INTERACTION OF PHOSPHORUS AND SULPHUR IN BLACK COTTON SOILS OF PALAKKAD (AEU: 23) UNDER GROUNDNUT (*Arachis hypogaea* L.) CULTIVATION

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(2017-11-040)

THESIS

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VELLANIKKARA, THRISSUR

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DECLARATION

I, hereby declare that the thesis entitled "**Interaction of phosphorus and sulphur in black cotton soils of Palakkad (AEU: 23) under groundnut (*Arachis hypogaea* L.) cultivation**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellanikkara

Date: 18/01/2020

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2017-11-040

CERTIFICATE

Certified that the thesis entitled "**Interaction of phosphorus and sulphur in black cotton soils of Palakkad (AEU: 23) under groundnut (*Arachis hypogaea* L.) cultivation**" is a record of research work done independently by **Ms. Shahana, C.K.** 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 her.

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Shahana, C. K.

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ABBREVIATIONS

B	Boron
Ca	Calcium
CD	Critical difference
CEC	Cation exchange capacity
cm	Centimeter
Cu	Copper
DAP	Days after planting
dS	Deci seimens
EC	Electrical conductivity
Fe	Iron
FYM	Farm yard manure
Ha	Hectare
K	Potassium
kg	Kilogram
LAI	Leaf area index
M	Meter
Mg	Magnesium
mg	Milligram
Mn	Manganese
MOP	Muriate of potash
N	Nitrogen
OC	Organic carbon
P	Phosphorus

S	Sulphur
Zn	Zinc

Introduction

1. INTRODUCTION

In Kerala, black cotton soils are seen in Chittur taluk of Palakkad district occupying an area of 2000 ha (Padmaja *et al.*, 1994). These soils are dark, low in organic matter, calcareous, neutral to alkaline (pH 7.0 to 8.5), high in clay content and CEC. The texture of soil ranges from clay loam to clay. The level of total nitrogen in the soil is satisfactory but, only very small fraction of phosphorus is in available form (less than 1 per cent) due to the process of fixation under high pH and clay content.

Even though these soils are fertile, the nutrient imbalances and poor physical conditions may adversely affect the yield of the crop (Krishnakumar, 1978; Padmaja *et al.*, 1994). Balanced supply of nutrients is one of the most important factors determining crop yield. Sometimes the applied nutrients may not be available for plant use, as their availability depends on interaction between the applied nutrients. When the supply of one of the nutrients affects absorption and utilization of the other nutrient element, the elements are said to be in interaction. Interaction between nutrients in soil affects the overall performance of crop. Nutrient interaction may be negative or positive. When nutrients are in combination and results in a greater response than individual response, the interaction is positive (synergism). When combination results in a lesser response, then interaction is negative (antagonism).

The black cotton soils of Chittur area is deficient in available P and S. The availability of P to plants for uptake and utilization is impaired in alkaline soils due to the formation of poorly soluble calcium phosphate.

The groundnut (*Arachis hypogaea* L.) belonging to the family *leguminosae*, originated in South America (southern Bolivia/north west Argentina region) and cultivation started as early as 1000 B.C. Groundnut is an important oilseed crop, about two third of world's groundnut production is used for oil production.

Palakkad is the only district in Kerala where groundnut cultivation is practiced in a large and commercial scale. Thus the area and production are also high in Plakkad district. Chittur taluk contributes a major share to this.

The nut (kernel) of groundnut is a rich source of edible oil, containing 36 to 54% oil and 25 to 32% protein. Even though groundnut can grow in soils of marginal fertility, proper fertilizer application will help to achieve full yield potential of crop. Groundnut has the capacity to utilize soil nutrients that are relatively unavailable to other crops, and therefore can make good use of residual fertility (Cox *et al.*, 1982).

Phosphorus is the second limiting nutrient for crop production (Mallikarjuna *et al.,* 2003). In majority of Indian soils, available P ranges from low to medium. It stimulates setting of pods, decreases the number of unfilled pods (pops) and hastens the maturity of the crop. P enhances nitrogen use efficiency by plants. It is essential for energy storage and transfer and hence called "energy currency" of the living system.

Sulphur is one of the most limiting nutrient for groundnut production, as it has a role in oil content, protein content and quality of kernels. Sulphur has vital role in the metabolism of groundnut plant. It is important for the synthesis of proteins. It helps in biological oxidation-reduction processes. Sulphur deficiency leads to stunted growth and chlorosis and delay maturity in groundnut crop.

In this context present study entitled "Interaction of phosphorus and sulphur in black cotton soils of Palakkad (AEU: 23) under groundnut (*Arachis hypogaea* L.) cultivation" was carried out with following objectives:

1. To find out the interactions of sulphur and phosphorus in black cotton soils of Palakkad.
2. To assess the treatment level of sulphur and phosphorus for maximizing groundnut yield.

Review of Literature

2. REVIEW OF LITERATURE

The results of various experiments conducted in India and elsewhere on nutrient uptake, growth, yield and quality parameters of groundnut and some related oilseed crops under the influence of different nutrients and their interaction effects are reviewed in this chapter.

2.1 EFFECT OF PRIMARY NUTRIENTS ON GROWTH PARAMETERS

2.1.1 Effect of nitrogen on growth parameters

Nitrogen (N) has an important role in the metabolism of plants and is an important structural constituent of the plant cell (Mahapatra *et al.*, 1985). Groundnut is a leguminous crop, with a biological nitrogen fixation capacity of 200-260 kg N ha^{-1} with the help of root nodules, which reduces the demand for applied N. Even though groundnut can fix atmospheric N, it shows good response to the application of nitrogenous fertilizers (York and Colwell, 1951 and Williams, 1979).

Application of N in early stages has beneficial effect on growth parameters of groundnut (Reddy and Rao, 1965). There was a significant increase in the number of leaves, branches and height of groundnut plant as a result of application of nitrogen (Punnoose, 1968). Singh and Ahuja (1985) observed increase in growth of groundnut due to the application of N at 25 kg ha^{-1}.

2.1.2 Effect of phosphorus on growth parameters

Phosphorus (P) is the second major essential nutrient element for crop growth. The most important effect of P is in the plant root system. Phosphorus requirement in nodulating legumes is higher compared to non-nodulating crops as it has an integral role in nodule formation and also in the fixation of atmospheric nitrogen (Brady and Weil, 2002). Phosphorus is essential for the storage and transfer of energy. Phosphate group is the major constituent of adenosine di and tri phosphate (ADP and ATP) known as energy currency of plants (Tisdale *et al.*, 1993). P requirement of plants is met by the uptake of phosphate anions from soil solution. P is important for the formation and growth of roots and N fixation (Lakshmamma and Raj, 1997).

