 [ab]	9.71	9.80	9.94
T_{12}	$OM_{2000}K_{75}L_{440}$	15.22	38.96 [bc]	64.44 [b]	79.54	90.07	4.31	7.88 [ab]	8.37	8.81	9.02

(R- Package of Practices Recommendations of KAU, MP- Mussoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K-Potassium, S- Sulphur and L-Lime)

4.1.2. Number of branches per plant

The numbers of branches per plant was increased up to harvesting stage, but at 40 DAS, only significant influence of treatments were seen. Compared to 20 DAS, there was a doubling in number of branches at 40 DAS and subsequent production of branches were very less.

At 40 DAS, the POP with P as mussooriephos (MP), T_1 recorded the highest number of branches which was on par with other treatments except T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$]. But at 60, 80 DAS and at harvest there was no significant difference in number of branches. However, T_{11} [$OM_{1500}N_5K_{75}L_{580}$] recorded the highest number of branches at 60 and 80 DAS. But at harvesting stage, T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] recorded highest the number of branches, which was closely followed by T_{11} [$OM_{1500}N_5K_{75}L_{580}$], T_9 [$OM_{500}N_{15}K_{75}L_{860}$] and T_1 [R(P as MP)].

4.1.3. Number of leaves per plant

The data on number of leaves per plant and leaf area per plant are presented in Table 9. The treatments significantly influenced the number of leaves per plant at 40 DAS and at harvesting stage. The number of leaves per plant increased with age upto 80 DAS, but at harvesting stage, there was a decrease in number of leaves. At 20 DAS, T_5 [$OM_{500}N_{15}K_{75}$] recorded the highest number of leaves which was on par with other treatments, but at harvesting stage this treatment showed the minimum number. Application of P as MP (T_1) resulted in significantly higher number of leaves per plant at 40 DAS, which was also on par with treatments receiving organic meal 500 kg with and without lime (T_5 and T_9). Organic meal 1500 kg with or without lime (T_7 and T_{11}) recorded the lowest number of leaves per plant at 40 DAS. T_{10}[$OM_{1000}N_{10}K_{75}L_{720}$] retained more number of leaves whereas T_5 [$OM_{500}N_{15}K_{75}$] and T_2 [R(P as SSP)] recorded the lowest number of leaves per plant at the time of harvesting. From 80 DAS to harvest, there was a shedding of around 20 leaves per plant.

4.1.4. Leaf area per plant

The leaf area per plant increased progressively up to 80 DAS, after which there was a reduction. There was significant difference only at 40 DAS and

Table : 9 Effect of treatments on number of leaves and leaf area per plant of groundnut.

Treatment		Number of leaves per plant					Leaf area per plant (cm^2)				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	13.13	50.66 ^{a}	65.70	89.47	67.55 ^{bc}	206	1171 ^{a}	2360	3084	1846 ^{bcd}
T_2	R (P as SSP)	12.91	40.61 ^{bc}	60.02	82.30	61.88 ^{c}	180	937 ^{b}	1964	2513	1666 ^{d}
T_3	R (P as OM)	12.38	43.41 ^{bc}	65.15	86.51	68.47 ^{bc}	175	904 ^{bc}	2080	2784	1922 ^{bcd}
T_4	R (P as OM)S_{56}	11.79	40.29 ^{bc}	59.59	94.89	74.03 ^{ab}	179	892 ^{bc}	2238	3205	2216 ^{a}
T_5	$OM_{500}N_{15}K_{75}$	14.58	46.58 ^{ab}	61.79	80.73	62.19 ^{c}	168	826 ^{bc}	2148	2469	1694 ^{d}
T_6	$OM_{1000}N_{10}K_{75}$	11.83	41.65 ^{bc}	57.52	89.86	69.70 ^{bc}	153	861 ^{bc}	2227	2907	1922 ^{abcd}
T_7	$OM_{1500}N_5K_{75}$	11.34	38.59 ^{c}	69.77	84.34	74.69 ^{ab}	142	785 ^{bc}	2768	3005	2018 ^{abc}
T_8	$OM_{2000}K_{75}$	11.98	43.67 ^{bc}	69.89	92.23	73.25 ^{b}	164	795 ^{bc}	2137	2888	1846 ^{bcd}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	12.71	46.85 ^{ab}	62.44	91.77	70.63 ^{bc}	164	897 ^{bc}	1909	2772	1845 ^{bcd}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	11.06	43.65 ^{bc}	66.23	102.05	82.22 ^{a}	158	909 ^{bc}	2137	3085	2134 ^{ab}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	11.90	37.18 ^{c}	70.74	85.10	66.07 ^{bc}	166	748 ^{c}	2345	2690	1783 ^{cd}
T_{12}	$OM_{2000}K_{75}L_{440}$	12.49	41.00 ^{bc}	58.46	84.50	70.75 ^{bc}	160	784 ^{bc}	1957	2682	1906 ^{bcd}

(**R**- Package of Practices **R**ecommendations of KAU, **MP- Mussoorie** rock **P**hosphate, **SSP**- **S**ingle **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**- Sulphur and **L**-Lime) harvesting stage. At 40 DAS, T_1 [R(P as MP)] recorded the highest and T_{11} [$OM_{1500}N_5K_{75}L_{580}$], recorded the lowest leaf area per plant.

At 60 DAS, also T_1 [R(P as MP)] showed higher leaf area even though there was no significant difference between treatments.

At harvesting stage, T_4 [R (P as OM)S_{56}] reported significantly higher leaf area per plant along with T_6 [$OM_{1000}N_{10}K_{75}$], T_7 [$OM_{1500}N_5K_{75}$] and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$]. The lowest leaf area per plant was shown by T_2 [R (P as SSP)] which was also on par with T_5 [$OM_{500}N_{15}K_{75}$]. The maximum leaf area was at 80 DAS, which was around 16 times higher than at 20 DAS. The highest rate of increase in leaf area was from 20 to 40 DAS.

4.1.5. Third leaf area

Generally, for physiological studies, third leaf from the tip of the plant ie. Recently matured leaf is taken as indicator leaf. The data on area and dry weights of third leaf are given in Table 10. The third leaf area increased up to 60 DAS in most of the treatments, the maximum being 18.64 cm^2. After this stage, the area of third leaf decreased and reached even 6.52 cm^2 at harvesting stage. The third leaf area showed significant variation due to treatments at all stages of growth.

At 20 DAS, treatments from T_1 to T_6, recorded higher third leaf area. At 40 DAS, the treatments which received S (T_2 and T_4) and T_7 [$OM_{1500}N_5K_{75}$] recorded higher leaf area where as T_5 [$OM_{500}N_{15}K_{75}$] recorded the lowest third leaf area.

At 60 DAS, the treatments showed wide variations in the area of index leaf and T_2 [R(P as SSP)] retained the top most position. The treatment receiving the highest dose of organic meal along with lime (T_{12}) recorded the lowest third leaf area. Where as, it showed the highest leaf area at 80 DAS, followed by T_8 [$OM_{2000}K_{75}$], T_9 [$OM_{500}N_{15}K_{75}L_{860}$] and T_6 [$OM_{1000}N_{10}K_{75}$]. The minimum third leaf area was recorded with T_{11} [$OM_{1500}N_5K_{75}L_{580}$].

At harvesting stage, T_4 [R (P as OM) S_{56}], T_5 [$OM_{500}N_{15}K_{75}$] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$] showed the maximum third leaf area (8.37 cm^2) and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] recorded the lowest leaf area (6.52 cm^2).

Table : 10 Effect of treatments on third leaf area and third leaf dry weight of groundnut.

Treatment		3rd leaf area (cm^2)					3rd leaf dry weight (mg)				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	7.09^{abcd}	12.94^{d}	15.23^{g}	14.68^{d}	7.62^{bc}	168.67^{d}	266.67^{bc}	297.00^{ef}	288.00^{ab}	199.67^{bc}
T_2	R (P as SSP)	7.27^{a}	14.00^{a}	18.64^{a}	15.53^{bcd}	8.15^{ab}	187.00^{bc}	296.00^{a}	376.00^{a}	293.67^{a}	193.67^{cd}
T_3	R (P as OM)	7.06^{abcde}	12.48^{e}	15.80^{f}	15.71^{bc}	7.61^{bc}	167.67^{d}	253.00^{cd}	304.00^{ef}	273.00^{abc}	186.67^{cd}
T_4	R (P as OM) S_{56}	7.16^{abc}	13.87^{ab}	17.65^{c}	14.81^{cd}	8.34^{a}	210.67^{a}	265.00^{bc}	369.67^{a}	239.67^{d}	217.67^{ab}
T_5	$OM_{500}N_{15}K_{75}$	7.25^{a}	12.06^{f}	14.69^{h}	15.15^{bcd}	8.37^{a}	177.67^{cd}	243.67^{de}	268.00^{g}	266.00^{c}	202.00^{bc}
T_6	$OM_{1000}N_{10}K_{75}$	7.20^{ab}	13.52^{bc}	17.05^{e}	15.98^{ab}	7.58^{bc}	190.00^{bc}	281.67^{ab}	316.00^{de}	276.00^{abc}	201.67^{bc}
T_7	$OM_{1500}N_5K_{75}$	6.97^{cdef}	13.85^{ab}	17.96^{b}	14.64^{d}	7.23^{c}	167.67^{d}	256.00^{cd}	374.00^{a}	235.00^{d}	190.67^{cd}
T_8	$OM_{2000}K_{75}$	7.00^{bcde}	13.52^{bc}	17.70^{c}	16.13^{ab}	7.11^{c}	167.00^{d}	264.00^{bc}	342.00^{bc}	279.00^{abc}	175.00^{d}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	6.88^{def}	13.23^{cd}	17.39^{d}	16.00^{ab}	8.31^{a}	198.00^{ab}	246.00^{de}	326.67^{cd}	288.67^{ab}	220.67^{a}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	6.77^{f}	13.16^{cd}	17.76^{bc}	15.57^{bcd}	6.52^{d}	198.00^{ab}	268.67^{bc}	359.00^{ab}	270.00^{bc}	175.00^{d}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	6.87^{def}	12.96^{d}	14.02^{I}	13.29^{e}	7.63^{bc}	168.66^{d}	225.00^{f}	301.33^{ef}	243.67^{d}	198.00^{c}
T_{12}	$OM_{2000}K_{75}L_{440}$	6.85^{ef}	12.91^{d}	13.74^{j}	16.95^{a}	7.14^{c}	181.67^{cd}	233.00^{ef}	292.67^{f}	291.67^{ab}	192.00^{cd}

(**R**- Package of Practices **R**ecommendations of KAU, **MP- Mussoorie** rock **P**hosphate, **SSP**- **S**ingle **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- **P**hosphorus, **K**- Potassium. **S**- Sulphur and **L**-Lime)

4.1.8. Third leaf weight

Third leaf weight also followed the same pattern of third leaf area. The treatments caused significant variations in third leaf weight. At 20 DAS, T_4 [R (P as OM)S_{56}], T_9 [$OM_{500}N_{15}K_{75}L_{860}$], T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_2[R (P as SSP)] recorded higher third leaf weight.

Similar to third leaf area, T_2 [R(P as SSP)] recorded maximum third leaf weight followed by T_4 [R(P as OM)S_{56}] at 40 and 60 DAS. But the lowest leaf dry weight was observed with T_{11} [$OM_{1500}N_5K_{75}L_{580}$].

Upto 80 DAS, T_2 [R (P as SSP)] recorded the maximum where as at harvesting stage, T_9 [$OM_{500}N_{15}K_{75}L_{860}$] recorded the maximum leaf weight of 220.67 mg leaf^{-1}.

4.1.10 Leaf chlorophyll content

The data on chlorophyll contents are presented in Table 11.

4.1.10.1 chlorophyll 'a'

There was an increase in chlorophyll 'a' content up to 100 DAS. The chlorophyll 'a' content significantly differed with treatments at 40, 60 and 100 DAS. At 20 DAS, T_2 [R(P as SSP)] recorded the maximum chlorophyll content even though there was no significant difference among different treatment.

At 40 DAS, T_5 [$OM_{500}N_{15}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] had more chlorophyll 'a' in leaf tissue. At 60 DAS stage, higher chlorophyll 'a' content was observed with T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$]. All other treatments recorded significantly lower chlorophyll 'a' content.

At 80 DAS, T_5 [$OM_{500}N_{15}K_{75}$] recorded the maximum (Plate 3), but there was no significant differences due to treatments. At 100 DAS, higher chlorophyll 'a' content was observed with T_4 [R (P as OM) S_{56}] where as the least was found with T_7 [$OM_{1500}N_5K_{75}$].

4.1.10.2 Chlorophyll 'b'

The chlorophyll 'b' was gradually decreasing from 20 DAS, reaching the minimum at 60 DAS. Afterwards, it increased up to 80 DAS without significant effect due to various treatments. Among five stages of observation, the effect was significant upto 60 DAS and again at 100 DAS.

Table : 11 Effect of treatments on chlorophyll content of groundnut leaves (mg g^{-1}).

Treatment		Chlorophyll 'a'					Chlorophyll 'b'					Total chlorophyll				
		20 DAS	40 DAS	60 DAS	80 DAS	100 DAS	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
T_1	R (P as MP)	1.08	1.06^{bc}	1.24^{bcd}	1.25	1.42^{b}	0.35^{b}	0.27^{bcd}	0.14^{cde}	0.28	0.23^{cde}	1.42^{bc}	1.33	1.38^{de}	1.53	1.65^{ab}
T_2	R (P as SSP)	1.24	1.08^{bc}	1.18^{cd}	1.18	1.24^{bc}	0.50^{a}	0.29^{abcd}	0.31^{a}	0.26	0.16^{def}	1.74^{a}	1.37	1.49^{b}	1.45	1.57^{ab}
T_3	R (P as OM)	1.17	1.11^{bc}	1.26^{bc}	1.23	1.25^{bc}	0.36^{b}	0.28^{bcd}	0.20^{bc}	0.28	0.14^{f}	1.53^{b}	1.06	1.46^{bcd}	1.50	1.48^{bc}
T_4	R (P as OM) S_{56}	1.10	1.08^{bc}	1.23^{bcd}	1.32	1.65^{a}	0.35^{b}	0.31^{abc}	0.16^{bcd}	0.30	0.26^{abc}	1.50^{bc}	1.40	1.39^{bcde}	1.62	1.56^{ab}
T_5	$OM_{500}N_{15}K_{75}$	1.14	1.24^{a}	1.26^{bc}	1.41	1.41^{b}	0.26^{b}	0.26^{cde}	0.16^{bcd}	0.31	0.32^{ab}	1.40^{bc}	1.50	1.41^{bcde}	1.73	1.74^{a}
T_6	$OM_{1000}N_{10}K_{75}$	1.14	1.05^{c}	1.18^{cd}	1.29	1.28^{bc}	0.32^{b}	0.27^{bcde}	0.18^{bc}	0.30	0.27^{abc}	1.45^{bc}	1.31	1.36^{e}	1.57	1.55^{ab}
T_7	$OM_{1500}N_5K_{75}$	1.17	1.18^{ab}	1.22^{bcd}	1.24	0.97^{d}	0.38^{b}	0.24^{de}	0.09^{e}	0.28	0.20^{cdef}	1.55^{b}	1.42	1.31^{ef}	1.52	1.17^{d}
T_8	$OM_{2000}K_{75}$	1.18	1.06^{bc}	1.15^{d}	1.26	1.21^{c}	0.30^{b}	0.29^{abcd}	0.11^{de}	0.29	0.24^{bcd}	1.48^{b}	1.35	1.25^{f}	1.55	1.46^{bc}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	1.16	1.12^{bc}	1.22^{bcd}	1.29	1.26^{bc}	0.38^{b}	0.32^{ab}	0.16^{bcd}	0.27	0.33^{a}	1.54^{b}	1.45	1.39^{cde}	1.56	1.60^{ab}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	1.10	1.12^{bc}	1.55^{a}	1.19	1.37^{bc}	0.36^{b}	0.27^{bcde}	0.16^{bcd}	0.27	0.20^{cdef}	1.45^{bc}	1.38	1.71^{a}	1.46	1.57^{ab}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	1.01	0.93^{d}	1.16^{cd}	1.32	1.33^{bc}	0.38^{b}	0.21^{e}	0.21^{b}	0.31	0.28^{abc}	1.38^{bc}	1.14	1.37^{de}	1.63	1.61^{ab}
T_{12}	$OM_{2000}K_{75}L_{440}$	0.97	1.12^{bc}	1.31^{b}	1.16	1.18^{c}	0.29^{b}	0.35^{a}	0.17^{bc}	0.23	0.16^{ef}	1.25^{c}	1.47	1.48^{bc}	1.41	1.34^{c}

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**- Sulphur and **L**-Lime)

Plate:3 A general view of experimental plot at various stages

20 DAS stage

60 DAS stage

80 DAS stage

Harvest stage

At 20 DAS, T_2 [R (P as SSP)] recorded maximum chlorophyll 'b' content. But, at 40 DAS, T_{12} [$OM_{2000}K_{75}L_{440}$] recorded significantly higher content of chlorophyll 'b' along with T_9 [$OM_{500}N_{15}K_{75}L_{860}$], T_4 [R (P as OM) S_{56}] and T_2 [R (P as SSP)].

At 60 DAS, T_2 [R(P as SSP)] retained higher chlorophyll 'b' content, where as T_7 [$OM_{1500}N_5K_{75}$] recorded the lowest content along with T_8 [$OM_{2000}K_{75}$]. T_5 [$OM_{500}N_{15}K_{75}$],T_6 [$OM_{1000}N_{10}K_{75}$] and T_4 [R (P as OM)S_{56}] recorded more chlorophyll 'b' content at 100 DAS. The lowest was in T_3 [R(P as OM)].

4.1.10.3 Total chlorophyll

The data on total chlorophyll content showed that it was decreasing slightly up to 40 DAS, there was not much difference up to 60 DAS, and then the content was increasing up to 100 DAS. At 20 DAS, T_2 [R(P as SSP)] recorded significantly higher total chlorophyll content.

The T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] recorded maximum total chlorophyll content at 60 DAS. At the same stage, T_8 [$OM_{2000}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] recorded the minimum amount of total chlorophyll content.

At 80 DAS, there was an increase in total chlorophyll content compared to 60 DAS, but no significant difference between treatment.

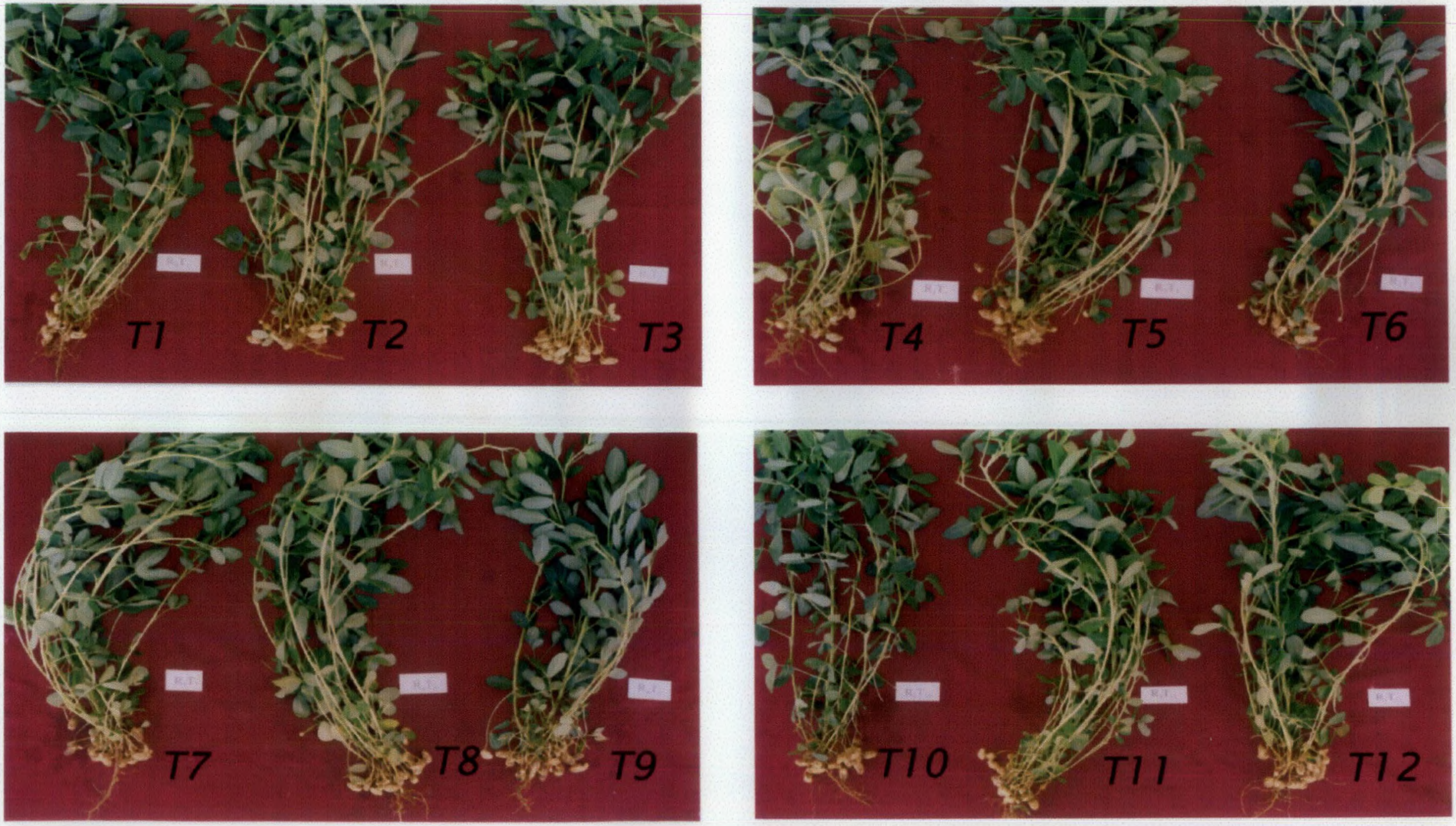
At 100 DAS, total chlorophyll content differed significantly and higher total chlorophyll were recorded with T_5 [$OM_{500}N_{15}K_{75}$], T_1 [R(P as MP)] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$]. The treatments, which received the highest dose of organic meal, showed the lowest level of total chlorophyll whether it was with or without lime application.

4.1.11 Shoot dry weight

The data on shoot and root dry weights are presented in Table 12. The progressive increase in shoot dry weight was observed with duration. The treatment effects on shoot dry weight were significant at 40, 60 and 80 DAS (Plate 4). The shoot dry weight recorded at 40 DAS was 8 to 10 times more than that of 20 DAS.

The maximum shoot dry weight at 40 DAS recorded with T_3 [R (P as OM)] where Package of Practices Recommendations were given replacing P fertilizer with organic meal. At 60 DAS, higher shoot weight was recorded with T_6

Plate: 4 A close view of plant samples at 80 DAS



[$OM_{1000}N_{10}K_{75}$] and lowest with T_7 [$OM_{1500}N_5K_{75}$]. All other treatments were on par with each other. But at 80 DAS also T_6 [$OM_{1000}N_{10}K_{75}$] maintained the superiority.

However, at harvest, the highest shoot weight was recorded with T_1 [R (P as MP)] and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] even though there was no significant difference between the treatment effect. At harvest, the shoot dry weight was ranging from 38.00 to 47.75 g plant^{-1}.

4.1.12 Root dry weight

The root dry weight was significantly different with treatments only up to 60 DAS. But there was progressive increase in root dry weight up to harvest.

At 20 DAS, the highest root weight was recorded with T_1[R (P as MP)] and T_2 [R (P as SSP)]. At 40 DAS, the highest root weight was recorded with T_9 where 500 kg organic meal was applied along with 860 kg lime.

At 60 DAS, the plots which received organic meal produced better root weight, the maximum again being shown by T_9 [$OM_{500}N_{15}K_{75}L_{860}$]. After that there was no significant difference between the root weights recorded. But at 80 DAS, the highest plant root weight was recorded with T_9 [$OM_{500}N_{15}K_{75}L_{860}$], T_4 [R (P as OM) S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$]. At harvest, root weight ranged from 1.34-1.72 g plant^{-1} and, T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$] recorded the highest root weight.

4.1.13 Number of nodules per plant

The data presented in the Table 13 showed that the number of nodules per plant increased up to 80 DAS and after that there was a reduction. During 40-60 DAS and 60-80 DAS there was nearly 100 per cent increase in nodule number. The number of nodules was significantly different at 40 and 80 DAS. At 40 DAS, T_1 [R (P as MP)] and T_7 [$OM_{1500}N_5K_{75}$], recorded significantly lower number of nodules per plant.

At 60 DAS, T_5 [$OM_{500}N_{15}K_{75}$] recorded maximum number of nodules per plant, but there was no significant difference due to treatments. At 80 DAS, T_1 [R (P as MP)] recorded maximum number and T_8 [$OM_{2000}K_{75}$] recorded the lowest

Table : 12 Effect of treatments on root and shoot dry weight of groundnut.

Treatment		Shoot dry weight (g $plant^{-1}$)					Root dry weight (g $plant^{-1}$)				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	1.29	9.17 ^{b}	24.01 ^{b}	28.67 ^{bc}	47.75	0.23 ^{a}	0.36 ^{c}	1.08 ^{e}	1.15	1.44
T_2	R (P as SSP)	1.24	10.25 ^{b}	20.86 ^{bc}	35.26 ^{ab}	39.75	0.20 ^{ab}	0.41 ^{bc}	1.22 ^{cde}	1.32	1.65
T_3	R (P as OM)	1.06	14.25 ^{a}	23.04 ^{bc}	33.51 ^{ab}	39.25	0.17 ^{b}	0.49 ^{ab}	1.48 ^{abcd}	1.27	1.59
T_4	R (P as OM) S_{56}	1.00	9.86 ^{b}	23.85 ^{b}	34.14 ^{ab}	42.75	0.15 ^{b}	0.39 ^{c}	1.16 ^{de}	1.38	1.72
T_5	$OM_{500}N_{15}K_{75}$	1.28	10.06 ^{b}	22.71 ^{bc}	36.05 ^{ab}	43.00	0.16 ^{b}	0.46 ^{abc}	1.38 ^{abcde}	1.47	1.58
T_6	$OM_{1000}N_{10}K_{75}$	1.14	11.42 ^{b}	30.48 ^{a}	38.70 ^{a}	46.75	0.15 ^{b}	0.51 ^{ab}	1.53 ^{abc}	1.58	1.72
T_7	$OM_{1500}N_5K_{75}$	0.93	9.54 ^{b}	16.60 ^{c}	30.09 ^{bc}	43.00	0.15 ^{b}	0.42 ^{bc}	1.26 ^{bcde}	1.33	1.41
T_8	$OM_{2000}K_{75}$	1.17	10.80 ^{b}	22.62 ^{bc}	29.47 ^{bc}	41.75	0.15 ^{b}	0.43 ^{abc}	1.30 ^{abcde}	1.33	1.41
T_9	$OM_{500}N_{15}K_{75}L_{860}$	1.10	10.02 ^{b}	21.15 ^{bc}	31.17 ^{abc}	40.50	0.18 ^{b}	0.54 ^{a}	1.61 ^{a}	1.65	1.68
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	1.27	10.43 ^{b}	24.63 ^{bc}	28.20 ^{bc}	47.50	0.16 ^{b}	0.45 ^{abc}	1.30 ^{abcde}	1.33	1.34
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	1.01	9.22 ^{b}	21.42 ^{b}	28.43 ^{bc}	38.00	0.14 ^{b}	0.43 ^{abc}	1.30 ^{abcde}	1.35	1.44
T_{12}	$OM_{2000}K_{75}L_{440}$	1.00	9.24 ^{b}	21.99 ^{bc}	25.38 ^{c}	41.00	0.16 ^{b}	0.43 ^{abc}	1.58 ^{ab}	1.60	1.68

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock **P**hosphate, **SSP**- Single Super Phosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- **P**hosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime) number of nodules per plant. The number of nodules per plant ranged from 235 to 277 at 80 DAS and 186 to 258 at harvesting stage. At harvesting stage, T_5 [$OM_{500}N_{15}K_{75}$] recorded higher number of nodules per plant even though there was no significant difference.

4.1.14 Dry weight of nodules per plant

The data on nodule dry weight given in Table 13 showed significant effect of treatments during 40, 60 and 80 DAS. At 20 DAS, it was varying from 20.5 to 39.5 mg plant $^{-1}$. At 40 DAS, T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_3 [R (P as OM)] recorded maximum dry weight where as T_7 [$OM_{1500}N_5K_{75}$] recorded the minimum.

At 60 DAS, T_5 [$OM_{500}N_{15}K_{75}$] and T_1 [R (P as MP)] recorded the maximum value. The nodule dry weight was maximum at 80 DAS, which was 188.8 mg plant^{-1} in T_1 [R (P as MP)]. It was also on par with T_5 [$OM_{500}N_{15}K_{75}$], T_6 [$OM_{1000}N_{10}K_{75}$], T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_{11} [$OM_{1500}N_5K_{75}L_{580}$].

There was no significant difference with regard to nodule dry weight at harvest. However, maximum was recorded with the treatment receiving lowest level of organic meal (T_5) without lime.

4.1.15 Shoot root ratio

The data on shoot root ratio and dry matter production are presented in Table 14. The shoot root ratio was significantly influenced by the treatment at 60 DAS. The shoot root ratio was progressively increased up to harvest.

Even at this stage, most of the treatments were statistically on par except T_7 [$OM_{1500}N_5K_{75}$], T_9 [$OM_{500}N_{15}K_{75}L_{860}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]. The highest ratio were recorded with T_1 [R (P as MP)] and T_4 [R (P as OM) S_{56}]. At this stage, there was a decrease in shoot root ratio because of the increase in root weight at higher rate.

At harvest, high ratio was observed with T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and the lowest with T_4 [R (P as OM) S_{56}]. At the time of harvest, shoot root ratio was varied from 25 to 36.

Table : 13 Effect of treatments on nodule count and nodule dry weight of groundnut.

Treatment		Number of nodules per plant					Dry weight of nodules (mg plant^{-1})				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	40.00	53.58 ^{bc}	138.00	276.80 ^{a}	195.00	39.50	45.25 ^{cd}	102.50^{ab}	188.80 ^{a}	138.00
T_2	R (P as SSP)	36.25	65.83 ^{ab}	129.00	249.50 ^{abcd}	190.75	22.50	54.00 ^{abc}	89.75 ^{abc}	170.00 ^{bc}	135.25
T_3	R (P as OM)	32.67	72.50 ^{a}	102.00	253.00 ^{abcd}	222.50	33.00	58.50 ^{ab}	78.50 ^{c}	173.80 ^{bc}	145.25
T_4	R (P as OM) S_{56}	26.65	56.00 ^{abc}	112.00	241.30 ^{bcd}	185.50	20.50	45.00 ^{cd}	82.25 ^{bc}	170.75 ^{bc}	135.75
T_5	$OM_{500}N_{15}K_{75}$	31.92	59.25 ^{abc}	150.00	267.80 ^{abcd}	227.50	25.25	46.75 ^{bcd}	110.30 ^{a}	179.00 ^{abc}	154.25
T_6	$OM_{1000}N_{10}K_{75}$	32.64	55.71 ^{abc}	117.75	261.80 ^{abcd}	208.13	23.75	43.50 ^{cd}	81.50 ^{bc}	178.50 ^{abc}	146.00
T_7	$OM_{1500}N_5K_{75}$	32.42	47.50 ^{c}	133.00	238.00 ^{cd}	199.00	23.00	39.00 ^{d}	93.50 ^{abc}	166.00 ^{c}	141.75
T_8	$OM_{2000}K_{75}$	32.42	61.50 ^{abc}	125.75	234.80 ^{d}	199.00	27.25	45.25 ^{cd}	93.00 ^{abc}	169.75 ^{bc}	143.00
T_9	$OM_{500}N_{15}K_{75}L_{860}$	30.03	60.00 ^{abc}	113.25	254.50 ^{abcd}	197.25	26.25	46.00 ^{cd}	83.75 ^{bc}	174.50 ^{bc}	138.25
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	41.80	70.33 ^{ab}	115.25	272.30 ^{ab}	216.75	26.25	60.00 ^{a}	84.50 ^{bc}	179.50 ^{abc}	143.00
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	39.42	69.00 ^{ab}	133.50	271.30 ^{abc}	206.00	26.25	51.25 ^{abcd}	95.00 ^{abc}	183.50 ^{ab}	146.25
T_{12}	$OM_{2000}K_{75}L_{440}$	30.00	67.50 ^{ab}	107.50	241.30 ^{bcd}	190.50	24.25	52.25 ^{abc}	84.75 ^{bc}	170.50 ^{bc}	142.00

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock **P**hosphate, **SSP**- **S**ingle **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- **P**hosphorus, **K**-Potassium, **S**- **S**ulphur and **L**-Lime)

Table : 14 Effect of treatments on shoot root ratio and dry matter production of groundnut.

Treatment		Shoot root ratio					Dry matter production (g $plant^{-1}$)				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	5.62	25.46	21.75^{a}	25.08	33.52	1.53	9.53^{b}	24.84^{b}	41.42^{g}	66.01
T_2	R (P as SSP)	6.26	25.72	17.31^{abc}	26.74	25.39	1.44	10.66^{b}	22.08^{bc}	48.61^{bcd}	60.65
T_3	R (P as OM)	6.16	29.00	16.00^{abc}	27.21	26.08	1.23	14.74^{a}	24.52^{b}	47.52^{cde}	62.30
T_4	R (P as OM)S_{56}	6.58	27.00	21.48^{a}	24.76	25.04	1.15	10.25^{b}	25.01^{b}	50.63^{b}	69.86
T_5	$OM_{500}N_{15}K_{75}$	7.93	22.02	16.55^{abc}	24.52	30.04	1.45	10.52^{b}	24.09^{bc}	49.59^{bc}	63.28
T_6	$OM_{1000}N_{10}K_{75}$	7.51	22.75	20.20^{ab}	24.49	27.42	1.29	11.93^{b}	32.01^{a}	57.97^{a}	73.44
T_7	$OM_{1500}N_5K_{75}$	6.27	22.79	13.57^{c}	24.62	32.98	1.08	9.96^{b}	17.85^{c}	44.89^{ef}	68.69
T_8	$OM_{2000}K_{75}$	7.80	25.19	17.58^{abc}	24.15	29.67	1.32	11.23^{b}	23.92^{bc}	42.85^{fg}	60.15
T_9	$OM_{500}N_{15}K_{75}L_{860}$	6.06	19.01	13.44^{c}	22.89	24.92	1.28	10.56^{b}	22.76^{bc}	46.51^{de}	60.94
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	7.88	23.17	18.32^{abc}	21.20	36.28	1.43	10.88^{b}	25.95^{b}	41.61^{g}	68.38
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	7.05	22.01	17.00^{abc}	21.05	27.38	1.15	9.65^{b}	22.72^{bc}	40.16^{g}	60.08
T_{12}	$OM_{2000}K_{75}L_{440}$	6.56	17.90	14.21^{c}	20.86	24.41	1.15	9.77^{b}	23.57^{bc}	37.12^{h}	62.16

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock **P**hosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, **N**-Nitrogen, **P**- Phosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime)

4.1.16. Dry matter production per plant

The dry matter production per plant increased progressively towards harvest. From 20-40 DAS, the increase in dry matter production was marked to a tune of 8-9 times. From 40-80 DAS, there was two fold increase in dry matter production and the treatment effects were significant. At 40 DAS, higher DMP was recorded with T_3 [R (P as OM)] and from 60 DAS onwards recorded with T_6 [$OM_{1000}N_{10}K_{75}$]. However, it was not significantly different at harvesting stage.

4.2. Physiological growth indices

4.2.1. Leaf area index (LAI)

The data on leaf area index (LAI) and leaf area ratio (LAR) are presented in Table 15. The LAI was increased from sowing to 80 DAS and at harvesting stage it was decreased. But LAI was significantly different at 40 and 60 DAS only. The rate of increase in LAI was 4-5 times from 20-40 DAS and there was more than two fold increase from 40-60 DAS, and after that the rate was slowed down.

At 40 DAS, the highest LAI was recorded with T_1 [R (P as MP)] and all other treatments were on par. At 60 DAS, the highest LAI was recorded with T_7 [$OM_{1500}N_5K_{75}$] which was on par with T_1 [R (P as MP)]. In S applied plots, there was a marginal increase in LAI from 60 DAS onwards. At 80 DAS, LAI varied from 6.17 to 8.01 and from 4.17 to 5.54 at harvesting stage.

4.2.2. Leaf area ratio (LAR)

LAR showed significant difference only at 80 DAS. LAR was increased at 60 DAS over 40 DAS, however, from 60 DAS, it was decreased upto harvesting stage. At 80 DAS, higher LAR were recorded with T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$], T_1 [R (P as MP)] and T_{12} [$OM_{2000}K_{75}L_{440}$]. At harvest stage, the LAR was as low as 26-33, where as it was 97-158 during 20 DAS.

4.2.3. Specific leaf area (SLA)

The observation on SLA and SLW are presented in Table 16. The SLA was not significantly different with treatments at any stage. But it was seen that the SLA was the highest at the early stages and the lowest at harvesting stage.

Table : 15 Effect of treatments on Leaf Area Index and Leaf Area Ratio of groundnut at different stages.

Treatment		Leaf Area Index (LAI)					Leaf Area Ratio (LAR)				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	0.52	2.93 [a]	5.90 [ab]	7.71	4.62	135.04	93.50	96.16	74.47 [a]	27.97
T_2	R (P as SSP)	0.45	2.34 [b]	4.91 [b]	6.23	4.17	135.35	89.29	89.02	52.97 [bc]	27.47
T_3	R (P as OM)	0.44	2.26 [bc]	5.20 [b]	6.96	4.81	137.35	64.13	85.63	60.62 [abc]	30.85
T_4	R (P as OM)S_{56}	0.45	2.23 [bc]	5.60 [b]	8.01	5.54	158.37	87.51	90.31	63.91 [abc]	31.72
T_5	$OM_{500}N_{15}K_{75}$	0.42	2.07 [bc]	5.37 [b]	6.17	4.23	123.83	78.55	89.06	50.29 [c]	26.77
T_6	$OM_{1000}N_{10}K_{75}$	0.38	2.15 [bc]	5.57 [b]	7.27	4.81	124.93	73.64	70.91	51.26 [bc]	26.17
T_7	$OM_{1500}N_5K_{75}$	0.31	1.97 [bc]	6.92 [a]	7.51	5.04	115.48	79.53	105.18	68.24 [ab]	29.37
T_8	$OM_{2000}K_{75}$	0.41	1.99 [bc]	5.34 [b]	7.22	4.62	123.88	71.31	89.53	68.39 [ab]	30.68
T_9	$OM_{500}N_{15}K_{75}L_{860}$	0.41	2.24 [bc]	4.77 [b]	6.93	4.61	133.45	87.44	83.84	60.54 [abc]	30.28
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	0.32	2.27 [bc]	5.35 [b]	7.71	5.33	97.13	84.14	84.21	75.01 [a]	33.67
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	0.42	1.87 [c]	5.86 [ab]	6.72	4.46	147.57	77.84	103.44	68.10 [ab]	29.67
T_{12}	$OM_{2000}K_{75}L_{440}$	0.40	1.96 [bc]	4.89 [b]	6.70	4.77	143.41	80.73	83.63	73.05 [a]	30.66

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, **P**- Phosphorus, K-Potassium, S- Sulphur and L-Lime).

4.2.4. Specific leaf weight (SLW)

SLW increased towards maturity and it was significantly different at 40 and 60 DAS. At 40 DAS, higher SLW was recorded with T_3 [R (P as OM)] and at 60 DAS, it was with T_6 [$OM_{1000}N_{10}K_{75}$] which was on par with other treatments except T_{11} [$OM_{1500}N_5K_{75}L_{580}$] and T_7 [$OM_{1500}N_5K_{75}$].

4.2.5. Relative growth rate (RGR)

The data on RGR and CGR at different stages are presented in Table 17. The RGR was higher during initial stages *i.e.,* 20-40 DAS, and it was decreasing towards maturity. But, RGR was not significantly affected by various treatments at any stages.

4.2.6. Crop growth rate (CGR)

The CGR was increased with duration in all the plots and differed significantly by treatments up to 60 DAS. After this stage, there was an increase in CGR, but it decreased towards harvest.

4.2.7. Net assimilation rate (NAR)

The data on NAR and LAD are presented in Table 18. NAR was significantly different with treatment up to 60 DAS. The NAR during 20-40 DAS ranged from 7.24 to 15.44 g m^{-2} day^{-1}. The highest NAR was recorded with T_3 [R (P as OM)] and the lowest with T_1 [R (P as MP)].

During 40-60 DAS, the highest NAR was recorded with T_6 [$OM_{1000}N_{10}K_{75}$] and the lowest was recorded with T_7 [$OM_{1500}N_5K_{75}$]. From 80 DAS to harvesting stage, higher NAR was recorded with T_1 [R (P as MP)] followed by higher level of organic meal application with lime even though their effects were not significant.

4.2.8. Leaf area duration (LAD)

The LAD was significantly different with treatments at all stages of growth and LAD was increasing from sowing to harvest. At 80 DAS to harvesting stage, it varied from 130.10 to 169.40 days.

T_1 [R (P as MP)] recorded higher LAD at all stages and all other treatments were on par at 20-40 DAS. During 40-80 DAS, T_7 [$OM_{1500}N_5K_{75}$] also recorded

Table : 16 Effect of treatments on Specific Leaf Area and Specific Leaf Weight of groundnut at different stages.

Treatment		Specific Leaf Area (SLA) ($cm^2\ g^{-1}$)					Specific Leaf Weight (SLW) ($g\ m^{-2}$)				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	346.89	220.89	231.72	266.08	94.62	29.12	31.00^{c}	45.21^{ab}	38.18	108.02
T_2	R (P as SSP)	346.64	232.38	226.06	209.97	104.13	39.24	45.25^{bc}	44.05^{ab}	48.21	98.06
T_3	R (P as OM)	348.30	166.17	219.24	251.46	120.81	31.15	64.31^{a}	47.14^{ab}	45.24	84.45
T_4	R (P as OM) S_{56}	398.52	227.58	226.83	226.94	126.95	27.18	44.25^{bc}	46.21^{ab}	47.25	74.16
T_5	$OM_{500}N_{15}K_{75}$	305.88	205.39	226.73	207.55	101.46	36.36	49.17^{b}	44.36^{ab}	49.29	104.19
T_6	$OM_{1000}N_{10}K_{75}$	307.35	192.49	178.89	168.75	100.84	35.41	53.19^{ab}	59.37^{a}	65.35	100.62
T_7	$OM_{1500}N_5K_{75}$	293.91	207.66	230.77	228.15	118.80	39.50	49.62^{b}	24.19^{c}	45.27	87.23
T_8	$OM_{2000}K_{75}$	304.36	185.43	227.08	240.88	112.48	33.48	55.04^{ab}	44.25^{ab}	42.19	95.25
T_9	$OM_{500}N_{15}K_{75}L_{860}$	341.14	231.13	216.63	220.88	114.54	31.35	47.26^{b}	46.11^{ab}	51.05	90.21
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	241.30	219.60	213.68	261.43	112.56	48.36	46.18^{b}	50.22^{ab}	40.06	91.28
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	367.76	203.98	263.70	262.93	118.24	30.27	50.40^{ab}	38.14^{b}	39.26	88.25
T_{12}	$OM_{2000}K_{75}L_{440}$	358.98	217.27	214.91	267.00	126.81	30.21	47.31^{b}	47.21^{ab}	38.11	92.26

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock **Phosphate**, **SSP**- Single Super **Phosphate**, **OM**- **Organic Meal**, N-Nitrogen, **P**- **Phosphorus**, **K**-Potassium, **S**- Sulphur and **L**-Lime)

Table : 17 Effect of treatments on Relative Growth Rate and Crop Growth Rate of groundnut at different stages.

Treatment		Relative Growth Rate (RGR) (g g^{-1} day^{-1})				Crop Growth Rate (CGR) (g m^{-2} day^{-1})			
		20-40 DAS	40-60 DAS	60-80 DAS	80-HAR	20-40 DAS	40-60 DAS	60-80 DAS	80-HAR
T_1	R (P as MP)	0.091	0.048	0.026	0.019	10.01 [c]	19.13 [ab]	20.73	26.03
T_2	R (P as SSP)	0.101	0.037	0.039	0.011	11.53 [bc]	14.27 [bc]	33.17	15.65
T_3	R (P as OM)	0.124	0.026	0.032	0.013	16.88 [a]	12.22 [bc]	28.75	16.36
T_4	R (P as OM) S_{56}	0.110	0.044	0.034	0.014	11.37 [bc]	18.45 [ab]	32.02	20.95
T_5	$OM_{500}N_{15}K_{75}$	0.102	0.041	0.036	0.011	11.34 [bc]	16.97 [bc]	31.63	15.48
T_6	$OM_{1000}N_{10}K_{75}$	0.112	0.049	0.030	0.011	13.30 [b]	25.10 [a]	32.21	17.56
T_7	$OM_{1500}N_5K_{75}$	0.112	0.014	0.061	0.018	11.09 [bc]	11.10 [c]	33.55	25.76
T_8	- $OM_{2000}K_{75}$	0.107	0.038	0.029	0.015	12.38 [bc]	15.86 [bc]	23.42	19.04
T_9	$OM_{500}N_{15}K_{75}L_{860}$	0.106	0.039	0.035	0.012	11.60 [bc]	15.25 [bc]	29.32	16.37
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	0.103	0.043	0.024	0.021	11.82 [bc]	18.88 [ab]	19.23	28.47
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	0.106	0.043	0.028	0.018	10.63 [bc]	16.34 [bc]	21.55	22.06
T_{12}	$OM_{2000}K_{75}L_{440}$	0.107	0.045	0.022	0.022	10.78 [bc]	17.25 [bc]	16.43	26.58

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, **N**-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**- Sulphur and **L**-Lime)

Table : 18 Effect of treatments on Net Assimilation Rate and Leaf Area Duration of groundnut at different stages.