Phosphorus application at 132 kg ha^{-1} increased haulm yield in groundnut (York and Colwell, 1951). Punnoose (1968) studied the effect of P on growth, yield and quality of groundnut and observed that application of P increased the number of leaves, branches, height of the plant and weight of nodules per plant. Patel *et al.* (1994) reported that higher dose of phosphatic fertilizer application increased the number of root nodules. The number and weight of root nodules, activity of nitrogenase enzyme, leghaemoglobin content, leaf area and dry matter production increased significantly by enhancing the P_2O_5 content from 0 to 30, 60 and 90 kg ha^{-1}.

Shelke and Khuspe (1980) observed highest dry matter production and P uptake by groundnut cv. Latur No.33 as a result of the application of 17.5 kg P_2O_5 ha^{-1}. Basha and Rao (1980) reported decrease in number of leaves and length of shoot in groundnut due to the deficiency of P. Higher levels of P increased growth of root and shoot significantly (Patel *et al.,* 1994). Change in the rate of P application from 30 to 90 kg ha^{-1} found to enhance the growth of plants (Singh and Ahuja, 1985).

Sebale and Khuspe (1986) observed higher plant height, number of leaves, branches and dry weight per plant due to the application of P at the rate of 60 kg ha^{-1}. P application increased the plant height and dry matter yield in groundnut crop (Juan *et al.* 1986). Kamara *et al.* (2011) reported an increase in biomass of groundnut after the application of phosphorus fertilizer and attributed it to the availability of soluble phosphate that enhanced extensive root development.

2.1.3 Effect of potassium on growth parameters

Rao (1979) reported an increased dry matter production with the application of higher levels of K in groundnut cv. TMV-2. Mathew *et al.* (1983) observed that growth parameters such as plant height, number of branches, number of leaves per plant and Leaf Area Index (LAI) were increased with potassic fertilizer application.

2.2 EFFECT OF PRIMARY NUTRIENTS ON YIELD AND YIELD ATTRIBUTES

2.2.1 Effect of nitrogen on yield and yield attributes

Plants require N in larger amounts compared to other elements. As groundnut belongs to *leguminosae* family, it can fix 40-80 kg N ha^{-1} yr^{-1} (Islam and Noor, 1982). Dart *et al.* (1983) reported that about 86-92 per cent of N uptake by groundnut occured through biological nitrogen fixation (BNF) which is equivalent to 125-178 kg N ha^{-1}.

Jadhar and Narkhende (1980) concluded that N played a significant role on the number of pods as well as number of filled pods per plant. According to Saradhi *et al.* (1990) higher doses of nitrogen led to production of more number of flowers and pegs in groundnut crop. Hasan (2018) concluded that there was a significant increase in yield of groundnut due to the application of nitrogen. Increase in pod yield and its subsequent reduction was observed due to the application of nitrogen @ 10-30 kg ha^{-1} (Pant and Katiyar, 1996; Patel *et al.*, 1994) whereas, application of 40-60 kg ha^{-1} nitrogen increased number of pods per plant (Reddy *et al.*, 1984).

Reddy and Rao (1965) reported significant reduction in yield of groundnut by the application of nitrogen @ 40 kg ha^{-1}. Nijhawan and Maini (1966) observed increase in yield of groundnut crop even at application of small doses of nitrogen. Study conducted by Puntamkar and Bathkal (1967) indicated that application of nitrogen at the rate of 20 kg ha^{-1} significantly increased the number of pods per plant and its weight in groundnut. Saini and Tripathi (1973) also investigated the effect of nitrogen on groundnut and concluded that application of 15 kg ha^{-1} nitrogen showed highest pod yield and oil content.

2.2.2 Effect of phosphorus on yield and yield attributes

Legume plants require higher amount of phosphorus compared to non-legume crops because of its role in the formation of nodules and atmospheric nitrogen fixation (Brady and Weil, 2002). Balasubramanian and Palaniappan (1991) revealed that higher the amount of phosphorus, higher will be the quantity of nitrogen fixed.

Total uptake of nitrogen and its proportion in kernel were highly influenced by the level of phosphorus and interaction between phosphorus and potassium showed significant influence on kernel yield (Balasubramanian and Palaniappan, 1991). Bala *et al.* (2011) opined that increased pod and seed index and shelling per cent of groundnut were due to early and greater availability of nitrogen and phosphorus to plants which favorably influenced the development and size of kernels. According to Samtana *et al.* (1994) there was a significant improvement in yield attributes of groundnut by the application of P. This improvement was due to the production and proliferation of new roots which led to their improved functional activity.

Ae *et al.* (1996) opined that in acid soils, groundnut showed superior ability to take up phosphorus from a soil with low P fertility status compared with sorghum and soybean. They also concluded that root cell walls of groundnut are characterized by higher P-solubilizing activity compared to those of soybean or sorghum. Response of crop to phosphatic fertilizer application is influenced by initial available P content in the soil. Agasimani and Hosmani (1989) revealed that response of applied P could be obtained when the available soil phosphorus content is less than 35 kg ha^{-1}.

Rao *et al.* (1984) reported that application of P above 60 kg ha^{-1} had no significant effect on number of pods and it depended on the fertility status of soil.

Hasan (2018) reported that there was a significant increase in yield of bambara groundnut due to the application of phosphorus along with nitrogen. Chauhan *et al.* (1987) opined that there was increase in shelling per cent as a result of application of moderate to high level of P. Banerjee *et al.* (1967) viewed an increase in yield of groundnut by the application of P_2O_5 up to the level of 67.2 kg ha^{-1}. Puri (1969) observed a significant response of groundnut crop to the application of superphosphate. According to Choudhary (1979), the pod yield of irrigated groundnut variety, TMV-2 was higher when applied with 60 kg P_2O_5 ha^{-1} than with 30 kg P_2O_5 ha^{-1}. Nakagawa *et al.* (1981) reported that application of 40 kg P_2O_5 ha^{-1} led to increase in pod yield from 1.42 to 2.5 t ha^{-1} and seed yield from 0.91 to1.58 t ha^{-1}. The P application increased seed size and 100 pod weight.

2.2.3 Effect of potassium on yield and yield attributes

Potassium nutrition showed favorable effect on photosynthesis as well as in translocation of food reserves from leaves to developing pods (Koch and Mengal, 1977). Groundnut is a heavy feeder of potassium. Adequate supply of this nutrient must be given to obtain a better yield (Geethalakshmi *et al.*, 1993). York and Colwell (1951) observed that groundnut grew well even in potassium deficient soils where other crops could not grow.