Treatment		Net Assimilation Rate (NAR) (g $m^{-2}day^{-1}$)				Leaf Area Duration (LAD)			
		20-40 DAS	40-60 DAS	60-80 DAS	80-HAR	20-40 DAS	40-60 DAS	60-80 DAS	80-HAR
T_1	R (P as MP)	7.24 ^{c}	4.56 ^{b}	3.04	0.37	34.42 ^{a}	88.28 ^{a}	136.10 ^{ab}	154.10 ^{abc}
T_2	R (P as SSP)	10.49 ^{b}	4.11 ^{bc}	6.06	0.16	27.92 ^{b}	72.53 ^{b}	111.90 ^{c}	130.60 ^{d}
T_3	R (P as OM)	15.44 ^{a}	3.49 ^{bc}	4.64	0.16	26.98 ^{bc}	74.60 ^{b}	121.60 ^{bc}	147.10 ^{bcd}
T_4	R (P as OM) S_{56}	10.40 ^{b}	5.13 ^{ab}	4.68	0.14	26.77 ^{bc}	78.25 ^{ab}	136.10 ^{ab}	169.40 ^{a}
T_5	$OM_{500}N_{15}K_{75}$	11.06 ^{b}	4.91 ^{ab}	5.44	0.13	24.85 ^{bc}	74.35 ^{b}	115.40 ^{bc}	130.10 ^{d}
T_6	$OM_{1000}N_{10}K_{75}$	13.06 ^{ab}	7.05 ^{a}	5.06	0.17	25.35 ^{bc}	77.20 ^{ab}	128.40 ^{abc}	150.90 ^{abcd}
T_7	$OM_{1500}N_5K_{75}$	12.92 ^{ab}	2.30 ^{c}	4.92	0.28	22.67 ^{c}	88.82 ^{a}	144.30 ^{a}	157.00 ^{abc}
T_8	$OM_{2000}K_{75}$	12.56 ^{ab}	4.70 ^{b}	3.79	0.27	23.98 ^{bc}	73.30 ^{b}	125.60 ^{abc}	147.90 ^{abcd}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	11.00 ^{b}	4.59 ^{b}	5.09	0.15	26.53 ^{bc}	70.15 ^{b}	117.00 ^{bc}	144.30 ^{bcd}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	11.97 ^{b}	5.32 ^{ab}	3.01	0.28	25.92 ^{bc}	76.15 ^{b}	130.60 ^{abc}	163.10 ^{ab}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	11.20 ^{b}	4.68 ^{b}	3.49	0.27	22.85 ^{c}	77.32 ^{ab}	125.90 ^{abc}	139.80 ^{cd}
T_{12}	$OM_{2000}K_{75}L_{440}$	11.03 ^{b}	5.41 ^{ab}	2.87	0.25	23.60 ^{bc}	68.53 ^{b}	116.00 ^{bc}	143.40 ^{bcd}

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, **P**- Phosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime) higher LAD. But during 80 DAS to harvesting stage higher LAD was recorded with T_4 [R (P as OM) S_{56}] and the lowest was recorded with T_2 [R (P as SSP)] and T_5 [$OM_{500}N_{15}K_{75}$].

4.3. Yield and related characters

The data on days to 50 percent flowering, yield attributes, yield related characters and yield are presented in Table 19 to 21.

4.3.1. Days to 50 % flowering

The data in Table 19 showed that the days taken for 50 per cent of the plants for flowering were not affected by the treatments and in most of the cases it was at the age of 26 days.

4.3.2. Number of pegs per plant

The number of pegs per plant, showed that it was increasing up to harvesting stage. But significant differences were noticed only at 60 DAS.

At 40 DAS, the number of pegs formed were 2-4 and T_8 [$OM_{2000}K_{75}$] recorded the maximum value. From 40-60 DAS, the number of pegs produced were around 15. There were 19-20 pegs in T_9 [$OM_{500}N_{15}K_{75}L_{860}$], T_3 [R(P as OM)] and T_8 [$OM_{2000}K_{75}$] at 60 DAS.

The production of pegs was around six during 60-80 DAS. Even at harvest, pegs were formed though it was marginal.

4.3.3. Number of pods per plant

The number of pods per plant at harvest ranged from 16 to 23 (Plate 5), but was not significantly affected by treatments. T_6 [$OM_{1000}N_{10}K_{75}$] recorded the highest number of pods per plant followed by T_7 [$OM_{1500}N_5K_{75}$] and T_4 [R (P as OM) S_{56}]. The lowest number of pods per plant was observed with the Package of Practices- Recommendations where P was applied as mussooriephos.

The treatments had marked effect on number of double and triple seeded pods. The number of single, double and triple seeded pods ranged from 1.84 to 3.54, 5.30 to 10.21 and 7.09 to 11.48 respectively. Higher number of double seeded pods were recorded with T_4 [R (P as OM)S_{56}] and higher number of triple

Plate: 5 A close view on plant roots with pods at 80 DAS

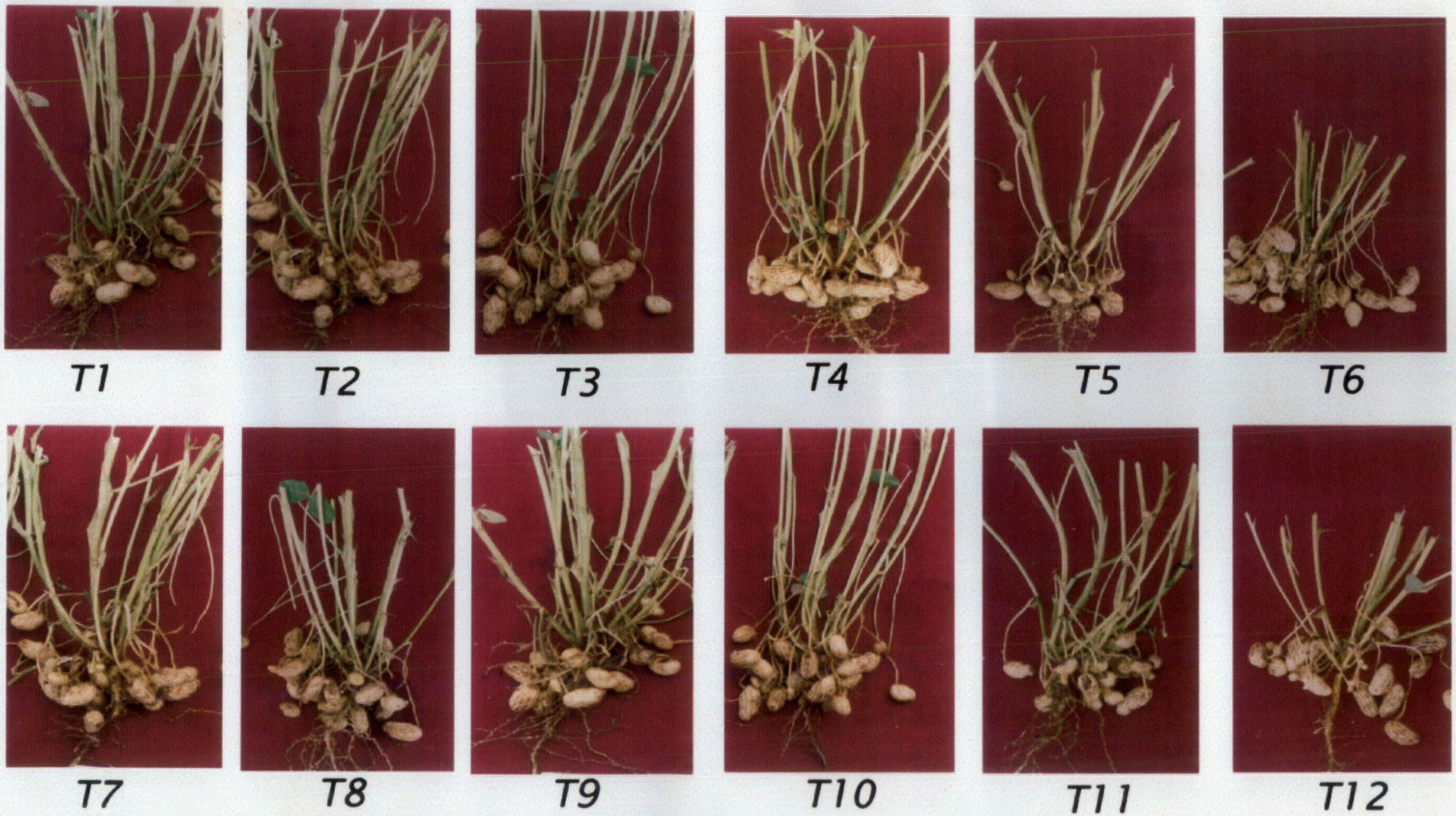


Table : 19. Effect of treatments on days to 50 per cent flowering and number of pegs per plant of groundnut.

Treatment		Days to 50 % flowering	Number of pegs per plant			
			40 DAS	60 DAS	80 DAS	*Harvest*
T_1	**R** (P as MP)	26	1.83	16.00 ^{bc}	22.50	*25.80*
T_2	**R** (P as SSP)	26	2.58	16.63 ^{bc}	25.00	*28.95*
T_3	**R** (P as OM)	26	3.88	19.25 ^{ab}	22.88	*26.25*
T_4	**R** (P as OM)S_{56}	26	2.04	18.75 ^{abc}	24.25	*28.50*
T_5	**$OM_{500}N_{15}K_{75}$**	26	3.04	18.38 ^{abc}	23.25	*29.40*
T_6	**$OM_{1000}N_{10}K_{75}$**	26	2.86	18.75 ^{abc}	21.75	*28.80*
T_7	**$OM_{1500}N_5K_{75}$**	27	1.76	16.00 ^{bc}	19.25	*24.90*
T_8	**$OM_{2000}K_{75}$**	27	4.28	19.25 ^{ab}	24.00	*27.90*
T_9	**$OM_{500}N_{15}K_{75}L_{860}$**	26	1.95	20.50 ^{a}	22.00	*26.70*
T_{10}	**$OM_{1000}N_{10}K_{75}L_{720}$**	26	1.88	15.25 ^{c}	21.75	*24.75*
T_{11}	**$OM_{1500}N_5K_{75}L_{580}$**	27	1.61	18.75 ^{abc}	23.75	*27.30*
T_{12}	**$OM_{2000}K_{75}L_{440}$**	27	3.05	18.13 ^{abc}	22.50	*26.10*

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- Musoorie rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**- Sulphur and **L**-Lime) seeded pods were recorded with T_6 [$OM_{1000}N_{10}K_{75}$]. The lower number of double seeded pods were recorded with T_1 [R (P as MP)] and triple seeded pods with T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$]. In general, triple seeded pods (40-53 per cent) were higher than double seeded pods (31-46 per cent) and single seeded pods (11-18 per cent).

4.3.4. Percentage of pod to peg

This was not significantly affected by the treatments. Application of T_7 [$OM_{1500}N_5K_{75}$] recorded the higher peg to pod conversion, which was followed by T_6 [$OM_{1000}N_{10}K_{75}$] with 80 per cent conversion efficiency and T_5 [$OM_{500}N_{15}K_{75}$] and T_8 [$OM_{2000}K_{75}$] recorded the lower conversion ratios.

4.3.5. Pod weight per plant

Pod weight per plant was significantly different and maximum pod weight was recorded with T_4 [R (P as OM)S_{56}] followed by T_6 [$OM_{1000}N_{10}K_{75}$], T_7 [$OM_{1500}N_5K_{75}$] and T_{11} [$OM_{1500}N_5K_{75}L_{580}$]. The average pod weight per plant ranged from 20.51 to 29.11 g $plant^{-1}$.

4.3.6. 100 pod weight

100 pod weight was one of the important yield attributing characters of groundnut and which was not affected by the P sources and levels of organic meal application. The 100 pod weight varied from 153-167 g. The highest 100 pod weight was recorded with T_4 [R (P as OM)S_{56}] (167 g).

4.3.7. 100 kernel weight

This parameter was also not affected by treatments. However, the highest 100 kernel weight (58.87 g) was recorded with T_6 [$OM_{1000}N_{10}K_{75}$] and the lowest (53.55 g) with T_2 [R (P as SSP)].

4.3.8. Shelling percentage

Shelling percentage of groundnut did not vary significantly, but the variation was from 70.93 to 75.51 per cent.

4.3.9. Yield

4.3.9.1. Total biomass production

The total biomass production was not affected significantly by the treatments (Table 21). However, it varied from 15 to 18 t ha^{-1}. Higher total

Table : 20 Effect of treatments on yield attributes of groundnut (air dry basis- eight per cent moisture level).

Treatment		No. of pods per plant							% of pod to peg	Pod wt. per plant (g)	100 pod weight (g)	100 kernel weight (g)	Shelling %
		Single seeded		Double seeded		Triple seeded		Total					
T_1	R (P as MP)	3.40	***18.30***	5.30^{d}	***31.14***	8.61^{bcd}	***50.56***	15.83	61.54	20.26^{c}	159.14	57.15	74.86
T_2	R (P as SSP)	2.20	***11.86***	7.31^{c}	***39.42***	9.03^{abcd}	***48.72***	18.13	62.65	22.55^{c}	153.44	53.55	72.76
T_3	R (P as OM)	2.03	***10.75***	6.88^{cd}	***36.00***	10.12^{abc}	***53.25***	18.72	71.36	25.07^{abc}	162.57	56.35	73.82
T_4	R (P as OM) S_{56}	2.18	***9.41***	10.21^{a}	***44.17***	10.74^{ab}	***46.42***	21.09	75.19	29.11^{a}	167.40	57.80	70.93
T_5	$OM_{500}N_{15}K_{75}$	1.93	***10.77***	7.43^{c}	***41.64***	8.48^{bcd}	***47.59***	17.34	59.08	22.29^{c}	160.56	54.57	73.10
T_6	$OM_{1000}N_{10}K_{75}$	2.63	***10.97***	9.89^{ab}	***41.16***	11.48^{a}	***47.87***	22.95	80.43	28.86^{a}	160.63	58.87	74.45
T_7	$OM_{1500}N_5K_{75}$	3.54	***16.20***	8.38^{bc}	***38.55***	9.83^{abcd}	***45.25***	21.58	87.22	28.04^{ab}	157.61	57.11	75.51
T_8	$OM_{2000}K_{75}$	1.84	***10.79***	7.19^{c}	***42.88***	7.88^{cd}	***46.33***	16.15	58.53	20.51^{c}	154.99	55.58	73.18
T_9	$OM_{500}N_{15}K_{75}L_{860}$	2.11	***11.84***	7.57^{c}	***42.24***	8.21^{bcd}	***45.92***	17.49	65.69	22.40^{c}	156.92	56.95	74.14
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	1.99	***13.68***	6.68^{cd}	***45.60***	7.09^{d}	***40.73***	17.65	71.69	22.99^{bc}	156.30	57.62	73.35
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	2.15	***11.60***	7.66^{c}	***41.08***	8.82^{abcd}	***47.33***	18.46	67.56	24.58^{abc}	152.60	55.97	71.46
T_{12}	$OM_{2000}K_{75}L_{440}$	2.10	***10.94***	7.73^{c}	***39.98***	9.48^{abcd}	***49.08***	18.62	71.51	22.92^{bc}	153.76	57.22	72.46

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, **N**-Nitrogen, **P**- Phosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime)
Percentage figures were given in italic bold letters

biomass was recorded with T_6 [$OM_{1000}N_{10}K_{75}$] and the lowest was recorded with T_8 [$OM_{2000}K_{75}$].

4.3.9.2. Pod yield

Pod yield per hectare was significantly influenced by treatments. The highest pod yield was recorded with T_4 [R (P as OM)S_{56}] followed by T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$]. The pod yield varied from 4.57 to 6.78 t ha^{-1}. However consistent pod yield was observed with graded levels of organic meal with lime treatments and lower pod yield was recorded with T_1 [R (P as MP)] and T_8 [$OM_{2000}K_{75}$]. Among S applied treatments, T_4 [R (P as OM) S_{56}] recorded higher pod yield than T_2 [R(P as SSP)].

4.3.9.3. Haulm yield

Haulm yield was not markedly affected by the treatments (Plate 6). However, haulm yield ranged from 10-12 t ha^{-1}. Higher haulm yield was recorded with T_1 [R (P as MP)] and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$]. Lower haulm yield was recorded with T_{11} [$OM_{1500}N_5K_{75}L_{580}$].

4.3.9.4. Kernel yield

The kernel yields of T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] were also on par with T_3 [R (P as OM)] and T_4 [R (P as OM) S_{56}]. Lime was not applied in T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$], but the quantity of organic meal was higher than T_3 [R (P as OM)] and T_4 [R (P as OM) S_{56}]. S application could not produce significant increase in kernel yield as seen in T_3 [R (P as OM)] and T_4 [R (P as OM)S_{56}]. The lower kernel yield was obtained with higher levels of organic meal whether lime was applied or not.

4.3.10. Harvest index (HI)

The harvest index was not significantly different with treatments and it varied from 27.6 to 38.9 per cent. However T_4 [R (P as OM)S_{56}] and T_7 [$OM_{1500}N_5K_{75}$] recorded higher HI which was followed by T_6 [$OM_{1000}N_{10}K_{75}$] and T_{11} [$OM_{1500}N_5K_{75}L_{580}$].

4.3.11. Haulm pod ratio and haulm kernel ratio

Haulm pod ratio (partitioning coefficient) was significantly different with treatments. However, haulm kernel ratio was not affected. The treatments other

Plate : 6 A close view of experimental plots at 80 DAS

Table : 21 Effect of treatments on yield and related characters of groundnut.

Treatment		Total biomass ($t\ ha^{-1}$)	Pod yield ($t\ ha^{-1}$)	Haulm yield ($t\ ha^{-1}$)	Kernel yield ($t\ ha^{-1}$)	Harvest index (%)	Haulm kernel ratio	Haulm pod ratio
T_1	R (P as MP)	16.50	4.57 ^{c}	11.94	3.47 ^{d}	27.60	3.50	2.63 ^{a}
T_2	R (P as SSP)	15.16	5.21 ^{bc}	9.94	3.79 ^{d}	34.70	2.64	1.92 ^{abc}
T_3	R (P as OM)	15.57	5.76 ^{abc}	9.81	4.26 ^{abc}	37.10	2.32	1.70 ^{bc}
T_4	R (P as OM) S_{56}	17.46	6.78 ^{a}	10.69	4.81 ^{abc}	38.90	2.24	1.58 ^{c}
T_5	$OM_{500}N_{15}K_{75}$	15.82	5.07 ^{c}	10.75	3.72 ^{d}	32.60	2.93	2.08 ^{abc}
T_6	$OM_{1000}N_{10}K_{75}$	18.37	6.72 ^{a}	11.66	5.00 ^{a}	36.60	2.34	1.74 ^{bc}
T_7	$OM_{1500}N_5K_{75}$	17.17	6.51 ^{ab}	10.75	4.94 ^{ab}	38.40	2.25	1.69 ^{bc}
T_8	$OM_{2000}K_{75}$	15.04	4.63 ^{c}	10.41	3.40 ^{d}	30.70	3.17	2.32 ^{ab}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	15.23	5.10 ^{c}	10.14	3.79 ^{cd}	33.90	2.71	2.01 ^{abc}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	17.10	5.25 ^{bc}	11.85	3.85 ^{cd}	31.20	3.14	2.28 ^{abc}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	15.02	5.52 ^{abc}	9.50	3.97 ^{bcd}	36.70	2.72	1.94 ^{abc}
T_{12}	$OM_{2000}K_{75}L_{440}$	15.49	5.24 ^{bc}	10.25	3.81 ^{d}	34.80	2.80	1.95 ^{abc}

(**R**- Package of Practices **Recommendations** of KAU, **MP- Mussoorie** rock **Phosphate**, **SSP- Single Super Phosphate**, **OM- Organic Meal**, **N-Nitrogen**, **P- Phosphorus**, **K-** Potassium, **S-** Sulphur and **L-Lime**) than T_3 [R (P as OM)], T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] recorded statistically higher and T_1 [R(P as MP)] recorded the highest haulm pod ratio followed by T_8 [$OM_{2000}K_{75}$] and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$]. The lowest haulm pod ratio was recorded with T_4 [R (P as OM)S_{56}].

4.4. Quality parameters

The data on quality parameters of kernel and ash content are presented in Table 22.

4.4.1. Protein content and yield

The protein content of groundnut kernels was significantly different due to various treatments. The protein content varied from 25.80 to 29.86 per cent.

The various P sources and T_6 [$OM_{1000}N_{10}K_{75}$] recorded higher protein content which was on par with other treatments except T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]. The lowest protein content was recorded with T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$].

The protein yield also significantly differed among treatments. T_4, the treatment which received elemental S and organic meal recorded statistically higher yield along with T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$]. The protein yield varied from 921.72 to 1505.56 kg ha^{-1}.

Graded levels of organic meal with lime combinations did not result in better protein yield whereas, organic meal combined with lime, FYM and elemental S recorded the highest protein yield. Similarly, higher dose of organic meal without lime (T_8 [$OM_{2000}K_{75}$]) and T_1 [R (P as MP)] also have not encouraged the protein yield.

4.4.2. Oil content and yield

The oil content and yield were significantly different due to various treatment effects. The oil content varied from 42.6 to 45.9 per cent. T_3 [R (P as OM)] and T_5 [$OM_{500}N_{15}K_{75}$] recorded the maximum oil content where as maximum oil yield (2212 kg ha^{-1}) was recorded with T_7 [$OM_{1500}N_5K_{75}$]. T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_3 [R(P as OM)] also recorded significantly higher oil yields. The lowest oil yield of 1509 kg ha^{-1} was recorded with T_8 [$OM_{2000}K_{75}$].

Table : 22 Effect of treatments on quality attributes of groundnut.

Treatment		Protein content (%)	Oil content (%)	Carbohydrate content (%)	Protein yield (kg ha^{-1})	Oil yield (kg ha^{-1})	Carbohydrate yield (kg ha^{-1})	Ash content (%)
T_1	R (P as MP)	28.89 ^{ab}	45.22 ^{ab}	10.69	989.96 ^{cd}	1554.31 ^{d}	365.95 ^{c}	2.55 ^{d}
T_2	R (P as SSP)	29.53 ^{a}	43.42 ^{bcd}	10.35	1120.55 ^{bcd}	1647.27 ^{d}	392.46 ^{c}	2.60 ^{cd}
T_3	R (P as OM)	29.39 ^{a}	45.79 ^{a}	10.67	1264.24 ^{abc}	1949.30 ^{abcd}	457.99 ^{abc}	2.65 ^{bcd}
T_4	R (P as OM) S_{56}	29.86 ^{a}	43.99 ^{abcd}	10.09	1505.56 ^{a}	2116.10 ^{abc}	483.20 ^{abc}	2.73 ^{abcd}
T_5	$OM_{500}N_{15}K_{75}$	28.20 ^{ab}	45.87 ^{a}	11.48	1009.83 ^{cd}	1709.05 ^{bcd}	422.58 ^{c}	2.58 ^{cd}
T_6	$OM_{1000}N_{10}K_{75}$	29.51 ^{a}	43.58 ^{bcd}	11.74	1469.38 ^{a}	2130.41 ^{ab}	587.93 ^{a}	2.85 ^{ab}
T_7	$OM_{1500}N_5K_{75}$	27.95 ^{ab}	44.66 ^{abc}	12.78	1293.55 ^{ab}	2212.21 ^{a}	573.69 ^{ab}	2.63 ^{cd}
T_8	$OM_{2000}K_{75}$	28.19 ^{ab}	44.99 ^{ab}	11.97	984.83 ^{d}	1509.27 ^{d}	396.57 ^{c}	2.88 ^{a}
T_9	.$OM_{500}N_{15}K_{75}L_{860}$	28.02 ^{ab}	42.93 ^{cd}	11.33	1138.81 ^{bcd}	1628.24 ^{d}	425.76 ^{c}	2.75 ^{abcd}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	25.80 ^{c}	43.88 ^{abcd}	11.35	979.73 ^{d}	1683.31 ^{cd}	434.88 ^{c}	2.85 ^{ab}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	28.07 ^{ab}	43.54 ^{bcd}	11.39	979.45 ^{cd}	1724.36 ^{bcd}	446.42 ^{c}	2.78 ^{abc}
T_{12}	$OM_{2000}K_{75}L_{440}$	27.00 ^{bc}	44.77 ^{abc}	10.74	921.72 ^{d}	1703.12 ^{bcd}	406.40 ^{c}	2.92 ^{a}

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock **Phosphate**, **SSP**- Single Super **Phosphate**, **OM**- **Organic** Meal, N-Nitrogen, **P**- Phosphorus, **K**-Potassium, S- Sulphur and **L**-Lime) (Kernels on air dry weight basis- eight per cent moisture level)

4.4.3. Carbohydrate content and yield

Carbohydrate content of kernels was not significantly different, but carbohydrate yield was significantly different due to various treatments. Organic meal applied treatment recorded higher carbohydrate content than FYM applied treatment. The carbohydrate content ranged between 10.09-12.78 per cent.

Higher doses of organic meal with and without lime reduced carbohydrate yield. T_6 [$OM_{1000}N_{10}K_{75}$] recorded the highest carbohydrate yield which was on par with T_7 [$OM_{1500}N_5K_{75}$]. Moderate levels of organic meal with out lime resulted in better carbohydrate yield.

4.4.4. Ash content

The ash content of groundnut kernels was significantly different. In general, graded levels of organic meal application resulted in higher ash content than FYM application. Higher ash content was recorded with T_{12} [$OM_{2000}K_{75}L_{440}$].

4.5. Correlation studies

4.5.1. Relationship between growth characters and yield

The correlation coefficient of growth and nodule characters and growth indices with yield are presented in Table 23 and 24. In general, plant height was negatively correlated with pod, kernel, oil and protein yield, whereas haulm yield was positively correlated even though it was negatively correlated up to 60 DAS.

Number of leaves also had negative influence up to 60 DAS on various aspects of economic yields. Later on towards harvest, the number of leaves retained had positive correlation with yield parameters.

Similarly, number of branches was negatively correlated with pod, kernel, oil and protein yields, but positively correlated with haulm yields.

4.5.2. Relationship between nodule characters and yield

The correlation coefficient between nodule count and weight with yield are presented in Table 23. Nodule count was positively associated with haulm yield at 20 DAS, and again at 80 DAS. During harvesting stage, the presence of nodules had a favourable effect on economic yields.

Table: 23 a. Correlation between growth characters at various stages and yield of groundnut.

Factors	Plant height					Number of leaves					Number of branches			
	20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS
Haulm yield	-0.110	-0.046	-0.073	0.015	0.022	-0.161	0.130	0.002	0.329	0.063	-0.136	0.166	0.118	0.246
Pod yield	-0.175	-0.011	-0.124	-0.173	-0.198	-0.125	-0.341	-0.225	-0.052	0.189	0.028	-0.315	-0.325	-0.295
Kernel yield	-0.116	0.084	-0.131	-0.166	-0.203	-0.111	-0.302	-0.198	0.005	0.181	-0.077	-0.285	-0.291	-0.258
Oil yield	-0.178	0.015	-0.189	-0.151	-0.161	-0.113	-0.302	-0.255	-0.065	0.178	0.087	-0.369	-0.408	-0.394
Protein yield	-0.037	-0.022	-0.044	-0.200	-0.227	-0.110	-0.179	-0.174	-0.008	0.091	-0.183	-0.256	-0.246	-0.217

Table : 23 b. Correlation between nodule characters at various stages and yield of groundnut.

Factors	Nodule count					Nodule weight				
	20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Haulm yield	0.082	-0.029	-0.093	0.162	-0.149	0.069	0.037	-0.099	-0.095	-0.122
Pod yield	-0.079	-0.078	-0.062	-0.039	0.029	-0.218	-0.032	-0.126	-0.034	0.118
Kernel yield	-0.032	-0.042	-0.026	0.036	0.051	-0.161	-0.042	-0.085	-0.013	0.110
Oil yield	-0.103	-0.129	-0.021	0.072	0.022	-0.123	-0.068	-0.065	-0.045	0.152
Protein yield	-0.147	-0.154	-0.050	-0.101	0.006	-0.239	-0.217	-0.150	-0.065	0.123

Nodule weight was positively correlated with economic yields only during harvesting stage, but it had positive correlation with haulm yield in the early stages.

4.5.3. Relationship between growth indices and yields

LAI from 60 DAS to harvest was positively correlated with haulm, pod, kernel, oil and protein yield.

The RGR during 40-60 DAS was positively correlated with haulm, kernel and protein yield. Whereas, during 60-80 DAS pod, oil and protein yields were positively correlated. Protein yield was negatively correlated with RGR from 80 DAS up to harvest.

During 60 DAS to harvest, NAR was positively correlated with pod, kernel, oil and protein yields, whereas, haulm yield was negatively correlated. But positive correlations were observed with kernel yield and protein yield from 20 DAS onwards.

Crop growth rate (CGR) during 60-80 DAS was highly positively correlated with pod, kernel, oil and protein yield, but negatively correlated with haulm yield. But reverse relationship was observed during 80 DAS to harvest.

LAR during 80 DAS to harvest was negatively correlated with economic yields. But leaf area duration (LAD) was positively correlated with haulm, pod, kernel, oil and protein yield from 40 DAS to harvest.

SLA at 60 DAS and at harvest was positively correlated with pod, oil and protein yields and negatively with haulm yield. But, SLW showed reverse impact on yield aspects.

4.5.4. Relationship between yield contributing characters and yield

The correlation coefficient between yield contributing character and yield are presented in Table 25. Economic yields were highly correlated with 100 pod weight and 100 kernel weight. Shelling percentage and pods per plant were positively correlated with economic yields and negatively with haulm yield.

Pegs at harvest was positively correlated with pod, kernel and oil yields, and negatively correlated with haulm as well as protein yields. Pod to peg ratio was positively correlated to all the yield aspects. Haulm kernel ratio and haulm pod

Table: 24 Correlation between growth indices at various stages and yield of groundnut.

Factors	Leaf Area Index					Relative Growth Rate (RGR)			
	20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20-40 DAS	40-60 DAS	60-80 DAS	80-Harvest
Haulm yield	-0.127	0.202	0.173	0.381	0.060	-0.239	0.364	-0.237	0.523
Pod yield	-0.034	-0.183	0.233	0.087	0.388	0.440	-0.205	0.242	0.048
Kernel yield	0.002	-0.125	0.243	0.138	0.358	0.358	0.111	-0.065	0.054
Oil yield	-0.046	-0.157	0.246	0.107	0.365	0.410	-0.274	0.300	0.026
Protein yield	0.068	0.023	0.211	0.142	0.263	0.228	0.029	0.078	-0.068

Factors	Net Assimilation Rate (NAR)				Crop Growth Rate (CGR)			
	20-40 DAS	40-60 DAS	60-80 DAS	80-Harvest	20-40 DAS	40-60 DAS	60-80 DAS	80-Harvest
Haulm yield	-0.162	0.307	-0.202	-0.175	-0.195	0.372	-0.082	0.143
Pod yield	0.278	-0.046	0.177	0.224	0.220	-0.014	0.247	-0.193
Kernel yield	0.276	0.189	0.034	0.151	0.259	0.226	0.126	-0.197
Oil yield	0.306	-0.134	0.201	0.179	0.243	-0.096	0.278	-0.195
Protein yield	0.112	0.086	0.166	0.063	0.174	0.150	0.243	-0.284

(Table: 24 contd.)

Factors	Leaf Area Ratio (LAR)					Leaf Area Duration (LAD)			
	20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20-40 DAS	40-60 DAS	60-80 DAS	80-Harvest
Haulm yield	-0.209	0.254	-0.235	0.215	-0.694	0.144	0.241	0.352	0.322
Pod yield	0.265	-0.231	0.259	-0.166	-0.070	-0.172	0.155	0.188	0.224
Kernel yield	0.207	-0.217	-0.099	-0.134	-0.107	-0.110	0.185	0.227	0.252
Oil yield	0.206	-0.216	0.312	-0.157	-0.057	-0.152	0.177	0.229	0.231
Protein yield	0.166	-0.061	0.005	-0.216	-0.141	0.040	0.210	0.213	0.217

Factors	Specific Leaf Area (SLA)					Specific Leaf Weight (SLW)				
	20 DAS	40 DAS	60 DAS	80 DAS	Harvest	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Haulm yield	-0.216	0.251	-0.244	-0.112	-0.813	0.228	-0.237	0.172	0.107	0.821
Pod yield	0.260	-0.234	0.260	-0.289	0.274	-0.140	0.228	-0.084	0.280	-0.284
Kernel yield	0.199	-0.220	-0.102	-0.245	0.191	-0.078	0.241	0.126	0.255	-0.197
Oil yield	0.205	-0.219	0.310	-0.270	0.279	-0.088	0.246	-0.142	0.259	-0.267
Protein yield	0.162	-0.066	0.004	-0.324	0.053	-0.103	0.081	0.048	0.326	-0.126

ratio was highly negatively correlated with economic yield and positively correlated with haulm yield.

Haulm yield was negatively correlated with pod, kernel and oil yield (Table 26). Pod yield was highly correlated with kernel, oil and protein yields. Oil yield also had high correlation with protein yield, showing that there was no decline in protein yield due to high oil yield.

4.6. Plant nutrient concentration and uptake

The nutrient concentrations and uptake at various stages of plant growth from 20 DAS are presented in Tables 27 to 36.

4.6.1. Nitrogen

The plant nitrogen concentration was high at initial stages of growth and decreased towards maturity. There was no significant difference between N content of plants due to various treatments at 40 DAS. In all other stages, there was a significant difference. At harvesting stage, haulm recorded lower concentration of N. The kernel N concentration was around 5 per cent. The lowest N concentration was observed in shells. In kernel, maximum N concentration was recorded with T_4 [R (P as OM)S_{56}] which was on par with other treatments except T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]. Higher shell nitrogen was recorded with T_{11} [$OM_{1500}N_5K_{75}L_{580}$].

The treatment effects were significantly different with regard to the N uptake at 40, 60 and 80 DAS. The total uptake from all the treatments were on par at harvest. Uptake of N by shell and kernel were significantly different. There was a geometric increase in N uptake till harvest. At 40 DAS, higher N uptake was shown by T_3 [R(P as OM)]. From 60 DAS onwards, T_6 [$OM_{1000}N_{10}K_{75}$] recorded higher uptake. The uptake at harvesting stage varied from 332 to 442 kg ha^{-1}. The lower uptake was recorded with T_8 [$OM_{2000}K_{75}$]. Higher accumulation of N was recorded by T_4 [R (P as OM) S_{56}] in shell followed by T_{11} [$OM_{1500}N_5K_{75}L_{580}$]. The N uptake by kernels was the highest with T_6 [$OM_{1000}N_{10}K_{75}$] and T_4 [R (P as OM) S_{56} and it ranged from 176 to 270 kg ha^{-1}.

Table: 25 Correlation between yield related characters and yield of groundnut.

Factors	100 pod weight	100 kernel weight	Shelling percentage	Pegs at harvest	Pods per plant	Peg to pod ratio	Kernel haulm ratio	Pod haulm ratio
Haulm yield	0.049	0.092	-0.068	-0.018	-0.008	0.019	0.676	0.677
Pod yield	0.498	0.315	0.030	0.169	0.908	0.719	-0.757	-0.754
Kernel yield	0.544	0.343	0.170	0.107	0.783	0.652	-0.693	-0.673
Oil yield	0.562	0.399	0.221	0.114	0.852	0.708	-0.752	-0.731
Protein yield	0.493	0.297	0.211	-0.041	0.606	0.567	-0.540	-0.519

Table: 26 Correlation half matrix between yield and yield.

Factors	Haulm yield	Pod yield	Kernel yield	Oil yield	Protein yield
Haulm yield	1.000	-0.085	-0.005	-0.089	0.034
Pod yield		1.000	0.918	0.962	0.718
Kernel yield			1.000	0.896	0.766
Oil yield				1.000	0.696
Protein yield					1.000

Table : 27 Effect of treatments on nitrogen concentration and uptake at various stages.

Treatment		Nitrogen concentration (%)							Nitrogen uptake (kg ha^{-1})							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	2.47^{c}	2.59	2.01^{c}	1.96^{bc}	1.37	0.98^{b}	5.29^{ab}	9.41	61.73^{b}	122.52^{bc}	203.04^{c}	163.15	11.29^{c}	181.30^{b}	**355.73**
T_2	R (P as SSP)	2.77^{abc}	2.33	2.17^{abc}	1.96^{bc}	1.70	0.93^{b}	5.41^{a}	9.86	61.94^{b}	119.58^{bc}	237.63^{bc}	171.01	13.14^{c}	205.21^{a}	**389.36**
T_3	R (P as OM)	2.94^{ab}	2.29	2.17^{abc}	2.14^{ab}	1.38	0.74^{c}	5.38^{a}	9.03	84.39^{a}	132.99^{b}	253.40^{bc}	135.98	11.12^{c}	230.20^{ab}	**377.29**
T_4	R (P as OM) S_{56}	2.77^{abc}	2.45	2.26^{a}	2.07^{ab}	1.44	0.96^{b}	5.47^{a}	7.96	62.80^{b}	140.50^{ab}	278.18^{ab}	153.26	19.03^{a}	263.27^{a}	**435.55**
T_5	$OM_{500}N_{15}K_{75}$	2.77^{abc}	2.57	2.05^{bc}	2.24^{a}	1.47	0.89^{bc}	5.17^{ab}	9.89	67.65^{b}	123.32^{bc}	273.91^{ab}	158.33	12.20^{c}	189.81^{b}	**360.34**
T_6	$OM_{1000}N_{10}K_{75}$	3.08^{a}	2.43	2.12^{abc}	2.24^{a}	1.35	0.88^{bc}	5.41^{a}	9.81	72.86^{ab}	169.67^{a}	325.52^{a}	156.91	14.99^{abc}	270.27^{a}	**442.16**
T_7	$OM_{1500}N_5K_{75}$	2.57^{bc}	2.35	2.00^{c}	2.00^{b}	1.44	0.91^{b}	5.12^{ab}	6.87	58.30^{b}	92.13^{c}	222.78^{bc}	155.40	14.50^{bc}	227.34^{ab}	**397.26**
T_8	$OM_{2000}K_{75}$	2.73^{abc}	2.49	2.17^{abc}	2.15^{ab}	1.38	0.95^{b}	5.16^{ab}	9.00	70.12^{ab}	129.29^{b}	228.61^{bc}	144.11	11.67^{c}	175.97^{b}	**331.74**
T_9	$OM_{500}N_{15}K_{75}L_{860}$	2.56^{bc}	2.61	2.05^{bc}	2.08^{ab}	1.44	0.82^{bc}	5.18^{ab}	8.17	69.19^{ab}	116.51^{bc}	240.71^{bc}	148.23	10.84^{c}	197.47^{b}	**356.53**
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	2.85^{abc}	2.47	2.07^{bc}	2.17^{ab}	1.61	0.84^{bc}	4.73^{c}	10.25	67.23^{b}	133.84^{b}	224.56^{bc}	187.88	11.83^{c}	182.42^{b}	**382.13**
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	2.89^{abc}	2.45	2.19^{ab}	2.10^{ab}	1.44	1.17^{a}	5.14^{ab}	8.25	59.18^{b}	124.92^{bc}	210.00^{bc}	135.67	17.69^{ab}	205.29^{b}	**358.92**
T_{12}	$OM_{2000}K_{75}L_{440}$	3.05^{a}	2.47	2.07^{bc}	2.10^{ab}	1.58	0.95^{b}	4.95^{bc}	8.72	60.07^{b}	121.54^{bc}	192.81^{bc}	161.35	13.51^{c}	187.26^{b}	**362.12**

(**R**- Package of Practices **R**ecommendations of KAU, **MP- Mussoorie** rock **P**hosphate, **SSP-** Single Super Phosphate, **OM-** Organic Meal, **N-**Nitrogen, **P-** Phosphorus, **K-** Potassium, S- Sulphur and **L**-Lime)

4.6.2. Phosphorus

The P concentration was also the highest at initial stages of growth and decreased towards maturity. But the drop in P concentration was greater from 40 to 60 DAS. The P concentration of groundnut was significantly different throughout the growing period except 80 DAS. At harvesting stage also the P concentrations in haulm, shell and kernel were significantly different. Upto 60 DAS, T_{11} [$OM_{1500}N_5K_{75}L_{580}$] recorded higher P concentration.

The P concentration in haulm, kernel and shell varied from 0.12-0.17, 0.40-0.49 and 0.052-0.085 per cent. The higher concentration of P in haulm was recorded with T_2 [R (P as SSP)] and shell P with T_{11} [$OM_{1500}N_5K_{75}L_{580}$]. The concentration of P in kernel was on par in all the treatments except T1 [R(P as MP)] and T_5 [$OM_{500}N_{15}K_{75}$].

However, the P uptake was not significantly affected by the treatments. But at the final stage, P uptake by haulm and kernel were significantly different. Maximum P accumulation was in the kernel compared to haulm and shell and it was observed in T_6 [$OM_{1000}N_{10}K_{75}$]. Very little P was found in shell (around 0.75 to 2.02 kg ha^{-1}). The total P uptake varied from 31-42 kg ha^{-1}.

4.6.3. Potassium

The K concentration was higher in general upto 40 DAS and it decreased towards maturity. The K concentration was significantly different during the growing stages except 60 DAS. At harvesting stage, the K content of haulm only was significantly different.

In haulms, the K concentration varied from 1.23-1.54 per cent. But, in general, the K concentration in haulms was higher with FYM applied treatments. However, the highest concentration in haulm was recorded with T_6 [$OM_{1000}N_{10}K_{75}$]. Potassium content in kernel and shell did not show significant variation with the treatments. It was seen that the K content in shell and kernel were almost equal (around 0.6 per cent) with a slight increase in kernel. Maximum K content was in haulm unlike N and P.

The K uptake by groundnut was significant at 40 and 80 DAS. T_3 [R(P as OM)] showed the highest K uptake at 40 DAS. At 80 DAS, the highest uptake was

Table : 28 Effect of treatments on phosphorus concentration and uptake at various stages.

Treatment		**Phosphorus concentration (%)**							**Phosphorus uptake (kg ha^{-1})**							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T$_1$	**R** (P as MP)	0.49^{c}	0.42^{bcd}	0.26^{a}	0.21	*0.16^{abc}*	*0.065^{bc}*	*0.40^{c}*	1.85	10.03	15.92	21.54	*16.68^{ab}*	*0.75*	*13.82^{c}*	**34.25**
T$_2$	**R** (P as SSP)	0.59^{abc}	0.45^{ab}	0.25^{abc}	0.20	*0.17^{ab}*	*0.069^{ab}*	*0.47^{ab}*	2.13	11.96	13.82	24.78	*17.00^{abcd}*	*0.97*	*17.74^{bc}*	**35.69**
T$_3$	**R** (P as OM)	0.59^{abc}	0.38^{de}	0.20^{g}	0.21	*0.12^{g}*	*0.052^{c}*	*0.47^{a}*	1.82	14.16	12.00	25.75	*12.10^{d}*	*0.80*	*20.36^{ab}*	**33.26**
T$_4$	**R** (P as OM) S_{56}	0.52^{bc}	0.46^{ab}	0.23^{def}	0.21	*0.13^{fg}*	*0.065^{bc}*	*0.45^{ab}*	1.41	10.38	14.20	26.44	*12.74^{cd}*	*2.02*	*21.17^{ab}*	**36.92**
T$_5$	**OM$_{500}$N$_{15}$K$_{75}$**	0.59^{abc}	0.40^{cde}	0.23^{ef}	0.22	*0.13^{efg}*	*0.065^{bc}*	*0.42^{bc}*	2.08	10.48	13.69	26.16	*14.92^{abcd}*	*0.90*	*15.51^{bc}*	**31.33**
T$_6$	**OM$_{1000}$N$_{10}$K$_{75}$**	0.61^{ab}	0.42^{abcd}	0.20^{g}	0.21	*0.14^{def}*	*0.073^{ab}*	*0.48^{a}*	1.97	12.62	16.25	30.05	*16.89^{abcd}*	*1.25*	*23.87^{a}*	**42.01**
T$_7$	**OM$_{1500}$N$_{5}$K$_{75}$**	0.54^{bc}	0.42^{bcd}	0.24^{def}	0.21	*0.14^{efg}*	*0.069^{ab}*	*0.47^{a}*	1.43	10.46	10.52	23.33	*14.64^{bcd}*	*1.12*	*21.05^{ab}*	**36.80**
T$_8$	**OM$_{2000}$K$_{75}$**	0.55^{abc}	0.41^{bcde}	0.24^{cde}	0.23	*0.15^{cde}*	*0.076^{ab}*	*0.49^{a}*	1.82	11.52	14.35	24.77	*15.69^{abcd}*	*0.94*	*16.92^{bc}*	**33.56**
T$_9$	**OM$_{500}$N$_{15}$K$_{75}$L$_{860}$**	0.48^{c}	0.44^{abc}	0.22^{f}	0.19	*0.13^{fg}*	*0.064^{bc}*	*0.47^{ab}*	1.55	11.44	12.58	22.44	*13.49^{cd}*	*0.84*	*17.81^{bc}*	**32.14**
T$_{10}$	**OM$_{1000}$N$_{10}$K$_{75}$L$_{720}$**	0.53^{bc}	0.36^{e}	0.20^{g}	0.21	*0.17^{ab}*	*0.064^{bc}*	*0.47^{ab}*	1.93	9.93	13.23	21.58	*20.11^{a}*	*0.90*	*18.01^{bc}*	**39.02**
T$_{11}$	**OM$_{1500}$N$_{5}$K$_{75}$L$_{580}$**	0.66^{a}	0.47^{a}	0.26^{ab}	0.20	*0.16^{bcd}*	*0.085^{a}*	*0.48^{a}*	1.90	11.43	14.64	20.33	*14.82^{abcd}*	*1.28*	*19.22^{ab}*	**35.32**
T$_{12}$	**OM$_{2000}$K$_{75}$L$_{440}$**	0.57^{abc}	0.43^{abcd}	0.25^{bcd}	0.22	*0.17^{a}*	*0.076^{ab}*	*0.47^{ab}*	1.62	10.54	14.45	20.43	*17.61^{abc}*	*1.09*	*17.90^{bc}*	**36.59**

(**R**- Package of Practices **R**ecommendations of KAU, **MP- Mussoorie** rock **P**hosphate, **SSP**- Single **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**-Sulphur and **L**-Lime)

Table : 29 Effect of treatments on potassium concentration and uptake at various stages.