Yakadri and Sathyanarayana (1992) investigated the effect of application of K_2O, and found that 40-60 kg ha^{-1} was the optimum dose of K for groundnut. Whereas, Nair *et al.* (1981) revealed that application of potassic fertilizer @ 80 kg ha^{-1} increased the number of pods per plant. According to Ramanathan *et al.* (1982) application K fertilizer at 50 kg ha^{-1} resulted in maximum number of pods per plant and highest test weight of seed.

According to Hadwani and Gundalia (2005), K fertilizer application increased the yield of pod and haulm. Study conducted by Loganathan and Krisnamoorthy (1980) concluded that there was an increase in yield and yield contributing characters as a result of increased K application level. If the K level in the pod zone is high, it is undesirable as it resulted in pod rot and interfered with uptake of Ca by pegs and pods, which in turn led to a higher per cent of pops formation and Ca deficiency in the seeds (Hallock and Garren, 1968; Csinos and Gaines, 1986).

Higher level of K increased the number of pods per plant and test weight of seeds in groundnut variety, TMV-2 (Rao, 1979). Loganathan and Krishnamoorthy (1980) emphasized that optimum dose of potassium for irrigated groundnut crop was 52 kg ha^{-1} and for rainfed crop was 26 kg ha^{-1}. It was identified by Chavan and Kalra (1983) that dry pod yield, shelling per cent, 1000 grain weight and oil content of groundnut cv. TG- 1 were higher when applied with 50 kg ha^{-1} of K than with 25 kg ha^{-1}.

2.3 EFFECT OF COMBINED APPLICATION OF PRIMARY NUTRIENTS ON GROUNDNUT

Venkateswaralu and Nath (1989) showed the importance of balanced fertilizer schedule and its influence on groundnut. Das (1982) reported that growth components were increased by the application of NPK. Combined application of NPK at the rate of 20: 40: 40 kg ha^{-1} gave highest yield (Pradhan and Das, 1989). Yadav (1990) also reported that the application of NPK at 20: 60: 40 kg ha^{-1} resulted in highest yield in groundnut crop. Whereas Balasubramaniam and Palaniappan (1991) opined that the application rate of 150 kg N and 50 kg K_2O ha^{-1} resulted in higher yield.

According to Patel *et al.* (1994) application of nitrogen @ 25 kg ha^{-1} along with 50 kg P_2O_5 ha^{-1} increased the pod and haulm yield of groundnut *cv.* GAUG-1. Kachot *et al.* (1984) recorded higher number of pegs per plant, number of pods per plant, pod weight and test weight per plant when groundnut crop was supplied with 12.5 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1}. Rana *et al.* (1984) observed that higher pod yield of 23.19 q ha^{-1} was obtained by the application of 20 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}.

Application of NPK at the rate of 50: 100: 50 kg NPK ha^{-1} significantly increased the number of branches per plant (Dholaria *et al.* 1972).

Long term application of manures and fertilizers significantly influenced the yield and productivity of groundnut crop grown in alfisols of Chittoor taluk in Andhra Pradesh (Parvathi *et al.*, 2015). Ghadekar *et al.* (1993) reported that pod yield was highest at the fertilizer application rate of 40 kg ha^{-1} N, 80 kg ha^{-1} P_2O_5 and 30 kg ha^{-1} K_2O. The application of NPK @ the rate of 25 kg ha^{-1} N + 75 kg ha^{-1} P_2O_5 + 37.5 kg ha^{-1} K_2O gave mean pod yield of 3.55, 4.10 and 4.99 t ha^{-1} respectively (Thimmegowda, 1993).

A study conducted by Sireesha *et al.* (2017) found that higher yield from groundnut crop was obtained when supplied with 50 per cent of recommended dose along with 4 t ha^{-1} FYM. Dahatonde (1982) reported that combined application of organic manure and inorganic fertilizers recorded favorable effects on various growth parameters and yield attributing characters of groundnut. They revealed that application of 25 kg N and 50 kg P_2O_5 ha^{-1} along with 5 t ha^{-1} FYM recorded highest plant height, spread, no.of branches per plant and total dry matter per plant at harvest and yield attributes *viz*., filled pod per plant, dry pod per plant and pod and haulm yield of summer groundnut.

Kuchanwar *et al.* (1997) opined that highest nitrogen and phosphorus uptake was observed with combination of 25:50 kg N and P_2O_5 ha^{-1} respectively. According to Dubey (1997) application of single super phosphate (SSP) at 60 kg P_2O_5 ha^{-1} gave highest, but was on par with 30 kg P_2O_5 ha^{-1} as SSP along with *Pseudomonas striata* with regard to N, P and K uptake (straw + grain) in black or medium clay soil (Vertisol). Shipkule *et al.* (2008) observed that application of 80:60:20 kg ha^{-1} N, P_2O_5 and K_2O respectively gave maximum nutrient content as well as highest uptake of nitrogen, phosphorus and potassium by kernel and haulm of groundnut. According to Sanchez and Owen (1978), application of 150 kg P_2O_5 ha^{-1} along with nitrogen and potassium increased pod yield from 0.75 to 2.07 t ha^{-1}.

Babu *et al.* (2007) observed that highly fertilized plots had higher uptake of NPK by the groundnut crop. But this higher uptake did not contribute to higher yield but enhanced vegetative growth. Dholaria *et al.* (1972) reported that pod weight, number of pods and number of branches per plant increased under higher fertilizer application rate (50: 100: 50 kg NPK ha^{-1}).

2.4 EFFECT OF SECONDARY NUTRIENTS ON GROWTH AND YIELD ATTRIBUTES

2.4.1 Effect of Ca on growth and yield parameters

Groundnut plants require calcium (Ca) from the beginning of pegging stage, fruit formation, until the maturity of pods (Walker, 1975). Ca deficiency led to high per cent of aborted seeds (empty pods), improperly filled pods and caused aborted or shrivelled fruit, including darkened plumules and production of pods without seed (Singh and Oswalt, 1995).

Mandal *et al.* (2005) reported that application of gypsum in summer and rainy season groundnut in sandy loam soils of West Bengal @ the rate of 400 kg ha^{-1} showed highest plant height (65.1cm). Calcium plays an important role in proper development of pod and production of high quality seeds (Cox *et al.*, 1982). Calcium deficiency led to lowering of yield, darkening of plumule in the seed, empty pods and sometimes plants remained green and continued to produce flowers and pegs without pods, that might be infertile (Sumner and Farina, 1986).

Application of soluble source of Ca helped to avoid Ca deficiency at early flowering stage. The surrounding soil of developing pods require high Ca level, as the calcium absorbed by root did not translocate into pods and the required calcium for pod development was directly absorbed from the soil solution (Skelton and Shear, 1971).

According to Sumner and Farina (1986) and Kvien *et al.* (1988) soil Ca level in the range of 600-800 mg kg^{-1} produced good quality groundnut kernel.

Kvien *et al.* (1988) reported that, morphological characters of pod such as surface area, volume, number of days for maturation of and shell thickness significantly influenced Ca uptake by the pods. Ca requirement showed variation with the size of seeds. Small seeded cultivars required less quantity of calcium compared to larger seeded types, because of its larger surface to volume ratio. Soil characters such as soil moisture content, soluble and exchangeable calcium and type of mineral present in the soil affected the uptake of Ca by groundnut (Keisling *et al.,* 1983).

2.4.2 Effect of magnesium on growth and yield parameters

Dowood (1982) opined that application of three levels of Mg *i.e.* 0, 120 and 240 kg $MgSO_4.7H_2O$ ha^{-1} significantly increased phosphorus uptake by the plant. Al-lami (1999) reported that increase in addition of $MgSO_4.7\ H_2O$ from 0 to 80 kg ha^{-1} resulted in significant increase in available phosphorus content in soil from 0.23 to 0.25 c mol kg^{-1}.

2.4.3 Effect of sulphur on growth and yield parameters

Rao *et al.* (2013) found that application of S at 45 kg ha^{-1} as gypsum recorded highest plant height (71.45 cm) in sandy loam soils of Andhra Pradesh. Application of S influenced growth, yield attributing characters, yield and oil content regardless of the sources and levels of S. Addition of S at 45 kg ha^{-1} recorded highest plant height, number of filled pods per plant, 100 pod weight, 100 kernel weight, pod yield, haulm yield and oil content of kernels in groundnut (Rao *et al.,* 2013). The S uptake by pods increased significantly with increasing levels of S and maximum uptake (10.89 kg ha^{-1}) was noticed with application of 60 kg S ha^{-1}.

Application of sulphur @ 60 kg ha^{-1} in groundnut gave higher number of total pods $plant^{-1}$ (37.80), 100 pods weight (96.82 g), 100 seeds weight (46.25 g), shelling per cent (85.29%), pod yield (3.13 t ha^{-1}), seed yield (2.67 t ha^{-1}), stover yield (6.84 t ha^{-1}), and harvest index (31.37 %) when compared with other treatments such as 0, 15, 30 and 45 kg ha^{-1} of S (Nurezannat *et al.,* 2019). Singh and Chaudhari (2008) observed that in calcareous soil, plants grown by addition of S had increased plant height, number of flowers, number and weight of nodules, higher dry matter, seed, haulm (leaves and stems), and oil content compared to those without S. Babu *et al.* (2007) reported that application of S through gypsum @ 40 kg ha^{-1} recorded highest pod and haulm yield. Giri *et al.* (2014) observed that number of pods per plant was highest in sandy loam soils when S was applied at 15 kg ha^{-1} (25.52). Umadevi *et al.* (1999) reported that pod yield enhanced by increasing S levels from 15 to 30 and 75 kg ha^{-1} in red loamy sandy soils of Ananthapur, Andhra Pradesh. Highest pod yield was recorded by addition of S at 75 kg ha^{-1}.

2.5 EFFECT OF MICRONUTRIENTS ON GROWTH AND YIELD ATTRIBUTES

2.5.1 Effect of micronutrients on growth and yield parameters

Soil pH, cation and anion exchange capacity and nutrient interactions are the factors affecting availability of micronutrients in soils. The application of B promoted absorption of N by groundnut and increased plant height, dry weight and the total number of pods per plant. Study conducted by Bharthi *et al.* (2010) revealed that application of micronutrients (Fe, Zn, B) along with recommended dose of fertilizers resulted in improvement of growth characters and chlorophyll content in groundnut. They observed that application of 20 kg ha^{-1} $ZnSO_4$ and 5 kg borax gave highest pod yield and dry matter content.

Mahamoud *et al.* (2006) observed that foliar application of boron at 25-50 ppm increased plant height, leaf area, total dry matter, number of pods and seed yield. Study conducted by Ravichandra *et al.* (2015) indicated that foliar spray of boron along with rhizobium in flowering and pod formation stages had positive impact on growth and yield of groundnut as it increased plant height, number of branches, number of pods per plant, plant dry weight, 100 pod weight, pod yield and seed index. Excess foliar application of boron led to decrease in the above mentioned growth and yield parameters.

Kamalakannan and Ravichandran (2013) recorded highest plant height at all critical stages of groundnut as a result of application of 100 per cent NPK, 25 kg ha^{-1} of $ZnSO_4$, 10 kg ha^{-1} of boron and 12.5 t ha^{-1} FYM. Subrahmaniyan *et al.* (2001) suggested that combined application of borax at 5 kg ha^{-1}, $ZnSO_4$ at 5 kg ha^{-1} and ferrous sulphate at 10 kg ha^{-1} recorded maximum number of pods per plant. Reddy *et al.* (2011) emphasized that soil application of micronutrients *viz.*, $ZnSO_4$ at 10 kg ha^{-1}, borax at 5 kg ha^{-1} and copper sulphate at 5 kg ha^{-1} resulted in increase in number of pods per plant.

Mahajan *et al.* (1994) reported that boron at 0.5 kg ha^{-1} applied as boronated super phosphate or borax increased dry pod yield (3200 kg ha^{-1}) followed by spray of 0.5 ppm boron in 2 sprays in such a way that first at 30 days after germination and second at the time of flowering gave higher yield than control. According to Singh *et al.* (2009) soil application of boron at 1 kg ha^{-1} as, solubor, agricol and borosol increased pod yield by 18, 23 and 12 per cent respectively, compared to the spray of 5 per cent as boric acid and 9 per cent as borax.

2.6 EFFECT OF NUTRIENTS ON PLANT NUTRIENT CONTENT AND UPTAKE

2.6.1 Effect of nitrogen on nutrient content and uptake

Nitrogen uptake is more intensive in flowering as well as pod formation stages. During reproductive stage, there is continuous mobilization of nitrogen from leaves to developing fruit, and this resulted in appearance of N deficiency symptoms on leaves (Kvien *et al.*, 1988). Chahal *et al.* (1983) reported that nitrogen content in shoot was high at early and mid-flowering stages. Reddy *et al.* (1984) studied uptake of nitrogen in groundnut and it was maximum by the application of 10 kg N as basal and 20 kg N at 30 DAP. Boote *et al.* (1985) observed that during seed filling stage, N content in leaf decreased from 4.01 to 2.85 per cent, in stem from 1.65 to 1.13 per cent and in root N from 2.19 to 1.50 per cent. Reddy and Murthy (1985) observed that N content was highest in kernel and lowest in the shell. N content decreased along with crop growth.