Treatment		Potassium concentration (%)							Potassium uptake (kg ha^{-1})								
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	3.45^{bcd}	3.66^{ab}	1.94	1.36^{abc}	*1.43^{bc}*	*0.55*	*0.56*	13.16	87.19^{b}	117.82	141.40^{bcd}	*170.25*	*6.32^{d}*	*19.29*	**195.86**
T_2	R (P as SSP)	3.18^{d}	3.84^{a}	1.85	1.45^{abc}	*1.53^{ab}*	*0.60*	*0.66*	11.46	102.26^{b}	102.05	175.57^{ab}	*151.35*	*8.49^{bc}*	*25.15*	**184.98**
T_3	R (P as OM)	3.40^{bcd}	3.40^{c}	1.64	1.41^{abc}	*1.28^{def}*	*0.53*	*0.59*	10.46	125.83^{a}	100.32	166.82^{abc}	*125.07*	*7.92^{bcd}*	*25.16*	**158.13**
T_4	R (P as OM) S_{56}	3.45^{bcd}	3.35^{c}	1.84	1.53^{a}	*1.51^{ab}*	*0.53*	*0.56*	9.91	85.83^{b}	114.61	193.82^{a}	*133.88*	*10.59^{a}*	*25.96*	**170.42**
T_5	$OM_{500}N_{15}K_{75}$	3.90^{a}	3.80^{ab}	1.83	1.41^{abc}	*1.33^{cdef}*	*0.55*	*0.63*	13.91	99.89^{b}	109.84	173.86^{ab}	*142.72*	*7.43^{cd}*	*23.25*	**173.39**
T_6	$OM_{1000}N_{10}K_{75}$	3.71^{ab}	3.55^{bc}	1.70	1.35^{abc}	*1.54^{a}*	*0.56*	*0.58*	11.86	105.36^{b}	136.33	194.39^{a}	*179.21*	*9.67^{ab}*	*28.81*	**217.69**
T_7	$OM_{1500}N_5K_{75}$	3.29^{cd}	3.33^{c}	1.68	1.30^{c}	*1.26^{ef}*	*0.53*	*0.61*	8.92	83.19^{b}	76.28	145.52^{bcd}	*136.47*	*8.41^{bcd}*	*27.32*	**172.19**
T_8	$OM_{2000}K_{75}$	3.63^{abc}	3.68^{ab}	1.63	1.49^{ab}	*1.39^{cd}*	*0.58*	*0.61*	12.00	103.36^{b}	96.63	157.59^{abcd}	*144.97*	*7.11^{cd}*	*20.50*	**172.58**
T_9	$OM_{500}N_{15}K_{75}L_{860}$	3.16^{d}	3.35^{c}	1.84	1.28^{c}	*1.35^{cde}*	*0.55*	*0.66*	10.17	87.83^{b}	104.81	146.61^{bcd}	*134.79*	*7.17^{cd}*	*25.16*	**167.12**
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	3.35^{bcd}	3.70^{ab}	1.74	1.34^{bc}	*1.34^{cdef}*	*0.54*	*0.64*	12.03	100.46^{b}	112.33	137.48^{bcd}	*158.49*	*7.50^{cd}*	*24.72*	**190.70**
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	3.54^{abcd}	3.75^{ab}	1.79	1.30^{c}	*1.23^{f}*	*0.59*	*0.64*	10.17	90.68^{b}	102.38	129.71^{cd}	*116.47*	*8.96^{abc}*	*25.44*	**150.86**
T_{12}	$OM_{2000}K_{75}L_{440}$	3.24^{cd}	3.79^{ab}	1.79	1.34^{bc}	*1.33^{cdef}*	*0.49*	*0.61*	9.31	92.16^{b}	104.28	122.92^{d}	*136.31*	*7.05^{cd}*	*23.60*	**166.96**

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4.6.4. Calcium

The calcium concentrations were significantly different with treatments at all stages. In general, the Ca concentration increased upto 40 DAS, and decreased towards maturity. The Ca concentration was higher in haulm compared to kernel and shell, which in turn were showing almost similar contents. The Ca concentration in haulm, shell and kernel varied from 0.71-1.11, 0.08-0.17 and 0.11-0.16 per cent respectively. At 40 DAS, MP and SSP applied treatments (T_1 and T_2) recorded higher Ca concentration. At 60 DAS, T_1 [R(P as MP)], T_8 [$OM_{2000}K_{75}$] and T_{12} [$OM_{2000}K_{75}L_{440}$] recorded the highest concentration. At 80 DAS, T_{12} [$OM_{2000}K_{75}L_{440}$] showed the highest concentration. At harvesting stage, relatively higher concentrations were recorded in haulms from plots receiving FYM. In shell, the highest concentration was recorded with T_4 [R (P as OM)S_{56}] and the lowest with T_1 [R(P as MP)], T_2 [R(P as SSP)], T_5 [$OM_{500}N_{15}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$].

The Ca uptake was highly influenced by treatments at most of the stages and in haulm and kernel. At 40 DAS, higher Ca uptake was recorded with T_3 [R (P as OM)]. But at 60 DAS, the superiority was shown by T_1 [R (P as MP)] followed by T_8 [$OM_{2000}K_{75}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]. At 80 DAS, higher uptake was recorded with T_3 [R (P as OM)]. At harvest, calcium uptake varied from 84.94 to 116.21 kg ha^{-1}. The total uptake at harvest was higher with T_3 [R (P as OM)].

The Ca uptake by shell was not significantly affected by the treatments and it varied from 0.98-2.35 kg ha^{-1}. The kernel uptake varied from 4.58-6.08 kg ha^{-1}. In general, higher calcium uptake was recorded with lime and FYM applied treatments.

Table : 30 Effect of treatments on calcium concentration and uptake at various stages.

Treatment		**Calcium concentration (%)**							**Calcium uptake (kg ha^{-1})**							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	1.12^{ef}	1.70^{bc}	1.88^{a}	0.81^{de}	*0.88^{c}*	*0.09^{de}*	*0.11^{cde}*	4.27	40.49^{cd}	114.44^{a}	86.12^{bc}	*105.01^{ab}*	*0.98*	*3.68^{de}*	**109.67^{ab}**
T_2	R (P as SSP)	1.06^{f}	1.73^{b}	1.23^{efg}	0.69^{f}	*0.98^{b}*	*0.08^{e}*	*0.14^{b}*	3.82	46.11^{bcd}	67.23^{bcd}	84.20^{bc}	*96.64^{abc}*	*1.08*	*5.12^{abc}*	**102.84^{abc}**
T_3	R (P as OM)	1.17^{def}	1.65^{bcd}	1.09^{g}	0.92^{bc}	*1.11^{a}*	*0.15^{b}*	*0.11^{cd}*	3.57	60.89^{a}	66.81^{bcd}	109.59^{a}	*109.18^{a}*	*2.22*	*4.81^{abcd}*	**116.21^{a}**
T_4	R (P as OM) S_{56}	1.30^{abc}	1.42^{d}	1.00^{g}	0.58^{g}	*0.85^{cd}*	*0.17^{a}*	*0.10^{e}*	3.76	36.39^{d}	62.50^{d}	72.68^{c}	*92.10^{abcd}*	*2.35*	*4.57^{bcde}*	**99.01^{abc}**
T_5	**$OM_{500}N_{15}K_{75}$**	1.18^{de}	1.66^{bc}	1.02^{g}	0.72^{f}	*0.80^{e}*	*0.08^{e}*	*0.10^{de}*	4.30	43.64^{bcd}	61.29^{d}	88.32^{bc}	*85.46^{cde}*	*1.11*	*3.79^{cde}*	**90.35^{bcde}**
T_6	**$OM_{1000}N_{10}K_{75}$**	1.22^{bcde}	1.65^{bcd}	1.13^{fg}	0.68^{f}	*0.77^{ef}*	*0.10^{cd}*	*0.10^{de}*	3.96	49.15^{bc}	90.43^{abc}	96.91^{ab}	*89.95^{bcd}*	*1.72*	*4.88^{abcd}*	**96.54^{bcd}**
T_7	**$OM_{1500}N_5K_{75}$**	1.27^{abcd}	1.81^{ab}	1.48^{cd}	0.80^{e}	*0.74^{fg}*	*0.08^{e}*	*0.11^{cd}*	3.44	45.06^{bcd}	65.92^{cd}	86.12^{abc}	*79.61^{cde}*	*1.32*	*4.97^{abcd}*	**85.90^{cde}**
T_8	**$OM_{2000}K_{75}$**	1.35^{a}	1.85^{ab}	1.81^{ab}	0.80^{e}	*0.77^{ef}*	*0.11^{c}*	*0.10^{de}*	4.48	51.96^{b}	108.20^{a}	83.40^{bc}	*80.14^{cde}*	*1.34*	*3.42^{abcd}*	**84.94^{cde}**
T_9	**$OM_{500}N_{15}K_{75}L_{860}$**	1.19^{cde}	1.49^{cd}	1.34^{def}	0.80^{e}	*0.71^{g}*	*0.10^{cd}*	*0.12^{bc}*	3.80	38.42^{d}	76.23^{bcd}	92.14^{abc}	*81.57^{de}*	*1.32*	*4.58^{e}*	**87.46^{cde}**
T_{10}	**$OM_{1000}N_{10}K_{75}L_{720}$**	1.21^{bcde}	1.67^{bc}	1.39^{de}	0.91^{c}	*0.66^{h}*	*0.11^{c}*	*0.14^{b}*	4.32	45.19^{bcd}	90.32^{abc}	94.06^{ab}	*87.65^{cde}*	*1.40*	*5.36^{bcde}*	**94.42^{cde}**
T_{11}	**$OM_{1500}N_5K_{75}L_{580}$**	1.28^{abcd}	1.63^{bcd}	1.63^{bc}	0.96^{b}	*0.70^{gh}*	*0.14^{b}*	*0.14^{b}*	3.67	44.76^{bcd}	92.61^{ab}	95.84^{ab}	*78.41^{e}*	*2.15*	*5.95^{ab}*	**84.51^{cde}**
T_{12}	**$OM_{2000}K_{75}L_{440}$**	1.31^{ab}	1.98^{a}	1.80^{ab}	1.05^{a}	*0.82^{de}*	*0.15^{b}*	*0.16^{a}*	3.78	48.41^{bc}	106.06^{a}	95.43^{ab}	*84.11^{cde}*	*2.21*	*6.08^{a}*	**92.39^{bcde}**

(**R**- Package of Practices **R**ecommendations of KAU, **MP- Mussoorie** rock **P**hosphate, **SSP**- Single **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**- Sulphur and **L**-Lime)

4.6.5. Magnesium

The Mg concentration was almost consistent over crop period and the concentrations were significantly different at 40, 60 and 80 DAS. At harvesting stage, the Mg concentration in haulm and kernel were comparable and ranging from 0.26-0.29 per cent and the highest was recorded with T_{12} $[OM_{2000}K_{75}L_{440}]$. The highest Mg concentration in shell was recorded with T_7 $[OM_{1500}N_5K_{75}]$.

The uptake of Mg increased with age of the crop, and there were significant differences at 40-80 DAS. From 60 DAS onwards higher uptake was recorded with T_6 $[OM_{1000}N_{10}K_{75}]$, but at harvesting stage, the uptake was on par with all other treatments. The Mg uptake in haulm varied from 26 to 32, kernel 9.0 to 14.0 and shells 1.0 to 2.6 kg ha^{-1}. The total Mg uptake ranged from 37.5 to 46.0 kg ha^{-1}.

4.6.6. Sulphur

The plant S concentration was higher at initial periods of growth and later on it was decreased. At harvest, almost equal contents of S were observed in haulm, shell and kernel. In haulm, the highest S concentration was recorded with T_9 $[OM_{500}N_{15}K_{75}L_{860}]$. The S uptake was significant with treatments at 20 and 40 DAS. At harvest, uptake by haulm and kernel was also significant. Among the P sources with FYM, T_4 [R (P as OM)S_{56}] recorded the highest S uptake. The S uptake varied from 9.73-13.48 kg ha^{-1}.

4.6.7. Iron

The iron content in plant was significantly affected by the treatments at most of the plant stages except 60 DAS. The Fe concentration was higher at initial periods of growth and the minimum was shown at 60 DAS. However haulm and kernel recorded lower iron content and the concentrations in shell was high.

At 20 and 40 DAS, the higher concentration was recorded with T_4 [R (P as OM) S56] and 80 DAS, T_6 $[OM_{1000}N_{10}K_{75}]$ took over the position. In haulm, higher concentration was recorded in shell with T_4 [R (P as OM) S_{56}]. The iron content in kernel, shell and haulm varied from 80-104, 609-949 and 166-259 ppm respectively.

Table : 31 Effect of treatments on magnesium concentration and uptake at various stages.

Treatment		Magnesium concentration (%)							Magnesium uptake (kg ha^{-1})							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	0.34	0.35^{c}	0.34^{a}	0.30^{abc}	*0.27^{bcd}*	*0.09^{bc}*	*0.27*	1.30	8.33^{c}	20.85^{b}	30.49^{bc}	*32.28*	*1.05^{d}*	*9.20*	**42.53**
T_2	R (P as SSP)	0.34	0.35^{de}	0.31^{ab}	0.28^{d}	*0.29^{ab}*	*0.12^{abc}*	*0.26*	1.22	9.42^{c}	16.82^{b}	33.09^{abc}	*28.45*	*1.70^{bcd}*	*9.98*	**40.10**
T_3	R (P as OM)	0.34	0.35^{de}	0.31^{ab}	0.29^{bcd}	*0.27^{cd}*	*0.14^{ab}*	*0.27*	1.05	12.96^{a}	18.99^{b}	33.67^{abc}	*26.03*	*2.15^{abc}*	*11.60*	**39.73**
T_4	R (P as OM) S_{56}	0.35	0.36^{bcde}	0.29^{ab}	0.28^{cd}	*0.27^{bcd}*	*0.13^{abc}*	*0.27*	1.00	9.28^{c}	18.03^{b}	35.33^{abc}	*28.83*	*2.58^{a}*	*13.03*	**44.43**
T_5	**$OM_{500}N_{15}K_{75}$**	0.35	0.37^{bcde}	0.32^{ab}	0.30^{ab}	*0.27^{cd}*	*0.13^{abc}*	*0.28*	1.25	9.60^{bc}	19.10^{b}	36.86^{ab}	*28.48*	*1.83^{abcd}*	*10.50*	**40.75**
T_6	**$OM_{1000}N_{10}K_{75}$**	0.34	0.39^{a}	0.32^{ab}	0.28^{cd}	*0.26^{d}*	*0.14^{abc}*	*0.28*	1.09	11.63^{ab}	25.28^{a}	40.28^{a}	*29.78*	*2.38^{ab}*	*13.90*	**45.98**
T_7	**$OM_{1500}N_{5}K_{75}$**	0.35	0.36^{bcde}	0.28^{b}	0.28^{d}	*0.27^{cd}*	*0.15^{a}*	*0.27*	0.94	8.96^{c}	12.19^{c}	30.57^{bc}	*28.48*	*2.43^{ab}*	*12.18*	**43.00**
T_8	**$OM_{2000}K_{75}$**	0.35	0.37^{bc}	0.33^{ab}	0.29^{abc}	*0.27^{cd}*	*0.09^{c}*	*0.26*	1.15	10.39^{bc}	19.90^{b}	31.22^{bc}	*27.48*	*1.15^{d}*	*8.90*	**37.50**
T_9	**$OM_{500}N_{15}K_{75}L_{860}$**	0.33	0.37^{bcd}	0.32^{ab}	0.29^{bcd}	*0.27^{cd}*	*0.14^{abc}*	*0.27*	1.07	9.69^{bc}	18.09^{b}	32.91^{bc}	*27.30*	*1.83^{abcd}*	*10.13*	**39.28**
T_{10}	**$OM_{1000}N_{10}K_{75}L_{720}$**	0.34	0.36^{cde}	0.31^{ab}	0.30^{ab}	*0.26^{d}*	*0.13^{abc}*	*0.27*	1.22	9.65^{bc}	20.29^{b}	31.23^{bc}	*31.13*	*1.83^{abcd}*	*10.20*	**43.13**
T_{11}	**$OM_{1500}N_{5}K_{75}L_{580}$**	0.35	0.37^{bcde}	0.34^{a}	0.30^{ab}	*0.28^{abc}*	*0.14^{abc}*	*0.27*	1.00	8.74^{c}	19.23^{b}	29.75^{bc}	*26.58*	*2.05^{abc}*	*10.80*	**39.43**
T_{12}	**$OM_{2000}K_{75}L_{440}$**	0.34	0.37^{b}	0.34^{a}	0.30^{ab}	*0.29^{a}*	*0.11^{abc}*	*0.29*	0.97	9.09^{c}	19.91^{b}	28.23^{c}	*29.53*	*1.55^{cd}*	*10.85*	**41.95**

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Table : 32 Effect of treatments on sulphur concentration and uptake at various stages.

Treatment	Sulphur concentration (%)							Sulphur uptake (kg ha^{-1})							
	20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
					Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T$_1$ R (P as MP)	0.26^{abc}	0.24^{a}	0.11^{abc}	0.08	*0.07^{cd}*	*0.07*	*0.08^{ab}*	1.00^{a}	5.65^{abc}	6.60	8.10	*7.80^{abcd}*	*0.78*	*2.68^{abcd}*	**11.25**
T$_2$ R (P as SSP)	0.22^{bcd}	0.15^{c}	0.09^{abc}	0.90	*0.06^{d}*	*0.09*	*0.08^{a}*	0.78^{abc}	3.98^{cd}	4.93	10.55	*6.10^{d}*	*1.30*	*3.20^{ab}*	**10.60**
T$_3$ R (P as OM)	0.20^{cd}	0.16^{bc}	0.09^{abc}	0.10	*0.08^{bc}*	*0.08*	*0.07^{abc}*	0.65^{bc}	5.83^{ab}	5.78	12.00	*7.83^{abcd}*	*1.25*	*3.15^{ab}*	**12.18**
T$_4$ R (P as OM) S$_{56}$	0.21^{cd}	0.18^{bc}	0.10^{abc}	0.12	*0.07^{bcd}*	*0.07*	*0.08^{abc}*	0.63^{bc}	4.60^{abcd}	6.13	16.70	*7.90^{abcd}*	*1.35*	*3.68^{ab}*	**12.93**
T$_5$ **OM$_{500}$N$_{15}$K$_{75}$**	0.25^{abc}	0.24^{a}	0.10^{abc}	0.09	*0.07^{bcd}*	*0.08*	*0.08^{ab}*	0.90^{abc}	6.28^{a}	6.13	11.85	*7.48^{bcd}*	*1.20*	*3.08^{abc}*	**11.75**
T$_6$ **OM$_{1000}$N$_{10}$K$_{75}$**	0.27^{abc}	0.21^{ab}	0.07^{c}	0.08	*0.07^{cd}*	*0.07*	*0.07^{bc}*	0.85^{abc}	6.23^{a}	5.63	11.78	*7.85^{abcd}*	*1.20*	*3.34^{ab}*	**12.40**
T$_7$ **OM$_{1500}$N$_5$K$_{75}$**	0.26^{abc}	0.19^{bc}	0.14^{a}	0.10	*0.08^{b}*	*0.07*	*0.04^{e}*	0.70^{abc}	4.63^{abcd}	6.83	11.20	*8.88^{abc}*	*1.15*	*1.98^{d}*	**11.98**
T$_8$ **OM$_{2000}$K$_{75}$**	0.20^{cd}	0.14^{c}	0.12^{ab}	0.09	*0.08^{bc}*	*0.10*	*0.08^{ab}*	0.65^{bc}	3.83^{d}	7.55	9.43	*8.10^{abcd}*	*1.28*	*2.80^{abcd}*	**12.15**
T$_9$ **OM$_{500}$N$_{15}$K$_{75}$L$_{860}$**	0.29^{ab}	0.16^{bc}	0.09^{abc}	0.12	*0.10^{a}*	*0.07*	*0.06^{cd}*	0.95^{ab}	4.20^{bcd}	4.93	14.05	*10.20^{a}*	*0.93*	*2.35^{bcd}*	**13.48**
T$_{10}$ **OM$_{1000}$N$_{10}$K$_{75}$L$_{720}$**	0.27^{abc}	0.18^{bc}	0.07^{bc}	0.10	*0.08^{bcd}*	*0.07*	*0.08^{ab}*	0.95^{ab}	5.08^{abcd}	4.88	13.88	*9.08^{ab}*	*1.00*	*3.05^{abc}*	**13.10**
T$_{11}$ **OM$_{1500}$N$_5$K$_{75}$L$_{580}$**	0.32^{a}	0.17^{bc}	0.13^{a}	0.10	*0.07^{cd}*	*0.08*	*0.05^{de}*	0.90^{abc}	3.98^{cd}	7.18	9.98	*6.35^{d}*	*1.28*	*2.08^{cd}*	**9.73**
T$_{12}$ **OM$_{2000}$K$_{75}$L$_{440}$**	0.20^{cd}	0.19^{bc}	0.12^{abc}	0.08	*0.06^{cd}*	*0.09*	*0.06^{cd}*	0.58^{c}	4.55^{abcd}	7.08	7.78	*6.58^{cd}*	*1.23*	*2.38^{bcd}*	**10.13**

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The iron uptake was increased up to 80 DAS, and decreased at harvesting. At 40 DAS, maximum uptake was recorded with T_3 [R (P as OM)] and T_6 [$OM_{1000}N_{10}K_{75}$] which were on par with T_4 [R (P as OM)S_{56}] and T_8 [$OM_{2000}K_{75}$]. But at 80 DAS, higher uptake was recorded with T_6 [$OM_{1000}N_{10}K_{75}$] and the lowest with T_{12} [$OM_{2000}K_{75}L_{440}$]. Iron uptake by haulm and kernel were significantly different with treatments and it was not significant in shell. The maximum uptake was in haulm followed by kernel and the lowest was in shell. The total iron uptake during harvesting stage varied from 3.1 to 4.8 kg ha^{-1}.

4.6.8. Manganese

The plant Mn content and uptake at all stages were significantly different with treatments. The plant Mn concentration was the highest at 20 DAS and later on it decreased. At harvest stage, the content of Mn in haulm and shell were the highest in T_6 [$OM_{1000}N_{10}K_{75}$] and all levels of organic meal with lime (T_9 to T_{12}) recorded equal Mn content in haulm. The shell Mn concentration was higher compared to kernel concentration. In kernel, higher concentrations were recorded with higher levels of organic meal with lime (T_{11} [$OM_{1500}N_5K_{75}L_{580}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]) which were on par with T_8 [$OM_{2000}K_{75}$].

The uptake of Mn showed significant variation between treatments. The Mn uptake was increased upto 80 DAS. At 80 DAS, the highest uptake was recorded with T_1 [R(P as MP)] which was on par with T_6 [$OM_{1000}N_{10}K_{75}$]. The lowest uptake of Mn was recorded with T_{12} [$OM_{2000}K_{75}L_{440}$]. Higher Mn uptake by haulm, kernel and shell were recorded with T_6 [$OM_{1000}N_{10}K_{75}$]. The Mn uptake by haulm varied from 1.12-1.2 kg ha^{-1}. In shell, higher uptake was recorded with T_{11} [$OM_{1500}N_5K_{75}L_{580}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]. In kernel along with T_6 [$OM_{1000}N_{10}K_{75}$], T_4 [R (P as OM)S_{56}] recorded higher uptakes.

4.6.9. Copper

The treatments had no significant effect on Cu content in plant during any of the growth stages. At harvest significant difference was noticed only in shell. The Cu concentration was high at 20-40 DAS and decreased at 60 DAS and again it increased towards maturity. The copper concentrations in haulm, kernel and shell varied from 51-59 ppm, 43-64 ppm and 46-64 ppm respectively.

Table : 33 Effect of treatments on iron concentration and uptake at various stages.

Treatment		**Iron concentration** (ppm)							**Iron uptake** (g ha^{-1})							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	1116^{e}	334^{d}	488	452^{bcde}	*226^{abc}*	*667^{bc}*	*97*	425	797^{c}	2965^{a}	4675^{bcd}	*2695^{ab}*	*333*	*760^{e}*	**3788**
T_2	R (P as SSP)	1282^{cde}	358^{cd}	332	447^{bcde}	*227^{abc}*	*693^{abc}*	*87*	432	943^{bc}	1821^{cd}	5345^{bc}	*2293^{ab}*	*332*	*964^{cde}*	**3589**
T_3	R (P as OM)	1502^{abcd}	389^{abcd}	408	446^{bcde}	*228^{abc}*	*825^{abc}*	*94*	451	1434^{a}	2488^{abc}	5537^{bc}	*2268^{ab}*	*406*	*1248^{bcd}*	**3921**
T_4	R (P as OM) S_{56}	1689^{a}	490^{a}	347	412^{de}	*198^{abc}*	*949^{a}*	*97*	489	1260^{ab}	2188^{bcd}	5085^{bcd}	*2138^{ab}*	*468*	*1853^{a}*	**4459**
T_5	$OM_{500}N_{15}K_{75}$	1504^{abcd}	365^{cd}	378	495^{abcd}	*234^{ab}*	*664^{bc}*	*92*	559	958^{bc}	2276^{abcd}	6159^{b}	*2507^{ab}*	*348*	*915^{cde}*	**3769**
T_6	$OM_{1000}N_{10}K_{75}$	1343^{bcde}	478^{ab}	355	567^{a}	*259^{a}*	*805^{abc}*	*84*	429	1430^{a}	2765^{ab}	8205^{a}	*3024^{a}*	*419*	*1388^{b}*	**4831**
T_7	$OM_{1500}N_5K_{75}$	1518^{abcd}	373^{bcd}	339	534^{ab}	*187^{bc}*	*774^{abc}*	*102*	405	923^{bc}	1557^{d}	5985^{b}	*2042^{ab}*	*462*	*1239^{bcd}*	**3744**
T_8	$OM_{2000}K_{75}$	1635^{ab}	447^{abc}	386	479^{bcde}	*183^{bc}*	*847^{a}*	*83*	546	1256^{ab}	2317^{abcd}	5097^{bcd}	*1918^{b}*	*284*	*1140^{bcde}*	**3341**
T_9	$OM_{500}N_{15}K_{75}L_{860}$	1607^{abc}	390^{abcd}	371	510^{abc}	*186^{bc}*	*743^{abc}*	*92*	514	1037^{bc}	2123^{bcd}	5878^{bc}	*1941^{ab}*	*351*	*953^{cde}*	**3245**
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	1358^{abcde}	373^{cd}	388	524^{ab}	*166^{c}*	*609^{c}*	*80*	483	1046^{bc}	2562^{abc}	5397^{bc}	*1967^{ab}*	*312*	*857^{de}*	**3136**
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	1474^{abcd}	401^{abcd}	327	424^{cde}	*177^{bc}*	*812^{abc}*	*93*	422	965^{bc}	1847^{cd}	4259^{cd}	*1672^{b}*	*366*	*1217^{bcd}*	**3256**
T_{12}	$OM_{2000}K_{75}L_{440}$	1232^{de}	399^{abcd}	308	404^{e}	*189^{bc}*	*903^{ab}*	*104*	358	990^{bc}	1802^{cd}	3713^{d}	*1849^{b}*	*402*	*1285^{bc}*	**3536**

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Table : 34 Effect of treatments on manganese concentration and uptake at various stages.

Treatment		**Manganese concentration** (ppm)							**Manganese uptake** (g ha^{-1})							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	518^{c}	355^{b}	178^{g}	250^{a}	*134^{def}*	*70^{h}*	*35^{bc}*	197^{ab}	848^{cde}	1081^{cdef}	2589^{a}	*1599^{b}*	*120^{bc}*	*80^{f}*	**1799^{b}**
T_2	R (P as SSP)	425^{f}	311^{e}	166^{h}	179^{c}	*148^{bc}*	*85^{g}*	*40^{ab}*	153^{bcd}	831^{cde}	918^{f}	2179^{abcd}	*1471^{bc}*	*152^{ab}*	*121^{def}*	**1744^{b}**
T_3	R (P as OM)	673^{a}	336^{c}	210^{ef}	194^{b}	*155^{b}*	*121^{b}*	*35^{bc}*	207^{a}	1236^{a}	1288^{bcde}	2298^{abc}	*1518^{bc}*	*150^{abc}*	*183^{bc}*	**1851^{b}**
T_4	R (P as OM) S_{56}	480^{d}	380^{a}	160^{h}	145^{e}	*136de*	*119^{b}*	*30^{cd}*	138^{cd}	973^{bc}	999^{def}	1829^{cde}	*1454^{bc}*	*146^{abc}*	*235^{a}*	**1835^{b}**
T_5	$OM_{500}N_{15}K_{75}$	453^{e}	324^{d}	214^{ef}	138^{e}	*140^{cd}*	*100de*	*35^{bc}*	164^{abc}	852^{cde}	1288^{bcde}	1696de	*1500^{bc}*	*130^{abc}*	*136de*	**1766^{b}**
T_6	$OM_{1000}N_{10}K_{75}$	389^{g}	359^{b}	149^{i}	169^{c}	*170^{a}*	*135^{a}*	*35^{bc}*	125^{cd}	1069^{ab}	1194^{bcdef}	2446^{ab}	*1980^{a}*	*175^{a}*	*232^{a}*	**2387^{a}**
T_7	$OM_{1500}N_5K_{75}$	605^{b}	285^{f}	220de	156^{d}	*135^{def}*	*124^{b}*	*26^{d}*	164^{abc}	710^{e}	976^{ef}	1747de	*1471^{bc}*	*115^{bc}*	*197^{ab}*	**1783^{b}**
T_8	$OM_{2000}K_{75}$	478^{d}	360^{b}	300^{a}	191^{b}	*130^{def}*	*93^{f}*	*40^{ab}*	158^{abc}	1011^{bc}	1793^{a}	2040^{bcde}	*1361^{bc}*	*136^{abc}*	*115^{def}*	**1613^{b}**
T_9	$OM_{500}N_{15}K_{75}L_{860}$	465de	381^{a}	264^{b}	190^{b}	*126^{f}*	*110^{c}*	*26^{d}*	149^{bcd}	1006^{bc}	1501^{ab}	2197^{abcd}	*1282^{bc}*	*99^{c}*	*145^{cde}*	**1526^{b}**
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	410^{f}	275^{f}	205^{f}	170^{c}	*125^{f}*	*74^{h}*	*39^{b}*	148^{bcd}	749de	1332^{bcd}	1758de	*1485^{bc}*	*150^{abc}*	*104^{ef}*	**1738^{b}**
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	358^{h}	355^{b}	246^{c}	190^{b}	*125^{f}*	*95^{ef}*	*45^{a}*	103^{d}	858^{cde}	1400^{bc}	1897^{cde}	*1185^{c}*	*180^{a}*	*150 cde*	**1514^{b}**
T_{12}	$OM_{2000}K_{75}L_{440}$	356^{h}	386^{a}	229^{d}	175^{c}	*125^{f}*	*106^{cd}*	*45^{a}*	103^{d}	943^{bcd}	1349^{bc}	1607^{e}	*1276^{bc}*	*172^{a}*	*153^{bcd}*	**1600^{b}**

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The Cu uptake was significant at 40 and 80 DAS. At 80 DAS, higher uptake was recorded by T_4 [R (P as OM)S_{56}] and at harvest, it was taken over by T_6 [$OM_{1000}N_{10}K_{75}$]. At harvest stage the uptake ranged from 801-1028 g ha^{-1}. In shells higher uptakes were recorded with T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$]. There were no significant differences in Cu accumulation in haulm and kernel.

4.6.10. Zinc

The plant zinc concentration was higher up to 40 DAS and near constant during 60-80 DAS. The plant Zn concentration was significant at 40 DAS only. The zinc concentration was more in kernel compared to shell and haulm. In haulm the Zn concentration varied from 26-30 ppm. In kernel and shell, it varied from 53-76 and 20-26 ppm respectively.

Zn uptake followed the same pattern as Ca and Fe. The uptake was higher at 80 DAS and decreased at harvest stage. The uptake was significant at 40 and 80 DAS. At 80 DAS, higher uptakes were recorded with T_3 [R (P as OM)], T_4 [R (P as OM) S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$]. At harvesting stage, the uptake varied from 238-345 g ha^{-1} and uptake by haulm continued to be more. However, the highest uptake at harvesting stage was recorded by T_6 [$OM_{1000}N_{10}K_{75}$].

4.6.11. Relationship between nutrient concentration at different stages and yields of groundnut

The correlation coefficient between primary, secondary and, micro nutrients with yields of crop are given in Table 37 a, b and c.

From 40 DAS, N concentration was positively correlated with haulm yield and negatively with other economic yields except protein yield at. 60 DAS. But plant P concentrations at 60 DAS was positively correlated with haulm yield and negatively with economic yields like pod, kernel, oil and protein yields. But at 80 DAS, all the yield parameters were negatively correlated with plant P content.

Plant K content up to 60 DAS was positively correlated with haulm yield. But, negative correlation was noticed at 80 DAS. Similarly in reverse order, up to 60 DAS, plant K content was negatively correlated with economic yields.

Table : 35 Effect of treatments on copper concentration and uptake at various stages.

Treatment		Copper concentration (ppm)							Copper uptake (g ha^{-1})							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	45	56	31	49	*59*	*60^{a}*	*56*	17	132^{bc}	187	502^{bc}	*704*	*189*	*69^{bc}*	**962**
T_2	R (P as SSP)	64	51	30	46	*57*	*59^{a}*	*43*	22	136^{abc}	165	550^{abc}	*567*	*165*	*84^{abc}*	**816**
T_3	R (P as OM)	51	49	31	47	*53*	*53^{ab}*	*56*	15	176^{a}	188	547^{abc}	*523*	*243*	*79^{abc}*	**845**
T_4	R (P as OM) S_{56}	57	47	28	55	*54*	*53^{ab}*	*48*	16	121^{c}	173	675^{a}	*572*	*230*	*104^{a}*	**906**
T_5	$OM_{500}N_{15}K_{75}$	56	51	27	48	*53*	*57^{a}*	*64*	20	135^{abc}	162	580^{abc}	*573*	*245*	*78^{abcc}*	**893**
T_6	$OM_{1000}N_{10}K_{75}$	55	56	29	45	*59*	*60^{a}*	*49*	17	168^{ab}	231	643^{ab}	*681*	*244*	*103^{a}*	**1028**
T_7	$OM_{1500}N_5K_{75}$	54	48	33	41	*50*	*57^{ab}*	*53*	15	119^{c}	152	457^{c}	*535*	*235*	*91^{ab}*	**861**
T_8	$OM_{2000}K_{75}$	62	56	29	46	*53*	*54^{ab}*	*53*	21	157^{abc}	172	489^{bc}	*561*	*178*	*66^{bc}*	**806**
T_9	$OM_{500}N_{15}K_{75}L_{860}$	55	58	29	48	*53*	*46^{b}*	*52*	17	153^{abc}	167	515^{bc}	*538*	*203*	*61^{c}*	**801**
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	49	52	31	46	*57*	*64^{a}*	*50*	18	139^{abc}	201	474^{c}	*664*	*190*	*89^{ab}*	**943**
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	60	51	34	45	*51*	*62^{a}*	*57*	17	122^{c}	191	447^{c}	*481*	*230*	*95^{ab}*	**806**
T_{12}	$OM_{2000}K_{75}L_{440}$	59	52	31	49	*58*	*56^{ab}*	*50*	17	128^{bc}	183	447^{c}	*583*	*187*	*80^{abc}*	**850**

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- **O**rganic Meal, N-Nitrogen, **P**- Phosphorus, **K**- Potassium, S-Sulphur and **L**-Lime)

Table : 36 Effect of treatments on zinc concentration and uptake at various stages.

Treatment		**Zinc concentration** (ppm)							**Zinc uptake** (g ha^{-1})							
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest			
						Haulm	*Shell*	*Kernel*					*Haulm*	*Shell*	*Kernel*	**Total**
T_1	R (P as MP)	110	110^{b}	55	48	*26*	*20*	*68*	42	262^{c}	333	495^{abc}	*314*	*230*	*23*	**567**
T_2	R (P as SSP)	138	108^{b}	40	40	*33*	*25*	*59*	52	214^{c}	222	486^{abc}	*323*	*225*	*35*	**583**
T_3	R (P as OM)	118	108^{b}	38	55	*33*	*21*	*53*	35	376^{ab}	231	637^{a}	*316*	*222*	*32*	**570**
T_4	R (P as OM) S_{56}	143	110^{b}	40	50	*29*	*24*	*55*	42	282^{bc}	250	629^{a}	*307*	*269*	*47*	**623**
T_5	$OM_{500}N_{15}K_{75}$	120	160^{a}	55	50	*28*	*20*	*76*	40	422^{a}	331	609^{ab}	*302*	*292*	*27*	**621**
T_6	$OM_{1000}N_{10}K_{75}$	123	108^{b}	50	45	*30*	*26*	*60*	39	322^{abc}	393	633^{a}	*352*	*300*	*45*	**697**
T_7	$OM_{1500}N_5K_{75}$	128	88^{b}	51	40	*28*	*24*	*56*	35	216^{c}	255	436^{bc}	*308*	*250*	*38*	**596**
T_8	$OM_{2000}K_{75}$	130	98^{b}	63	48	*29*	*24*	*60*	44	270^{bc}	373	512^{abc}	*298*	*208*	*30*	**536**
T_9	$OM_{500}N_{15}K_{75}L_{860}$	128	123^{b}	66	45	*29*	*21*	*61*	42	323^{abc}	381	517^{abc}	*297*	*230*	*28*	**555**
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	105	113^{b}	43	50	*30*	*20*	*59*	38	305^{bc}	280	515^{abc}	*353*	*226*	*28*	**607**
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	115	105^{b}	53	35	*30*	*26*	*54*	33	252^{c}	304	353^{c}	*285*	*218*	*39*	**542**
T_{12}	$OM_{2000}K_{75}L_{440}$	115	119^{b}	58	50	*33*	*24*	*61*	33	292^{bc}	331	458^{abc}	*324*	*228*	*34*	**586**

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime)

The plant Ca concentration from 40 DAS onwards, was negatively correlated with all yield parameters. Mg content was negatively correlated with yield parameters at 80 DAS. Only at 60 DAS, Mg concentration was positively correlated with haulm yield.

However, at all stages of crop growth, S content had positive correlation with haulm, pod and kernel yield. But the oil and protein yields were negatively correlated with S concentrations at 60 DAS, even though later on there was a positive correlation towards oil yield.

Up to 40 DAS, Fe content was negatively correlated with haulm yield and after that it was positively correlated. The Fe content towards the later stages had the positive correlation with all the yield aspects. After 60 DAS, Mn concentration was negatively correlated with economic yields.

At 40 and 60 DAS, Cu concentration was negatively correlated with haulm and economic yields of groundnut. But at 80 DAS, haulm and oil yield was negatively correlated. At 40 DAS, Zn was positively correlated with haulm and economic yields. But at 60 DAS, haulm yield and at 80 DAS, protein yield were postively correlated.

4.6.12. Nutrient uptake by 1000 kg haulm

The estimations of the nutrient removal in a specific management system are important to design the uptake pattern and to improve the yield further more. The nutrient contents in 1000 kg haulm and 1000 kg pod are presented in Table 38 to 39. In the experiment, the average uptake of nutrients by 1000 kg haulm were 13.66-17.20 kg N, 1.19-1.72 kg P and 12.24-14.26 kg K. Relatively higher N, P uptake was recorded with T_2 [R(P as SSP)]. Lime and organic meal applied plots also had shown relatively higher uptake of N and P in 1000 kg haulm. It was noticed that relatively higher K was taken by plants in T_1 [R (P as MP)] and T_2 [R(P as SSP)] for the production of unit quantity of haulm.

Lime treated plots were recorded relatively higher uptake of Ca. Higher doses of organic meal without lime (T_7 [$OM_{1500}N_5K_{75}$] and T_8 [$OM_{2000}K_{75}$]) and all levels of organic meal with lime (T_9 [$OM_{500}N_{15}K_{75}L_{860}$] to T_{12} [$OM_{2000}K_{75}L_{440}$]) influenced the iron uptake and resulted with relatively lower uptake by unit quantity of haulm. In a similar fashion, reduction in Mn uptake was noticed with graded

Table: 37 a. Correlation between primary nutrient concentrations in the plant at various stages and yield of the groundnut.

Factors	Nitrogen concentration (%)				Phosphorus concentration (%)				Potassium concentration (%)			
	20 DAS	40 DAS	60 DAS	80 DAS	20 DAS	40 DAS	60 DAS	80 DAS	20 DAS	40 DAS	60 DAS	80 DAS
Haulm yield	-0.029	0.074	0.088	0.191	-0.263	-0.090	0.053	-0.190	0.228	0.218	0.335	-0.206
Pod yield	0.273	-0.229	-0.132	-0.192	0.228	0.055	-0.257	-0.059	-0.090	-0.382	-0.263	0.122
Kernel yield	0.224	-0.233	-0.033	-0.176	0.169	0.095	-0.291	-0.049	-0.047	-0.368	-0.239	0.142
Oil yield	0.222	-0.297	-0.173	-0.217	0.225	0.058	-0.273	-0.022	-0.128	-0.436	-0.268	0.071
Protein yield	0.066	-0.071	0.011	-0.247	-0.157	-0.138	-0.315	-0.143	-0.086	-0.416	-0.197	0.228

Table: 37 b. Correlation between secondary nutrient concentrations in the plant at various stages and yield of the groundnut.

Factors	Calcium concentration (%)				Magnesium concentration (%)				Sulphur concentration (%)			
	20 DAS	40 DAS	60 DAS	80 DAS	20 DAS	40 DAS	60 DAS	80 DAS	20 DAS	40 DAS	60 DAS	80 DAS
Haulm yield	-0.090	-0.060	-0.065	-0.044	0.020	-0.101	0.198	-0.084	0.093	0.198	0.186	0.140
Pod yield	0.059	-0.251	-0.365	-0.313	0.029	0.025	-0.263	-0.335	0.057	0.032	0.018	0.087
Kernel yield	0.008	-0.277	-0.375	-0.283	0.019	0.024	-0.258	-0.342	0.064	0.025	0.005	0.101
Oil yield	0.039	-0.216	-0.344	-0.281	0.055	-0.046	-0.239	-0.360	0.061	0.044	-0.008	0.054
Protein yield	0.055	-0.429	-0.519	-0.504	-0.253	0.133	-0.312	-0.395	-0.095	-0.037	-0.035	-0.019

Table: 37 c. Correlation between micro nutrient concentrations in the plant at various stages and yield of the groundnut.