2.6.2 Effect of phosphorus on nutrient content and uptake

Basha and Rao (1980) reported that deficiency of P decreased N,P,K and Ca contents in 30 days old groundnut plants. According to Shelke and Khuspe (1980) P uptake and dry matter production by groundnut cv. Latur No. 33 was highest with the application of P at 17.5 kg ha^{-1} than with 0 or 35 kg ha^{-1}. Nakagawa *et al.* (1981) revealed that highest rate of P application significantly increased P content in seeds. Patel *et al.* (1994) recorded the effect of application of 100 ppm P_2O_5 on nutrient uptake and growth of groundnut in calcareous soil. High phosphorus level increased growth of shoot and uptake of P by root and shoot. Higher level of P was also effective in increasing the uptake of nitrogen by the plant. Chahal *et al.* (1983) observed that application of P increased the uptake of N and P and dry matter yield.

Application of P_2O_5 @ 60 kg ha^{-1} increased uptake and content of N and P in seed (Islam and Noor, 1982). Chavan and Kalra (1983) reported that P increased the N content and NPK uptake in plants. Bell (1985) reported that the tissue P content during vegetative growth was 0.3 per cent of dry matter and declined during reproductive stage as 0.27 per cent at 60 Days After Emergence to 0.12 per cent at 100 days.

2.6.3 Effect of potassium on nutrient content and uptake

Rao (1979) revealed that uptake of N and P increased with application of K @ 0, 40, 80 kg ha^{-1} in groundnut variety, TMV-2 under irrigated condition. According to Reddy *et al.* (1983) uptake of K in groundnut was maximum when it was applied as basal dose a the rate of 40 kg ha^{-1}. Survase *et al.* (1986) concluded that average plant N, P and K contents at flowering stage were 2.7, 0.21, and 2.28 per cent respectively.

2.6.4 Effect of secondary nutrients on nutrient content and uptake

Giri *et al.* (2014) reported that uptake of nutrients such as N, P, K and S by kernel, shell and haulm of groundnut and also total uptake of nutrients by groundnut were significantly influenced by levels of sulphur. Umadevi *et al.* (1999) reported that S application @ 75 kg ha^{-1} recorded highest nitrogen (100.7 kg ha^{-1}), phosphorus (10.40 kg ha^{-1}), potassium (40.4 kg ha^{-1}), sulphur (12.21 kg ha^{-1}), calcium (34.6 kg ha^{-1}) and magnesium (15.59 kg ha^{-1}) uptake by groundnut. Singh *et al.* (2009) viewed that S uptake by groundnut pods increased significantly with increased levels of S up to 60 kg ha^{-1} (10.89 kg ha^{-1}). Patel *et al.* (2009) observed that successive increase in sulphur application rate up to 40 kg ha^{-1} improved NPS uptake by groundnut. The maximum uptake of nutrients was observed at S application of 15 kg ha^{-1} and minimum uptake in no S treatment.

Rao and Shaktawat (2002) reported that gypsum application at the rate of 250 kg ha^{-1} (half at sowing + half at 35 DAS) in groundnut crop significantly increased nitrogen, phosphorus, potassium, calcium, sulphur and magnesium uptake by 13.2, 11.0, 10.6, 11.1, 10.4 and 8.9 per cent respectively over control.

Study conducted by Veerabhadrappa and Yeledhalli (2005) revealed that foliar application (N, P, K, Ca and S - commercial formulation of urea, SSP and MOP at 1 per cent level each) 60 DAS along with the application of 100 per cent RDF recorded higher levels of nitrogen (252 kg ha^{-1}), phosphorus (28.9 kg ha^{-1}), potassium (204 kg ha^{-1}), calcium (74.8 kg ha^{-1}) and sulphur (31.4 kg ha^{-1}) uptake by groundnut.

2.6.5 Effect of micronutrients on nutrient content and uptake

Mahajan *et al.* (1994) concluded that soil application of B at the rate of 0.5 kg ha^{-1} through boronated superphosphate recorded higher nitrogen (127.4 kg ha^{-1}) and phosphorus (11.7 kg ha^{-1}) uptake in clayey soils. Study conducted by Kamalakannan and Ravichandran (2013) indicated that application of 100 per cent NPK, borox at 10 kg ha^{-1} , zinc sulphate at 25 kg$ha^{-1}$and FYM at 12.5 t ha^{-1}

showed highest NPK uptake in all the growth stages of groundnut crop. Nadaf and Chidanandappa (2015) reported that borax at 5 kg ha^{-1} and zinc sulphate at 20 kg ha^{-1} recorded highest uptake of nitrogen (95.72 kg ha^{-1}), phosphorus (23.50 kg ha^{-1}), potassium (92.68 kg ha^{-1}), calcium (38.34 kg ha^{-1}), magnesium (20.87 kg ha^{-1}) and sulphur (28.16 kg ha^{-1}).

2.7 EFFECT OF PRIMARY NUTRIENTS ON QUALITY PARAMETERS

2.7.1 Oil content

2.7.1.1 Effect of nitrogen

Most of the experiments on the influence of nitrogen on oil content of oil seed crops emphasized that there was a reduction as a result of application of nitrogen in the oil content.

Maini and Bhander (1965) investigated and concluded that oil content of seeds was adversely affected by the application of nitrogen in oil seed crops. Punnoose (1968) noticed significant reduction in oil content due to application of nitrogen fertilizers on groundnut in a trial conducted at College of Agriculture, Vellayani.

According to Salini and Tripathi (1973) nitrogen application @ 15 kg ha^{-1} produced better oil content and it was decreased with the increase in the nitrogen dose.

Singh and Ahuja (1985) opined that growth, nutrient uptake, pod yield and oil content increased significantly with seed inoculation of nitrogen @ 25 kg ha^{-1}.

2.7.1.2 Effect of phosphorus

Cheema *et al.*, (2001) reported that application of phosphorus resulted in higher protein content in oilseed crops. The oil concentration increased from 43.2 to 47.3 g per 100 g of seeds due to the application of phosphorus (Lickfett, 1999), whereas Brennan and Bolland (2007) opined that application of phosphorus had no effect on the concentration of oil in oilseeds.

2.7.1.3 Effect of potassium

Farhad *et al.* (2010) reported that combined application of potassium at the rate of 40 kg ha^{-1} and sulphur at the rate of 20 kg ha^{-1} resulted in the production of high amount of oil.

2.7.2 Protein content

2.7.2.1 Effect of nitrogen

Nijhawan (1962) reported beneficial effect of nitrogen application in increasing the protein content.

2.7.2.2 Effect of phosphorus

Punnoose (1968) observed that graded doses of phosphorus resulted in the enhancement of protein content in groundnut kernels. Study conducted by Basha and Rao (1980) indicated that P deficiency led reduction in protein content of groundnut. Nair and Sadanandan (1981) reported that protein content showed increase with increased phosphatic fertilizer application at the rate of 50-100 kg ha^{-1}.