Factors	Iron concentration (ppm)				Manganese concentration (ppm)			
	20 DAS	40 DAS	60 DAS	80 DAS	20 DAS	40 DAS	60 DAS	80 DAS
Haulm yield	-0.148	-0.207	0.291	0.242	0.011	-0.039	-0.178	0.084
Pod yield	0.125	0.253	-0.117	0.182	0.107	-0.036	-0.365	-0.388
Kernel yield	0.006	0.223	-0.023	0.206	0.074	0.005	-0.383	-0.318
Oil yield	0.091	0.156	-0.052	0.222	0.234	-0.107	-0.335	-0.359
Protein yield	0.152	0.287	0.110	0.307	0.264	0.046	-0.429	-0.295

Factors	Copper concentration (ppm)				Zinc concentration (ppm)			
	20 DAS	40 DAS	60 DAS	80 DAS	20 DAS	40 DAS	60 DAS	80 DAS
Haulm yield	-0.024	-0.163	-0.005	-0.091	0.064	0.064	0.265	-0.007
Pod yield	0.103	-0.211	-0.200	0.023	0.053	0.029	-0.162	-0.067
Kernel yield	0.187	-0.218	-0.181	0.058	0.073	0.069	-0.090	-0.054
Oil yield	0.061	-0.261	-0.143	-0.004	0.053	0.018	-0.140	-0.118
Protein yield	-0.104	-0.016	-0.284	0.182	-0.006	0.073	-0.091	0.030

level of organic meal with lime treatments (T_9 [$OM_{500}N_{15}K_{75}L_{860}$] to T_{12} [$OM_{2000}K_{75}L_{440}$]). The Mg, S, Zn and Cu uptake pattern by haulm was not much affected by treatments.

4.6.12. Nutrient uptake by 1000 kg pods

The N, P and K consumption by 1000 kg pods varied from 37.15-42.45, 3.19-3.86 and 5.49-6.46 kg respectively. Lower uptake of P in unit quantity of pods were recorded with T_1 [R(P as MP)].

Graded level of organic meal with lime (T_9 [$OM_{500}N_{15}K_{75}L_{860}$] to T_{12} [$OM_{2000}K_{75}L_{440}$]) recorded concomitant uptake of P and K. As similar in haulm, relatively higher uptake of Ca was realized with lime applied treatments. The uptake of Ca, Mg and S varied as 0.97-1.58, 2.09-2.42 and 0.5-0.88 kg respectively by 1000 kg pods. The treatments had not much influence in the uptake of secondary and micronutrients in the unit quantity of pods.

4.6.13. Nutrient use efficiency in terms of oil and protein production

The data on nutrient use efficiency in terms of oil and protein production are presented in Table 39.

4.6.13.1. Oil production

Higher N use efficiency (107-111 per cent) in oil production was recorded with T_7 [$OM_{1500}N_5K_{75}$] which was followed by T_6 [$OM_{1000}N_{10}K_{75}$] and T_4 [R (P as OM)S_{56}]. The lower N use efficiencies were recorded with T_8 [$OM_{2000}K_{75}$] and T_1 [R (P as MP)] (75-77 per cent)

The highest P use efficiency in oil production was achieved with T_3 [R (P as OM)] and T_4 [R (P as OM) S_{56}] and the lowest with T_8 [$OM_{2000}K_{75}$] and T_{12} [$OM_{2000}K_{75}L_{440}$].

The higher K use efficiencies in oil production were recorded with T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] and the lowest with T_8 [$OM_{2000}K_{75}$] (17.35 per cent). T_5 [$OM_{500}N_{15}K_{75}$] and T_6 [$OM_{1000}N_{10}K_{75}$] recorded the highest Ca use efficiency in oil production (11-17 per cent) and the lowest (1.85 per cent) was with T1 [R(P as MP)].

Table : 38 a. Effect of treatments on nutrient uptake for the production of 1000 kg haulms in groundnut.

Treatment		Nutrient uptake									
		N (kg)	P (kg)	K (kg)	Ca (kg)	Mg (kg)	S (kg)	Fe (g)	Mn (g)	Cu (g)	Zn (g)
T_1	R (P as MP)	13.66	1.40	14.26	8.79	2.70	0.65	226	134	59	26
T_2	R (P as SSP)	17.20	1.71	15.23	9.72	2.86	0.61	231	148	57	33
T_3	R (P as OM)	13.86	1.23	12.75	11.13	2.65	0.80	231	155	53	32
T_4	R (P as OM) S_{56}	14.37	1.19	12.52	8.25	2.70	0.74	200	136	54	29
T_5	$OM_{500}N_{15}K_{75}$	14.73	1.39	13.28	7.95	2.65	0.70	233	140	53	28
T_6	$OM_{1000}N_{10}K_{75}$	13.46	1.45	12.24	7.71	2.55	0.67	259	170	58	30
T_7	$OM_{1500}N_5K_{75}$	14.46	1.36	12.70	7.41	2.65	0.83	190	137	50	29
T_8	$OM_{2000}K_{75}$	13.84	1.51	13.92	7.70	2.64	0.78	184	131	54	29
T_9	$OM_{500}N_{15}K_{75}L_{860}$	14.62	1.33	13.29	8.04	2.69	1.01	191	126	53	29
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	15.85	1.70	13.37	7.40	2.63	0.77	166	125	56	30
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	14.28	1.56	12.26	8.25	2.80	0.67	176	125	51	30
T_{12}	$OM_{2000}K_{75}L_{440}$	15.74	1.72	13.30	8.20	2.88	0.64	180	125	57	32

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock **P**hosphate, **SSP**- Single Super Phosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- Phosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime)

Table : 38 b. Effect of treatments on nutrient uptake for the production of 1000 kg pods in groundnut.

	Treatment	Nutrient uptake									
		N (kg)	P (kg)	K (kg)	Ca (kg)	Mg (kg)	S (kg)	Fe (g)	Mn (g)	Cu (g)	Zn (g)
T_1	**R** (P as MP)	42.14	3.19	5.60	1.02	2.24	0.76	239	44	57	55
T_2	**R** (P as SSP)	41.90	3.59	6.46	1.19	2.24	0.86	249	52	48	50
T_3	**R** (P as OM)	41.89	3.67	5.74	1.22	2.39	0.81	287	58	56	44
T_4	**R** (P as OM) S_{56}	41.64	3.42	5.39	1.02	2.09	0.75	342	56	49	47
T_5	$OM_{500}N_{15}K_{75}$	39.84	3.24	6.05	0.97	2.43	0.84	249	53	64	63
T_6	$OM_{1000}N_{10}K_{75}$	42.45	3.73	5.73	0.98	2.42	0.68	269	61	52	51
T_7	$OM_{1500}N_5K_{75}$	37.15	3.41	5.49	0.97	2.24	0.50	261	48	50	44
T_8	$OM_{2000}K_{75}$	40.53	3.86	5.96	1.02	2.17	0.88	307	54	53	51
T_9	$OM_{500}N_{15}K_{75}L_{860}$	40.85	3.66	6.34	1.16	2.35	0.64	256	48	52	51
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	37.00	3.60	6.14	1.29	2.29	0.77	223	48	53	48
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	40.39	3.71	6.23	1.47	2.33	0.61	287	60	59	60
T_{12}	$OM_{2000}K_{75}L_{440}$	38.31	3.62	5.85	1.58	2.37	0.69	322	62	51	62

(**R**- Package of Practices Recommendations of KAU, **MP**- **Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime)

The higher S use efficiencies in oil production (854-975 per cent) were recorded with T_3 [R(P as OM)] and T_5 [$OM_{500}N_{15}K_{75}$], T_2 [R(P as SSP)], T_4 [R (P as OM)S_{56}] and T_1 [R(P as MP)] were showing the lowest S use efficiency.

4.6.13.2. Protein production

The highest N use efficiency (73-75 per cent) in terms of protein production was recorded with T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$] whereas the lowest (46 per cent) was with T_{12} [$OM_{2000}K_{75}L_{440}$].

T_4 [R (P as OM)S_{56}] recorded the highest P use efficiency (18 per cent) in protein production and T_{12} [$OM_{2000}K_{75}L_{440}$] as well as T_8 [$OM_{2000}K_{75}$] (3.1-3.3 per cent) recorded lowest P use efficiency in protein production.

T_6 [$OM_{1000}N_{10}K_{75}$] recorded the highest K use efficiency (18.14 per cent) and T_{12} [$OM_{2000}K_{75}L_{440}$] recorded the lowest (10.6 per cent) in terms of protein production.

With regard to Ca use efficiency in terms of protein production, the maximum efficiency was with T_5 [$OM_{500}N_{15}K_{75}$] (10 per cent) and minimum efficiency with T_1 [R (P as MP)] (1.18 per cent).

In protein production, the highest S use efficiency was recorded with T_3 [R(P as OM)] (632 per cent) and the lowest with T_2 [R(P as SSP)] (20 per cent).

4.7. Soil chemical analysis

The data on pH, EC, organic carbon and available nutrients are presented in Table 40-42.

4.7.1. Soil reaction and Electrical conductivity

The soil pH varied from 5.44 to 5.66 before cropping and after cropping it varied from 5.21 to 5.70. The treatments did not cause significant changes in soil pH. However, groundnut cropping resulted with a drop in soil pH and EC. After the crop, the EC varied from from 0.34 to 0.49 dSm^{-1}.

4.7.2. Organic carbon

The organic carbon content of 15 cm top soil varied from 1.04 to 1.31 per cent before cropping and 0.87 to 1.06 after cropping. Groundnut cropping in

Table : 39 Effect of treatments on nutrient use efficiency in terms of oil and protein production in groundnut.

Treatment		Nutrient use efficiency - Oil					Nutrient Use Efficiency - Protein				
		N	P_2O_5	K_2O	Ca	S	N	P_2O_5	K_2O	Ca	S
T_1	R (P as MP)	77.71	18.73	18.28	1.85	91.43	49.50	11.93	11.65	1.18	58.24
T_2	R (P as SSP)	82.34	19.84	19.37	2.04	29.40	56.03	13.50	13.18	1.39	20.01
T_3	R (P as OM)	97.48	25.99	24.99	2.40	974.80	63.22	16.86	16.21	1.55	632.10
T_4	R (P as OM) S_{56}	105.83	25.50	24.90	2.68	36.49	75.28	18.14	17.72	1.91	25.96
T_5	$OM_{500}N_{15}K_{75}$	85.43	22.78	21.90	17.08	854.30	50.49	13.47	12.95	10.10	504.90
T_6	$OM_{1000}N_{10}K_{75}$	106.53	14.20	26.30	10.66	532.60	73.47	9.79	18.14	7.35	367.30
T_7	$OM_{1500}N_5K_{75}$	110.61	9.83	26.33	7.37	368.70	64.68	5.75	15.40	4.31	215.60
T_8	$OM_{2000}K_{75}$	75.45	5.03	17.35	3.77	188.60	49.24	3.29	11.32	2.46	123.10
T_9	$OM_{500}N_{15}K_{75}L_{860}$	81.40	21.70	20.87	2.28	814.00	56.94	15.19	14.60	1.59	569.40
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	84.18	11.20	20.78	2.36	420.90	48.99	6.53	12.10	1.37	244.90
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	86.23	7.67	20.53	2.42	287.40	48.97	4.35	11.66	1.37	163.20
T_{12}	$OM_{2000}K_{75}L_{440}$	85.15	5.68	19.58	2.39	212.90	46.09	3.07	10.60	1.29	115.20

(R- Package of Practices Recommendations of KAU, MP- Mussoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime) general resulted with depletion of 0.3 per cent organic carbon in soil. The organic carbon content after the crop was significantly different with treatments and T_3 [R(P as OM)] recorded higher organic carbon content.

4.7.3. Soil nutrient contents.

Before the experiment, all the experimental plots were having similar nutrient status except in the case of available P and exchangeable K. After the experiment the available P, exchangeable Ca, $CaCl_2$ extractable S and available Fe showed significant difference due to various treatments.

There was a general decline in available N, P, K, Fe, Zn and Cu and exchangeable Mg and S. But there was an increase in exchangeable Ca in all the plots except the plots receiving graded levels of organic meal with lime application.

Addition of SSP (T_2) resulted with an increase in soil available S content after cropping. But addition of elemental S showed slight reduction in soil available S. In general, depletion of around 27 kg N, 149 kg K, 29 kg Mg and 5 kg S was noticed.

4.8. Rhizosphere microbial population

Soil microbial populations (cfu g^{-1}) of fungi, bacteria, actinomycetes and Rhizobium with their relative percentage increase/decrease are given in the Table 43 to 46.

4.8.1. Fungal population

The fungal population in rhizosphere varied widely during the crop growth period.

The population was higher at 20 DAS and decreased till harvest. The fungal population increased linearly and found to be in the range of 10.7×10^4 cfu g^{-1} of soil at harvest. There was a statistical difference among 60, 80 DAS and at harvest stage. The number was less at the time sowing with T_1 [R (P as MP)]. But in all other treatments, the number was high at harvest, when compared with sowing time. In the case of T_5 [$OM_{500}N_{15}K_{75}$], the fungal population at the time of harvest showed 17 per cent increase over initial population at the time of sowing.

Table : 40 Effect of treatments on soil pH , Electrical Conductivity and organic carbon before and after the groundnut crop.

Treatment		Soil pH		EC (d S m^{-1})		Organic carbon (%) [upto 15 cm depth]	
		Before	After	Before	After	Before	After
T_1	R (P as MP)	5.44	5.30	0.52	0.39	1.13	0.87 [bc]
T_2	R (P as SSP)	5.55	5.40	0.51	0.49	1.16	1.00 [abc]
T_3	R (P as OM)	5.66	5.70	0.60	0.43	1.17	1.15 [a]
T_4	R (P as OM) S_{56}	5.59	5.44	0.68	0.45	1.15	0.99 [abc]
T_5	$OM_{500}N_{15}K_{75}$	5.50	5.33	0.56	0.34	1.17	0.95 [abc]
T_6	$OM_{1000}N_{10}K_{75}$	5.66	5.38	0.54	0.37	1.31	1.04 [ab]
T_7	$OM_{1500}N_5K_{75}$	5.65	5.44	0.57	0.41	1.24	1.05 [ab]
T_8	$OM_{2000}K_{75}$	5.63	5.35	0.59	0.36	1.18	1.06 [ab]
T_9	$OM_{500}N_{15}K_{75}L_{860}$	5.66	5.21	0.58	0.34	1.04	0.84 [c]
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	5.61	5.41	0.45	0.36	1.15	0.88 [bc]
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	5.50	5.31	0.57	0.39	1.17	0.99 [abc]
T_{12}	$OM_{2000}K_{75}L_{440}$	5.53	5.45	0.55	0.36	1.16	0.95 [bc]

(**R**- Package of Practices Recommendations of KAU, **MP**- Musoorie rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, **N**-Nitrogen, **P**- Phosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime)

Table : 41. Effect on soil nutrient contents – Available nitrogen, phosphorus, exchangeable potassium, calcium and magnesium.

Treatment		Avaiable Nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Exchangeable potassium (kg ha^{-1})		Exchageable calcium (kg ha^{-1})		Exchangeable magnesium (kg ha^{-1})	
		Before	After	Before	After	Before	After	Before	After	Before	After
T_1	R (P as MP)	340.48	301.25	12.32 ^{bc}	6.86 ^{d}	458.00 ^{ab}	285.80	176.70	188.10 ^{ab}	188.20	163.00
T_2	R (P as SSP)	337.34	288.69	13.47 ^{abc}	10.32 ^{bcd}	420.23 ^{cd}	324.80	184.88	235.20 ^{a}	186.80	185.40
T_3	R (P as OM)	331.06	342.04	13.65 ^{abc}	10.62 ^{bcd}	423.48 ^{cd}	298.30	163.58	211.90 ^{ab}	191.00	164.40
T_4	R (P as OM) S_{56}	343.61	329.49	15.60 ^{a}	10.21 ^{bcd}	474.98 ^{a}	319.20	171.35	233.80 ^{a}	206.40	172.89
T_5	$OM_{500}N_{15}K_{75}$	348.32	299.68	12.83 ^{abc}	7.65 ^{d}	429.82 ^{bcd}	322.00	178.23	189.60 ^{a}	210.60	184.00
T_6	$OM_{1000}N_{10}K_{75}$	343.61	307.53	14.14 ^{ab}	13.52 ^{ab}	445.10 ^{abc}	280.00	180.55	200.80 ^{ab}	213.40	161.00
T_7	$OM_{1500}N_5K_{75}$	331.06	307.53	14.81 ^{ab}	11.76 ^{abc}	457.31 ^{ab}	293.90	172.35	180.60 ^{ab}	196.60	174.20
T_8	$OM_{2000}K_{75}$	351.46	307.53	11.29 ^{c}	15.31 ^{a}	472.67 ^{a}	288.35	173.85	207.20 ^{ab}	194.40	163.20
T_9	$OM_{500}N_{15}K_{75}L_{860}$	335.77	315.37	11.29 ^{ab}	6.89 ^{d}	460.78 ^{a}	252.00	185.70	160.80 ^{c}	191	172.20
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	334.20	310.66	13.6 ^{abc}	7.63 ^{d}	420.05 ^{cd}	294.00	183.70	179.20 ^{ab}	189.60	175.80
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	327.92	337.34	14.59 ^{ab}	8.98 ^{cd}	411.32 ^{d}	281.00	174.10	163.80 ^{bc}	192.40	165.00
T_{12}	$OM_{2000}K_{75}L_{440}$	340.48	283.99	14.29 ^{ab}	13.24 ^{ab}	420.21 ^{cd}	272.00	164.40	178.25 ^{ab}	200.80	161.00

(**R**- Package of Practices Recommendations of KAU, **MP**- Musoorie rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, **P**- Phosphorus, **K**- Potassium, **S**-Sulphur and **L**-Lime)

Table : 42. Effect of treatments on soil nutrient contents- $CaCl_2$ extractable sulphur, available iron, zinc and copper.

Treatment		$CaCl_2$ extractable Sulphur (kg ha^{-1})		Available iron (ppm)		Available zinc (ppm)		Available Copper (ppm)	
		Before	After	Before	After	Before	After	Before	After
T_1	R (P as MP)	31.75	32.88 ^{b}	354	346 ^{cd}	1.75	1.50	2.5	2.4
T_2	R (P as SSP)	33.64	36.93 ^{ab}	392	390 ^{abcd}	1.50	1.00	3.0	3.2
T_3	R (P as OM)	38.85	29.08 ^{bc}	422	441 ^{abc}	1.75	2.00	3.1	3.3
T_4	R (P as OM) S_{56}	33.94	32.56 ^{b}	410	398 ^{abcd}	2.00	1.75	3.1	2.9
T_5	$OM_{500}N_{15}K_{75}$	38.46	22.17 ^{c}	482	407 ^{abcd}	2.00	2.00	3.2	3.2
T_6	$OM_{1000}N_{10}K_{75}$	43.84	40.32 ^{a}	508	460 ^{ab}	2.25	1.50	3.0	3.4
T_7	$OM_{1500}N_5K_{75}$	36.32	32.20 ^{b}	447	390 ^{abcd}	2.00	2.00	3.3	3.2
T_8	$OM_{2000}K_{75}$	28.81	28.13 ^{bc}	424	463 ^{a}	2.25	2.00	2.9	2.7
T_9	$OM_{500}N_{15}K_{75}L_{860}$	30.90	29.05 ^{bc}	433	358 ^{bcd}	2.00	1.25	3.1	3.1
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	34.11	34.84 ^{ab}	387	310 ^{d}	1.75	1.25	3.1	2.2
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	40.80	33.20 ^{b}	397	321 ^{d}	2.00	1.50	3.1	2.3
T_{12}	$OM_{2000}K_{75}L_{440}$	28.30	27.18 ^{bc}	443	362 ^{abcd}	3.00	2.50	3.3	3.6

(**R**- package of practices Recommendations, **MP**- Musoorie rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, **N**-Nitrogen, **P**- Phosphorus, **K**-Potassium, **S**- Sulphur and **L**-Lime)

However, T_2 [R(P as SSP)] recorded the highest fungal population (170 per cent) among all the treatments at harvesting stage, over the initial population.

Among the different phosphorus source used, the fungal population was found to be maximum at harvest, when the crop was fertilized with SSP as P source.

The lime application resulted in an increased fungal population at the time of harvest except in the case of T1 [R (P as MP)]. However, the fungal population was maximum at the time of harvest, when 500 kg organic meal was applied and fungal population showed slight increase at the time of harvest in the case of T_5 [$OM_{500}N_{15}K_{75}$], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] when compared to initial population.

4.8.2. Bacterial population

The bacterial population differed significantly at all the stages of plant growth. In all the treatments, the bacterial population was more at the time of harvest when compared to the bacterial population at the time of sowing. At harvest, all the treatments significantly recorded higher bacterial population except T_6 [$OM_{1000}N_{10}K_{75}$].

Among P source level treatments, T_3 [R(P as OM)] and among graded level of organic meal treatments, T_5 [$OM_{500}N_{15}K_{75}$] recorded the maximum bacterial population at the time of harvest.

The bacterial population increased in all the treatments up to 20 DAS and decreased thereafter, till the harvest except in the case of T_3 [R (P as OM)] and T_7 [$OM_{1500}N_5K_{75}$]. The maximum bacterial population was noticed in the case of T_5 [$OM_{500}N_{15}K_{75}$] at harvest.

4.8.3. Actinomycetes population

The actinomycetes population in rhizosphere significantly differed with treatment in all the stages of crop growth except 20 and 60 DAS. The awctinomycetes population was higher in most of the stages and also at harvest than the population at sowing.

However, T1 [R(P as MP)] recorded the lowest actinomycetes population at the time of harvest among different P sources added.

Table : 43 Effect of treatments on rhizosphere fungal population.

Treatment		Soil fungi (x 10 [4] cfu g^{-1})					
		Sowing	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	15.00	58.67 (414)*	16.00 (113)	9.00 [bc] (61)	9.33 [c] (63)	10.67 [b] (73)
T_2	R (P as SSP)	9.00	42.33 (556)	15.33 (207)	8.33 [bc] (108)	12.33 [bc] (153)	18.00 [a] (270)
T_3	R (P as OM)	15.67	52.00 (319)	15.00 (109)	7.67 [c] (59)	13.00 [bc] (80)	15.00 [ab] (125)
T_5	$OM_{500}N_{15}K_{75}$	15.33	89.00 (549)	15.33 (101)	10.67 [bc] (72)	14.33 [ab] (90)	15.00 [ab] (112)
T_6	$OM_{1000}N_{10}K_{75}$	11.00	33.67 (292)	17.00 (170)	16.33 [a] (158)	16.33 [ab] (152)	12.33 [b] (117)
T_7	$OM_{1500}N_5K_{75}$	7.67	73.67 (951)	15.33 (203)	14.00 [ab] (186)	18.33 [a] (244)	14.33 [ab] (186)

(R- Package of Practices Recommendations of KAU, MP- Musoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime) * figure in brackets denotes percentage increase.

Table : 44 Effect of treatments on rhizosphere bacterial population.

Treatment		Soil bacteria (x 10^6 cfu g^{-1})					
		Sowing	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	9.00 [b]	42.67 [a] (487)*	23.00 [ab] (271)	4.67 [b] (53)	12.00 [ab] (136)	25.33 [ab] (308)
T_2	R (P as SSP)	13.00 [ab]	29.33 [ab] (301)	29.00 [a] (300)	6.00 [ab] (61)	12.33 [ab] (135)	28.00 [a] (281)
T_3	R (P as OM)	12.67 [b]	21.00 [b] (201)	18.33 [b] (164)	4.67 [b] (45)	13.33 [ab] (137)	30.67 [a] (289)
T_5	$OM_{500}N_{15}K_{75}$	20.67 [a]	41.33 [a] (214)	21.00 [ab] (104)	5.67 [ab] (28)	10.00 [b] (48)	32.00 [a] (157)
T_6	$OM_{1000}N_{10}K_{75}$	12.33 [b]	18.00 [b] (156)	15.67 [b] (134)	6.67 [a] (59)	11.00 [b] (93)	17.33 [b] (153)
T_7	$OM_{1500}N_5K_{75}$	14.00 [ab]	14.33 [b] (113)	21.33 [ab] (172)	6.67 [a] (49)	16.00 [a] (113)	24.00 [ab] (191)

(R- Package of Practices Recommendations of KAU, MP- Musoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime) * figure in brackets denotes percentage increase.

Among the graded levels of organic meal applied, T_5 [$OM_{500}N_{15}K_{75}$] recorded maximum population of actinomycetes.

In general, actinomycetes population at the time of harvest varied from 20-27 x 10^6 cfu g^{-1} of soil and T_2 [R(P as SSP)], T_3 [R(P as OM)] and T_5 [$OM_{500}N_{15}K_{75}$] registered higher population of actinomycetes.

4.8.4. Rhizobial population

The rhizobial population was higher at the time of harvest than the population at the time of sowing. The population varied from 4.0 to 7.7 x 10^6 cfu g^{-1} of soil.

The rhizobial population increased at 20 DAS and decreased at 40 DAS. The population was relatively stable up to 60 DAS and decreased at 80 DAS. However, in general the rhizobial population in soil was high in soil up to 60 DAS.

Among the P source level treatments, T_2 [R(P as SSP)] recorded higher rhizobial population in soil. Among the graded level of organic meal applied treatments, T_5 [$OM_{500}N_{15}K_{75}$] and T_6 [$OM_{1000}N_{10}K_{75}$] recorded higher but on par rhizobial population. However, T_7 [$OM_{1500}N_5K_{75}$] recorded 58 per cent increase over initial population and was on par with T_5 [$OM_{500}N_{15}K_{75}$] and T_6 [$OM_{1000}N_{10}K_{75}$] at harvest.

In general, the rhizobial population increased at the time of harvest and recorded higher population with T_2 [R(P as SSP)] and T_3 [R(P as OM)].

Among all treatments, T_2 [R(P as SSP)] recorded higher fungi, bacteria, actinomycetes and rhizobial population in rhizosphere soil.

4.9. Economics of groundnut production

The economic aspects of crop production is given in Table 47, which is important for the selection of suitable management practices. The amount spent on manures and fertilizers (variable cost) was high with T_1 [R (P as MP)] and T_2 [R (P as SSP)] which received inorganic P fertilizers. Relatively lower variable costs were incurred for T_5 [$OM_{500}N_{15}K_{75}$], T_6 [$OM_{1000}N_{10}K_{75}$], T_7 [$OM_{1500}N_5K_{75}$] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$] which received primarily organic meal. Manures and fertilizers shared nearly 9-28 per cent of cost of cultivation. The total cost of cultivation ranged from 18823 to 23853 Rs ha^{-1}.

Table : 45 Effect of treatments on rhizosphere actinomycetes population

Treatment		Soil actinomycetes (x 10^6 cfu g^{-1})					
		Sowing	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	4.67 [b]	22.00 (452)*	10.33 [b] (247)	7.00 (167)	3.33 [e] (76)	21.33 [b] (525)
T_2	R (P as SSP)	3.33 [b]	19.00 (623)	11.33 [b] (387)	8.67 (316)	8.67 [c] (280)	27.00 [a] (927)
T_3	R (P as OM)	2.67 [b]	13.67 (553)	17.33 [a] (646)	7.00 (266)	8.67 [bc] (323)	26.00 [a] (993)
T_5	$OM_{500}N_{15}K_{75}$	11.67 [a]	12.00 (107)	11.33 [b] (402)	7.67 (70)	10.33 [ab] (95)	26.00 [a] (234)
T_6	$OM_{1000}N_{10}K_{75}$	4.33 [b]	22.67 (605)	13.33 [ab] (350)	8.00 (234)	6.33 [d] (194)	20.00 [b] (586)
T_7	$OM_{1500}N_5K_{75}$	4.67 [b]	12.67 (330)	11.00 [b] (256)	7.67 (175)	11.33 [a] (276)	20.33 [b] (454)

(R- Package of Practices Recommendations of KAU, MP- Musoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime) * figure in brackets denotes percentage increase. * figure in brackets denotes percentage increase.

Table : 46 Effect of treatments on rhizosphere rhizobial population

Treatment		Soil *Rhizobium* (x 10^6 cfu g^{-1})					
		Sowing	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T_1	R (P as MP)	3.67 [a]	4.33 [c] (125)*	4.67 (126)	4.67 (130)	1.00 [c] (28)	4.67 [c] (128)
T_2	R (P as SSP)	2.33 [b]	12.33 [ab] (520)	4.33 (278)	5.67 (330)	0.67 [c] (38)	7.67 [a] (426)
T_3	R (P as OM)	3.00 [ab]	3.67 [c] (124)	4.33 (163)	3.67 (126)	1.00 [c] (35)	6.00 [b] (217)
T_5	$OM_{500}N_{15}K_{75}$	2.00 [b]	8.33 [bc] (417)	5.00 (250)	3.67 (183)	2.33 [a] (117)	4.67 [c] (233)
T_6	$OM_{1000}N_{10}K_{75}$	2.00 [b]	6.33 [bc] (317)	5.00 (250)	4.33 (217)	1.33 [bc] (67)	4.67 [c] (233)
T_7	$OM_{1500}N_5K_{75}$	2.67 [ab]	16.33 [a] (599)	3.67 (139)	5.00 (201)	2.00 [ab] (77)	4.00 [c] (158)

(R- Package of Practices Recommendations of KAU, MP- Musoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S- Sulphur and L-Lime) * figure in brackets denotes percentage increase.

Relatively higher returns were recorded with T_4 [R (P as OM) S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$]. But the highest net return was recorded with T_6 [$OM_{1000}N_{10}K_{75}$] (Rs. 50329) followed by T_4 [R (P as OM) S_{56}] and T_7 [$OM_{1500}N_5K_{75}$]. The lowest net return of RS. 25486 was recorded with T_1 [R (P as MP)]. Graded levels of organic meal with lime application produced almost equal income. The highest net returns per rupee invested (Rs.3.54) was recorded with T_6 [$OM_{1000}N_{10}K_{75}$] followed by T_7 [$OM_{1500}N_5K_{75}$] and T_4 [R (P as OM) S_{56}].

Table : 47 Economics of groundnut production (Rs ha^{-1}).

Treatment		Cost			Returns			Net return	Return per rupee invested (Benefit : Cost)
		Fixed	Variable	Total	Pod	Haulm	Total		
T_1	R (P as MP)	17084	6115	*23199*	45700	2985	*48685*	**25486**	2.10
T_2	R (P as SSP)	17084	6769	*23853*	52100	2485	*54585*	**31002**	2.29
T_3	R (P as OM)	17084	5451	*22535*	57600	2453	*60053*	**37518**	2.66
T_4	R (P as OM) S_{56}	17084	5751	*22835*	67800	2673	*70473*	**47638**	3.08
T_5	$OM_{500}N_{15}K_{75}$	17084	1739	*18823*	50700	2688	*53388*	**34565**	2.84
T_6	$OM_{1000}N_{10}K_{75}$	17084	2702	*19786*	67200	2915	*70115*	**50329**	3.54
T_7	$OM_{1500}N_5K_{75}$	17084	3663	*20747*	65100	2688	*67788*	**47041**	3.26
T_8	$OM_{2000}K_{75}$	17084	4625	*21709*	46300	2603	*48903*	**27195**	2.25
T_9	$OM_{500}N_{15}K_{75}L_{860}$	17084	3459	*20543*	51000	2535	*53535*	**32992**	2.61
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	17084	4142	*21226*	52500	2963	*55463*	**34237**	2.61
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	17084	4823	*21907*	55208	2375	*57583*	**35676**	2.63
T_{12}	$OM_{2000}K_{75}L_{440}$	17084	5505	*22589*	52400	2563	*54963*	**32374**	2.43

(R- Package of Practices Recommendations of KAU, MP- Mussoorie rock Phosphate, SSP- Single Super Phosphate, OM- Organic Meal, N-Nitrogen, P- Phosphorus, K-Potassium, S- Sulphur and L-Lime)

DISCUSSION

5. DISCUSSION

Although, groundnut is considered as one of the most important oil seed crops in India, it failed miserably to prove its significance in the agriculture scenario of Kerala. This was mainly attributed to the prominent laterite soils available in Kerala, which was usually considered as unsuitable for the groundnut cultivation. Moreover, it is mainly cultivated in the summer rice fallows, which faced problems of water scarcity and higher temperature. Higher yields of groundnut can be achieved through integration of better varieties with suitable management practices (based on crop physiological nature and response to various management practices). The present experiment was intended to study the functional efficiency of organic meal in groundnut production and to understand the physiological basis for production of higher yields with various nutrient sources. The results obtained in this study are discussed hereunder.

5.1. Climatic parameters

In groundnut, growth is a genotypic character though largely influenced by seasonal and other environmental conditions (Reddy, 1988) and it is a lover of warmth and sunshine.

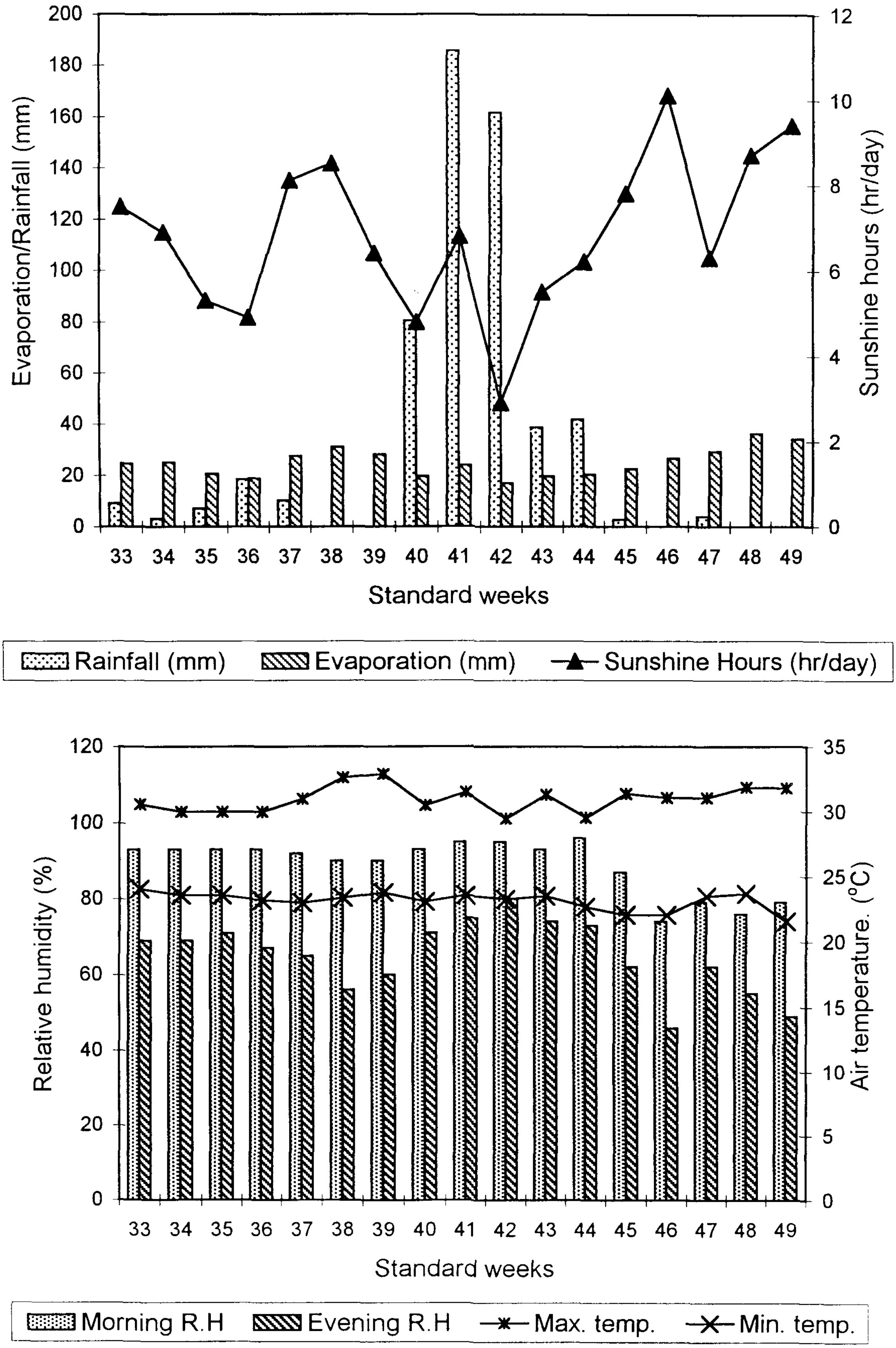
The crop received light showers during early stages and adequate rainfall during 40-65 days, followed by comparatively lesser rainfall and no rainfall towards harvest (Fig.2). Supplemental irrigation was given whenever necessary.

During later periods of active flowering, the crop received rains as well as optimum sunshine hours and moderate temperature. This resulted in better production and entry of the pegs into the soil, which was facilitated by the timely rainfall and ultimately a better yield. Seshadri (1962) also had reported that rain spells interspersed with bright weather are beneficial during the reproductive stage.

The optimum temperature reported for vegetative growth of groundnut is from 27 to 30^{o} C and for reproductive phase is from 24-27^{o} C (Reddy, 1988), and the crop experienced a temperature between 26.6 to 27.4^{o} C during vegetative and 26.1 to 27.8^{o} C during reproductive phase.

The recorded RH in the morning hours was more than 90 per cent up to 12th week of cropping and the RH during evening was more than 70 per cent which

Fig. 2 Weekly weather data during crop period (Aug. 13 to Dec. 3, 1999) at Vellanikkara, Thrissur



favoured the better growth of groundnut as reported by Fortainer (1957). Towards maturity the RH was less which reduced the incidence of pests and diseases and better filling of pods.

These favourable climatic factors might have contributed to a great extent towards a two fold increase in yield of groundnut than the average yield reported.

5.2. Growth parameters

An increase in plant height was noticed even up to harvesting stage indicating an exceptionally good growth of plants in general.

The number of branches, plant height, number of leaves and nodule weight as a whole (20 to 80 DAS) were not affected by the imposed treatments, but affected by the crop growth (Appendix- 8a.). However, the expression of these parameters at a particular stage might have been influenced by treatments.

Leaf characters like specific leaf weight and specific leaf area as a whole significantly affected by imposed treatments and age of the plants (Appndix 8c). Similarly, leaf length, leaf width, plant weight and shoot weight was significantly affected by treatments. But the significant difference in DMP as a whole with treatments was due to significant variations in leaf weight, root weight and in leaf area (Appendix 8a.).

The chlorophyll contents were not significantly affected by treatments as a whole (Appendix 8b). But, the treatments caused variations at particular stages, which resulted in varying rate of photosynthesis which in turn resulting in different yields.

Higher plant height and number of branches and number of leaves per plant were recorded with T_1 [R (P as MP)] at 40 DAS (Fig. 3). This might be because of gradual and greater availability of P from rock phosphate due to organic acids, which formed during FYM decomposition. These factors in turn resulted with higher number of branches, leaves and plant height. The availability of P is important in energy transformation, faster cell division and rapid meristemic activity (Tomar *et al.*, 1983 and Singh and Dhar, 1986).

Organic meal 2000 kg with or without lime (T_8 and T_{12}) recorded lower plant height up to 40 DAS. This might be because of absence of readily available N and other nutrients during initial periods of mineralisation. At 60 DAS, T_9

$[OM_{500}N_{15}K_{75}L_{860}]$ recorded higher plant height which was due to liming effect on mineralisation and availability of nutrients.

At 80 DAS and harvesting stage, the plant height was reduced with increasing levels of organic meal with lime. This might be due to greater availability of P, which was more than required, leading to reduction in plant height. This is in conformity with the results obtained by Choudhery *et al.* (1991) and Prasad *et al.* (1996).

T_2 [R(P as SSP)] recorded lower plant height, number of leaves and leaf area compared to all other treatments from 40 DAS onwards. It might be due to fixation of water soluble P in acid soils, but in T_4 [R (P as OM)S_{56}] availability of S and P was better.

Application of elemental S (T_4 [R (P as OM)S_{56}]) did not produce any significant influence on plant height. The S present in organic meal and in the soil might be sufficient to produce enough plant height.

The plant height was positively correlated with number of branches and number of leaves at all stages, which in turn resulted in positive correlation with haulm yield. The other economic yields like pod, kernel, oil and protein were negatively correlated with plant height.

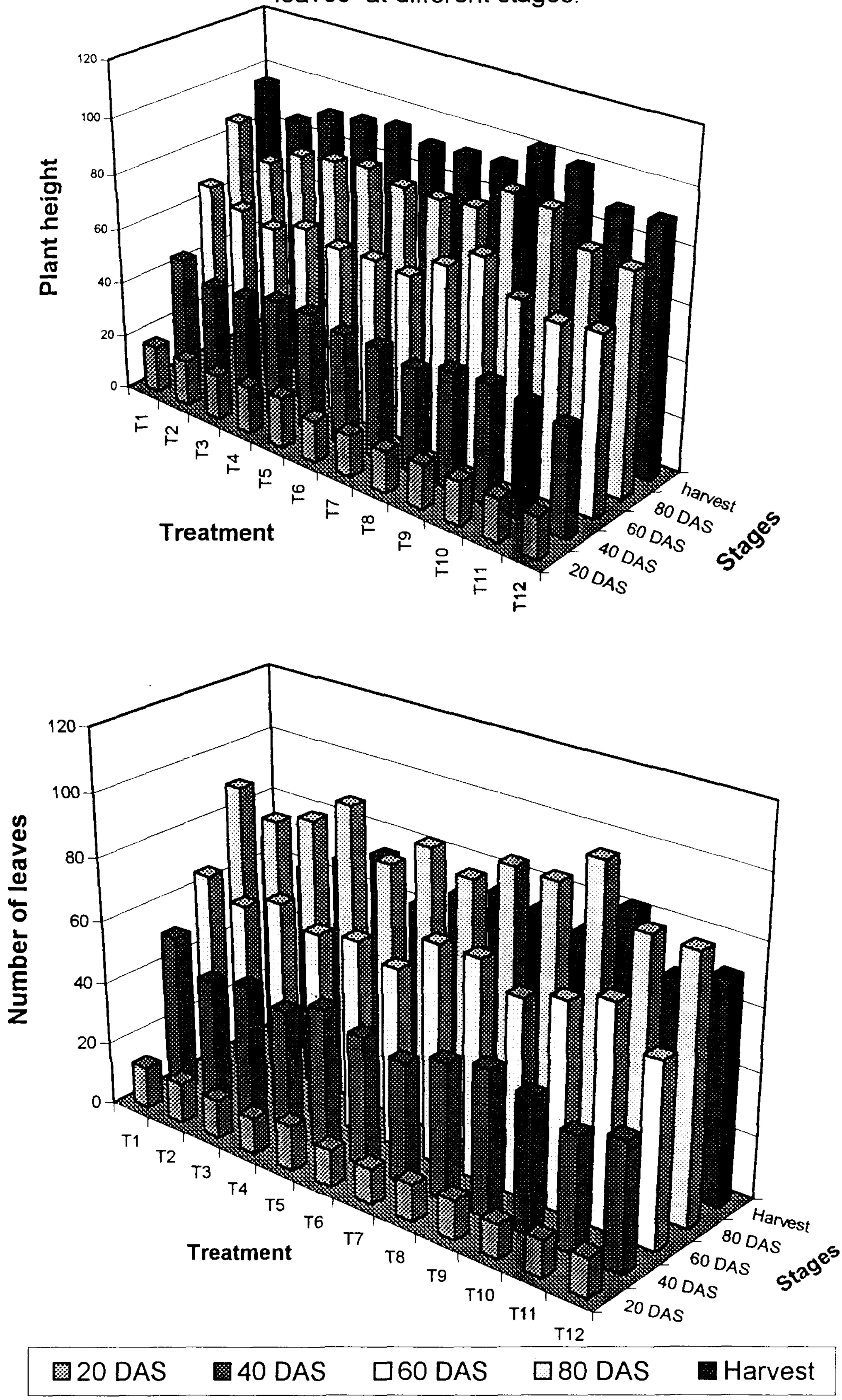
The number of branches (Table 8) increased at a very high rate from 20-40 DAS and subsequent production of branches was very less. It was because of secondary (n+2) branches which arose from basal nodes of primary vegetative axis (n+1) along with flowers starting from 20 DAS onwards leading to visualization of branches at 40 DAS (Reddy, 1988).

At 40 DAS, the number of branches produced was less in T_6 $[OM_{1000}N_{10}K_{75}]$ and T_7 $[OM_{1500}N_5K_{75}]$, which gave the maximum kernel yield at harvest. It indicated that the branching was negatively affecting the yield.

It was also shown from correlation Table 23 that the number of branches had positive effect only with haulm yield and all the other parameters like oil and protein yield were negatively correlated.

During early stages, the branching was crucial in this variety (VRI 4), because of absence of flowers in main axis (Varman et *al.*, 1996). That is why the number of primary branches (n+1) formed during 20-40 days was important for

Fig 3. Effect of treatments on plant height and number of leaves at different stages.



higher number of flower production. But production of higher number of branches with more number of flower buds in T_1 [R (P as MP)], T_2 [R (P as SSP)] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$] resulted with lower peg to pod conversion which might be due to want of higher proportion of metabolites in multiple shoot tips.

The faster rate of increase in number of leaves per plant (Table 9) was observed form 20-40 DAS and later on it was decreased, indicating that the active growth of groundnut plants lies between 20-40 DAS (flowering period). This was evidenced from Table 18, that higher NAR was observed during 20-40 DAS. Similarly Rao (1936) observed higher net assimilation rate up to 54 days.

The rate of increase in the number of leaves per plant was not affected by flowering, but affected by pod formation and pod development, which was evidenced from decrease in rate of production of leaves after 40 days.

The highest leaf number was recorded at 80 DAS and the decrease in leaf number at harvest was due to leaf senescence and fall after physiological maturity (Fig. 3). Up to 40 DAS, T_1 [R (P as MP)] recorded the maximum number of leaves which might be due to higher plant height with higher number of branches. From 40 DAS onwards, similar leaf production was recorded in all the plots, as a result of mineralization and better absorption of nutrients.

But retention of leaves towards harvest stage had a positive influence on yield. In earlier periods of crop growth, the number of leaves was negatively correlated with yield.

The increase in total leaf area per plant (Table 9) was up to 80 DAS and decreased towards harvest due to leaf fall. Even though there was a constant increase in number of leaves per plant from 60-80 DAS, the rate of increase in leaf area was less after 60 DAS. This was because of active pod development and diversion of photosynthates towards developing pods resulting in production of small sized leaves as reported by Forestier (1973).

At 40 DAS, the highest leaf area was recorded by T_1 [R (P as MP)] which was because of higher number of leaves. Similarly, T_{11} [$OM_{1500}N_5K_{75}L_{580}$] recorded lesser number of leaves which resulted in the least leaf area per plant.

At harvest, in general T_4 [R (P as OM) S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$], T_7 [$OM_{1500}N_5K_{75}$] and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] recorded higher leaf area per plant, which was because of retention of higher number of leaves at harvest. Similar to this, T_2 [R (P as SSP)] and T_5 [$OM_{500}N_{15}K_{75}$] also recorded lower leaf area at harvest due to higher leaf fall (23-25 per cent).

It was also observed that higher leaf production and leaf area during later stages (40-80 DAS) of growth at the expense of valuable photosynthates could not produce concomitant yield increase.

At harvest, T_4 [R (P as OM)S_{56}] recorded the highest leaf area per plant, even though it had not retained higher number of leaves when compared to T_6 [$OM_{1000}N_{10}K_{75}$], T_7 [$OM_{1500}N_5K_{75}$] and T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$]. This was because of production of leaves with higher leaf area which was evidenced from the observation on third leaf area (Table 10). This was also because of production and retention of higher chlorophyll during 80 to 100 DAS (Table 11) resulting with higher photosynthesis. The chlorophyll stability might have been imparted from the gradual uptake of S from elemental S applied. Sagare (1986) also reported the importance of S for chlorophyll production and stability. Leaf area per plant was positvely correlated with yields from 60 DAS indicating the relative importance of leaf area with yield.

The third leaf area and weight (Table 10) were increased up to 60 DAS, and after that it decreased. This indicated that active growth and expansion of leaves was up to pegging stage. This might be because of relative utilization of absorbed Ca and the photosynthates by developing pods. Tisdale *et al.* (1993) explained the importance of Ca for cell division and multiplication. Similarly Forestier (1973) recorded increase in leaf area from 3rd leaf stage to pod formation.

However, from 80 DAS onwards, the third leaf area decreased to a half, but the weight was decreased by one third only. This might be because of development of thicker leaves towards harvest, which led to slight reduction in leaf weight even after shedding of lower leaves.

At 20, 40 and 60 DAS, higher leaf area was recorded with T_2 [R(P as SSP)], and the same treatment produced higher third leaf weight up to 80 DAS. This might be because of better availability of P and S from SSP in earlier stages and later it was maintained by constant rate of absorption (Table. 32).

When elemental S was added (T_4 [R (P as OM)S_{56}]), there was an increase in third leaf area and weight, total number of leaves, leaf area and leaf chlorophyll 'a' content, which indicates the role of S in chlorophyll stability and leaf area duration. Higher doses of organic meal with lime (T_{11} and T_{12}) recorded lower third leaf area at 60 DAS and it was because of relative fixation of mineralised P by applied Ca. But this was not so with T_8 [$OM_{2000}K_{75}$] which had resulted in higher third leaf area than T_{11} [$OM_{1500}N_5K_{75}L_{580}$] and T_{12} [$OM_{2000}K_{75}L_{440}$].

A perusal of data on chlorophyll content showed that the chlorophyll content had been remarkably stable and the variation due to treatments had been marginal and inconsistent over time. However, T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] at 60 DAS recorded the maximum chlorophyll 'a' during entire crop growth phase, where as T_4 [R (P as OM)S_{56}] have recorded the highest content beyond 60 DAS. Chlorophyll is considered as seat of photosynthesis and as such higher chlorophyll content would be expected to register a higher yield, which however has not come through in the present study. This is apparently the cause of uniqueness as well as peculiarity of this crop. Groundnut as a leguminous crop fixes N and the process consumes lot of carbohydrate. If this fact is considered along with total dry matter production, it would be seen that higher chlorophyll content had really seen meaningful. But it has not reflected in kernel and pod yield because they are differentiated products and not direct resultant of carbohydrate accumulation. This process of differentiation is naturally affected by other factors including nutritional levels especially Ca consumption. This might have been the underlying fact, which in turn was responsible for absence of any apparent relation of chlorophyll with kernel yield.

Number of nodules and nodule weight per plant (Table 13) progressively increased up to 80 DAS and there was a slight decrease towards harvest. This observation is in confirmation with Balasubramanian (1993). This decrease in nodule number and weight at harvest might be due to senescence and disintegration of nodules after physiological maturity of the crop. Rao (1979) and Lakshmamma and Raj (1997) also expressed similar views.

Even at harvest stage, the crop retained appreciable number of nodules because of the continuous nodule formation up to harvest (ICRISAT,1978 and Nambiar *et al.*, 1987).

At 60 DAS, lime applied plots showed on par nodule count with no lime applied plots which indicated that liming was not having any significant effect on nodulation (Munns, 1977). Absence of response to applied lime in acid soil by inoculated *Rhizobium* might be because of inherent capacity of native culture to survive in acid soil conditions.

The recorded nodule number and weight was much higher even at 80 DAS than the reported ones by Bhuiyan *et al.* (1997) with inorganic fertilizer treatments. These results confirmed that application of any form of organic manure should be necessary for maintaining rhizobial population along with other organisms. The same view was also expressed by Rovira and Davay (1974).

Since multiplication of rhizobia in soil and nodule formation are energy demanding processes, soil organic matter serves as a storehouse of food and energy for soil microbes. Similarly Ram *et al.* (1993) and Balasubramanian (1993) reported higher number of nodules with enriched FYM and FYM application.

At 80 DAS, higher doses of organic meal showed reduction in nodule count and weight (T_7 [$OM_{1500}N_5K_{75}$], T_8 [$OM_{2000}K_{75}$] and T_{12} [$OM_{2000}K_{75}L_{440}$]). This might be due to toxic effect of higher level of P on rhizobial population and nodulation (Rao, 1979 and Kulkarni *et al.*, 1986).

Sulphur application through SSP and elemental S did not exhibit any significant effect on nodule count and weight at all stages.

The progressive increase in dry matter production (Table 12 and 14) was the result of successive increase in the weight of its component factors. The DMP production at 40 DAS, showed nearly 8-10 times increase over 20 DAS. This was because of active growth of plants as shown by high net assimilation rate and relative growth rate as reported by Reddy (1988).

However, maximum dry matter accumulation was recorded between 60 DAS to harvest, which was evidenced from recorded high crop growth rate during this period (Table 17). Similar observations were made by Ali *et al.* (1932) indicating that the maximum growth was between 56 and 97 DAS in bunch varieties.

Initial higher root weight was recorded with T_1 [R (P as MP)] and T_2 [R (P as SSP)]. It was because of better availability of N and P and its favourable effect during initial stages, which in turn led to better root proliferation, better shoot development at 20 DAS. Similar observations were made by Lakshmamma and Raj (1997) with rock phosphate and SSP. The importance of P for root activity and production was also reported by Surajbhan and Misra (1971).

But increased root weight was retained by T_1 [R (P as MP)] up to 40 DAS as a result of slow availability of mineral P to plants.

However, graded levels of organic meal applied plots were on par in root weight from 40 DAS. This was because of slow availability of nutrients from organic meal. Even the lowest quantity of organic meal was enough to produce satisfactory dry matter production.

T_4 [R (P as OM) S_{56}], which received elemental S over T_3 [R(P as OM)], recorded lower shoot, root and total DMP in early stages. But higher DMP in later stages was because of availability of S.

From 60 DAS onwards, T_6 [$OM_{1000}N_{10}K_{75}$] recorded the maximum shoot and root weight which resulted in higher DMP. This might be because of better availability of required mineral nutrients in favourable combinations and balance. Graded levels of organic meal with lime could not produce any significant change in shoot dry weight. At harvest, it was recorded that the contribution of the root in total DMP was around 2-3 per cent only (Fig. 4).

Progressive increase in shoot root ratio with age was the indication of higher rate of growth of shoots. At 60 DAS, higher shoot root ratio was observed with T_1 [R (P as MP)] which might be because of reduction in root growth than initial stages.

However, T_4 [R (P as OM)S_{56}] recorded higher shoot root ratio, due to higher shoot weight which was because of the effect of S on chlorophyll formation, leaf area development and subsequent vegetative growth.

5.3. Growth indices

The LAI (Table 15) increased up to 80 DAS and decreased at harvest due to decrease in leaf number and area. This decrease in LAI at harvest was also reported by Enyi (1977) and Reddy (1988). LAI is important for the identification of relative leafiness, which in turn decides the magnitude of solar energy harvest.

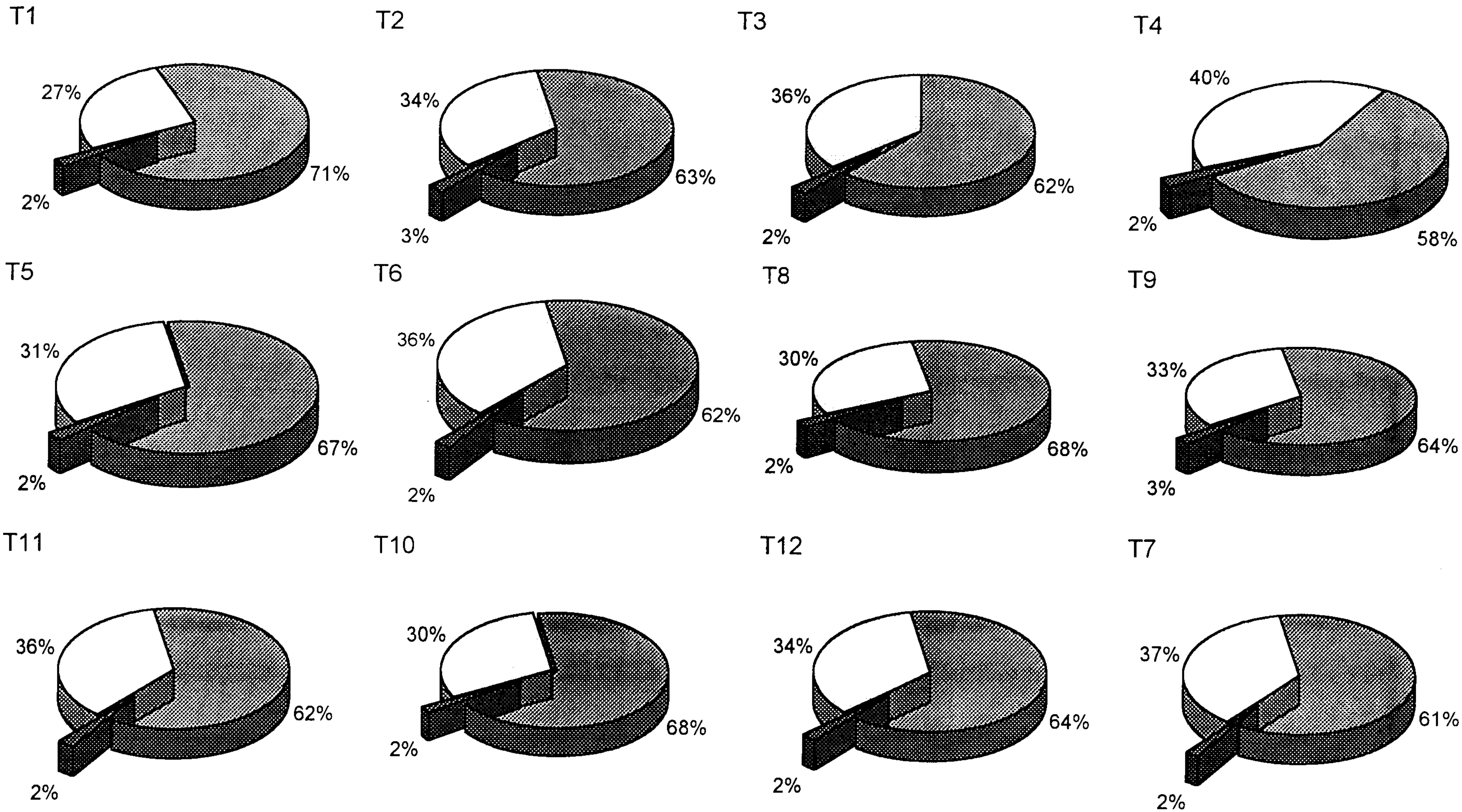


Fig.4. Effect of treatments on distibution of dry matter at harvest

▨ Shoot ■ Root □ Pod

The rate of increase in LAI was slowed down after 60 DAS due to production of smaller leaves (Table 10). The same was explained by Williams *et al.*, (1976) as the resultant of low stem growth and increased pod growth. However, Reddy (1988) suggested that maintenance of the maximum LAI was advantageous combined with greater availability of sunlight. The crop recorded LAI of 6.23 to 8.01 at 80 DAS. This might be the key factor for better performance of the crop.

At 40 DAS, higher LAI was shown by T_1 [R (P as MP)] and on 60 DAS, T_7 [$OM_{1500}N_5K_{75}$] and T_{11} [$OM_{1500}N_5K_{75}L_{580}$] recorded higher values. It was because of the production of higher number of leaves with greater area.

The LAR (Table 15) was decreased from 20 DAS to harvest due to relative gain in shoot weight over time. At 80 DAS, higher leaf area ratio was recorded with T_1 [R (P as MP)], T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_{12} [$OM_{2000}K_{75}L_{440}$] which was primarily because of lower shoot weight than all other treatments.

However organic meal applied plots recorded on par LAR except T_5 [$OM_{500}N_{15}K_{75}$] which was because of lower leaf area at 80 DAS, due to shortage of nutrients. This was evidenced from nutrient uptake by plants of T_5. S application also could not produce favourable effect on LAR.

The SLA (Table 16) was not significantly affected by treatments. But it reduced towards maturity because of less moisture content or succulence of leaves. However liming and S application had not much effect on SLA and SLW.

LAD is an important physiological index showing the relative leafiness and persistence of leaves. Higher LAD means higher receptivity to sunlight for a longer period for photosynthesis, which in turn results in higher production. This was also evidenced from (Table 24) showing high correlation between yield and LAD.

Higher LAD recorded with T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] during later peiods resulted in higher pod yield than haulm yield compared to other treatments. At harvest, lower LAD was observed in T_5 [$OM_{500}N_{15}K_{75}$] due to higher leaf fall (23 per cent) at maturity. Application of S (T_4 [R (P as OM)S_{56}]) had favourable effect on LAD during 80 DAS to harvest which was because of higher number of leaves and leaf activity.

The maximum LAR and RGR were shown between 20-40 DAS (Table 15 and 17) and were not significantly influenced by the treatments because these are basically genetic factors and management practices can change these at a particular stage or time, but not wholly (Appndix 8b.).

CGR (Table 17) was influenced by treatments up to 60 DAS. Organic meal 1000 kg with or without lime (T_6 and T_{10}) showed better crop growth in general, which might be due to better availability of nutrients and dry matter production. CGR during 60-80 DAS was positively correlated with economic yields and later on negatively correlated.

NAR (Table 18) was influenced by treatment up to 60 DAS like CGR. But NAR during 60 DAS to maturity was important for better pod development, which was evidenced from Table 24 showing that the positive relationship between economic yields and NAR at later stages.

5.4. Yield and related characters

The time taken for 50 per cent of plants for flowering (Table 19) was 26 to 27 days in the present experiment, irrespective of treatments. Under normal conditions, only 50-80 per cent flowers usually develop into fruits.

The number of pegs at different stages as a whole, was not varied due to treatments, but by the age of the crop (Appendix 8a).

The increase in number of pegs per plant up to harvest was an indication of continued flowering up to harvest. Similarly Teng and Hor (1975) had reported flowering period lasting from 85 to 100 days. The increase in peg production from 2-4 to 16-20 from 40-60 DAS indicated that the time taken for peg formation is around 15 days. The number of pegs at 60 DAS decided the ultimate pod and kernel yield as seen in T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] as reported by Gregory *et al.* (1951), Shear and Miller (1955), Hartzook and Goldin, (1967), Cahaner and Ashri (1974) and Hemsey *et al.* (1974).

The treatments were significantly affecting the yield attributes as a whole, however it was brought out by the significant pod number per plant (Appendix 8g).

T_1 [R (P as MP)] and T_2 [R(P as SSP)] recorded lower number of pods per plant at 60 DAS, which was the reason for lower yields. This was in agreement with Helmsy *et al.* (1974), who stated that flowers appearing during 60-70 DAS do not form pods and fail to increase the yield. Because of lower number of pods, better filling was reported with T_1 [R (P as MP)] with higher 100 kernel weight.

The percentage of double and triple seeded pods was significantly different with treatments. In all the plots relatively higher production of three seeded pods were seen except in T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$], where double seeded pods were the highest.

However, T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$] recorded on par pod numbers but the distribution of double and triple seeded pods were significantly different (Fig. 5). T_6 [$OM_{1000}N_{10}K_{75}$] favoured relatively higher number of three seeded pods. But T_4 [R (P as OM)S_{56}] favoured the production of double seeded pods than triple and single seeded pods. This higher number of pods with thick shells resulted with lower shelling percentage.

The treatment T_1 [R (P as MP)] gave the lowest pod yield because of higher production of single seeded pods and lower total number of pods compared to all other treatments. Even though there was no significant difference between total pods produced, T_4 [R (P as OM)S_{56}] , T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] produced the maximum pod yield per ha because of production of higher percentage of triple seeded pods.

T_2 [R(P as SSP)] recorded higher number of pods than T_1 [R(P as MP)] which might be due to favourable effect of S and P in SSP. Higher number of pods with SSP was also reported by Ramesh *et al.* (1998).

Percentage of pod to peg was the highest in T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] with 1000 to 1500 kg organic meal. This might be due to availability of P even during later period of growth from organic meal. This available P had favourable influence in pod development and filling by indirectly affecting protein synthesis (Rao and Singh, 1985).

T_4 [R (P as OM)S_{56}] recorded higher 100 pod and kernel weight even though there was no significant difference. This might be due to the application of elemental S, but it produced the lowest shelling percentage.

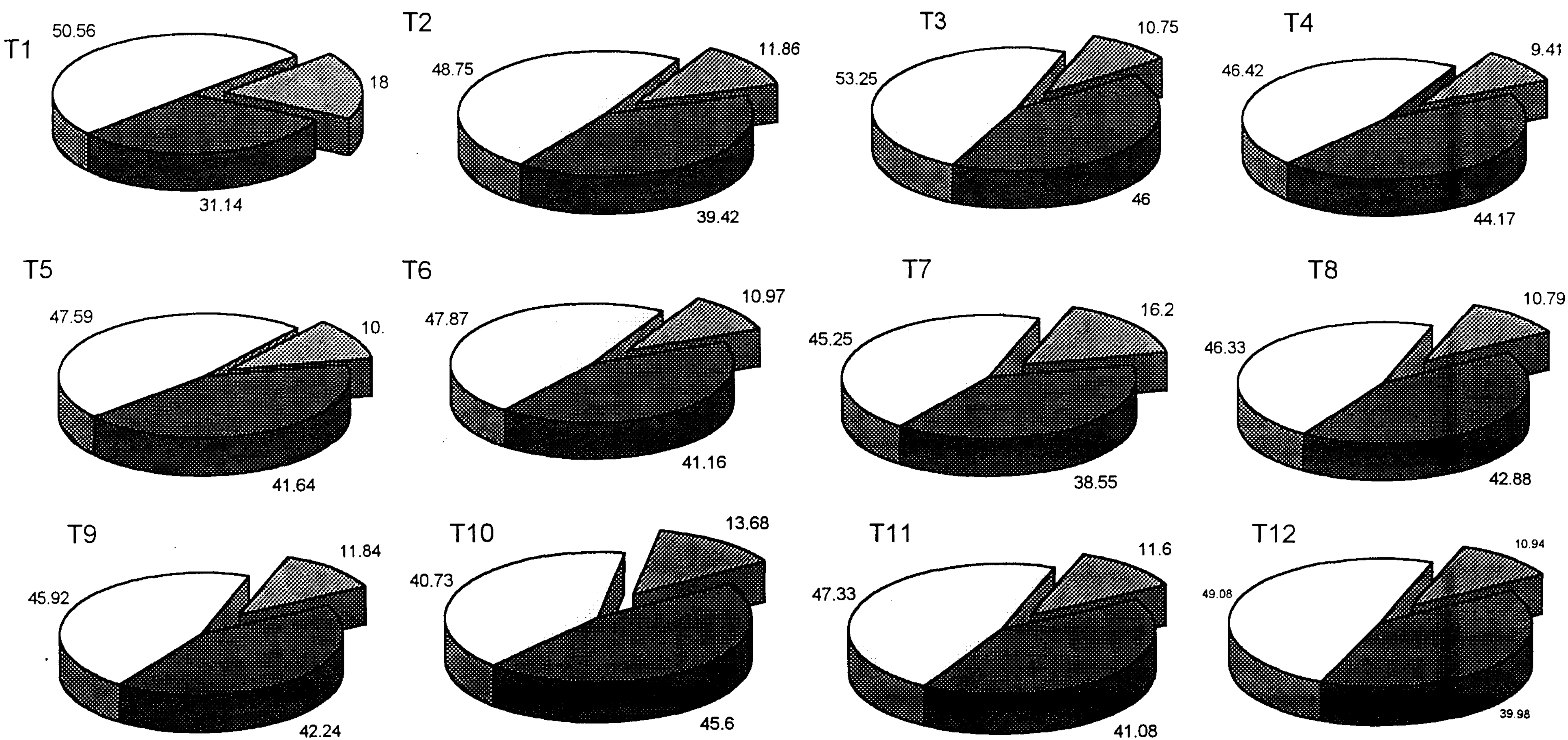


Fig. 5. Influence of treatments on percentage distribution of pods.

Along with T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] also recorded higher pod weight per plant which might be due to favorable effect of nutrient ratios on the production and maintenance of high leaf number, area, chlorophyll content during pod filling and pod development stage.

The results showed that at higher doses of organic meal (1000-1500 kg), there is no need of application of FYM and lime.

T_1 [R (P as MP)], T_2 [R(P as SSP)], T_5 [$OM_{500}N_{15}K_{75}$] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$] recorded lower pod weight per plant. Lower pod weight per plant with T_1 [R (P as MP)] was due to lower number of pods per plant. But the lower pod weight with respect to T_2 [R (P as SSP)], T_5 [$OM_{500}N_{15}K_{75}$] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$] was because of lack of adequate nutrients during the reproductive stage.

T_6 [$OM_{1000}N_{10}K_{75}$] recorded the maximum biomass production as well as pod and kernel yields (Fig. 6). It might be because of availability of nutrients in proper combinations and balance. P being a major element for groundnut, it is required for the crop to express its full potential. Being an immobile element, P concentration in plant was maintained by constant release of P up to harvest. Its role in root development and its influence on the uptake of other nutrients are well established. This might have favoured desirable root system during pod filling and development, which in turn promoted higher nutrient uptake, growth and finally pod yield. Even though, there were no significant difference in total biomass production between treatments, T_1 [R (P as MP)] produced the maximum haulm yield and haulm to pod and kernel ratios indicating the negative influence of higher vegetative growth on kernel yield. The harvest index was also the least in that treatment.

In the present experiment, even though the number of pods per plant was not much affected, higher proportion of triple seeded pods (46-53 per cent) among total pods might be a contributory factor for greater yield than expected (Plate 7). The reported dry pod yield of VRI 4 is only 2392 kg ha^{-1} with 39 per cent three seeded pods (Varman *et al.*, 1996). The crop also had four seeded pods, which was not accounted.

The vigorous nature of the crop was exhibited starting from germination to harvest by increase of around 30-40 cm than the reported height. The reduction in number of n+2 and n+3 branches with relatively higher CGR resulted in higher bio mass production and pod yield.

It was also seen that 100 pod weight and 100 kernel weight were higher by around 35-40 g and 15-18 g respectively over reported ones. This increase might be because of conducive soil and environmental conditions and source of nutrients in favourable combinations resulting in higher nutrient uptake. Presence of active nodules till harvest, along with retention of leaves with efficient photosynthesis augmented better filling of pods.

In the path analysis of yield relative characters with pod and kernel yield are presented in Table 49 and 50. The total biomass has a positive direct effect on pod yield (1.742), but indirect effects of total biomass through haulm pod ratio (HPR), haulm kernel ratio (HKR), 100 pod weight, shelling percentage (% shell), 100 kernel weight, days to 50 per cent of plants for flowering, average pod number are not prominent. But it is seen that the indirect effect of total biomass through haulm yield is negative which indicates when haulm yield increases, the pod yield decreases. These resulted in higher positive correlation between total biomass and pod.

The direct effect of pod to haulm ratio was, found to be not prominent. However, the indirect effects of HPR through total biomass and haulm yield are shown to be negative finally yielding a total correlation coefficient –0.854**. That means increasing HPR reduces the pod yield, which is generally true. This is the clear cut case of partitioning effect which is revealed by the path analysis. In the same way, the haulm kernel ratio also marched with pod yield. This was because of kernel yield is always positive with pod yield (0.980**). The direct effect as such was very small and however, the indirect effects through total biomass and haulm yield were negative and large. Finally the summation of both direct and indirect effects yields a positive and significant correlation coefficient of –0.876**.

100 kernal weight manifested in higher pod yield and total biomass.

The direct effect of average pod number has a positive indirect effect through total biomass (1.233) though its own direct effect is very small. However, the final correlation coeffcient is large and significant (r = 0.963**).

Fig. 6. Influence of treatments on total biomass, pod, haulm and kernel yield.

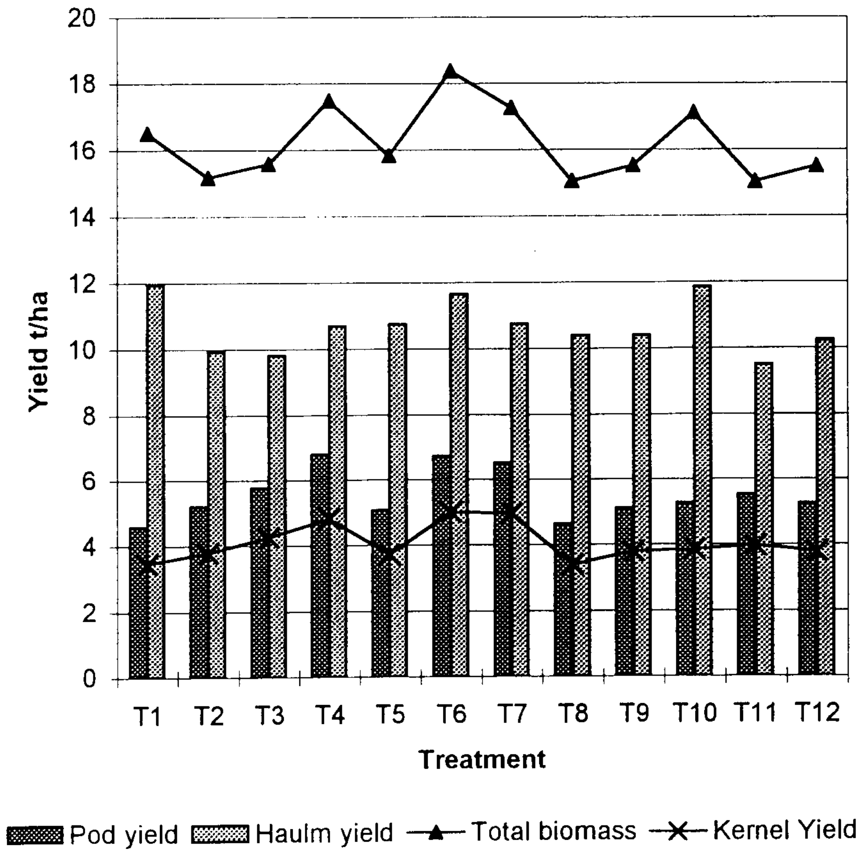


Fig. 7. Influence of treatments on oil, protein and carbohydrate content in kernel.

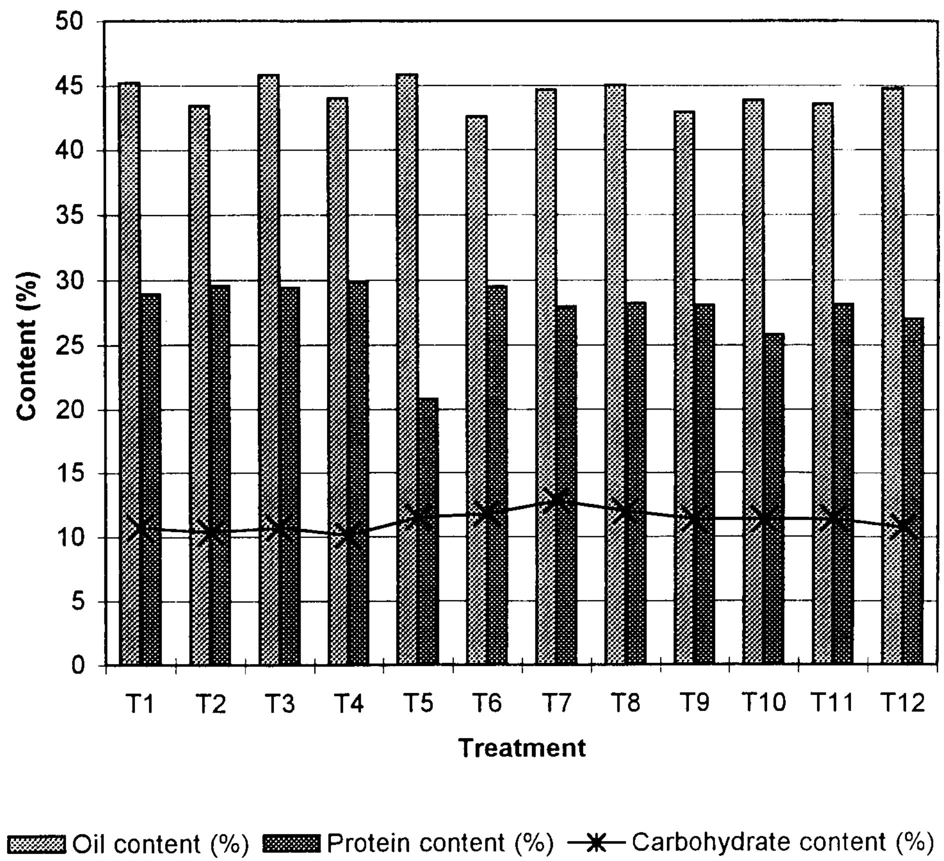


Plate: 7 A close view of harvested pods

Table : 48 Correlation between different yield attributes.

	Pod yield ha^{-1}	Oil yield ha^{-1}	Total biomass	Haulm pod ratio	Haulm kernel ratio	100 pod weight	Haulm yield ha^{-1}	No. of pods plant^{-1}	Pod yield plant^{-1}
Total biomass	0.701*	0.705*							
Haulm pod ratio	-0.854**	-0.817**	-0.266						
Oil percentage	-0.342	-0.151	-0.254	0.252					
Oil yield	0.968**	1.000**	0.706*	-0.818*					
Haulm kernel ratio	-0.876**	-0.856**	-0.319	0.986**					
100 pod weight	0.543	0.580**	0.577*	-0.378	-0.403				
Shelling percentage	-0.048	0.126	0.278	0.222	-0.089	-0.017			
100 kernel wt.	0.513	0.495	0.730**	-0.163	-0.200	0.387			
No. of pods plant^{-1}	0.963**	0.917**	0.708**	-0.802**	-0.820**	0.347	0.092		
Haulm yield ha^{-1}	0.998**	0.964**	0.689*	-0.850**	-0.871**	0.532	0.033	0.963**	
Kernel yield kg ha^{-1}	0.047	0.088	0.745**	0.427	0.372	0.294	1.000*	0.092	0.033
Haulm yield plant^{-1}	0.980**	0.936**	0.726**	-0.826**	-0.851**	0.590*	0.096	0.949**	0.977**

Table : 49 Direct and indirect effect of yield attributes on pod yield per ha.

	Total Biomass	Haulm pod ratio	Haulm kernel ratio	100 pod wt.	Shelling %	100 kernel wt.	No. of pods plant^{-1}	Haulm yield	Kernel yield	r
Total biomass	1.742	0.007	-0.021	0.004	0.011	0.004	0.009	-0.951	-0.104	0.701*
Haulm pod ratio	-0.463	-0.026	0.066	-0.003	0.009	-0.001	-0.010	-0.545	0.118	-0.854**
Haulm kernel ratio	-0.555	-0.025	0.067	-0.003	0.003	-0.001	-0.010	-0.475	0.122	-0.876**
100 pod wt.	1.006	0.010	-0.027	0.007	-0.001	0.002	0.004	-0.0376	-0.084	0.543
Shelling %	0.484	-0.006	0.006	0.000	0.039	0.001	0.000	-0.576	0.005	-0.048
100 kernel wt	1.271	0.004	-0.013	0.003	0.009	0.005	0.007	-0.672	-0.080	0.513
No. of pods plant^{-1}	1.233	0.021	-0.055	0.002	0.000	0.003	0.012	-0.117	-0.136	0.963**
Haulm yield $^{-1}$	1.298	-0.011	0.025	0.002	0.018	0.003	0.001	-1.276	-0.014	0.047
Kernel yield^{-1}	1.264	0.021	-0.057	0.004	-0.001	0.003	0.012	-0.123	-0.143	0.980**

R^2= 0.423 Residual = 0.759

Table : 50 Direct and indirect effects of yield attributes on kernel yield.

	Pod yield ha^{-1}	Haulm pod ratio	Haulm kernel ratio	100 pod wt.	Shell %	100 kernel wt.	No. of pods $plant^{-1}$	Haulm yield	r
Pod yield ha^{-1}	<u>-1.308</u>	-1.222	1.588	0.286	0.014	0.035	1.582	0.002	0.980**
Haulm pod ratio	1.116	<u>1.432</u>	-1.787	-0.200	-0.064	-0.011	-1.318	0.015	-0.826**
Haulm kernel ratio	1.146	1.412	<u>-1.812</u>	-0.213	-0.026	-0.014	-1.347	0.013	0.851**
100 pod wt.	-0.710	-0.541	0.730	<u>0.528</u>	0.005	0.027	0.569	0.010	0.590*
Shelling %	0.062	0.318	-0.162	-0.009	<u>-0.286</u>	0.015	0.004	0.016	-0.035
100 kernel wt	-0.671	-0.234	0.363	0.204	-0.064	<u>0.069</u>	0.881	0.019	0.562
No. of pods $plant^{-1}$	-1.260	-1.148	1.486	0.183	-0.001	0.037	<u>1.643</u>	0.003	0.949**
Haulm yield	-0.062	0.612	-0.674	0.155	-0.129	0.037	0.150	<u>0.035</u>	0.096

$R^2 = 0.358$ Residual = 0.801

The role of haulm yield on pod yield was clearly negative as shown by the value (r = -1.276). However, its indirect effect through total biomass was positive finally nullifying the correlation which resulted in a very low r value (0.047).

It is imperative that the kernal yield is positively correlated to pod yield as seen by the value of r (0.980**). But interestingly, its direct effect on pod yield is small though negative (-0.143) whereas it's indirect effect through total biomass is prominent and positive (1.264).

Finally, the path analysis model could explain the variability to the tune of 42.3 per cent which might be due to several factors which were not included in this model.

Haulm pod ratio gave higher direct effect with kernel yield, but because of larger indirect effect through haulm kernel ratio resulted with negative coefficient (-0.826). But the direct effect of haulm kernel ratio along with indirect effect through average pod number resulted with negative correlation.

5.5. Quality parameters

Higher oil and protein content combined with higher biomass yield is not generally seen. But against the principle of negative correlation of quality and quantity, the experimental crop recorded very high yield with better quality parameters. Forbes and Watson (1992) had reported increase in protein content along with increasing total dry matter. Sreekumaran *et al.* (2000) had reported the ways and means to achieve higher yield in pepper along with high oleoresin content. The nutrient ratios were more important than individual content.

However, the positive correlation between the oil and protein content and yield (Table 26) was the indication of chances of increasing pod yield further without much loss in quality. This was in contradiction to the earlier reports of Hung (1975), Walker and Hymourtz (1972) and Rao and Rao (1981). The crop produced nearly 3-5 per cent of higher protein content than the average reported (24-26 per cent) with the expense of nearly 6-8 per cent carbohydrate. The reported average carbohydrate content of the kernel was around 19 per cent. This might be because of higher efficiency of applied P, which in turn resulted in RNA reported average carbohydrate content of the kernel was around 19 per cent. This might be because of higher efficiency of applied P, which in turn resulted in RNA and ATP production and subsequent protein yield. The decrease in carbohydrate content with increase in P was also reported by Reddy (1988).

Among the treatments, better protein content was recorded with T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$], which might be because of better availability of N and P for protein synthesis and S for amino acid production and calcium for better pod formation (Fig. 7). Importance of P, S and N for protein production was also reported by Rao and Singh (1985), Tandon (1991b) and Mahapatra *et al.*, (1985) respectively. It is interesting to note that S content of haulm, kernel and shell was almost equal whereas Ca was seen more in haulms.

Higher oil content was recorded with T_3 [R(P as OM)] and T_5 [$OM_{500}N_{15}K_{75}$] which received 500 kg organic meal. It might be because of comparatively lower proportion of pods and better availability of S and the favourable environment for the uptake of soil S. This could be evidenced from higher depletion of available sulphur from soil (Table 42 b). However, FYM application favoured relatively less depletion of S from soil through increased use efficiency.

The importance of P and S for fatty acid synthesis and increase in production of phospho lipids and fatty acid is reported by Munshi *et al.* (1983), Shukhija *et al.* (1983) and Kaur *et al.* (1994). Higher protein yield was recorded with T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$] which was on par with T_7 [$OM_{1500}N_5K_{75}$] due to higher kernel yield and protein content. Lower protein yield with T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] was because of lower protein content. But the lower protein yield with T_8 [$OM_{2000}K_{75}$] and T_{12} [$OM_{2000}K_{75}L_{440}$] was because of lower kernel yield.

Even though T_4 [R (P as OM)S_{56}] recorded higher oil content, T_7 [$OM_{1500}N_5K_{75}$] recorded higher oil yield because of higher kernel yield. But higher kernel yield of T_6 [$OM_{1000}N_{10}K_{75}$] resulted with better oil yield next to T_7 [$OM_{1500}N_5K_{75}$] and T_4 [R (P as OM)S_{56}] because of lesser oil content.

Inorganic sources of P resulted in lower oil yield because of lack of influence of sources on pod yield. Though the carbohydrate content was not significantly affected, carbohydrate yield was affected by treatments due to variations in pod and kernel yield. T_8 [$OM_{2000}K_{75}$] and T_{12} [$OM_{2000}K_{75}L_{440}$] recorded higher ash content because of relative higher uptake of P, Fe, Mn, Zn and Mg than other treatments.

5.6. Nutrient concentrations and uptake

Nutrient concentration in the plant is influenced by variety of crop, soil, climate and management factors, which ultimately results in the nutrient removal by crop, which is also directly related to yield (Biswas and Tewatia, 1991). In the experiment, it is clear that the treatments caused significant variation in the plant nutrient concentration, nutrient ratios and uptake at all stages of plant growth (20 to 80 DAS) as a whole (Annexure 8d, 8e and 8f). Similar to these, nutrient ratios as a whole at 20, 40, 60 and 80 DAS also significantly differed by the treatment.

The plant N, K, Ca, Mg, Fe and Mn content up to 80 DAS, were significantly affected by the treatments. These observed variations were because of aging and treatment effects. The P, S, Zn and Cu content of the plant as a whole was not significantly affected by treatments but affected the process of aging (Appendix 8d). However, the treatments might have some influence on nutrient concentration at particular stage.

The total uptake of nutrients as a whole except Ca and S were significantly affected by the treatments due to variations in DMP. The non-significant relationship between Ca and S uptake as a whole with treatments might be because of specific ionic interaction, which governed the rate of uptake and concentration at specific conditions.

The plant N content decreased from early growth period till pod formation started (60 DAS) after which they remained fairly constant till maturity. The same was also observed by Williams (1979).

Nearly more than 60 per cent of N taken up was present in kernels (Fig. 8). This was in agreement with reports of Muralidharan and George (1971) and Balasubramanian *et al.* (1980). However, this was contradictory with the findings of Naphade (1970). He reported that the uptake of N by haulms was more than pods. Sichmann *et al.* (1970) reported N removal of around 342 kg ha^{-1} by groundnut crop. In the present experiment it varied from 332 to 442 kg ha^{-1}.

Relatively, higher content of plant N was recorded with organic meal applied treatments than mineral P applied treatments at 80 DAS. This might be synergetic effect of organic N, P and S on nitrogen fixation and uptake. Relatively higher N content in kernel was recorded with treatments, which received FYM. This might be because of synergetic effect of FYM on nutrient availability, nodulation and N fixation (Patil *et al.*, 1998). Higher uptake of N in kernel was also reported by Chawale *et al.* (1995), Loganathan *et al.* (1996) and Asha *et al.* (1996) with FYM application.

Higher quantity of N in kernel was observed with T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$], which was because of higher kernel yield and nitrogen content. This was also because of favourable effect of P, Ca and S on nitrogen uptake (Pasricha *et al.*, 1972).

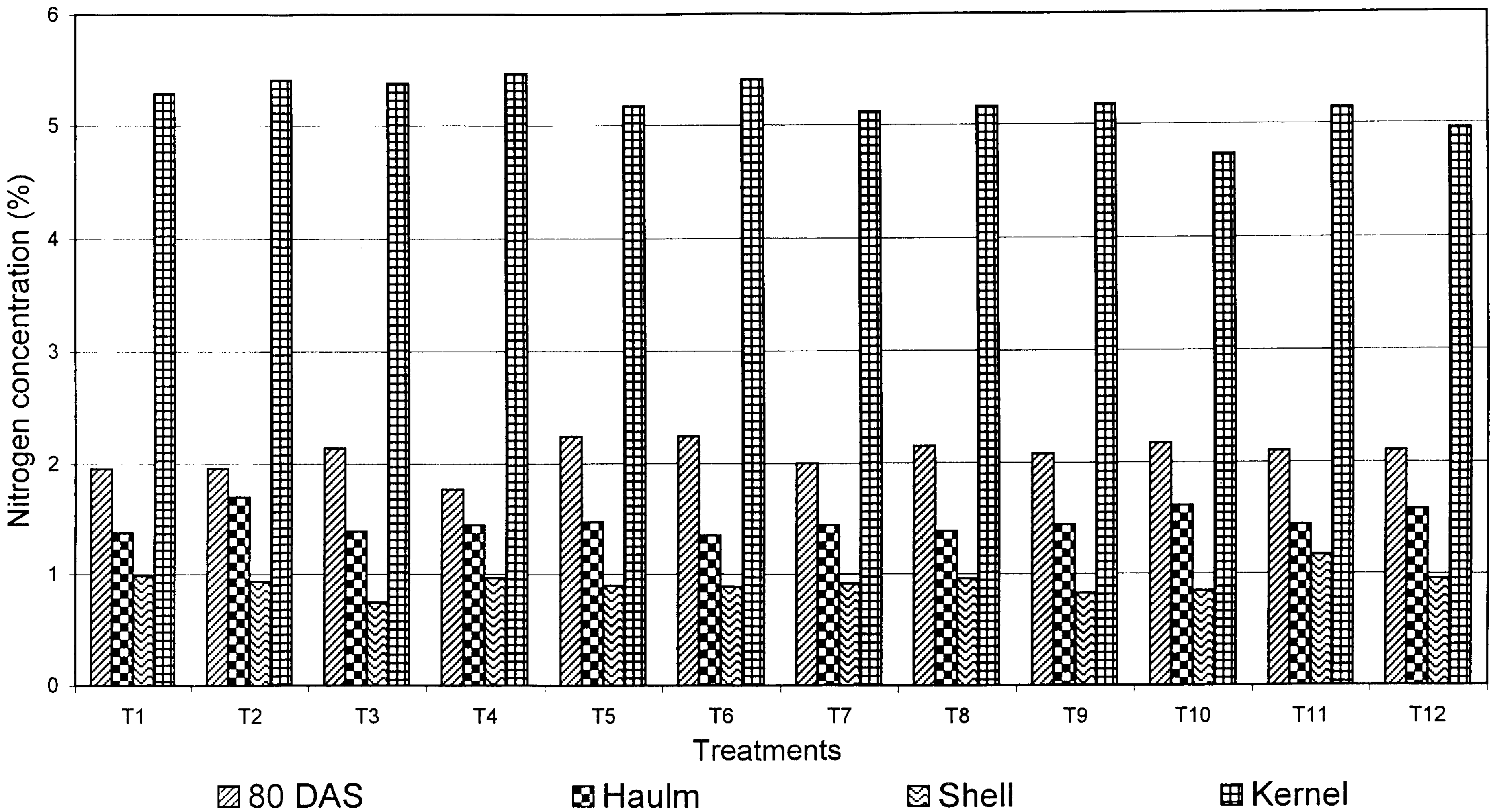
Higher shell N concentration was recorded with T_1 [R (P as MP)], T_2 [R(P as SSP)] and T_4 [R (P as OM)S_{56}]. However, high N uptake in shell was reported with T_4 [R (P as OM) S_{56}] which was because of higher shell yield and relative higher N content. This was also the synergetic effect of FYM with applied Ca and S (Sharma, 1983).