2.7.2.3 Effect of potassium

According to Nair and Sadanandan (1981) the protein content decreased with increased dose of potassium from 25 to 75 kg ha^{-1}.

2.8 EFFECT OF COMBINED APPLICATION OF PRIMARY NUTRIENTS ON QUALITY PARAMETERS

Bandopadhyay *et al.* (2003) reported increased oil production with increased N and P fertilizer application.

2.9. EFFECT OF SECONDARY NUTRIENTS ON QUALITY PARAMETERS

2.9.1 Oil content

Tripathi and Hazra (2003) found that there was significant improvement in the oil per cent of groundnut pods along with the application of sulphur containing fertilizers. Bandopadhyay *et al.* (2003) also reported increased oil production with increased S fertilizer application. Gypsum or SSP application followed by elemental S increased the oil content in groundnut seeds (Dutta and Patra, 2005).

2.9.2 Protein content

According to Tripathi and Hazra (2003) application of S fertilizers improved the protein content in groundnut pods. Sulphur application showed significant increase in kernel protein content (Kalaiyarasan *et al.*, 2003).

2.10 EFFECT OF MICRONUTRIENTS ON QUALITY PARAMETERS OF GROUNDNUT

2.10.1 Effect of micronutrients on oil and protein content

Foliar application of $FeSO_4$ increased oil content in groundnut kernels (Akhtar *et al.*, 2018).

2.11 INTERACTION OF NUTRIENTS

2.11.1 **Interaction of P and S**

Teotia *et al.*, (2000) observed that increase in the levels of P and S significantly increased the grain and straw yield in rice. According to Aulakh *et al.* (1990) there was increase in yield of vegetative tissues and grains as a result of application of S and P individually but decreased when they were applied as different combinations. Sulphur application led to increase in sulphur content whereas decrease in phosphorus content in grains as well as in straw. They also observed that increased total P content with the application of P and decreased with the application of sulphur. By the application of phosphorus, protein content decreased and it increased by sulphur fertilization in grains of moong.

Das (2017) conducted an experiment in green gram with four levels of sulphur (0, 20, 40 and 60 kg ha $^{-1}$) and two levels of phosphorus (30 and 60 kg ha^{-1}). He concluded that interaction of P and S at higher doses had a negative impact on the yield of crop.

2.11.2 Interaction of P with other nutrients

Phosphorus deficiency is a major yield limiting factor for crop production in acid as well as alkaline soils (Fageria, 1983). Assessment of interaction of phosphorus with other nutrients is critical to keep up a balanced nutrient supply for enhancing crop growth and yield. Phosphorus showed a positive interaction with nitrogen and also in plant development (Sumner and Farina, 1986). Sumner and Farina (1986) also concluded that increased growth required more quantity of both N and P and the mutually synergistic effects resulted in growth stimulation and enhanced uptake of nitrogen and phosphorus.

If large quantity of P is supplied, P: Fe and P: Zn ratio in plant tissues increased and led to deficiency of these nutrients (Loneragan *et al.,* 1979; Loneragan *et al.,* 1982).

High available P resulted in the deficiencies of Zn and Mn in potato (Adriano *et al.*, 1971) and maize (Adriano and Murphy, 1970). There was formation of chemical bond by P with Zn, at high levels of P and P bounds large quantity of Zn resulted in P induced Zn deficiency, which led to reduction in shoot growth. Friesen *et al.* (1980) observed increase in total uptake of Zn with P addition which led to increased root growth, however extreme levels of P caused Zn deficiency. According to Saeed and Fox (1979) there was an increase in Zn sorption in Hawaiian soil due to the application of P. Sorption of P on the surface of Fe and Al oxides led to increase in negative charges on them and resulted in increased sorption of Zn. Gupta and Raj (1983) viewed positive interaction between Zn and K on yield of wheat.

Heavy application of P also led to the deficiency of Fe. Interaction of P with Fe produced Fe- phosphates which resulted in Fe chlorosis in plants (Ayed, 1970). Inhibition of Fe absorption by roots occurred due to higher level of P. It also inhibited Fe transport from roots to shoots and inactivates Fe content in plants (Elliott and Laeuchli, 1985; Moraghan and Mascagni, 1991).

Interaction of P with Ca was complex; it showed both synergistic and antagonistic effects. The synergistic effect was due to simultaneous uptake of Ca and P. Antagonistic effect was due to precipitation of P into less soluble calcium phosphate (Jakobsen, 1979). Fageria (1983) reported decreased uptake of P and Ca with increased concentration of potassium in rice. Lundergardh (1934) observed a higher absorption of P and Ca at lower concentration of potassium. Acidifying effect of S application played an important role in mobilization of P, Fe, Zn and Mn in calcareous soils (Soliman *et al.,* 1992).

2.11.3 Interaction of S with other nutrients

Abdin *et al.* (2003) reported that sulphur is known to interact with almost all essential macronutrients, secondary and micronutrients. These interactions can either enhance or reduce growth and yield of crops by influencing the nutrient uptake and utilization. Soliman *et al.,* (1992) reported that S application increased Mn content in corn plants grown in calcareous soils.

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Interaction of phosphorus and sulphur in black cotton soils of Palakkad (AEU: 23) under groundnut (*Arachis hypogaea* L.) cultivation" was carried out in College of Horticulture, Vellanikkara during 2017-19. The study consists of a field experiment with groundnut in black cotton soils of Chittur Taluk in Palakkad district followed by laboratory analysis of soil and plant samples taken from the experimental field. The materials used and methods followed in the study are described in this chapter.

3.1 COLLECTION OF SOIL SAMPLES AND ANALYSIS

Soil samples were collected from different locations of Chittur Taluk and analyzed the status of available phosphorus and sulphur. Four to five samples were collected from each location at a depth of 0-15 cm. Collected samples were air dried, processed and sieved through 2mm sieve. These samples were analyzed for available P and S. The details of available P and S status of soil samples collected from different locations of Chittur are given below.

Table 1: Available status of P and S in soil samples collected from different locations of Chittur

Sl. no.	Place	Available P ($kg\ ha^{-1}$)	Available S ($mg\ kg^{-1}$)
1	Kambalathara	11.65	4.90
2	Kannimari	13.51	4.68
3	Kulappurakkad	7.33	6.03
4	Erimedu	7.04	6.32
5	Meenakshipuram	9.09	5.94
6	Plachimada	16.30	6.33
7	Mullamthodu	12.30	4.29
8	Veloor	8.94	5.14
9	Nellimedu-1	8.13	4.50
10	Nellimedu-2	9.01	3.19

Plate 1: Initial soil sample collection from the experimental field

Plate 2: View of the experimental field after ploughing

The experiment was conducted in a field deficient in both P and S. The methods of analysis followed for estimating the physico – chemical properties of soil are given below.

Table 2: Methods followed for the analysis of soil samples

Parameter	Method	Reference
Bulk density	Keen – Raczkowski cup	Piper (1966)
Texture	International pipette method	
pH and electrical conductivity	1: 2.5 soil water suspension- pH meter and conductivity meter	Jackson (1973)
Organic carbon	Walkley and Black method	Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorus	Olsen extraction (0.5 M $NaHCO_3$ at pH 8.5) and estimation by spectrophotometer	Watanabe and Olsen (1965)
Available potassium	Neutral normal ammonium acetate extraction and estimation by flame photometer	Jackson (1973)
Available calcium and magnesium	Neutral normal ammonium acetate extraction and estimation by AAS	
Available sulphur	$CaCl_2$ extraction and estimation by Spectrophotometer	
Available boron	Hot water extraction and estimation by spectrophotometer	
Available micronutrients (Fe, Mn, Zn, Cu)	DTPA extraction and estimation by ICP-OES	Lindsay and Norvell (1978)

Table 3: Physico – chemical properties of soil in the field before experiment

Parameter	Value
Bulk density (Mg m^{-3})	1.35
Texture	Sandy clay loam
Coarse sand (%)	31.80
Fine sand (%)	27.30
Silt (%)	18.65
Clay (%)	22.25
pH	7.89
Electrical conductivity (dS m^{-1})	0.245
Organic carbon (%)	1.24
Available nitrogen (kg ha^{-1})	286.50
Available phosphorus (kg ha^{-1})	9.10
Available potassium (kg ha^{-1})	234.90
Available calcium (mg kg^{-1})	1654.97
Available magnesium (mg kg^{-1})	497
Available sulphur (mg kg^{-1})	3.19
Available B (mg kg^{-1})	2.99
Available Fe (mg kg^{-1})	18.34
Available Mn (mg kg^{-1})	7.78
Available Zn (mg kg^{-1})	1.09
Available Cu (mg kg^{-1})	3.10

3.2 GENERAL DETAILS OF FIELD EXPERIMENT

3.2.1 Experimental site

The experiment was conducted in black soils at Chittur, Palakkad. Geographically it is situated at eastern side of Palakkad district at 10^0 38' 3.88" N latitude and 76^0 44' 53.90" E longitude and at an elevation of 129 m from mean sea level.

3.2.2 Climate and weather

The climate was humid tropical during the experiment. Temperature range was 30-33^{0}C.

3.2.3 Cropping season

Experiment was conducted during May - August 2018.

3.2.4 Cropping history of field

Maize and cowpea were the main crops cultivated in the field till 2016 and then field was left fallow for one year.

3.2.5 Crop variety

Groundnut variety used for the study is K-6 (Kadiri-6). This variety was released from Agricultural Research station, Kadiri, Andhra Pradesh, which is semi spreading in nature. It is a short duration variety suitable for both kharif and rabi seasons. The variety is resistant to leaf spot disease.

3.3 EXPERIMENTAL DETAILS

Soil samples were collected from different locations of Chittur and experiment was conducted where deficiencies of both P and B are noticed. The experimental details are given below.

Crop	: Groundnut
Variety	: K-6
Season	: May - August
Design	: RBD (factorial)
Treatments	: 4^2+1
Replications	: 3
Spacing	: 15cm x 15cm.
Plot size	: 4.05 x 2.5 m^2

POP recommendations of groundnut- 10:75:75 N:P:K kg ha^{-1}

Seeds were collected from Agricultural Research Station, Kadiri, Andhra Pradesh.

3.3.1 Treatment details

Different doses of P and S and their combinations were used as treatments. Treatment combinations are made with four levels of P and four levels of S. Soil test based recommendations is taken as control.

Factor A

Levels of phosphorus (P) – 4

P_0 -Control

P_1 -60 kg P_2O_5 ha^{-1}

P_2 -75 kg P_2O_5 ha^{-1}

P_3 -90 kg P_2O_5 ha^{-1}

Factor B

Levels of sulphur (S) – 4

S_0 - Control

S_1 – 10 kg ha^{-1}

S_2 – 20 kg ha^{-1}

S_3 – 30 kg ha^{-1}

Plate 3: Groundnut crop at flowering stage

Treatment combinations

T_1 : Soil test based recommendations

Treatment	Notation	Treatment	Notation
T_2	P_0 S_0	T_{10}	P_2 S_0
T_3	P_0 S_1	T_{11}	P_2 S_1
T_4	P_0 S_2	T_{12}	P_2 S_2
T_5	P_0 S_3	T_{13}	P_2 S_3
T_6	P_1 S_0	T_{14}	P_3 S_0
T_7	P_1 S_1	T_{15}	P_3 S_1
T_8	P_1 S_2	T_{16}	P_3 S_2
T_9	P_1 S_3	T_{17}	P_3 S_3

Nitrogen and potassium levels are kept same based on POP recommendations of Kerala Agricultural University for all the treatments except for the first treatment where soil test based recommendations were followed.

3.4.1 Land preparation

Land was made into fine tilth by ploughing thoroughly using tractor. Gross area of the selected field was 18 cents in which net area used for the experiment was 13 cents. The experimental field was divided into three blocks and it was further divided into 17 treatment plots. Drainage furrow of 1m width was taken in between the blocks.

3.4.2 Application of manures and fertilizers

All the fertilizers were applied as basal dose at the time of sowing. Equal quantity of farmyard manure was applied in all the plots. Based on POP recommendations of KAU, nitrogen was applied in equal quantities in all experimental plots except in T_1 where all the fertilizer nutrients are given according