The favourable climatic and edaphic conditions along with suitable management practices might be the probable reasons for better N fixation in present experiment, which was to the tune of 200-250 kg ha^{-1}, where as the reported values are from 183-189 kg ha^{-1} by Giller and Wilson (1991).

P uptake by groundnut is important for better pod, oil and protein yields. The efficiency of applied P was comparatively low compared to other nutrients.

In haulm, higher concentration of P was recorded with T_1 [R (P as MP)] and T_2 [R (P as SSP)], which received P from inorganic sources (Fig. 9). These inorganics favoured early uptake of P and failed in later periods. Being an immobile element most of absorbed P was retained in haulm itself. These resulted with higher uptake of P in haulm than kernel. But the P uptake in kernel was more in all the plots receiving organic meal compared to haulm except in T_5 [$OM_{500}N_{15}K_{75}$]. This was because of relative insufficiency of P when applied without lime and FYM.

Fig.8 Influence of treatments on plant nitrogen concentration at 80 DAS and in different parts at harvest.



Among the 500 kg organic meal applied treatments, T_5 [$OM_{500}N_{15}K_{75}$] recorded lower P uptake than T_3 [R(P as OM)] and T_4 [R (P as OM)S_{56}]. T_9 [$OM_{500}N_{15}K_{75}L_{860}$] recorded the higher uptake compared to T_5 [$OM_{500}N_{15}K_{75}$]. This was because of increased availability of P in acid soils by the action of liming. The synergetic effect on P uptake by Ca was reported by Tisdale *et al.* (1993).

Application of P and S favoured higher P uptake in T_2 [R(P as SSP)] over T_1 [R(P as MP)] and T_4 [R (P as OM)S_{56}] over T_3 [R(P as OM)] in haulm, shell and kernel. This favourable effect of S on P uptake was also reported by Yadav and Singh (1970) and Pathak and Pathak (1972).

The groundnut crop requires large amount of K and it takes up much more K than required (Reid and Cox, 1973). The concentration of K was observed to be high in initial stages and again decreased there after. Compared to N and P, K content in shell was higher and was almost equal to the content in kernel (Fig. 10). The concentration of K was the highest in haulms. The K uptake was as high as around 200 kg ha^{-1}. So, it was well recognized that groundnut is a heavy feeder of K and adequate supply of this nutrient is indispensable to obtain better yield (Lakshminarayana and Subbiah, 1996). Higher uptake of K was also due to favourable effect on N, P, Ca and S in the experiment. The favourable effect of P, Ca and S also reported by Chevalior (1976) and Soundararajan (1976).

The relative Ca content was 6-8 times in haulm than shell and kernel. Chalal and Virmani (1973) reported that 66 per cent of absorbed Ca was in leaves and only 13.8 per cent in pods. The Ca content in shell and kernel was almost equal. But Pillai *et al.* (1984) reported that the Ca content of shell was twice that of kernels.

The relative proportion of Ca was the highest in haulms followed by kernel and shell. In the present experiment, higher concentration of Ca by shell might be because of increased absorbing pod area which in turn resulting with higher absorption and retention of Ca by shells (Nijhawan and Maini, 1966).

From 80 DAS onwards, the calcium concentration in the plants applied with levels of organic meal with lime was higher than the non-lime applied plots because of liming effect (Fig. 11). Application of SSP (T_2 [R (P as SSP)]) resulted with higher Ca concentration in haulm and kernel than T_1 [R(P as MP)]. This might be because of favourable effect of S on Ca uptake. But in comparison of T_3 [R (P

Fig. 9 Influence of treatments on plant phosphorus concentration at 80 DAS and in different parts at harvest.

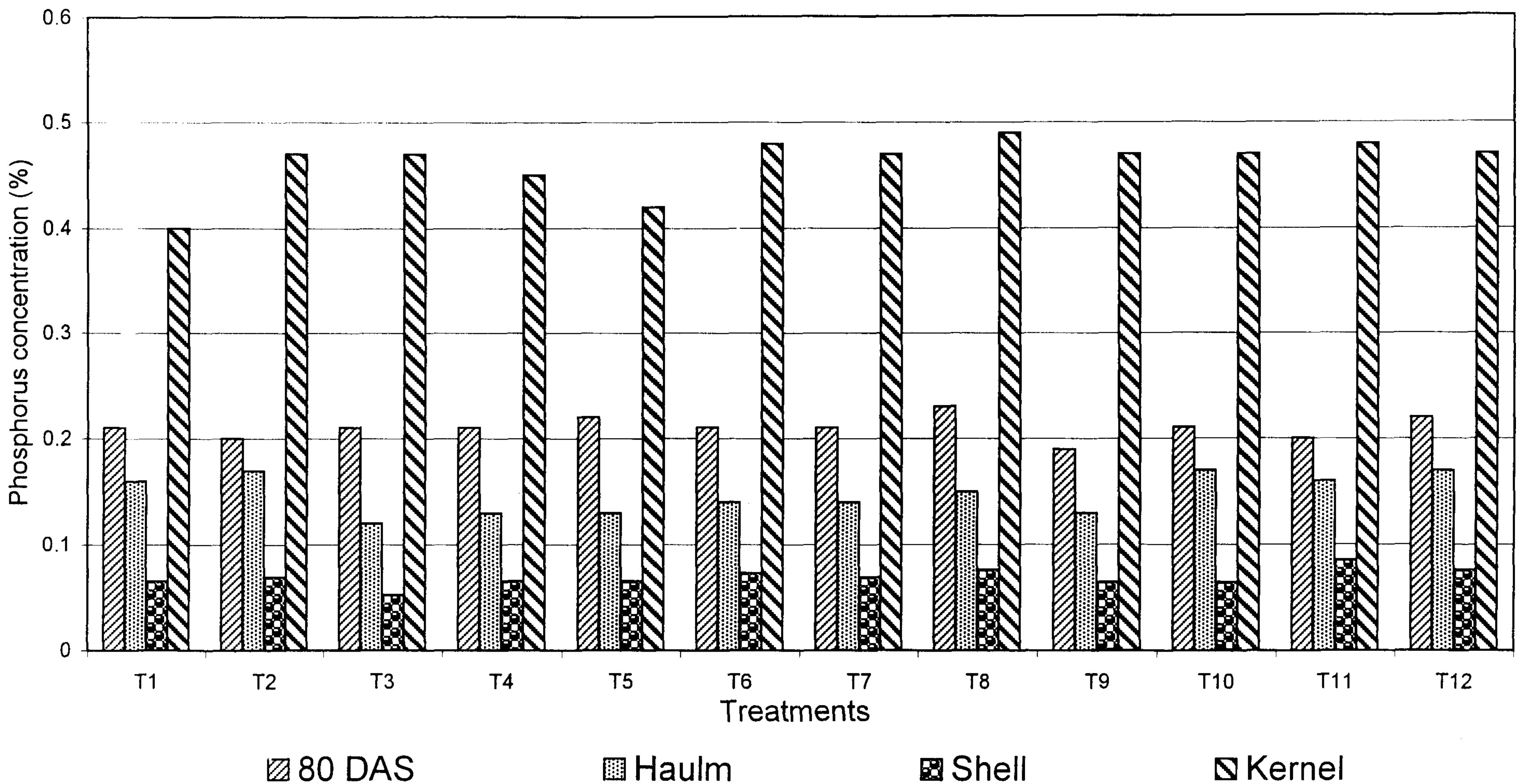
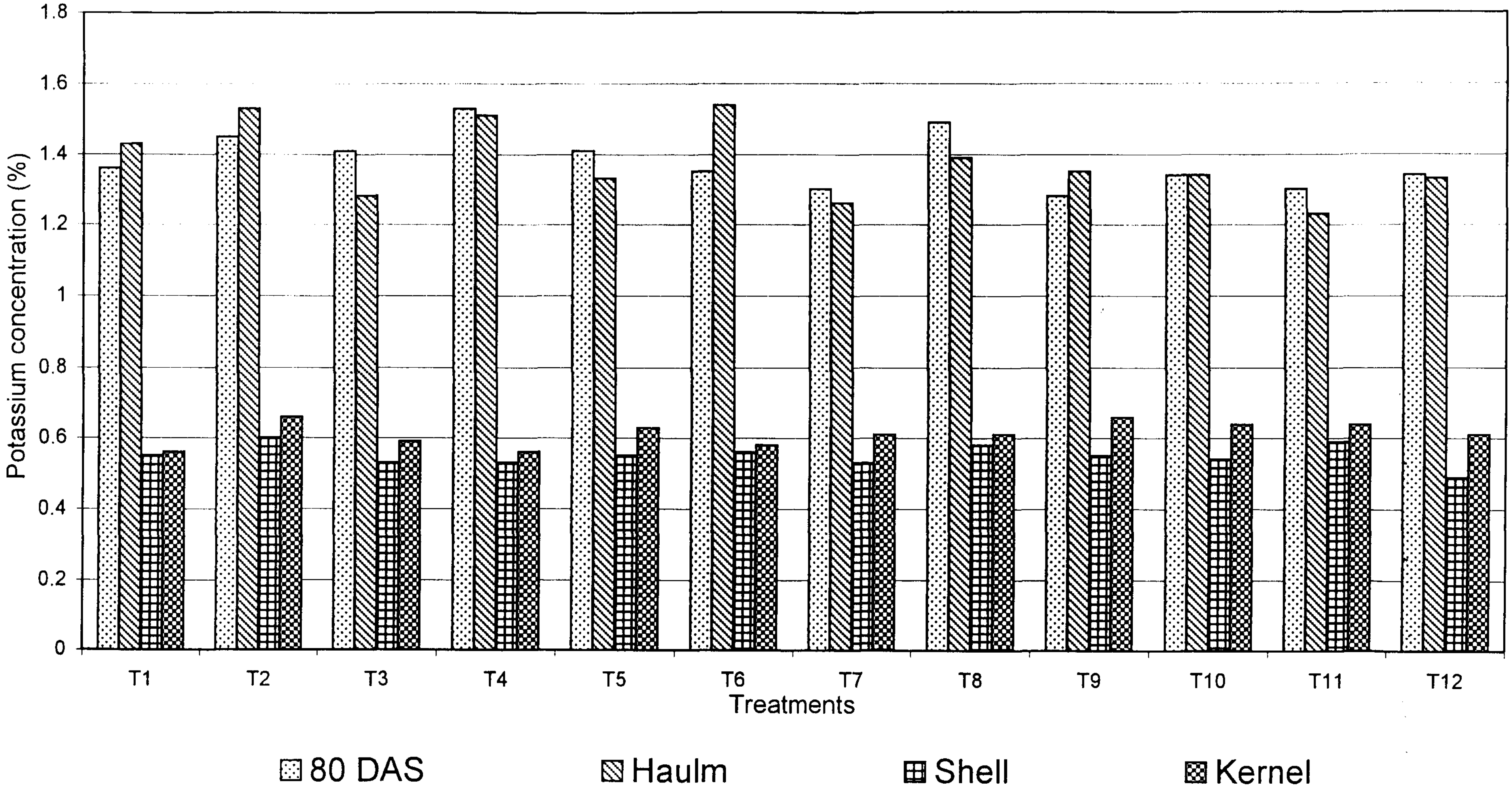


Fig.10 Influence of treatments on plant potassium concentration at 80 DAS and in different parts at harvest.



as OM)] and T_4 [R (P as OM)S_{56}], T_4 recorded higher Ca concentration in shells only.

Among the graded level of organic meal treatments higher Ca concentration in kernel and shell were observed with lime applied treatments. This might be because of higher availability of Ca than non-lime applied treatments.

In some treatments, the observed Ca uptake at harvest was lower than that of uptake at 80 DAS. This might be because of shedding of leaves, which was the main sink of Ca. Similar reduction in Ca uptake was also experienced by Rao (1977).

The Mg uptake after 60 DAS, was the highest with T_6 [$OM_{1000}N_{10}K_{75}$] due to higher biomass yield. However, the Mg uptake in haulms and kernel was not significantly affected by treatments during harvest and the content was almost equal with less content in shell (Fig. 12).

The S concentration and uptake was significantly affected by treatments during the initial stages only. The addition of S through fertilizer or elemental S did not influence plant S content and uptake at later stages. This was mainly because of availability of adequate amount of S in the soil. But the added S fertilizers and manures might have played a significant role in nutrient proportion and balance. Initial plant S content was higher and decreased towards maturity. The S content in haulm, shell and kernel was almost equal showing the peculiar role of S in groundnut nutrition (Fig. 13). It is reported that to produce one tonne of grain or seed on an average of 12 kg S for oil seeds, 8 kg for pulses and 3-4 kg for cereals are required (Tandon, 1991a).

The Fe concentration in the shell was 3-4 times higher than haulms and 8-10 times higher than kernel (Fig. 14). Higher doses of organic meal, T_7 [$OM_{1500}N_5K_{75}$] and T_8 [$OM_{2000}K_{75}$] registered lower haulm iron content. This might be because of neutralization effect of organic meal. Organic meal with lime treatments T_{10} [$OM_{1000}N_{10}K_{75}L_{720}$] and T_{11} [$OM_{1500}N_5K_{75}L_{580}$] recorded lower iron uptake at harvest, even though there was no significant difference.

T_6 [$OM_{1000}N_{10}K_{75}$] and T_4 [R (P as OM)S_{56}] recorded higher iron uptake at most of the stages and at harvest. It might be because of higher Fe concentration and biomass yield. The treatments that received FYM and Lime (T_1 to T_4) had failed miserably to reduce the Fe and Mn concentration in haulm. This might be

Fig.11 Influence of treatments on plant calcium concentration at 80 DAS and in different parts at harvest.

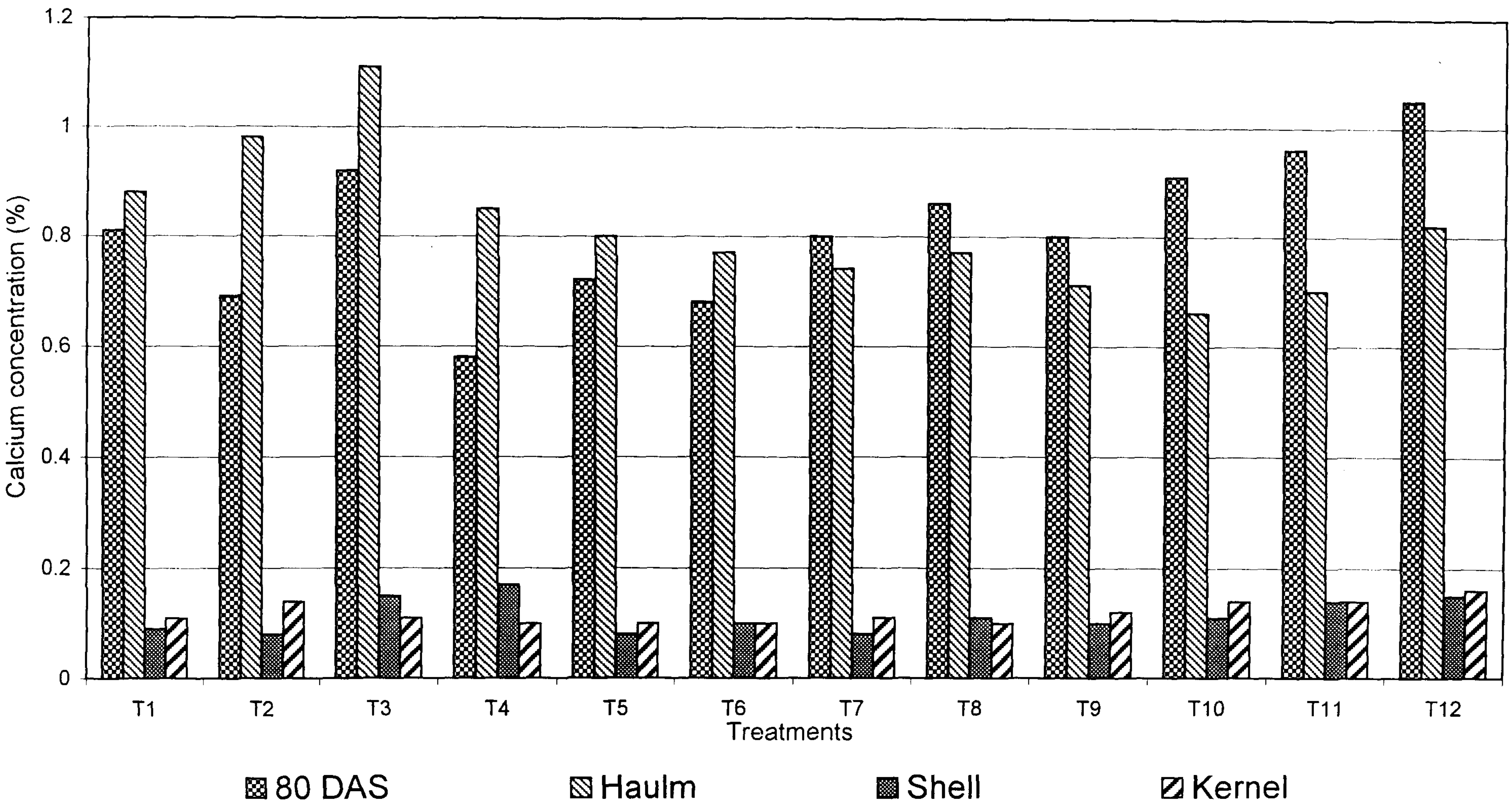


Fig.12 Influence of treatments on plant magnesium concentration at 80 DAS and in different parts at harvest.

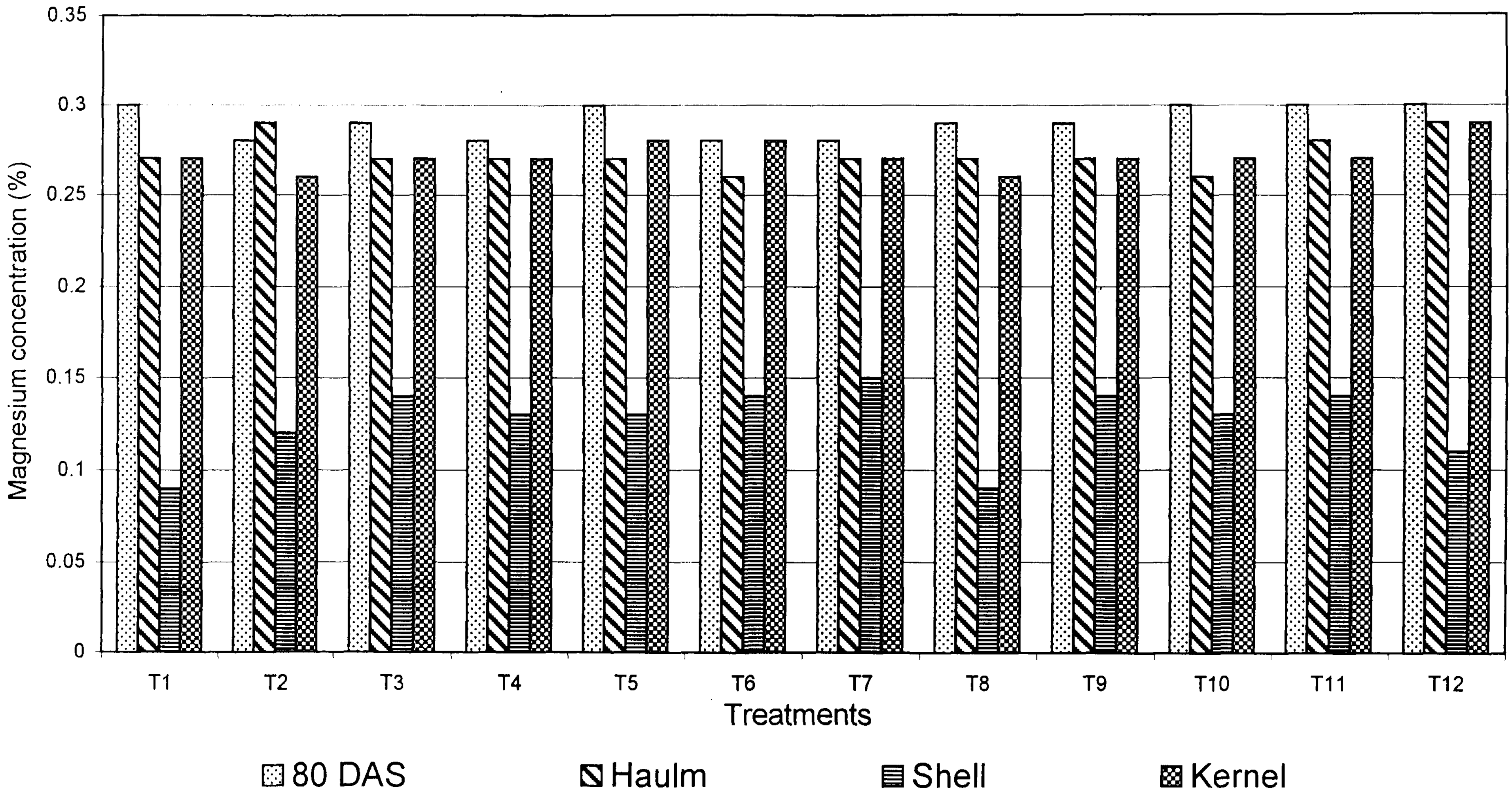
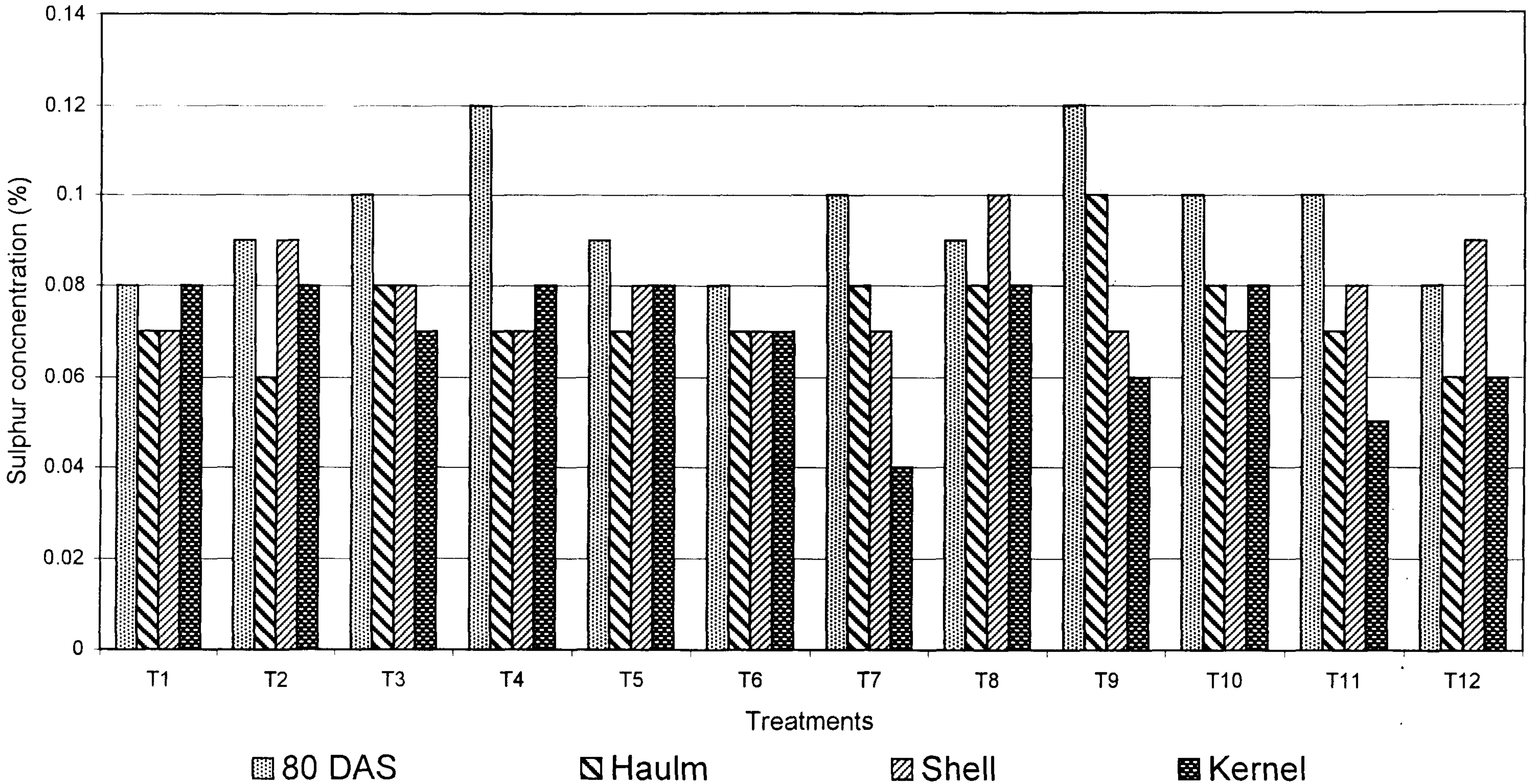


Fig.13 Influence of treatments on plant sulphur concentration at 80 DAS and in different parts at harvest.



due to immobilization of applied Ca by the organic acids produced during decomposition.

Similar to Fe, Mn concentration was also affected by doses of organic meal. High dose of organic meal without lime T_7 [$OM_{1500}N_5K_{75}$] and T_8 [$OM_{2000}K_{75}$] and graded levels of organic meal with lime T_9 [$OM_{500}N_{15}K_{75}L_{860}$] to T_{12} [$OM_{2000}K_{75}L_{440}$] recorded the lower Mn content in haulm, due to neutralization effect of organic meal and lime (Fig. 15).

Mn content at harvest was the highest in haulm followed by shell and kernel. However, T_6 [$OM_{1000}N_{10}K_{75}$] recorded higher haulm and shell Mn content resulting in higher Mn uptake.

Zn and Cu concentration at harvesting stage did not differ significantly. However, the highest uptake was recorded with T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$] due to higher yield. The Zn content was higher in kernal than haulm and shell (Fig. 16). But, Cu concentration of haulm, shell and kernel did not follow a particular pattern.

The nutrient ratios like N/S, P/S, K/S, Ca/S, N/Mg, K/Mg, S/Mg ratios as a whole (20 to 80 DAS) were not affected by imposed treatments, but the aging process caused significant influence on these nutrient ratios. However, the Ca/Mg and P/Mg ratio as a whole were not affected by treatments and aging (Appendix 8f). This is a mutual antagonistic effect of Ca on Mg uptake. The scenario of groundnut cultivation, balancing Ca and Mg ratio is important for higher production. The lower Ca/Mg ratio at harvest was recorded with T_4 [R (P as OM)S_{56}] (2.14). Frageria (1973) reported the favourable ratio for higher yield as 2:1. But the realized higher yield in T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] was because of the indirect effect of another antagonistic element like K which resulted in favorable K:Ca:Mg ratio of 5:3:1. Rao *et al.* (1980) suggested that the optimum ratio for higher production should be around 4:2:1.

This is the clear indication that, the relative nutrient content in the plant may change because of treatments, but nutrient ratios may not be affected. In the plant system, low yield expression is because of direct interaction of nutrients, which decides the uptake pattern of the crop. From this it is concluded that, additive, deletive and ameliorative management systems can effectively control the excessive interference of any element. On an average of 42 kg N, 3.5 kg P, 5.75

Fig.14 Influence of treatments on plant iron concentration at 80 DAS and in different parts at harvest.

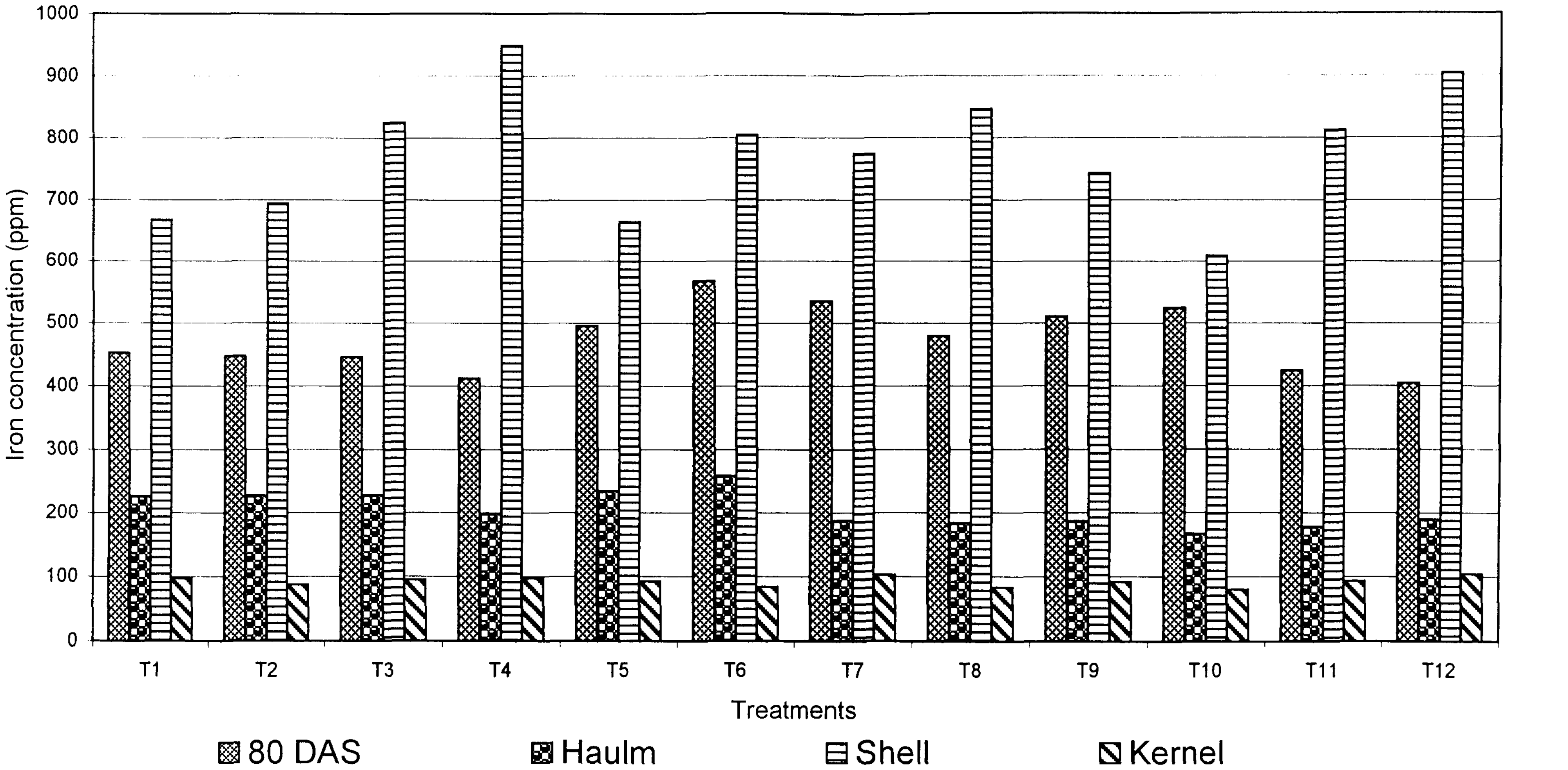


Fig. 15 Influence of treatments on plant manganese concentration at 80 DAS and in different parts at harvest.

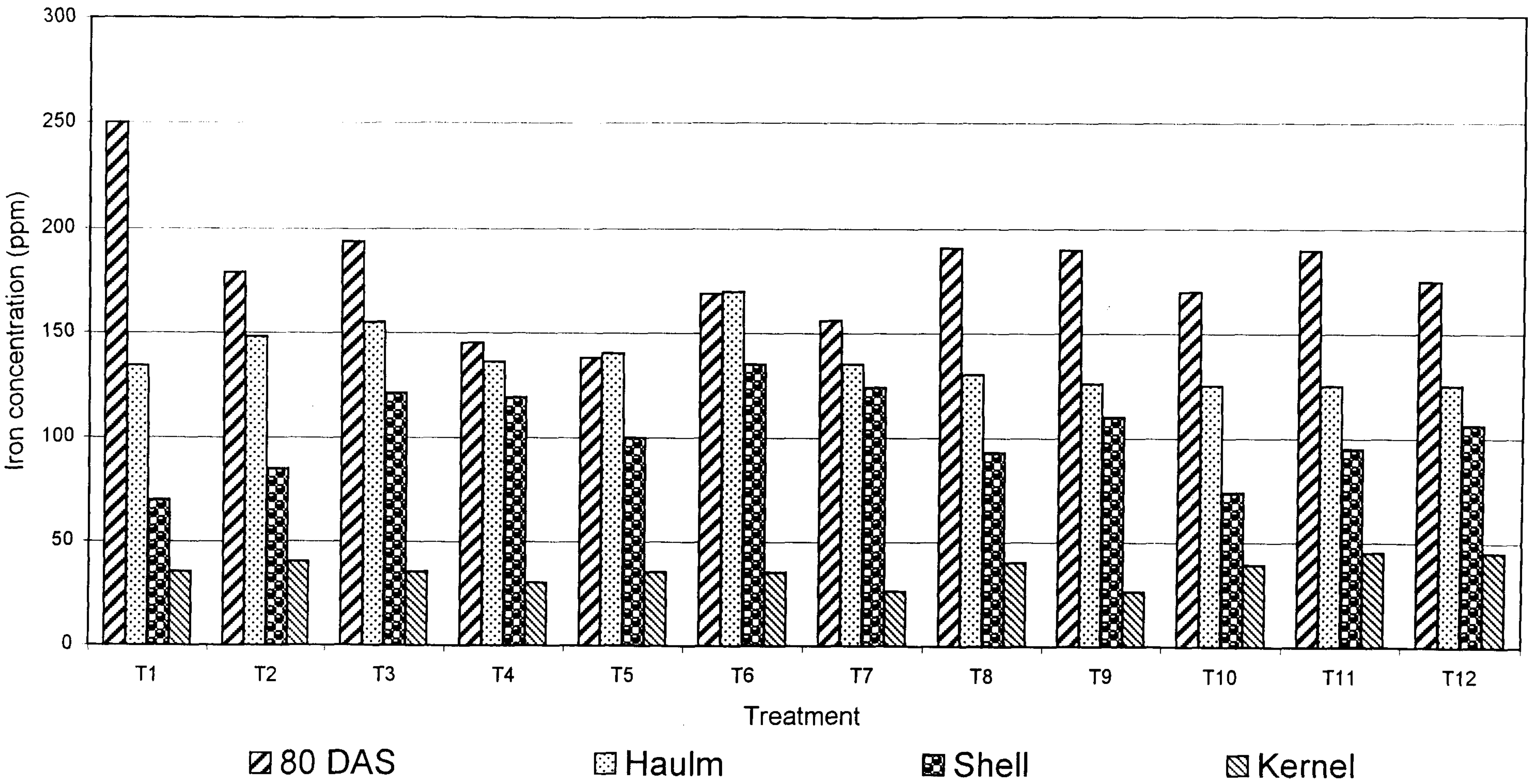


Fig. 16 Influence of treatments on plant zinc concentration at 80 DAS and in different parts at harvest.

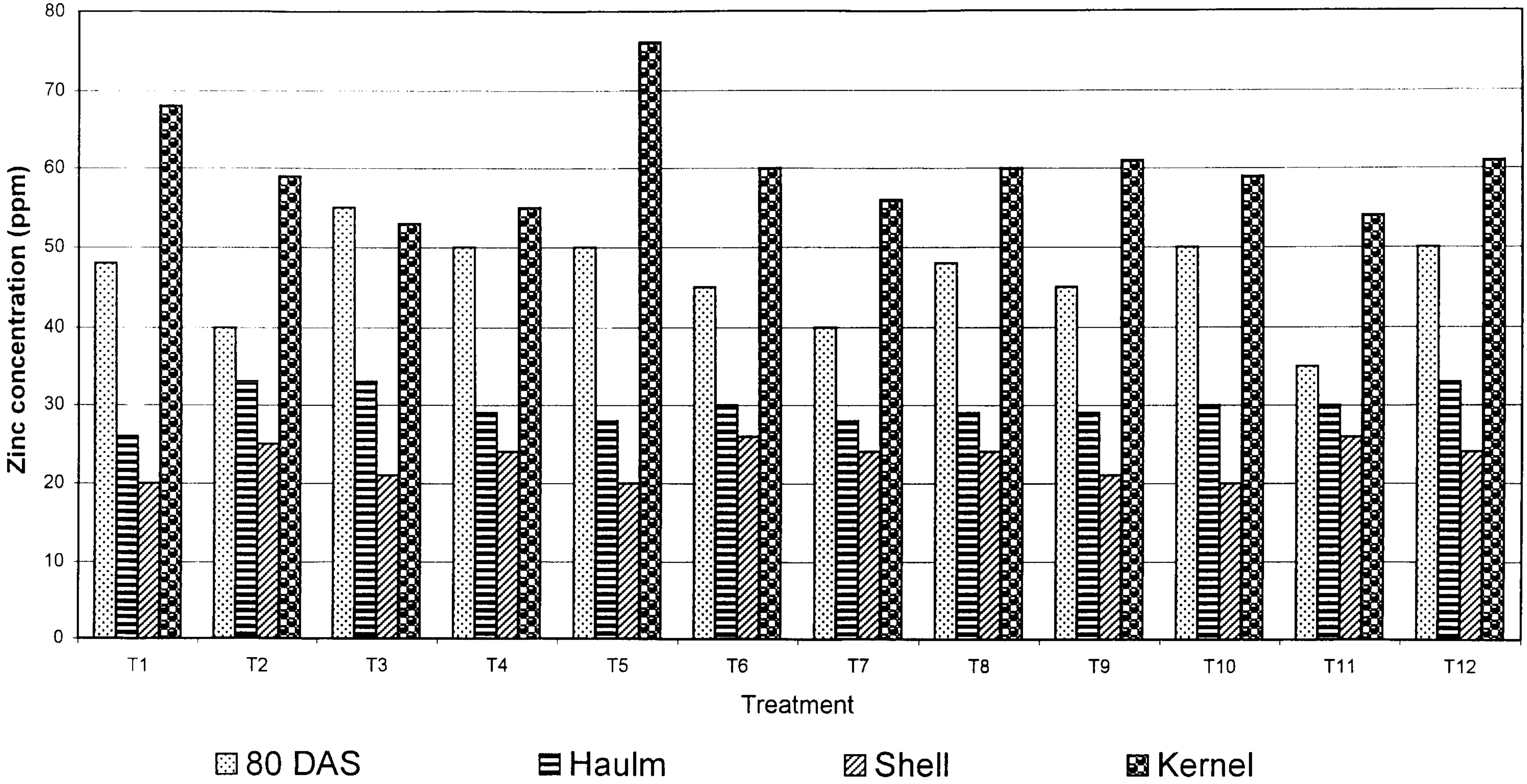
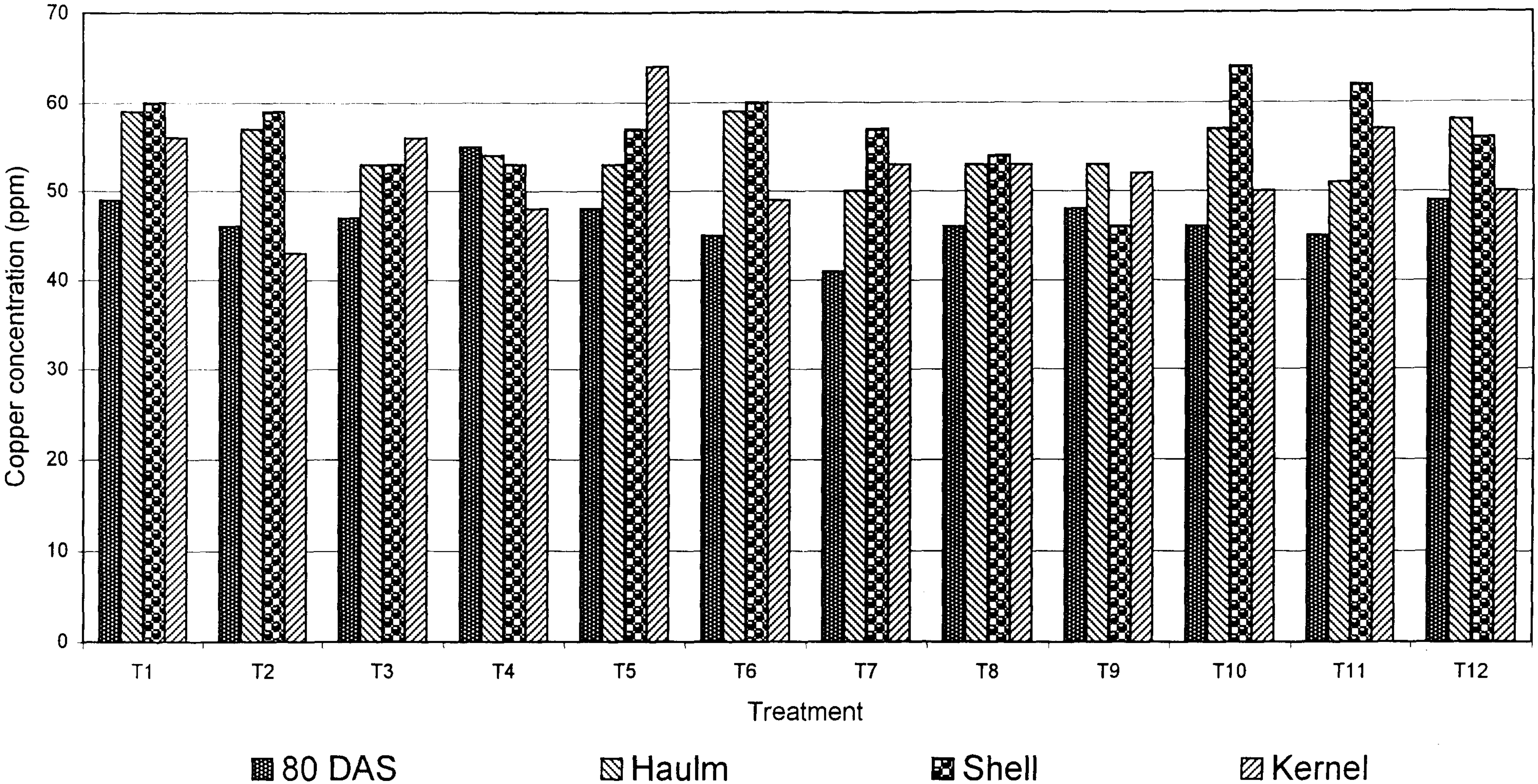


Fig.17 Influence of treatments on plant copper concentration at 80 DAS and in different parts at harvest.



kg Ca, 1.1 kg K, 2.3 kg Mg, 0.8 kg S, 250 g Fe, 55 g Zn, 55 g Mn and 55 g of Cu were taken up by 1000 kg pods.

The average nutrient uptake by 1000 kg haulm was around 14.5 kg N, 1.3 kg P, 14 kg K, 8 kg Ca, 2.65 kg Mg, 0.8 kg S, 180 g Fe, 130 g Mn, 30 g Zn and 55 g Cu. However, the haulm and pod yields varied among treatments, the nutrient taken for the production of unit kernel and haulm were almost same between treatments. So it is concluded that realized yield variations are due nutrient to ratios rather than contents present in the plant.

T_1 [R(P as MP)] recorded lower efficiency of all elements (Table 39), where as with same level N, P_2O_5 and K_2O application in T_4 [R (P as OM)S_{56}] resulted with higher efficiency of N, P_2O_5 and K_2O. Similar to this T_6 [$OM_{1000}N_{10}K_{75}$] recorded on par yield with T_4 [R (P as OM)S_{56}], with higher efficacy of N, K_2O and S in this treatment. T_7 [$OM_{1500}N_5K_{75}$] recorded higher efficiency of N and K_2O. The low efficacy of nutrients was due to their higher levels and the yield could be further improved by reducing the levels of these elements. This would mean that realized yield of any normal situation is the result of high input use efficiency of some elements and low efficiency of some others, which may be due to ionic interaction of elements in soil and plants. The combination of nutrients in higher efficiency levels may result in increased yield with low input use.

5.7. Soil parameters

A perusal of data presented in Table 40 showed that the soil properties such as organic carbon, soil pH and EC have shown decline in its value after the experiment. The range of reduction in organic carbon content which is the reflection of nitrogen status of the soil would be expected as the groundnut being a leguminous crop which could fix atmospheric nitrogen and use it for growth. A reduction in organic carbon would mean that the plant had been dependent on soil N as well as symbiotically fixed nitrogen resulting in the plant uptake of 331 to 442 kg ha^{-1}.

There are indications that under optimum conditions groundnut plant can fix atmospheric nitrogen to an extent of 200 to 260 kg ha^{-1} (Williams, 1979 and Dart and Krantz, 1997).

It is possible that very high N content of plant across the treatments, might be the sum total of effect of N absorbed from soil as well as N fixed by the crop. This position is supported by reduction in soil pH inspite of added Ca. This can be explained by possible production of organic acids by mineralization of organic carbon. A very high microbial activity in early stages of growth (Table 45-47) in rhizosphere would add credence to this hypothesis.

The increased uptake of almost all elements at early stages of growth as evidenced from Table 27-37 might have increased the N uptake in early stages of crop growth. This might have been the predisposing factor in the high use of native nitrogen. These results would tend to suggest that the phenomenal yield level recorded by this crop be at least in part due to use of native nitrogen. The relatively high N content of soil before experiment as evidenced by the organic carbon ratio above one per cent and its subsequent decline stand in testimony to this hypothesis. And hence, VRI-4 groundnut is a leguminous crop combining with non-leguminous nature.

The characteristic expression of wild features by the plant possibly is the indications in this direction. Decline in number of nodules in maturity phase combined with 10-25 per cent increase in root weight 55-66 per cent increase in growth of above ground portion, with an increase in N uptake would mean that there might have been utilization of the soil N almost up to harvest.

Higher availability of native organic carbon was also the indication of better availability of other soil nutrients. Before and after the experiment soil available N, exchangeable Mg and available Cu and Zn were not affected by treatments. However, an average of 30 kg of available N depletion was observed due to groundnut cropping.

The P depletion from soil was not significant. However the available P content before and after was significantly different due to treatments. Because of higher application of organic meal, T_8 recorded an increase in soil available P. Higher depletion of soil available P was reported with organic meal with lime applied plots. This might be because of relative immobilization of P by added lime and faster depletion by the growing crop. In general higher uptake of soil K of around 100-200 kg was observed.

The treatments had favourable effect over soil exchangeable Ca content. Addition of lime with FYM (T_1 to T_4) resulted with increase in exchangeable Ca content. Organic meal without lime favoured better availability of exchangeable Ca present in soil at harvest. But when lime was applied with organic meal it resulted in depletion of available pool, which might be because of relative fixation of mineralized P from organic meal along with mineral Ca.

An average of 30 to 50 kg Mg was depleted because of groundnut cropping. Addition of S resulted with enhanced availability in soil solution (T_2 to T_4). In T_4 [R (P as OM)S_{56}], application of mineral S resulted with minimum depletion from soil. However organic meal application with or without lime also resulted with depletion in soil exchangeable pool.

Relative lower level of available Fe in soil after the crop was because of liming in T_9 [$OM_{500}N_{15}K_{75}L_{860}$] to T_{12} [$OM_{2000}K_{75}L_{440}$]. There were not much differences in the available Zn and Cu even after cropping because of very little absorption of these nutrients.

5.8. Rhizosphere microbial activity and dynamics

The population and activity of soil microfauna is important in cropping environment and it may also affect the expression of yield pattern of the crop. In general, legumes are having pronounced rhizospheric effect by the way of exudation of organic compounds (Starkey, 1929), which was evidenced from the increase in soil microbial population after sowing to the extent of 200-900 per cent (Table 43-46) in the present study.

In general, the microbial population varied highly between stages and treatments. In an earlier studies, Katznelson (1965) and Goyal *et al.* (1992) reported that the change in microbial biomass might be because of cropping, change in soil conditions and fertilizer treatments, which is in accordance with the present study.

The population of fungi, bacteria, actinomycetes and rhizobia in general were higher at 20 DAS, declined with crop growth and again increased from 80 DAS to harvest. This trend of population was in contradictory to the reports of Arunachalam (1975) as the microbial population increased progressively towards maturity. However, the pattern of dynamics of fungal population was in agreement with El-Hissy *et al.* (1980), who reported that the fungal population was higher up to peak flowering, decreased at pod formation stage and increased towards harvest. Similar to this, Lynch and Panting (1982) reported that the microbial population increased up to maximum root production and in this present experiment, higher rate of root production was observed from 20-40 DAS (Table 12) might be triggered due to the microbial population.

In the present study, higher population of bacterial, fungi and actinomycetes population at harvest might be due to addition of dead and decaying root materials as organic matter to the rhizosphere soil after the physiological maturity of the crop, which might have resulted in higher microbial activity.

Higher rhizobial population in rhizosphere at harvest was because of release of bacteroids from the matured nodules by senescence and disintegration after attaining the physiological maturity.

In all the treatments, addition of FYM and organic meal with small dose of N and P fertilizer, resulted with increased microbial activity over organic matter as a mineralization process (Parkar, 1977 and Sharma *et al.*, 1983) resulted in higher microbial activity and population at 20 DAS.

The population of bacteria and *Rhizobium* were not affected by the treatments as a whole, but time duration played major role in variations in population at particular stage. The treatments may have indirect effect on these populations but not direct. The population of fungi and actinomycetes were affected by treatments and time duration (Appendix 8h).

In the study, the fungal population increased linearly and found to be in the range of 11-18 x 10^4 cfu g^{-1} of soil. In earlier studies, it has been observed that the fertilizer NPK application stimulated the growth of bacteria and fungi in the rhizosphere during the early stages of plant growth. In the present study, the same trend was observed (Emmninath and Rangaswami, 1971).

The lime application resulted with increase in the fungal population at the time of harvest except in the case of T_1 [R (P as MP)]. In a similar study, the lime as well as urea together increased the bacterial population. In the present study, the increase in fungal population along with bacterial population due to lime application may be attributed to the stimulatory effect on the rhizosphere population of fungi and bacteria (Chandra *et al.*, 1981).

Except T_1 [R (P as MP)], all treatments recorded increased fungal population at harvest. Earlier studies have reported that the P appliction recorded the maximum bacterial population (Bagyaraj and Rangaswami, 1967). But in the present study, the fungal population was found to be increased at the time of harvest when compared to the time of sowing, which is unusual. This may be attributed to the influence of the legume which are known to exert pronounced effect on the rhizosphere microorganisms (Starkey, 1929).

In all the treatments, the bacterial population was more at the time of harvest, when compared to the population at the time of sowing (Table 44). These results are in concurrence with the earlier results (Gautom *et al.*, 1984 and Bagyaraj and Rangaswami, 1967), where the increase in bacterial population was noticed due to the application of NPK and FYM (Bagyaraj and Rangaswami, 1967). In the present study, the maximum bacterial population was noticed in the case of T_5 [$OM_{500}N_{15}K_{75}$] at harvest, which indicates organic amendment of soil increases the bacterial population. However, organic amendments can also have marked stimulatory/inhibitory effects on the rhizosphere population of fungi and bacteria (Chandra *et al.*, 1981).

In the present study, the rhizobial population in the soil influenced at the time of harvest. The increase in rhizobial population might be due to senescence and disintegration of 20-25 % nodules at the time of maturity and release of bacteriods into the soil as reported by Erdman (1959) and Rao (1979).

The legumes are generally known to exert pronounced rhizosphere effect (Starkey, 1929) and the bacteria in general favoured in the rhizosphere till the flowering stage in groundnut (Katznelson *et al.*, 1965).

This may also be attributed to the influence of rhizosphere effect due to root exudates of the host plant. More over the SSP and organic meal as P providers and energy source to the soil organisms especially nitrogen fixers (McLaughlin *et al.*, 1990 and Krishna, 1997).

However, T_2 [R(P as SSP)] recorded higher fungal, bacterial, actinomycetes and rhizobial population which might be due to the favorable effect of sulphur in combination with FYM on microorganisms. This was confirmed with the results of Bagyaraj and Rangaswamy (1967). Higher number of microbial population at 20 DAS after addition of organic manure might be beneficial for crop growth through the process of mineralization.

5.9. Economics of groundnut cultivation

Adaptability and sustainability of a management practice depends upon the nature of the practice, conditions present, availability of necessary materials and economic viability of the practice etc.

The variable cost *i.e.*, cost of fertilizers and manures of T_1 [R (P as MP)] and T_2 [R (P as SSP)] were high due to requirement of higher quantity of P fertilizers and its higher cost. Organic meal applied treatments recorded lower variable cost because of local availability and less cost. T_9 [$OM_{500}N_{15}K_{75}L_{860}$] to

T_{12} [$OM_{2000}K_{75}L_{440}$] recorded relatively higher variable cost due to cost of lime involved.

The variations in total cost occurred because of variation in the share of cost (9-28 per cent) caused by the expenditure on fertilizers and manures.

Higher returns were recorded with T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] because of higher pod production. But higher net return obtained from T_6 [$OM_{1000}N_{10}K_{75}$] was due to lesser cost of cultivation as compared to T_4 [R (P as OM)S_{56}]. The lowest net return was recorded with T_1 [R (P as MP)] which had a higher haulm production and it resulted in a benefit cost ratio of 2.1. The highest benefit cost ratio was recorded in the treatments T_6 [$OM_{1000}N_{10}K_{75}$], T_7 [$OM_{1500}N_5K_{75}$] and T_4 [R (P as OM)S_{56}].

SUMMARY AND CONCLUSION

6. SUMMARY AND CONCLUSION

An investigation on "**Functional efficiency of organic meal on groundnut production**" was carried out in the Department of Agronomy, College of Horticulture, Kerala Agricultural University, Vellanikkara during 1999. The main objectives of the study included the elucidation of functional efficiency of organic meal in groundnut nutrition, its mechanism of influence in relation to other mineral and organic sources and role of organics in soil rhizosphere characteristics. The study also included the role of S on groundnut production and its role in modifying the availability of P in organic meal.

The salient findings of the study are summarized below:

- Groundnut can be grown successfully in laterite soils of Kerala with selection of suitable variety and season.
- Application of mineral or fertilizer P favoured the earlier growth and development and failed to maintain it during later periods where as organic meal encouraged better crop growth in later periods.
- Reduction in lime application (<1000 kg ha^{-1}) could favour the higher yield and around 200-300 kg of Ca ha^{-1} will be sufficient.
- Higher levels of organic meal showed negative effect on some growth characters and ultimately on yield.
- The low response of applied S for groundnut might be due to higher level of available S in soil.
- Excessive branching reduced pod yield.
- The leaf chlorophyll content was remarkably stable and variations due to treatments were marginal and inconsistent over time.
- Increase in dry matter production and chlorophyll content after 80 DAS indicated that the pod yield can be further improved by intervening the process of carbohydrate diversion and differentiation.
- Medium to high doses of organic meal without lime (T_7 [$OM_{1500}N_5K_{75}$] and T_8 [$OM_{2000}K_{75}$]) and high dose of organic meal with lime (T_{12} [$OM_{2000}K_{75}L_{440}$]) showed negative effect on nodule count and weight.
- Inoculation with native soil *Rhizobium* favoured better nodulation. Liming had no favourable effect on nodulation.

- Sulphur application had favourable effect on LAD during 80 DAS to harvest through retention of higher number of leaves.
- The time taken for 50% of the plants for flowering was around 26-27 days and was not affected by treatments.
- In T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$], the pod distribution pattern (Single, double and triple seeded) was different even though they could produce comparable number of pods and pod yield. This reveled that the pod distribution pattern could be altered through applied nutrients.
- T_1 [R(P as MP)] produced relatively higher haulm yield due to lack of reproductive sinks. Higher pod yield was obtained in T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$].
- T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] recorded higher shelling percentage. The yield of T_4 [R (P as OM)S_{56}] could be further improved by improving the shelling percentage.
- There was lower pod weight in T_2 [R (P as SSP)], T_5 [$OM_{500}N_{15}K_{75}$] and T_9 [$OM_{500}N_{15}K_{75}L_{860}$] which received only 75 kg P_2O_5 ha^{-1}. This was because of apparent insufficiency of P. The present study also revealed that the requirement of P_2O_5 would be more than 100 kg for groundnut.
- The percentage of pod to peg was higher with T_7 [$OM_{1500}N_5K_{75}$] and T_6 [$OM_{1000}N_{10}K_{75}$]. So the yield of T_4 [R (P as OM)S_{56}] can be further improved through improvement of pod to peg ratio.
- An increase in 100 pod weight and 100 kernel weight over the earlier reported ones contributed towards very high yields.
- There was a positive correlation between pod yield and the oil and protein yields.
- Relative better availability of nutrients especially P with higher chlorophyll content and stability favoured the better conversion of carbohydrates to protein which was evidenced from the lower level of carbohydrate and higher level of protein than earlier reports.
- T_4 [R (P as OM)S_{56}] and T_6 [$OM_{1000}N_{10}K_{75}$] recorded the highest protein yield because of balanced and better availability of S and P along with N.
- T_4 [R (P as OM)S_{56}] recorded higher oil content and pod yield than T_7 [$OM_{1500}N_5K_{75}$], but T_7 recorded higher oil yield because of higher shelling percentage.

- The P, S, Zn and Cu contents in plants were not affected by treatments. Similarly Ca and S uptake was also not affected by treatments. This was because of specific ionic relation and interaction.
- Nearly 60 per cent of plant N was in kernels. Higher kernel N content was registered with treatments receiving FYM (T_1 to T_4).
- Higher haulm P concentration was recorded in T_1 [R (P as MP)] and T_2 [R(P as SSP)]. The higher concentration of P in T_2 [R(P as SSP)] and T_4 [R (P as OM)S_{56}] than T_1 [R(P as MP)] and T_3 [R(P as OM)] revealed the favourable effect of S and P concentration and uptake.
- Higher Ca contents was in haulm than shell and kernel. Lime application favoured higher plant Ca concentration.
- The favourable effect of S on Ca uptake was observed from the higher Ca content of shell and haulm in T_2 [R (P as SSP)] and T_4 [R (P as OM)S_{56}].
- The relative high Fe content was in shell. Higher dose of organic meal and all levels of organic meal with lime resulted with lower plant Fe content and uptake.
- The average N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn uptake was 345.0, 36.0, 151.0, 81.0, 42.0, 11.0, 3.5, 1.8, 0.8 and 0.6 kg respectively.
- The plant nutrient ratios like N/S, P/S, K/S, N/Mg, Ca/S, K/Mg and S/Mg were not affected by treatments.
- Favourable K:Ca:Mg ratio (5:3:1) was one of the key factor for higher yields in T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$]. In T_4 [R (P as OM)S_{56}] yield can be further improved through altering the applied nutrients level especially Ca.
- There was a very high microbial activity in the soil at 20 DAS and at harvest of the crop. Lime favoured higher fungal population.
- Addition of any form of organic manure with NPK is necessary for better soil microbial population and activity. Addition of S through SSP also favoured the soil microbial population.
- Higher returns per rupee invested (3.30-3.54) was recorded in T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] followed by T_4 [R (P as OM)S_{56}] (3.08).
- A depletion of around 25 per cent of organic carbon was observed after cropping. Drop in pH and EC was observed even in lime applied plots.
- The yield can be further improved through nutrient use efficiency analysis.

Conclusions

The yield of T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] could be further improved through manipulations in levels of input use. Among T_4 [R (P as OM)S_{56}], T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$] , T_4 recorded the lower number of triple seeded pods, pod to peg ratio and shelling percentage. These are important yield attributing characters. Further improvement of these factors to the level realized in T_6 and T_7 could bring out additional 780-800 kg kernel yield (1000 to 1100 kg pods).

Based on the efficiency analysis the realized yield is the combination of higher input use efficiency of some elements and lower input use efficiency of some other elements and its nutrient interactions also. From the data on nutrient use efficiency it is clear that reducing the level of calcium (lime) could increase the pod yield in T_4 [R (P as OM)S_{56}]. This revealed that the present level of lime recommendation was not necessary for getting high yield in groundnut. Reduction in the level of applied S also can increase the yield.

Similarly, the manipulations in input level (Ca and P) could increase the yield in T_6 [$OM_{1000}N_{10}K_{75}$] and T_7 [$OM_{1500}N_5K_{75}$]. The marginal reduction in soil fertility noticed after cropping could be compensated if the groundnut residue is incorporated.

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APPENDICES

APPENDIX - 1

Weekly rainfall (mm), evaporation (mm), surface air temperature (°C), relative humidity (%) and sunshine hours (h/day) at CoH, Vellanikkara From January to December 1999
(Latitude 10°31'N, Longitude 76°13' and Altitude 40.29 MSL)

Week No.	Rainfall		Evaporation (mm)	Surface air temperature (°C)			Relative Humidity (%)		Sunshine Hours (h/day)
	Amount (mm)	NRD		Max.	Min.	Mean	Morning	Evening	
1	0.0	0	39.5	31.9	21.8	26.9	75	45	9.4
2	0.0	0	34.8	32.5	21.9	27.2	79	43	9.5
3	0.0	0	48.2	32.2	22.8	27.5	70	40	10.0
4	0.0	0	41.2	32.5	19.5	26.0	74	32	7.9
5	0.0	0	31.5	33.9	22.1	28.0	83	39	10.1
6	22.8	1	35.8	34.0	23.4	57.4	80	44	9.2
7	0.0	0	43.9	34.7	23.2	29.0	79	39	10.0
8	0.0	0	53.0	34.2	24.5	29.4	70	33	6.9
9	0.0	0	53.4	36.4	22.2	29.3	74	33	10.4
10	0.0	0	40.6	36.5	23.8	30.2	92	34	9.9
11	0.0	0	34.2	35.2	25.0	30.1	89	54	8.4
12	0.0	0	31.7	34.8	25.0	29.9	91	55	8.4
13	0.0	0	34.3	34.9	25.1	30.0	89	54	7.5
14	26.2	2	39.6	34.9	24.5	29.7	90	55	7.8
15	0.0	0	32.3	33.2	25.8	29.5	86	59	7.4
16	7.6	1	27.0	33.1	26.2	29.6	89	62	4.6
17	5.2	1	25.1	32.0	25.9	29.0	90	59	4.2
18	35.0	1	30.7	33.6	25.8	29.7	89	59	6.3
19	37.0	3	21.6	31.0	25.2	28.1	90	66	6.4
20	51.6	4	22.6	30.4	25.1	27.8	88	74	5.5
21	221.2	6	20.1	29.0	23.8	26.4	95	85	2.6
22	143.2	7	21.5	29.8	23.5	26.7	96	75	5.0
23	134.7	6	22.7	29.1	22.8	26.0	94	81	4.8
24	170.9	7	17.3	28.4	22.7	25.5	95	81	1.8
25	114.8	6	20.6	29.6	23.2	26.4	95	76	5.1
26	21.6	1	26.4	30.9	23.0	27.0	92	67	8.9
27	114.7	6	20.5	29.6	23.1	26.4	95	80	3.7
28	124.6	7	18.0	29.0	22.9	26.0	96	76	3.1
29	326.5	7	12.6	26.9	22.8	24.9	97	92	3.2
30	182.8	7	13.0	27.7	22.7	25.2	95	83	1.1
31	194.1	6	17.1	28.7	23.3	26.0	95	84	2.7
32	121.5	5	20.8	29.5	23.7	26.6	95	74	5.2
*33	8.9	1	24.7	30.6	24.1	27.4	93	69	7.5
*34	3.2	1	25.1	30.0	23.6	26.8	93	69	6.9
*35	7.1	0	20.6	30.0	23.6	26.8	93	71	5.3
*36	18.3	1	18.7	30.0	23.2	26.6	93	67	4.9
*37	10.1	1	27.6	31.0	23.0	27.0	92	65	8.1
*38	0.0	0	31.0	32.6	23.4	28.0	90	56	8.5
*39	0.0	0	28.2	32.9	23.8	28.4	90	60	6.4
*40	80.5	4	19.6	30.5	23.1	26.8	93	71	4.8
*41	185.7	2	23.8	31.5	23.6	27.6	95	75	6.8
*42	161.6	5	16.8	29.5	23.3	26.4	95	80	2.9
*43	38.8	1	19.6	31.3	23.5	27.4	93	74	5.5
*44	41.9	3	20.3	29.6	22.7	26.2	96	73	6.2
*45	2.8	1	22.4	31.4	22.1	26.8	87	62	7.8
*46	0	0	26.6	31.1	22.1	26.6	74	46	10.1
*47	4	0	29.4	31.1	23.5	27.3	79	62	6.3
*48	0	0	36.4	31.9	23.7	27.8	76	55	8.7
*49	0	0	34.3	31.8	21.6	26.7	79	49	9.4
50	0	0	31.5	31.8	22.6	27.2	78	50	8.1
51	0	0	44.8	31.4	22.6	27.0	72	47	8.7
52	0	0	49.0	31.4	23.4	27.4	68	43	8.8
Total/ Mean	**2618.9**	**104**	**1502**	**31.57**	**23.44**	**28.07**	**87.23**	**61.09**	**6.71**

* Crop period

APPENDIX 2

Morphological and quality characteristics of VRI 4 groundnut

Botanical type	:	Spanish bunch
Branching	:	Irregular without flowers on main stem
Growth habit	:	Erect bunch
Stem	:	Medium thick, light green (a light purple tinge appears on maturity)
Number of n+1 branches	:	5
Number of n+2 branches	:	10
Number of n+3 branches	:	5
Length of main axis (n)	:	45.5 cm
Length of n+1 branches	:	51.5 cm
Length of n+2 branches	:	18.4 cm
Length of n+3 branches	:	12 cm
Branching pattern	:	Irregular
Pubescence on the stem	:	Sparse
Leaf	:	Small size, dark green. Oblong and elliptic
Type of inflorescence	:	Compound
Flower	:	Standard petal orange coloured, purple vein radiating from the basal
Flowers on main axis	:	Absent
Pod thickness	:	Thick
Pod size	:	Medium to big bold
Number of pods per plant	:	18.0
Pod beak	:	Slight to moderate
Pod constriction	:	None to slight
Pod reticulation	:	Moderate to prominent
Shell thickness	:	Thick
Number of seeds per pod	:	One to four seeded with the frequency of about, 9.25, 50.50, 39.00 and 1.25 percent respectively
Kernel size and shape	:	Medium in size, round to flat either one or both sides
Seed colour	:	Tan

Days to maturity	:	105.0
Dry pod yield (irrigated)	:	2392 kg ha^{-1}
Dry haulm yield (irrigated)	:	4120 kg ha^{-1}
Shelling percentge	:	72.1
100 pod weight	:	117.7 g
100 kernel weight	:	40.8 g
Oil content	:	47.0%
Oleic / linoleic ratio	:	2.2
Total soluble sugars	:	10.9 %
Protein	:	21.2 %
Tolerance	:	Field tolerance to late leaf spot and rust

(Varma *et al.*, 1996 and Varma *et al.*, 1999).

APPENDIX-3

Calendar of operations for groundnut in the experiment

Operations	Date	DBS/DAS
Tractor ploughing - I	22.07.99	22 DBS
Tractor ploughing II	31.07.99	15 DBS
Elemental sulphur application	31.07.99	15 DBS
Shelling of seed pods	11.08.99	3 DBS
Rhizobium seed treatment	14.08.99	-
Sowing	14.08.99	-
Gap filling	21.08.99	8 DAS
I st hand weeding	30.08.99	17 DAS
I st biometric observation	03.09.99	20 DAS
II nd hand weeding and earthing up with lime application	18.09.99	35 DAS
II nd biometric observation	23.09.99	40 DAS
III rd biometric observation	13.10.99	60 DAS
Soil application of insecticide Quinolphos 0.05 %	18.10.99	65 DAS
IV biometric observation	02.11.99	80 DAS
V biometric observation	27.11.99	105 DAS
Harvesting	01 /02. 12.99	108 DAS

APPENDIX – 4

Composition of culture media

*1. **Yeast Extract Mannitol Agar (YEMA)** (Rao, 1995)*

Mannitol	10.00 g
K_2HPO_4	0.50 g
Mg SO_4. 7 H_2O	0.20 g
Na Cl	0.10 g
Yeast extract	0.50 g
Agar	20.00 g
Congo red dye (1%)	1.0 %
Distilled water	1000 ml

*2. **Nutrient Agar (NA)** (Fred and Waksman, 1928 and Tuite, 1969)*

Peptone	5.00 g
Beef extract	3.00 g
NaCl	5.00 g
Agar	20.00 g
Distilled water	1000 ml

*3. **Martins Rose Bengal Agar (RBA)**(Martin, 1950)*

Dextrose	10.00 g
Peptone	5.00 g
KH_2 PO_4	0.50 g
Mg SO_4. 7 H_2O	0.20 g
Rose bengal dye	0.032 g
Streptomycin	0.025 g
Agar	20.00 g
Distilled water	1000 ml

*4. **Kenknight's Agar (KKA)**(Harrigan and McCanna, 1966)*

Glucose	1.00 g
K PO_4	0.10 g
$NaNO_3$	0.10 g
KCl	0.10 g
Mg SO_4. $7H_2O$	0.10 g
Agar	20.00 g
Distilled water	1000 ml
pH	7.0 – 7.2

Appendix : 5 Effect of treatments on nutrient ratios at various stages.

a) N/P and P/K ratios.

Treatment		N / P Ratio							N / K Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest		
						Haulm	Shell	Kernel					Haulm	Shell	Kernel
T_1	**R** (P as MP)	5.15	6.21^{abc}	7.85^{e}	9.61^{abc}	8.35^{d}	15.19	13.28^{a}	0.72^{cd}	0.71^{abc}	1.07^{d}	1.45^{ab}	0.96^{bcd}	1.74^{ab}	9.43^{abc}
T_2	**R** (P as SSP)	4.80	5.28^{c}	8.72^{cde}	9.69^{abc}	10.25^{abcd}	13.43	11.71^{bcd}	0.87^{ab}	0.61^{c}	1.18^{bcd}	1.36^{bc}	1.12^{abc}	1.41^{bc}	8.21^{cde}
T_3	**R** (P as OM)	5.00	6.07^{abc}	11.14^{a}	10.00^{ab}	11.63^{a}	14.09	11.37^{bcde}	0.86^{ab}	0.68^{bc}	1.33^{ab}	1.51^{ab}	1.09^{abc}	1.28^{c}	9.19^{abcd}
T_4	**R** (P as OM) S_{56}	5.36	5.30^{c}	9.84^{abcd}	8.41^{c}	10.71^{abc}	15.18	12.14^{abc}	0.80^{abcd}	0.73^{ab}	1.23^{abcd}	1.16^{c}	0.95^{cd}	1.71^{ab}	9.74^{a}
T_5	$OM_{500}N_{15}K_{75}$	4.85	6.65^{ab}	9.06^{bcde}	10.49^{ab}	10.76^{abc}	13.70	12.33^{ab}	0.71^{d}	0.68^{bc}	1.13^{cd}	1.58^{ab}	1.11^{abc}	1.43^{bc}	8.29^{bcde}
T_6	$OM_{1000}N_{10}K_{75}$	5.05	5.80^{abc}	10.42^{ab}	10.86^{a}	9.45^{bcd}	12.13	11.32^{bcde}	0.83^{abcd}	0.69^{abc}	1.25^{abc}	1.59^{a}	0.88^{d}	1.52^{abc}	9.52^{ab}
T_7	$OM_{1500}N_5K_{75}$	4.81	5.65^{bc}	8.48^{de}	9.73^{abc}	10.61^{abc}	13..34	10.83^{bcde}	0.79^{abcd}	0.71^{abc}	1.19^{abcd}	1.67^{ab}	1.14^{abc}	1.49^{bc}	8.37^{bcde}
T_8	$OM_{2000}K_{75}$	4.98	6.06^{abc}	9.04^{bcde}	9.32^{bc}	9.22^{cd}	12..51	10.52^{de}	0.76^{bcd}	0.68^{bc}	1.36^{a}	1.54^{a}	1.00^{abcd}	1.56^{abc}	8.51^{bcde}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	5.41	6.01^{abc}	9.26^{bcde}	10.74^{ab}	11.25^{ab}	13.13	11.06^{bcde}	0.81^{abcd}	0.78^{a}	1.12^{cd}	1.45^{ab}	1.08^{abcd}	1.24^{c}	7.82^{e}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	5.38	6.93^{a}	10.23^{abc}	10.41^{ab}	9.42^{bcd}	13..56	10.10^{e}	0.85^{abc}	0.67^{bc}	1.19^{abcd}	1.65^{a}	1.21^{a}	1.32^{c}	7.44^{e}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	4.44	5.18^{c}	8.51^{de}	10.31^{ab}	9.23^{cd}	13..91	10.65^{cde}	0.82^{abcd}	0.65^{bc}	1.25^{abc}	1.62^{a}	1.17^{ab}	1.84^{a}	8.08^{de}
T_{12}	$OM_{2000}K_{75}L_{440}$	5.49	5.87^{abc}	8.41^{de}	9.57^{ab}	9.17^{cd}	12..91	10.53^{de}	0.94^{a}	0.65^{bc}	1.19^{abcd}	1.58^{ab}	1.19^{a}	1.58^{abc}	8.25^{cde}

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Appendix : 5 b. Effect of treatments on P/K and N/Ca ratios at various stages.

Treatment		P / K Ratio							N / Ca Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest		
						Haulm	Shell	Kernel					Haulm	Shell	Kernel
T_1	**R** (P as MP)	0.14 ^{e}	0.11 ^{cd}	0.14 ^{abcd}	0.15	0.12 ^{ab}	0.12 ^{c}	0.71 ^{bc}	2.22	1.52 ^{abcd}	1.07 ^{e}	2.41 ^{de}	1.55 ^{cd}	11.74 ^{a}	50.41 ^{bc}
T_2	**R** (P as SSP)	0.18 ^{a}	0.12 ^{bcd}	0.14 ^{abc}	0.14	0.11 ^{bc}	0.12 ^{c}	0.70 ^{bc}	2.61	1.35 ^{bcd}	1.95 ^{b}	2.84 ^{bc}	1.74 ^{bc}	12.71 ^{a}	40.15 ^{efg}
T_3	**R** (P as OM)	0.17 ^{abc}	0.11 ^{cde}	0.12 ^{de}	0.15	0.10 ^{cde}	0.10 ^{d}	0.81 ^{ab}	2.57	1.39 ^{abcd}	1.99 ^{ab}	2.32 ^{de}	1.24 ^{d}	5.04 ^{e}	47.94 ^{cd}
T_4	**R** (P as OM) S_{56}	0.15 ^{de}	0.14 ^{a}	0.13 ^{bcde}	0.14	0.09 ^{e}	0.12 ^{c}	0.80 ^{ab}	2.13	1.73 ^{ab}	2.26 ^{a}	3.07 ^{ab}	1.69 ^{bc}	5.68 ^{de}	58.42 ^{a}
T_5	$OM_{500}N_{15}K_{75}$	0.15 ^{de}	0.10 ^{de}	0.12 ^{cde}	0.15	0.10 ^{bcde}	0.12 ^{c}	0.67 ^{c}	2.35	1.55 ^{abcd}	2.01 ^{ab}	3.15 ^{ab}	1.85 ^{bc}	11.54 ^{a}	50.82 ^{bc}
T_6	$OM_{1000}N_{10}K_{75}$	0.16 ^{bcd}	0.12 ^{bcd}	0.12 ^{de}	0.15	0.09 ^{de}	0.13 ^{bc}	0.85 ^{a}	2.55	1.47 ^{abcd}	1.87 ^{b}	3.34 ^{a}	1.74 ^{bc}	8.91 ^{bc}	55.73 ^{ab}
T_7	$OM_{1500}N_5K_{75}$	0.17 ^{bcd}	0.13 ^{abc}	0.14ab	0.16	0.11 ^{bcd}	0.13 ^{bc}	0.78 ^{abc}	2.03	1.30 ^{cd}	1.35 ^{cde}	2.50 ^{cd}	1.93 ^{bc}	11.03 ^{ab}	45.62 ^{cde}
T_8	$OM_{2000}K_{75}$	0.15 ^{de}	0.11 ^{cde}	0.15 ^{a}	0.16	0.11 ^{bcd}	0.13^{bc}	0.82 ^{ab}	2.02	1.34 ^{bcd}	1.20 ^{de}	2.51 ^{cd}	1.80^{bc}	8.46 ^{bc}	51.94 ^{bc}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	0.15 ^{de}	0.13 ^{ab}	0.12 ^{cde}	0.15	0.10 ^{cde}	0.12 ^{c}	0.71 ^{bc}	2.15	1.75 ^{a}	1.53 ^{c}	2.61 ^{cd}	2.04 ^{b}	8.25 ^{cd}	43.20 ^{def}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	0.16 ^{cd}	0.10 ^{e}	0.12 ^{e}	0.16	0.13 ^{a}	0.12 ^{c}	0.74 ^{abc}	2.40	1.48 ^{abcd}	1.49 ^{cd}	2.39 ^{de}	2.45 ^{a}	7.64 ^{cde}	35.05 ^{gh}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	0.19 ^{a}	0.13 ^{abc}	0.15 ^{a}	0.16	0.13 ^{a}	0.15 ^{ab}	0.76 ^{abc}	2.26	1.67 ^{abc}	1.35 ^{cde}	2.19 ^{de}	2.07 ^{b}	8.65 ^{bc}	38.09 ^{fgh}
T_{12}	$OM_{2000}K_{75}L_{440}$	0.18 ^{ab}	0.11 ^{cde}	0.14 ^{ab}	0.17	0.13 ^{a}	0.16 ^{a}	0.78 ^{abc}	2.33	1.25 ^{d}	1.15 ^{e}	2.01 ^{e}	1.93 ^{bc}	6.24 ^{cde}	31.96 ^{h}

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Appendix : 5 c. Effect of treatments on P/Ca and K/Ca ratios at various stages.

Treatment		P / Ca Ratio							K / Ca Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest		
						Haulm	Shell	Kernel					Haulm	Shell	Kernel
T_1	**R** (P as MP)	0.44[ab]	0.25[bc]	0.14[c]	0.25[cdef]	0.19[cd]	0.77[abc]	3.79[cd]	3.09[ab]	2.15	1.03[efg]	1.67[cd]	1.62[de]	6.60[bc]	5.35[ab]
T_2	**R** (P as SSP)	0.55[a]	0.26[abc]	0.22[ab]	0.29[bcd]	0.17[de]	0.94[a]	3.45[de]	299[abc]	2.22	1.63[ab]	2.10[b]	1.56[e]	8.21[a]	4.91[b]
T_3	**R** (P as OM)	0.51[ab]	0.23[bc]	0.18[bc]	0.23[ef]	0.11[f]	0.36[e]	4.22[c]	2.95[abc]	2.06	1.50[bc]	1.54[cde]	1.15[f]	3.59[fg]	5.23[ab]
T_4	**R** (P as OM) **S_{56}**	0.40[b]	0.33[a]	0.23[a]	0.37[a]	0.16[e]	0.38[e]	4.82[ab]	2.66[bc]	2.36	1.84[a]	2.65[a]	1.78[bcd]	3.09[g]	6.00[a]
T_5	**$OM_{500}N_{15}K_{75}$**	0.51[ab]	0.24[bc]	0.22[ab]	0.30[bc]	0.17[de]	0.85[ab]	4.15[c]	3.32[a]	2.29	1.79[a]	1.98[b]	1.67[cde]	7.18[ab]	6.18[a]
T_6	**$OM_{1000}N_{10}K_{75}$**	0.50[ab]	0.26[abc]	0.18[bc]	0.31[b]	0.19[cd]	0.75[abc]	4.95[a]	3.07[ab]	2.15	1.51[bc]	2.00[b]	1.99[a]	5.76[bcde]	5.97[a]
T_7	**$OM_{1500}N_5K_{75}$**	0.42[b]	0.23[bc]	0.16[c]	0.26[bcdef]	0.18[cd]	0.84[ab]	4.22[bc]	2.59[bc]	1.84	1.13[ef]	1.63[cd]	1.70[cde]	6.37[bcd]	5.46[ab]
T_8	**$OM_{2000}K_{75}$**	0.41[b]	0.22[bc]	0.13[c]	0.27[bcde]	0.20[c]	0.68[bcd]	4.96[a]	2.69[bc]	1.99	0.90[g]	1.74[c]	1.80[bc]	5.19[cde]	6.16[a]
T_9	**$OM_{500}N_{15}K_{75}L_{860}$**	0.40[b]	0.29[ab]	0.16[c]	0.24[def]	0.18[cd]	0.65[bcd]	3.91[cd]	2.66[bc]	2.25	1.37[cd]	1.60[cde]	1.90[ab]	5.57[cde]	5.53[ab]
T_{10}	**$OM_{1000}N_{10}K_{75}L_{720}$**	0.45[ab]	0.22[c]	0.15[c]	0.23[ef]	0.26[a]	0.58[cde]	3.47[de]	2.82[abc]	2.22	1.25[de]	1.47[def]	2.04[a]	4.89[def]	4.74[bc]
T_{11}	**$OM_{1500}N_5K_{75}L_{580}$**	0.52[ab]	0.32[a]	0.16[c]	0.21[f]	0.22[b]	0.63[bcd]	3.59[cde]	2.77[bc]	2.56	1.10[efg]	1.35[ef]	1.76[bc]	4.31[efg]	4.71[bc]
T_{12}	**$OM_{2000}K_{75}L_{440}$**	0.44[ab]	0.22[c]	0.14[c]	0.21[f]	0.21[b]	0.50[de]	3.03[e]	2.48[c]	1.91	0.99[fg]	1.28[f]	1.62[de]	3.20[g]	3.95[c]

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Appendix : 5 d. Effect of treatments on N/S and P/S ratios at various stages.

Treatment		N / S Ratio							P / S Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest		
						Haulm	Shell	Kernel					Haulm	Shell	Kernel
T_1	R (P as MP)	9.73 ^{cde}	11.26 ^{d}	19.73 ^{bc}	25.24	21.01 ^{bc}	14.79	67.80 ^{cde}	2.19	2.05 ^{e}	4.13	3.36 ^{a}	3.18 ^{ab}	2.46	0.83
T_2	R (P as SSP)	13.02 ^{abcd}	16.01 ^{abc}	26.76 ^{abc}	22.62	29.51 ^{a}	10.34	64.25 ^{de}	3.11	3.99 ^{ab}	5.40	2.92 ^{ab}	3.47 ^{a}	1.86	0.80
T_3	R (P as OM)	14.70 ^{ab}	14.98 ^{abcd}	23.84 ^{abc}	21.22	18.31 ^{bc}	9.89	74.27 ^{cde}	2.93	3.85 ^{abc}	4.21	1.94 ^{bc}	2.82 ^{ab}	1.60	0.72
T_4	R (P as OM) S_{56}	13.45 ^{abcd}	14.68 ^{abcd}	24.82 ^{abc}	15.70	20.26 ^{bc}	14.72	72.50 ^{cde}	2.61	2.88 ^{cde}	4.61	2.08 ^{bc}	2.78 ^{ab}	1.74	1.94
T_5	$OM_{500}N_{15}K_{75}$	11.36 ^{abcde}	11.02 ^{d}	21.61 ^{abc}	26.96	20.98 ^{bc}	11.08	62.36 ^{de}	2.61	2.56 ^{de}	4.28	2.66 ^{ab}	3.10 ^{ab}	1.73	0.79
T_6	$OM_{1000}N_{10}K_{75}$	11.58 ^{abcde}	11.77 ^{cd}	32.10 ^{a}	28.03	20.05 ^{bc}	13.86	81.41 ^{bcd}	2.16	2.98 ^{bcde}	6.47	2.53 ^{abc}	3.08 ^{ab}	2.33	1.10
T_7	$OM_{1500}N_5K_{75}$	10.28 ^{cde}	12.60 ^{cd}	15.57 ^{c}	21.55	17.32 ^{bc}	13.10	118.10 ^{a}	2.43	2.89 ^{cde}	6.23	2.52 ^{abc}	2.48 ^{bc}	1.96	1.59
T_8	$OM_{2000}K_{75}$	13.82 ^{abc}	18.91a	22.35 ^{abc}	25.83	17.74 ^{bc}	10.44	68.45 ^{cde}	3.12	4.16 ^{a}	4.20	2.81 ^{ab}	2.98 ^{ab}	1.69	1.02
T_9	$OM_{500}N_{15}K_{75}L_{860}$	8.73 ^{e}	17.14 ^{ab}	25.26 ^{abc}	19.74	14.57 ^{c}	11.65	85.47 ^{bc}	2.28	3.29 ^{abcd}	5.40	2.08 ^{bc}	1.94 ^{c}	1.85	1.07
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	10.71 ^{bcde}	13.55 ^{bcd}	29.97 ^{ab}	17.47	21.79 ^{abc}	11.68	60.38 ^{e}	2.43	2.92 ^{cde}	5.27	1.57 ^{c}	2.81 ^{ab}	2.38	0.84
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	9.63 ^{de}	14.84 ^{abcd}	18.25 ^{c}	21.84	21.33 ^{bc}	15.23	98.37 ^{b}	2.10	4.00 ^{ab}	3.92	2.69 ^{ab}	3.02 ^{ab}	1.99	1.63
T_{12}	$OM_{2000}K_{75}L_{440}$	15.03 ^{a}	13.30 ^{bcd}	18.13 ^{c}	25.78	24.85 ^{ab}	11.94	85.75 ^{bc}	3.12	3.05 ^{bcde}	3.86	3.00 ^{ab}	3.49 ^{a}	2.19	1.29

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Appendix : 5 e. Effect of treatments on K/S and Ca/S ratios at various stages.

Treatment		**K / S Ratio**							**Ca / S Ratio**						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest: Haulm	Harvest: Shell	Harvest: Kernel	20 DAS	40 DAS	60 DAS	80 DAS	Harvest: Haulm	Harvest: Shell	Harvest: Kernel
T_1	R (P as MP)	20.70^{abc}	14.99^{c}	35.80^{abc}	24.80	20.93^{ab}	21.37	7.04^{c}	1.57^{c}	4.87^{d}	16.63	24.19^{a}	12.84^{bc}	13.14	1.08^{fg}
T_2	R (P as SSP)	25.59^{a}	21.66^{bc}	46.47^{ab}	21.47	24.97^{a}	17.05	7.14^{c}	2.19^{abc}	7.25^{bc}	20.93	4.38^{cd}	11.94^{bc}	10.87	0.89^{g}
T_3	R (P as OM)	26.94^{a}	22.13^{ab}	37.43^{abc}	16.23	18.74^{ab}	17.00	7.25^{c}	2.38^{ab}	7.49^{b}	18.13	10.82^{cd}	12.11^{bc}	14.92	2.03^{bc}
T_4	R (P as OM) S_{56}	26.41^{a}	20.67^{bc}	36.70^{abc}	16.46	21.40^{ab}	18.11	7.13^{c}	2.12^{abc}	7.83^{b}	15.48	9.08^{d}	8.16^{b}	13.06	2.26^{ab}
T_5	$OM_{500}N_{15}K_{75}$	21.53^{abc}	16.83^{bc}	39.92^{abc}	21.12	20.14^{ab}	16.08	6.65^{c}	1.75^{bc}	5.04^{cd}	17.52	12.05^{cd}	10.20^{cd}	9.72	0.97^{g}
T_6	$OM_{1000}N_{10}K_{75}$	20.28^{abc}	18.01^{bc}	53.77^{a}	21.31	20.14^{ab}	24.64	8.44^{c}	1.80^{bc}	5.91^{bcd}	24.89	14.11^{cd}	10.08^{cd}	12.49	1.50^{def}
T_7	$OM_{1500}N_5K_{75}$	20.39^{abc}	17.76^{a}	26.17^{c}	17.77	15.66^{bc}	18.31	12.26^{a}	1.89^{abc}	6.83^{bcd}	14.34	15.95^{bcd}	9.65^{cd}	10.81	1.92^{bcd}
T_8	$OM_{2000}K_{75}$	26.19^{a}	27.83^{bc}	36.73^{abc}	18.92	19.16^{ab}	15.41	7.74^{c}	2.49^{a}	10.35^{a}	18.63	21.19^{ab}	11.01^{bcd}	8.58	1.49^{def}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	17.80^{bc}	21.32^{bc}	41.46^{abc}	17.06	12.64^{c}	19.13	9.09^{bc}	1.61^{c}	8.06^{b}	18.27	12.70^{cd}	7.98^{d}	10.07	1.65^{cde}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	17.94^{bc}	18.40^{bc}	53.66^{a}	13.96	17.63^{bc}	18.55	6.90^{c}	1.77^{bc}	6.72^{bcd}	24.11	11.03^{cd}	12.19^{bc}	9.17	1.29^{efg}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	17.02^{bc}	21.40^{bc}	30.91^{bc}	18.97	19.30^{ab}	15.68	11.18^{ab}	1.61^{c}	7.73^{cb}	15.29	17.01^{bc}	14.27^{ab}	8.86	2.62^{a}
T_{12}	$OM_{2000}K_{75}L_{440}$	24.63^{ab}	17.45^{bc}	33.01^{bc}	21.38	21.06^{ab}	16.91	8.30^{c}	2.34^{ab}	7.07^{bcd}	17.45	22.10^{ab}	16.30^{a}	10.45	2.59^{a}

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock **P**hosphate, **SSP**- **S**ingle **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, **N**-Nitrogen, **P**- **P**hosphorus, **K**- Potassium, **S**-Sulphur and **L**-Lime)

Appendix : 5 f. Effect of treatments on N/Mg and P/Mg ratios at various stages.

Treatment		N / Mg Ratio							P / Mg Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest		
						Haulm	Shell	Kernel					Haulm	Shell	Kernel
T_1	R (P as MP)	7.25^{d}	7.40	5.94^{c}	6.65^{bc}	5.06	13.62	19.80	1.66^{cd}	1.39^{bc}	1.25	0.89^{ab}	0.77	2.23	0.24
T_2	R (P as SSP)	8.21^{abcd}	6.61	7.12^{abc}	7.19^{abc}	5.95	7.86	20.65	1.97^{ab}	1.67^{ab}	1.47	0.92^{a}	0.72	1.44	0.26
T_3	R (P as OM)	8.58^{abc}	6.51	7.05^{abc}	7.50^{ab}	5.22	5.22	19.96	1.72^{bcd}	1.68^{ab}	1.23	0.68^{de}	0.81	0.88	0.20
T_4	R (P as OM) S_{56}	8.02^{abcd}	6.76	7.84^{a}	6.33^{c}	5.32	7.45	20.31	1.57^{d}	1.35^{bc}	1.39	0.81^{abcd}	0.76	0.96	0.55
T_5	$OM_{500}N_{15}K_{75}$	7.90^{bcd}	7.05	6.53^{bc}	7.57^{ab}	5.55	6.83	18.65	1.79^{abcd}	1.63^{abc}	1.27	0.77^{bcde}	0.81	1.07	0.23
T_6	$OM_{1000}N_{10}K_{75}$	9.61^{a}	6.28	6.70^{abc}	8.03^{a}	5.29	6.40	19.50	1.72^{bcd}	1.59^{abc}	1.34	0.72^{cde}	0.82	1.06	0.27
T_7	$OM_{1500}N_5K_{75}$	7.42^{cd}	6.52	7.18^{ab}	7.27^{abc}	5.42	6.07	19.24	1.76^{abcd}	1.49^{abc}	1.51	0.86^{ab}	0.78	0.91	0.27
T_8	$OM_{2000}K_{75}$	7.91^{bcd}	6.74	6.61^{bc}	7.35^{abc}	5.23	13.97	19.74	1.76^{abcd}	1.50^{abc}	1.26	0.82^{abc}	0.88	2.26	0.29
T_9	$OM_{500}N_{15}K_{75}L_{860}$	7.68^{cd}	7.09	6.46^{bc}	7.31^{abc}	5.35	5.88	19.39	2.00^{a}	1.31^{c}	1.38	0.78^{bcde}	0.73	0.94	0.24
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	8.38^{abcd}	6.94	6.61^{bc}	7.20^{abc}	6.14	6.80	17.92	1.88^{abc}	1.50^{abc}	1.16	0.68^{e}	0.80	1.39	0.24
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	8.32^{abcd}	6.77	6.50^{bc}	7.06^{abc}	5.12	9.03	19.09	1.84^{abcd}	1.82^{a}	1.40	0.87^{ab}	0.73	1.19	0.32
T_{12}	$OM_{2000}K_{75}L_{440}$	9.02^{ab}	6.63	6.14^{bc}	6.87^{bc}	5.51	10.83	17.36	1.83^{abcd}	1.54^{abc}	1.27	0.81^{abcde}	0.77	2.02	0.27

(**R**- Package of Practices Recommendations of KAU, **MP- Mussoorie** rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, P- Phosphorus, K- Potassium, S-Sulphur and L-Lime)

Appendix : 5 g. Effect of treatments on K/Mg and Ca/ Mg ratios of groundnut at various stages.

Treatment		K / Mg Ratio							Ca / Mg Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest			20 DAS	40 DAS	60 DAS	80 DAS	Harvest		
						Haulm	Shell	Kernel					Haulm	Shell	Kernel
T_1	**R** (P as MP)	15.57	9.86 ^{abc}	10.86	6.56	5.05 ^{abc}	19.35	2.06	1.18 ^{c}	3.19 ^{d}	5.03 ^{cd}	6.38 ^{a}	3.09 ^{c}	11.69	0.32 ^{ef}
T_2	**R** (P as SSP)	16.10	9.02 ^{bc}	12.60	6.80	5.09 ^{abc}	12.84	2.29	1.39 ^{ab}	3.01 ^{e}	5.68 ^{bc}	4.52 ^{de}	2.43 ^{d}	8.20	0.29 ^{f}
T_3	**R** (P as OM)	15.72	9.65 ^{abc}	11.01	5.76	5.34 ^{abc}	9.19	1.95	1.38 ^{ab}	3.31 ^{cd}	5.35 ^{bc}	3.83 ^{ef}	3.48 ^{ab}	8.00	0.55 ^{b}
T_4	**R** (P as OM) S_{56}	15.80	9.53 ^{abc}	11.65	6.58	5.66 ^{a}	10.25	2.00	1.28 ^{abc}	3.59 ^{a}	4.96 ^{cd}	3.57 ^{f}	2.14 ^{e}	6.56	0.63 ^{a}
T_5	$OM_{500}N_{15}K_{75}$	14.82	10.70 ^{a}	12.09	6.18	5.33 ^{abc}	10.10	1.99	1.21 ^{bc}	3.24 ^{cd}	5.29 ^{bcd}	3.43 ^{f}	2.70 ^{d}	6.08	0.29 ^{f}
T_6	$OM_{1000}N_{10}K_{75}$	16.04	9.64 ^{abc}	11.18	6.08	5.29 ^{abc}	11.20	2.03	1.41 ^{a}	3.15 ^{de}	5.21 ^{bcd}	4.05 ^{ef}	2.66 ^{d}	5.62	0.36 ^{def}
T_7	$OM_{1500}N_5K_{75}$	14.74	9.13 ^{bc}	12.04	6.12	4.91 ^{bc}	8.49	1.96	1.37 ^{ab}	3.53 ^{ab}	6.50 ^{a}	5.39 ^{bcd}	3.02 ^{c}	4.98	0.31 ^{ef}
T_8	$OM_{2000}K_{75}$	14.96	9.85 ^{abc}	11.26	5.57	5.64 ^{ab}	20.92	2.19	1.43 ^{a}	3.66 ^{a}	5.66 ^{bc}	6.19 ^{ab}	3.24 ^{bc}	11.91	0.43 ^{cd}
T_9	$OM_{500}N_{15}K_{75}L_{860}$	15.64	8.61 ^{c}	10.57	6.46	4.79 ^{c}	9.64	2.06	1.41 ^{a}	3.25 ^{cd}	4.62 ^{d}	4.71 ^{cde}	2.99 ^{c}	5.09	0.37 ^{def}
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	13.96	9.45 ^{abc}	11.84	5.76	5.10 ^{abc}	10.82	2.04	1.38 ^{ab}	3.41 ^{bc}	5.33 ^{bcd}	4.61 ^{cde}	3.47 ^{ab}	5.40	0.38 ^{de}
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	14.80	9.97 ^{ab}	11.12	6.00	4.64 ^{c}	9.44	2.18	1.39 ^{a}	3.53 ^{ab}	5.52 ^{bc}	5.48 ^{abc}	3.43 ^{ab}	5.33	0.51 ^{bc}
T_{12}	$OM_{2000}K_{75}L_{440}$	14.72	8.94 ^{bc}	11.29	5.88	4.66 ^{c}	15.81	1.71	1.40 ^{a}	3.53 ^{ab}	5.90 ^{ab}	5.89 ^{ab}	3.61 ^{a}	9.74	0.54 ^{b}

(**R**- Package of Practices **R**ecommendations of KAU, **MP**- **Mussoorie** rock **P**hosphate, **SSP**- **S**ingle **S**uper **P**hosphate, **OM**- **O**rganic **M**eal, N-Nitrogen, **P**- **P**hosphorus, **K**- Potassium. S-Sulphur and L-Lime)

Appendix : 5 h. Effect on nutrient ratios of groundnut at differnent stages.

Treatment		S / Mg Ratio						
		20 DAS	40 DAS	60 DAS	80 DAS	Haulm	Shell	Kernel
T_1	R (P as MP)	0.77 [abc]	0.68 [a]	0.32	0.27	0.24 [bc]	0.89	0.30 [ab]
T_2	R (P as SSP)	0.67 [bc]	0.43 [cd]	0.29 [b]	0.32	0.22 [c]	0.77	0.32 [a]
T_3	R (P as OM)	0.59 [c]	0.45 [cd]	0.30 [b]	0.35	0.30 [bc]	0.60	0.27 [abc]
T_4	R (P as OM)S_{56}	0.62 [c]	0.50 [cd]	0.35 [b]	0.45	0.28 [bc]	0.55	0.28 [abc]
T_5	$OM_{500}N_{15}K_{75}$	0.72 [abc]	0.62 [ab]	0.32 [b]	0.32	0.27 [ab]	0.65	0.30 [ab]
T_6	$OM_{1000}N_{10}K_{75}$	0.80 [c]	0.54 [bc]	0.22 b	0.30	0.27 [bc]	0.50	0.25 [abcd]
T_7	$OM_{1500}N_5K_{75}$	0.73 [ab]	0.52 [bc]	0.51 [a]	0.36	0.32 [ab]	0.48	0.17 [d]
T_8	$OM_{2000}K_{75}$	0.59 [abc]	0.37 [d]	0.37 [ab]	0.31	0.29 [bc]	0.57	0.32 [a]
T_9	$OM_{500}N_{15}K_{75}L_{860}$	0.88 [a]	0.43 [cd]	0.27 [b]	0.42	0.39 [a]	0.51	0.23 [abcd]
T_{10}	$OM_{1000}N_{10}K_{75}L_{720}$	0.78 [c]	0.52 [bc]	0.24 [b]	0.48	0.30 [bc]	0.59	0.30 [ab]
T_{11}	$OM_{1500}N_5K_{75}L_{580}$	0.91	0.46 [cd]	0.38 [ab]	0.33	0.24 [bc]	0.61	0.20 [cd]
T_{12}	$OM_{2000}K_{75}L_{440}$	0.62	0.50 [cd]	0.36 [ab]	0.28	0.23 [c]	1.06	0.21 [bcd]

(**R**- Package of Practices Recommendations of KAU, **MP**- Musoorie rock Phosphate, **SSP**- Single Super Phosphate, **OM**- Organic Meal, N-Nitrogen, P- Phosphorus, **K**- Potassium, S- Sulphur and L-Lime)

Appendix: 6 Cost of cultivation of groundnut.

S.No.	Particulars	Number of labours @ Rs. 100.00 / day		Cost
		Men	Women	
A.	***Fixed cost for all treatments***			
1.	*Field preparation*			
a.	Tractor ploughing two times and harrowing (2x3+2=8 hrs) @ Rs. 200.00 hr^{-1}			1600.00
b.	Bunding	14		1400.00
2.	*Seeds and sowing*			
a.	Cost of seeds 130 kg @ Rs. 24 kg^{-1}			3120.00
b.	Shelling and seed treatment		2	264.00
c.	Sowing		15	1500.00
3.	*Intercultural operations*			
a.	Application of manures and fertilizers	2	1	300.00
b.	Irrigation charges	10		1000.00
c.	Gap filling		2	200.00
d.	First weeding (Chemical) at 15-20 DAS	1	2	500.00
e.	Second hand weeding, earthing up and liming	1	19	2000.00
f.	Plant protection (chemical and application charges)	2	2	1200.00
4.	*Harvesting and post harvest operations*			
a.	Harvesting and stripping of pods		30	3000.00
b.	Drying and packing	2	8	1000.00
	Total			***17084.00***

Variable cost for all treatments.

1. FYM @ Rs. 350.00 per 1000 kg
2. Organic meal @ Rs.2.00 per kg
3. Urea @ Rs. 3.50 per kg
4. Single super phosphate @ Rs. 5.00 per kg
5. Mussooriephos (Rock phosphate) @ Rs. 4.00 per kg
6. Muriate of potash @ Rs. 5.00 per kg
7. Elemental S @ Rs. 5.00 per kg
8. Lime @ Rs. 2.00 per kg

Returns

Cost of pods @ Rs. 10.00 per kg
Cost of haulm @ Rs. 250.00 per 1000.00 kg

Appendix 7 MONOVA Results

STAT. GENERAL MONOVA Summary of all effects

Treatment	Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
Plant nutrient content at 20 DAS	1	0.000118*	4.596948*	110*	215*	0.000000*
Plant nutrient content at 40 DAS	1	0.000035*	5.756465*	110*	215*	0.000000*
Plant nutrient content at 60 DAS	1	0.000145*	4.422893*	110*	215*	0.000000*
Plant nutrient content at 80 DAS	1	0.000096*	4.782572*	110*	215*	0.000000*
Plant nutrient uptake at 20 DAS	1	0.000868*	3.064464*	110*	215*	0.000000*
Plant nutrient uptake at 40 DAS	1	0.000264*	3.929292*	110*	215*	0.000000*
Plant nutrient uptake at 60 DAS	1	0.000233*	4.029744*	110*	215*	0.000000*
Plant nutrient uptake at 80 DAS	1	0.000636*	3.277597*	110*	215*	0.000000*
Plant nutrient ratios at 20 DAS	1	0.019603*	1.575.64*	99*	208*	0.003380*
Plant nutrient ratios at 40 DAS	1	0.21099*	1.536837*	99*	208*	0.005227*
Plant nutrient ratios at 60 DAS	1	0.006754*	2.176105*	99*	208*	0.000001*
Plant nutrient ratios at 80 DAS	1	0.012128*	1.834704*	99*	208*	0.000140*
Based on soil available nutrients, pH and EC (before crop)	1	0.005978*	1.665845*	121*	219*	0.00059*
Based on soil available nutrients, pH and EC (after crop)	1	0.004179*	1.828044*	121*	219*	0.000057*

APPENDIX-8 ANOVA of repeated measures

a. Plant growth characters

ANOVA Table for Plant height

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	11	1713.192	155.745	1.937	0.0669
Subject(Group)	36	2894.745	80.41		
Category for Plant height	4	190691.628	47672.907	1883.621	<.0001
Category for Plant height * Treatment	44	1260.746	28.653	1.132	0.2889
Category for Plant height * Subject(Group)	144	3644.523	25.309		

ANOVA Table for Leaf number

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	11	1451.437	131.949	1.866	0.0783
Subject(Group)	36	2545.028	70.695		
Category for Leaf number	4	163504.529	40876.132	893.123	<.0001
Category for Leaf number * Treatment	44	3171.183	72.072	1.575	0.0243
Category for Leaf number * Subject(Group)	144	6590.537	45.768		

ANOVA Table for Leaf length

	DF	SS	MS	F-Value	P-Value
TREATME	11	2.1	0.19	6.05	<.0001
Subject(Group)	36	1.14	0.03		
Category for Leaf length	4	150.46	37.62	985.31	<.0001
Category for Leaf length * TREATME	44	3.46	0.08	2.06	0.0008
Category for Leaf length * Subject(Group)	144	5.5	0.04		

ANOVA Table for Leaf width

	DF	SS	MS	F-Value	P-Value
TREATME	11	0.84	0.08	3.64	0.0016
Subject(Group)	36	0.75	0.02		
Category for Leaf width	4	14.84	3.71	235.74	<.0001
Category for Leaf width * TREATME	44	1.25	0.03	1.81	0.0048
Category for Leaf width * Subject(Group)	144	2.27	0.02		

ANOVA Table for TLA

	DF	SS	MS	F-Value	P-Value
Treatment	8	18.04	2.26	2.28	0.052
Subject(Group)	27	26.67	0.99		
Category for TLA	4	2749.89	687.47	1338.14	<.0001
Category for TLA * Treatment	32	58.23	1.82	3.54	<.0001
Category for TLA * Subject(Group)	108	55.49	0.51		

ANOVA Table for TLW

	DF	SS	MS	F-Value	P-Value
Treatment	8	9692.74	1211.59	1.89	0.1041
Subject(Group)	27	17341.9	642.29		
Category for TLW	4	501742.6	125435.7	358.13	<.0001
Category for TLW * Treatment	32	31503.87	984.5	2.81	<.0001
Category for TLW * Subject(Group)	108	37827.1	350.25		

ANOVA Table for Leaf Number

	DF	SS	MS	F-Value	P-Value
Treatment	11	2.2	0.2	6.4	<.0001
Subject(Group)	36	1.13	0.03		
Category for Leaf Number	4	151.07	37.77	1010.32	<.0001
Category for Leaf Number * Treatment	44	3.56	0.08	2.17	0.0003
Category for Leaf Number * Subject(Group)	144	5.38	0.04		

ANOVA Table for Leaf weight

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.84	0.08	3.64	0.0016
Subject(Group)	36	0.75	0.02		
Category for Leaf weight	4	14.84	3.71	235.74	<.0001
Category for Leaf weight * Treatment	44	1.25	0.03	1.81	0.0048
Category for Leaf weight * Subject(Group)	144	2.27	0.02		

ANOVA Table for Leaf area

	DF	SS	MS	F-Value	P-Value
Treatment	11	24.48	2.23	6.21	<.0001
Subject(Group)	36	12.9	0.36		
Category for Leaf area	4	898.14	224.54	719.55	<.0001
Category for Leaf area * Treatment	44	27.52	0.63	2	0.0011
Category for Leaf area * Subject(Group)	144	44.94	0.31		

ANOVA Table for Branches

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	11	25.859	2.351	1.391	0.2192
Subject(Group)	36	60.843	1.69		
Category for Branches	3	822.54	274.18	598.115	<.0001
Category for Branches * Treatment	33	19.458	0.59	1.286	0.1684
Category for Branches * Subject(Group)	108	49.508	0.458		

ANOVA Table for Nodule weight

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	11	3927.133	357.012	1.938	0.0667
Subject(Group)	36	6631.2	184.2		
Category for Nodule weight	4	750341.933	187585.483	1651.644	<.0001
Category for Nodule weight * Treatment	44	7266.867	165.156	1.454	0.0521
Category for Nodule weight * Subject(Group)	144	16354.8	113.575		

ANOVA table for plant DMP per plant

	DF	SS	MSS	F-value	P-value
TREATMENT	11	811.13	73.74	4.31	0.0004
Subject (group)	36	615.32	17.09		
Category for DMP per plant	3	53037.46	17679.15	1000.35	<0.001
Category for DMP per plant*TREATMENT	33	1163.53	35.26	2.01	0.0004
Category for DMP per plant*Subject(Group)	108	1899.18	17.59		

ANOVA table for plant DMP per ha

	DF	SS	MSS	F-value	P-value
TREATMENT	11	40810279	37100025.4	4.32	0.0004
Subject (group)	36	30886500	857958.32		
Category for DMP per ha	4	4.31E+09	1.078E+09	1231.99	<0.001
Category for DMP per ha*TREATMENT	44	82482168	1874594	2.14	0.0004
Category for DMP per ha*Subject(Group)	144	125943497	874607.62		

ANOVA Table for Root weight

	DF	SS	MS	F-Value	P-Value
Treatment	11	1.133	0.103	1.31	0.2586
Subject(Group)	36	2.829	0.079		
Category for Root weight	4	68.832	17.208	645.414	<.0001
Category for Root weight * Treatment	44	1.693	0.038	1.443	0.0557
Category for Root weight * Subject(Group)	144	3.839	0.027		

ANOVA Table for Plant weight

	DF	SS	MS	F-Value	P-Value
Treatment	11	608.5	55.32	2.66	0.0131
Subject(Group)	36	747.95	20.78		
Category for Plant weight	4	52183.1	13045.77	630.24	<.0001
Category for Plant weight * Treatment	44	1072.11	24.37	1.18	0.2357
Category for Plant weight * Subject(Group)	144	2980.76	20.7		

ANOVA Table for Shoot weight

	DF	SS	MS	F-Value	P-Value
Treatment	11	198.06	18.01	2.74	0.011
Subject(Group)	36	236.24	6.56		
Category for Shoot weight	4	16480.3	4120.07	569.3	<.0001
Category for Shoot weight * Treatment	44	375.7	8.54	1.18	0.2328
Category for Shoot weight * Subject(Group)	144	1042.15	7.24		

ANOVA Table for Shoot root ratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	417.97	38	1.6	0.142
Subject(Group)	36	857.31	23.81		
Category for Shoot root ratio	3	10647.9	3549.3	332.07	<.0001
Category for Shoot root ratio * Treatment	33	560.43	16.98	1.59	0.0398
Category for Shoot root ratio * Subject(Group)	108	1154.34	10.69		

ANOVA of repeated measures on number of pegs at different times

ANOVA Table for Pegs

	DF	SS	MS	F-Value	P-Value
Treatment	11	180.36	16.40	1.789	0.093
Subject(Group)	36	329.98	9.17		
Category for Pegs	3	13080.08	4360.03	1159.432	<.0001
Category for Pegs * Treatment	33	146.57	4.44	1.181	0.2586
Category for Pegs * Subject(Group)	108	406.13	3.76		

b. Chlorophyll content

ANOVA of Repeated measures on Chlorophylls and total leaf area and weight

ANOVA Table for Chlorophyll A

	DF	SS	MS	F-Value	P-Value
Treatment	8	0.237	0.03	1.317	0.2771
Subject(Group)	27	0.608	0.023		
Category for Chlorophyll A	4	1.169	0.292	22.158	<.0001
Category for Chlorophyll A * Treatment	32	0.83	0.026	1.965	0.0054
Category for Chlorophyll A * Subject(Group)	108	1.425	0.013		

ANOVA Table for Chlorophyll B

	DF	SS	MS	F-Value	P-Value
Treatment	8	0.04	0.01	1.29	0.2917
Subject(Group)	27	0.11	4.09E-03		
Category for Chlorophyll B	4	0.67	0.17	41.68	<.0001
Category for Chlorophyll B * Treatment	32	0.19	0.01	1.45	0.0832
Category for Chlorophyll B * Subject(Group)	108	0.43	4.00E-03		

ANOVA Table for Total chlorophyll

	DF	SS	MS	F-Value	P-Value
Treatment	8	0.23	0.03	0.69	0.6942
Subject(Group)	27	1.1	0.04		
Category for Total chlorophyll	4	0.95	0.24	10.52	<.0001
Category for Total chlorophyll * Treatment	32	1.2	0.04	1.66	0.0282
Category for Total chlorophyll * Subject(Group)	108	2.43	0.02		

c. Growth indices

ANOVA Table for LAI

	DF	SS	MS	F-Value	P-Value
Treatment	11	15.97	1.45	2.77	0.0103
Subject(Group)	36	18.85	0.52		
Category for LAI	4	1368.78	342.2	929.09	<.0001
Category for LAI * Treatment	44	24.32	0.55	1.5	0.039
Category for LAI * Subject(Group)	144	53.04	0.37		

ANOVA Table for LAR

	DF	SS	MS	F-Value	P-Value
TREATME	11	41522.022	3774.729	1.258	0.2874
Subject(Group)	36	108053.6	3001.489		
Category for LAR	4	142832.86	35708.216	12.754	<.0001
Category for LAR * TREATME	44	177403.68	4031.902	1.44	0.0568
Category for LAR * Subject(Group)	144	403181.16	2799.869		

ANOVA Table for RGR

	DF	SS	MS	F-Value	P-Value
TREATME	11	4.60E-04	4.18E-05	1.08	0.4039
Subject(Group)	36	1.39E-03	3.87E-05		
Category for RGR	3	0.53	0.18	632.57	<.0001
Category for RGR * TREATME	33	0.01	3.58E-04	1.29	0.1648
Category for RGR * Subject(Group)	108	0.03	2.77E-04		

d. Plant nutrient content at different times

ANOVA of repeated measures: Plant nutrient content at different times

ANOVA Table for Plant N

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.902	0.082	2.546	0.017
Subject(Group)	36	1.159	0.032		
Category for Plant N	3	16.058	5.353	140.938	<.0001
Category for Plant N * Treatment	33	2.234	0.068	1.782	0.0141
Category for Plant N * Subject(Group)	108	4.102	0.038		

ANOVA Table for Plant K

	DF	SS	MS	F-Value	P-Value
Treatment	11	1.53	0.14	2.74	0.0111
Subject(Group)	36	1.82	0.05		
Category for Plant K	3	185.91	61.97	1511.45	<.0001
Category for Plant K * Treatment	33	3.02	0.09	2.23	0.0011
Category for Plant K * Subject(Group)	108	4.43	0.04		

ANOVA Table for Plant P

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.07	0.01	1.72	0.1091
Subject(Group)	36	0.13	3.74E-03		
Category for Plant P	3	3.9	1.3	611.07	<.0001
Category for Plant P * Treatment	33	0.13	3.91E-03	1.84	0.0104
Category for Plant P * Subject(Group)	108	0.23	2.13E-03		

ANOVA Table for Plant Ca

	DF	SS	MS	F-Value	P-Value
Treatment	11	3.71	0.34	39.33	<.0001
Subject(Group)	36	0.31	0.01		
Category for Plant Ca	3	19.82	6.61	941.28	<.0001
Category for Plant Ca * Treatment	33	3.03	0.09	13.07	<.0001
Category for Plant Ca * Subject(Group)	108	0.76	0.01		

ANOVA Table for Plant Mg

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.01	9.80E-04	3.27	0.0035
Subject(Group)	36	0.01	3.00E-04		
Category for Plant Mg	3	0.15	0.05	86.95	<.0001
Category for Plant Mg * Treatment	33	0.02	5.11E-04	0.91	0.6125
Category for Plant Mg * Subject(Group)	108	0.06	5.62E-04		

ANOVA Table for Plant S

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.07	0.01	1.38	0.2251
Subject(Group)	36	0.15	4.29E-03		
Category for Plant S	3	0.66	0.22	52.38	<.0001
Category for Plant S * Treatment	33	0.2	0.01	1.47	0.0724
Category for Plant S * Subject(Group)	108	0.45	4.19E-03		

ANOVA Table for Plant Fe

	DF	SS	MS	F-Value	P-Value
Treatment	11	523904.29	47627.66	3.68	0.0015
Subject(Group)	36	465825.38	12939.59		
Category for Plant Fe	3	37490096	12496699	991.63	<.0001
Category for Plant Fe * Treatment	33	1263478	38287.21	3.04	<.0001
Category for Plant Fe * Subject(Group)	108	1361042.1	12602.24		

ANOVA Table for Plant Zn

	DF	SS	MS	F-Value	P-Value
Treatment	11	6941.42	631.04	1.02	0.4532
Subject(Group)	36	22378.8	621.63		
Category for Plant Zn	3	224622.76	74874.25	121.36	<.0001
Category for Plant Zn * Treatment	33	20323.53	615.86	1	0.4825
Category for Plant Zn * Subject(Group)	108	66630.14	616.95		

ANOVA Table for Plant Cu

	DF	SS	MS	F-Value	P-Value
Treatment	11	317.78	28.89	0.41	0.9435
Subject(Group)	36	2553.37	70.93		
Category for Plant Cu	3	18376.76	6125.59	70.51	<.0001
Category for Plant Cu * Treatment	33	2060.37	62.44	0.72	0.861
Category for Plant Cu * Subject(Group)	108	9382.64	86.88		

ANOVA Table for Plant Mn

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	11	150045.182	13640.471	96.315	<.0001
Subject(Group)	36	5098.438	141.623		
Category for Plant Mn	3	2508200.391	836066.797	11986.92	<.0001
Category for Plant Mn * Treatment	33	433448.047	13134.789	188.317	<.0001
Category for Plant Mn * Subject(Group)	108	7532.813	69.748		

e. Plant nutrient uptake

ANOVA of repeated measures on nutrient uptake at different times

ANOVA Table for N uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	50790.8	4617.346	4.073	0.0007
Subject(Group)	36	40807.93	1133.554		
Category for N uptake	4	4152196	1038049	1007.092	<.0001
Category for N uptake * Treatment	44	68922.96	1566.431	1.52	0.0346
Category for N uptake * Subject(Group)	144	148426.5	1030.739		

ANOVA Table for P uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	296.3	26.94	1.69	0.1157
Subject(Group)	36	573.88	15.94		
Category for P uptake	4	32053.52	8013.38	715.33	<.0001
Category for P uptake * Treatment	44	649.61	14.76	1.32	0.1151
Category for P uptake * Subject(Group)	144	1613.14	11.2		

ANOVA Table for K uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	22281.97	2025.63	3.32	0.0031
Subject(Group)	36	21968.8	610.24		
Category for K uptake	4	798533.8	199633.5	477.63	<.0001
Category for K uptake * Treatment	44	32301.11	734.12	1.76	0.007
Category for K uptake * Subject(Group)	144	60187.2	417.97		

ANOVA Table for Ca uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	7460.88	678.26	4.11	0.0006
Subject(Group)	36	5944.24	165.12		
Category for Ca uptake	4	282943.5	70735.86	530.21	<.0001
Category for Ca uptake * Treatment	44	21128.26	480.19	3.6	<.0001
Category for Ca uptake * Subject(Group)	144	19211.12	133.41		

ANOVA Table for Mg uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	480.54	43.69	2.64	0.0139
Subject(Group)	36	596.63	16.57		
Category for Mg uptake	4	52007.73	13001.93	972.62	<.0001
Category for Mg uptake * Treatment	44	754.36	17.14	1.28	0.1393
Category for Mg uptake * Subject(Group)	144	1924.99	13.37		

ANOVA Table for S uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	414.08	37.64	0.95	0.5043
Subject(Group)	36	1422.48	39.51		
Category for S uptake	4	4873.28	1218.32	32.24	<.0001
Category for S uptake * Treatment	44	1547.83	35.18	0.93	0.598
Category for S uptake * Subject(Group)	144	5441.94	37.79		

ANOVA Table for Fe uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	29.09	2.64	5.98	<.0001
Subject(Group)	36	15.92	0.44		
Category for Fe uptake	4	785.28	196.32	547.09	<.0001
Category for Fe uptake * Treatment	44	47.59	1.08	3.01	<.0001
Category for Fe uptake * Subject(Group)	144	51.67	0.36		

ANOVA Table for Zn uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.27	0.02	2.79	0.0099
Subject(Group)	36	0.32	0.01		
Category for Zn uptake	4	5.65	1.41	191.36	<.0001
Category for Zn uptake * Treatment	44	0.44	0.01	1.37	0.0865
Category for Zn uptake * Subject(Group)	144	1.06	0.01		

ANOVA Table for Cu uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	182302.8	16572.98	2.73	0.0112
Subject(Group)	36	218227.1	6061.86		
Category for Cu uptake	4	23583389	5895847	787.42	<.0001
Category for Cu uptake * Treatment	44	329684.4	7492.83	1	0.4816
Category for Cu uptake * Subject(Group)	144	1078205	7487.53		

ANOVA Table for Mn uptake

	DF	SS	MS	F-Value	P-Value
Treatment	11	2948170	268015.5	4.44	0.0003
Subject(Group)	36	2174081	60391.13		
Category for Mn uptake	4	1.04E+08	26079318	552.86	<.0001
Category for Mn uptake * Treatment	44	7481180	170026.8	3.6	<.0001
Category for Mn uptake * Subject(Group)	144	6792734	47171.76		

f. Plant nutrient ratios

ANOVA of repeated measures on nutrient ratios measures at different times

ANOVA Table for NSratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	509.778	46.343	1.628	0.1324
Subject(Group)	36	1024.937	28.47		
Category for NSratio	3	4868.273	1622.758	50.28	<.0001
Category for NSratio * Treatment	33	1663.765	50.417	1.562	0.0458
Category for NSratio * Subject(Group)	108	3485.64	32.274		

ANOVA Table for PS ratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	16.204	1.473	1.466	0.1872
Subject(Group)	36	36.166	1.005		
Category for PS ratio	3	132.115	44.038	42.263	<.0001
Category for PS ratio * Treatment	33	55.515	1.682	1.614	0.0348
Category for PS ratio * Subject(Group)	108	112.536	1.042		

ANOVA Table for KS ratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	1013.146	92.104	1.658	0.124
Subject(Group)	36	1999.753	55.549		
Category for KS ratio	3	13183.71	4394.569	74.705	<.0001
Category for KS ratio * Treatment	33	3613.025	109.486	1.861	0.0091
Category for KS ratio * Subject(Group)	108	6353.186	58.826		

ANOVA Table for CaS ratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	320.895	29.172	1.765	0.098
Subject(Group)	36	595.058	16.529		
Category for CaS ratio	3	8244.197	2748.066	195.299	<.0001
Category for CaS ratio * Treatment	33	1298.183	39.339	2.796	<.0001
Category for CaS ratio * Subject(Group)	108	1519.679	14.071		

ANOVA Table for NMg ratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	5.601	0.509	1.448	0.1945
Subject(Group)	36	12.657	0.352		
Category for NMg ratio	3	63.361	21.12	44.381	<.0001
Category for NMg ratio * Treatment	33	33.458	1.014	2.13	0.0019
Category for NMg ratio * Subject(Group)	108	51.396	0.476		

ANOVA Table for PMg ratio

	DF	SS	MS	F-Value	P-Value
Treatment	11	0.858	0.078	2.352	0.0263
Subject(Group)	36	1.194	0.033		
Category for PMg ratio	3	25.485	8.495	262.511	<.0001
Category for PMg ratio * Treatment	33	1.52	0.046	1.423	0.0906
Category for PMg ratio * Subject(Group)	108	3.495	0.032		

ANOVA table for plant K/Mg ratio

	DF	SS	MSS	F-value	P-value
TREATMENT	11	15.118	1.374	1.51	0.1685
Subject (group)	36	32.637	0.907		
Category for K/Mg	3	2079.059	693.059	443.686	
Category for K/Mg*TREATMENT	33	39.897	1.208	0.774	<0.0001
Category for K/Mg*Subject(Group)	108	168.701	1.562		0.2986

ANOVA table for plant Ca/Mg ratio

	DF	SS	MSS	F-value	P-value
TREATMENT	11	21.206	1.928	13.346	<0.001
Subject (group)	36	5.2	0.144		
Category for K/Ca	3	473.552	157.851	739.369	<0.001
Category for K/Ca*TREATMENT	33	37.134	1.125	5.271	<0.001
Category for K/Ca*Subject(Group)	108	23.057	0.213		

ANOVA table for plant S/Mg ratio

	DF	SS	MSS	F-value	P-value
TREATMENT	11	0.64	0.06	1.24	0.2958
Subject (group)	36	1.69	0.05		
Category for S/Mg	3	4.38	1.46	30.28	<0.001
Category for S/Mg*TREATMENT	33	2.1	0.06	1.32	0.1451
Category for S/Mg*Subject(Group)	108	5.21	0.05		

g. MONOVA of yield attributes of groundnut

General Linear Model - MANOVA OF YIELD ATTRIBUTES OF GROUNDNUT

Multivariate Tests[d]

Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	Pillai's Trace	1.000	156578.4[b]	18.000	19.000	.000	2818412	1.000
	Wilks' Lambda	.000	156578.4[b]	18.000	19.000	.000	2818412	1.000
	Hotelling's Trace	148337.5	156578.4[b]	18.000	19.000	.000	2818412	1.000
	Roy's Largest Root	148337.5	156578.4[b]	18.000	19.000	.000	2818412	1.000
TREATMEN	Pillai's Trace	4.759	1.228	198.000	319.000	.052	243.221	1.000
	Wilks' Lambda	.000	1.307	198.000	204.042	.029	207.944	1.000
	Hotelling's Trace	15.126	1.313	198.000	189.000	.030	259.894	1.000
	Roy's Largest Root	4.384	7.063[c]	18.000	29.000	.000	127.135	1.000

a. Computed using alpha = .05

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

d. Design: Intercept+TREATMEN

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	KMR	7.242[b]	11	.658	1.343	.242	14.770	.597
	KNLORIN	2.012[c]	11	.183	1.721	.108	18.935	.732
	OILPC	51.343[d]	11	4.668	2.585	.016	28.440	.913
	PHR	4.070[e]	11	.370	1.493	.177	16.424	.655
	PROTEIN	60.613[f]	11	5.510	1.803	.090	19.837	.756
	TBIM	55.760[g]	11	5.069	1.269	.281	13.957	.567
	Pod wt(100)	820.951[h]	11	74.632	.850	.594	9.348	.380
	SHELL PC	78.536[i]	11	7.140	1.979	.061	21.772	.803
	Knl wt(100)	94.339[j]	11	8.576	1.026	.445	11.282	.461
	HLM YLD	28.535[k]	11	2.594	.677	.750	7.452	.300
	Flw (50pc)	3.917[l]	11	.356	.534	.867	5.875	.236
	Avgpod No	119.602[m]	11	10.873	3.480	.002	38.284	.979
	Pod yld pl-1	413.380[n]	11	37.580	3.563	.002	39.189	.981
	pod yld kg ha-1	2.6E+07[o]	11	2321414	3.351	.003	36.860	.973
	hlm yld ha-1	2.9E+07[k]	11	2594114	.677	.750	7.452	.300
	Oil kgha-1	2526769[p]	11	229706.2	3.012	.006	33.136	.954
	kernel kg ha-1	1.1E+07[q]	11	1035157	2.508	.019	27.592	.903
	PN YIELD	1776503[r]	11	161500.2	5.148	.000	56.632	.999
	OIL YLD	2.547[s]	11	.232	3.039	.006	33.431	.956

Multivariate Tests[d]

Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	Pillai's Trace	.999	7208.561[b]	5.000	32.000	.000	36042.805	1.000
	Wilks' Lambda	.001	7208.561[b]	5.000	32.000	.000	36042.805	1.000
	Hotelling's Trace	1126.338	7208.561[b]	5.000	32.000	.000	36042.805	1.000
	Roy's Largest Root	1126.338	7208.561[b]	5.000	32.000	.000	36042.805	1.000
TREATMEN	Pillai's Trace	1.024	.843	55.000	180.000	.767	46.373	.902
	Wilks' Lambda	.300	.819	55.000	151.708	.801	41.280	.834
	Hotelling's Trace	1.441	.796	55.000	152.000	.833	43.804	.863
	Roy's Largest Root	.688	2.253[c]	11.000	36.000	.033	24.782	.862

a. Computed using alpha = .05

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

d. Design: Intercept+TREATMEN

Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	Pillai's Trace	.998	3333.564[b]	5.000	32.000	.000	16667.819	1.000
	Wilks' Lambda	.002	3333.564[b]	5.000	32.000	.000	16667.819	1.000
	Hotelling's Trace	520.869	3333.564[b]	5.000	32.000	.000	16667.819	1.000
	Roy's Largest Root	520.869	3333.564[b]	5.000	32.000	.000	16667.819	1.000
TREATMEN	Pillai's Trace	.862	.682	55.000	180.000	.951	37.521	.798
	Wilks' Lambda	.372	.657	55.000	151.708	.963	33.159	.706
	Hotelling's Trace	1.146	.633	55.000	152.000	.974	34.827	.737
	Roy's Largest Root	.497	1.626[c]	11.000	36.000	.133	17.887	.701

a. Computed using alpha = .05

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

d. Design: Intercept+TREATMEN

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	KMR	358.067	1	358.067	730.281	.000	730.281	1.000
	KNLORIN	1297.712	1	1297.712	12213.44	.000	12213.441	1.000
	OILPC	94219.01	1	94219.01	52190.17	.000	52190.171	1.000
	PHR	189.171	1	189.171	763.411	.000	763.411	1.000
	PROTEIN	38626.32	1	38626.32	12641.35	.000	12641.353	1.000
	TBIM	12537.90	1	12537.90	3138.359	.000	3138.359	1.000
	Pod wt(100)	1198161	1	1198161	13643.17	.000	13643.166	1.000
	SHELL PC	258133.3	1	258133.3	71562.37	.000	71562.374	1.000
	Knl wt(100)	153558.1	1	153558.1	18364.34	.000	18364.339	1.000
	HLM YLD	5433.422	1	5433.422	1419.029	.000	1419.029	1.000
	Flw (50pc)	33180.08	1	33180.08	49770.12	.000	49770.125	1.000
	Avgpod No	10045.65	1	10045.65	3215.609	.000	3215.609	1.000
	Pod yld pl-1	23509.58	1	23509.58	2228.731	.000	2228.731	1.000
	pod yld kg ha-1	1.5E+09	1	1.5E+09	2118.036	.000	2118.036	1.000
	hlm yld ha-1	5.4E+09	1	5.4E+09	1419.029	.000	1419.029	1.000
	Oil kgha-1	1.6E+08	1	1.6E+08	2034.827	.000	2034.827	1.000
	kernel kg ha-1	7.8E+08	1	7.8E+08	1883.156	.000	1883.156	1.000
	PN YIELD	6.2E+07	1	6.2E+07	1982.103	.000	1982.103	1.000
	OIL YLD	155.034	1	155.034	2034.757	.000	2034.757	1.000
TREATMEN	KMR	7.242	11	.658	1.343	.242	14.770	.597
	KNLORIN	2.012	11	.183	1.721	.108	18.935	.732
	OILPC	51.343	11	4.668	2.585	.016	28.440	.913
	PHR	4.070	11	.370	1.493	.177	16.424	.655
	PROTEIN	60.613	11	5.510	1.803	.090	19.837	.756
	TBIM	55.760	11	5.069	1.269	.281	13.957	.567
	Pod wt(100)	820.951	11	74.632	.850	.594	9.348	.380
	SHELL PC	78.536	11	7.140	1.979	.061	21.772	.803
	Knl wt(100)	94.339	11	8.576	1.026	.445	11.282	.461
	HLM YLD	28.535	11	2.594	.677	.750	7.452	.300
	Flw (50pc)	3.917	11	.356	.534	.867	5.875	.236
	Avgpod No	119.602	11	10.873	3.480	.002	38.284	.979
	Pod yld pl-1	413.380	11	37.580	3.563	.002	39.189	.981
	pod yld kg ha-1	2.6E+07	11	2321414	3.351	.003	36.860	.973
	hlm yld ha-1	2.9E+07	11	2594114	.677	.750	7.452	.300
	Oil kgha-1	2526769	11	229706.2	3.012	.006	33.136	.954
	kernel kg ha-1	1.1E+07	11	1035157	2.508	.019	27.592	.903
	PN YIELD	1776503	11	161500.2	5.148	.000	56.632	.999
	OIL YLD	2.547	11	.232	3.039	.006	33.431	.956

h. Microbial population in soil

ANOVA Table for Fungi

	DF	SS	MS	F-Value	P-Value
Treatment	5	1033.7	206.74	0.665	0.6547
Subject(Group)	18	5595.833	310.88		
Category for Fungi	7	43828.08	6261.154	22.895	<.0001
Category for Fungi * Treatment	35	8508.658	243.105	0.889	0.6473
Category for Fungi * Subject(Group)	126	34456.83	273.467		

ANOVA Table for Bacteria

	DF	SS	MS	F-Value	P-Value
Treatment	5	1901.29	380.26	3.4	0.0246
Subject(Group)	18	2014.42	111.91		
Category for Bacteria	7	30310.78	4330.11	46.02	<.0001
Category for Bacteria * Treatment	35	13101.48	374.33	3.98	<.0001
Category for Bacteria * Subject(Group)	126	11854.92	94.09		

ANOVA Table for Actinomycetes

	DF	SS	MS	F-Value	P-Value
Treatment	5	57.86	11.57	1.32	0.3013
Subject(Group)	18	158.25	8.79		
Category for Actinomycetes	7	8483.06	1211.87	103.42	<.0001
Category for Actinomycetes * Treatment	35	1203	34.37	2.93	<.0001
Category for Actinomycetes * Subject(Group)	126	1476.42	11.72		

ANOVA Table for Rhizobium

	DF	SS	MS	F-Value	P-Value
Treatment	5	60.8	12.16	4.39	0.0087
Subject(Group)	18	49.92	2.77		
Category for Rhizobium	7	949.23	135.6	32.73	<.0001
Category for Rhizobium * Treatment	35	619.3	17.69	4.27	<.0001
Category for Rhizobium * Subject(Group)	126	522.08	4.14		

ABSTRACT

FUNCTIONAL EFFICIENCY OF ORGANIC MEAL IN GROUNDNUT PRODUCTION

By

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ABSTRACT OF THE THESIS
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ABSTRACT

An experiment entitled "**Functional efficiency of organic meal on groundnut production**" was carried out in the Department of Agronomy, College of Horticulture, Kerala Agricultural University, Vellanikkara during Aug.-Dec. 1999. The main objectives of the study included the elucidation of functional efficiency of organic meal in groundnut nutrition, its mechanism of influence in relation to other mineral and organic sources and role of organics in soil rhizosphere characteristics. The study also included the role of S on groundnut production and its role in modifying the availability of P component of organic meal.

The Package of Practices-Recommendations (POP) with various P sources and graded levels of organic meal with or without lime were tried in Randomized Block Design with four replications.

Organic meal @ 1000-1500 kg ha^{-1} without lime and POP where P was applied as organic meal with elemental S were found to have pronounced effect on various plant growth, nutrient uptake and yield attributing characters of groundnut. These treatments also favoured the better oil and protein content and yield, which in turn resulted in higher returns per rupee invested.

Addition of any form of organic manure is necessary for the better rhizosphere microbial activity in the soil. The very high yields of groundnut resulted with depletion of soil organic carbon level, which necessitated a higher level of application of organic matter to the soil, or incorporation of groundnut residue to compensate it.

Nutrient use efficiency analysis suggested that the yield could be further improved through altering the applied input level of Ca, P and S. This experiment also conveyed that the present recommendation level of lime and sulphur was not necessary for higher production in Vellanikkara situations. But additional amount of phosphorus than POP recommendations for high yielding varieties of groundnut like VRI-4 is required.