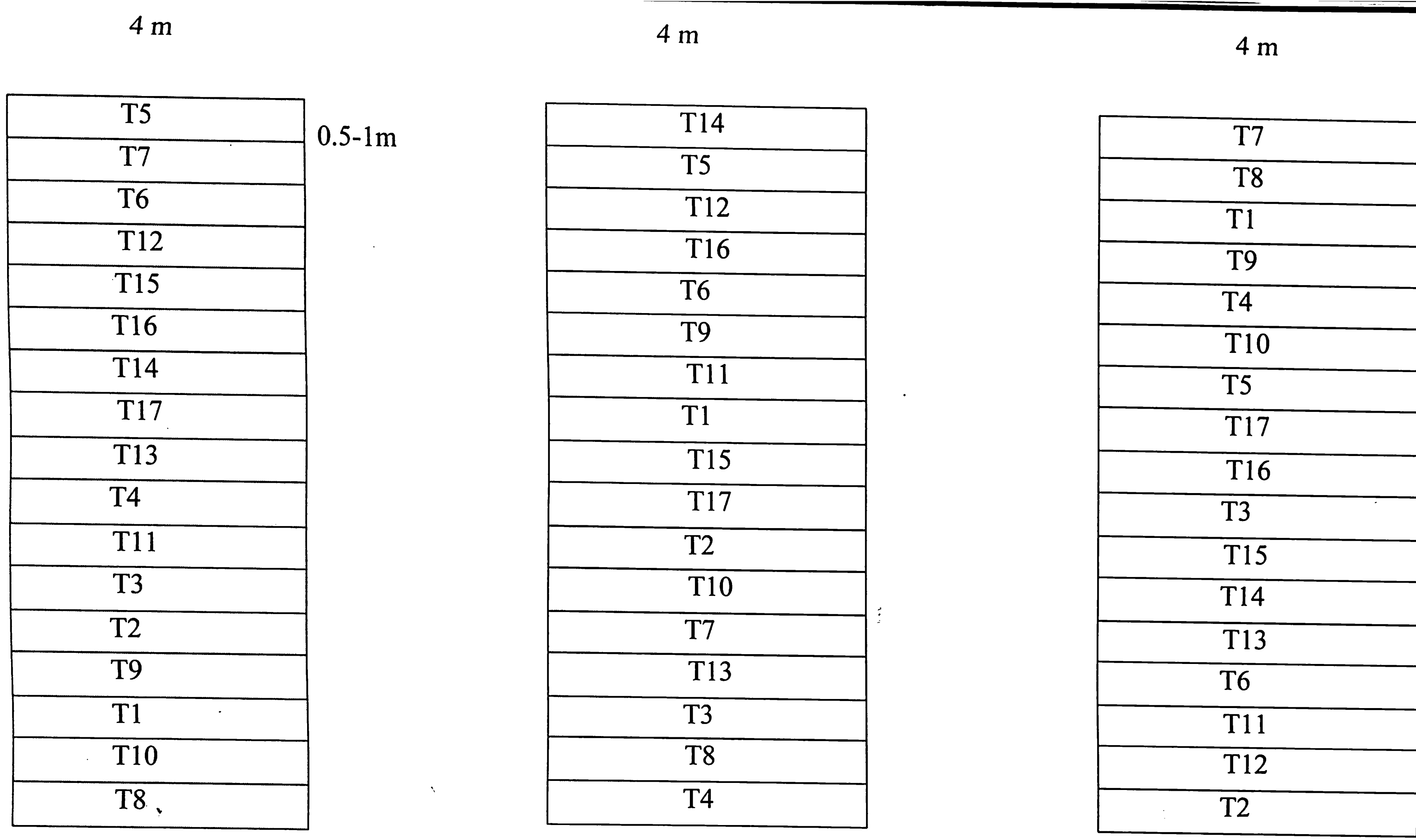
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Plate 4: Field view at pegging stage of groundnut crop

Plate 5: Pod formation stage of groundnut crop

to soil test based recommendations. Potassium dihydrogen phosphate (KH_2PO_4) and elemental sulphur (ES) were used as the source of P and S respectively. Different levels of KH_2PO_4 and elemental sulphur and their combinations were supplied based on the treatment requirements. MOP was used to supplement potassium requirement of the crop.

Table 4: Rate of application of fertilizers in the experimental field

Treatments	Urea (kg ha^{-1})	MKP* (kg ha^{-1})	MOP (kg ha^{-1})	Elemental sulphur (kg ha^{-1})
T_1	18.26	152.88	46.04	0
T_2	21.74	0	150	0
T_3	21.74	0	150	11.11
T_4	21.74	0	150	22.22
T_5	21.74	0	150	33.33
T_6	21.74	115.38	71.54	0
T_7	21.74	115.38	71.54	11.11
T_8	21.74	115.38	71.54	22.22
T_9	21.74	115.38	71.54	33.33
T_{10}	21.74	144.23	51.92	0
T_{11}	21.74	144.23	51.92	11.11
T_{12}	21.74	144.23	51.92	22.22
T_{13}	21.74	144.23	51.92	33.33
T_{14}	21.74	173.08	32.30	0
T_{15}	21.74	173.08	32.30	11.11
T_{16}	21.74	173.08	32.30	22.22
T_{17}	21.74	173.08	32.30	33.33

***MKP- Monopotassium phosphate**

3.4.3 Irrigation

Irrigation was given through furrows made in between the blocks. Furrows were irrigated at an interval of 7 days.

3.4.4 Weed management

Hand weeding was done at an interval of 15 days. At the time of flowering, along with weeding, earthing up was also done to improve anchorage of tiny roots. After 45 days of sowing field was kept undisturbed.

3.4.5 Plant protection

Pest and disease incidence was very less in the field. Peacock menace was controlled by tying bird repellent ribbons across the field.

3.4.6 Harvesting

Harvesting was started when groundnut leaves started yellowing and began to dry up. Plants were ready for harvest at 90 days after sowing. The plants were uprooted and pods were separated manually.

3.5 OBSERVATIONS

3.5.1 Biometric observations

Five plants were selected randomly from each experimental plot and tagged for taking biometric observations. The biometric observations recorded from these plants during the period of experiment were at four different growth stages namely flowering, pegging, pod formation and harvesting. The mean values were calculated for all the observations made. The biometric observations recorded are given below.

Plant height

Height of plant was measured from labelled plants at flowering, pegging, pod formation and harvesting stages and mean values were computed.

Plate 6: Harvesting of groundnut crop

Number of leaves

Counted the number of leaves at flowering, pegging, pod formation and harvesting stages and mean values were calculated.

Number of pods/plant

No. of pods/plant were counted at harvesting stage and computed the mean values.

Yield

The pods and haulm were harvested, weighed separately and mean values were recorded.

3.5.2 Soil analysis

Soil samples were collected from a depth of 0-15 cm for analysis. The collected samples were analyzed and estimated pH, EC, OC, major nutrients (N, P, K), secondary nutrients (Ca, Mg, S) and micronutrients (Fe, Mn, Zn, Cu, B) both before and after the crop. Physical properties of soil *viz.* soil texture, bulk density and soil moisture were also analyzed. The methods employed for soil analysis are given in table no. 2.

3.5.3 Plant analysis

Collection of samples

Plant samples were collected at flowering, pegging, pod formation and harvesting stages. Inorder to remove dirt and soil, plant samples were first washed with tap water. These were then washed with single and double distilled water, and kept for shade drying for a period of one week. The shade dried samples were kept in an oven @ 60 ^{0}C and dry weight was recorded. The samples were powdered, labelled and stored in polythene bags. The content of major nutrients (N, P, and K), secondary nutrients (Ca, Mg, and S) and micronutrients (Fe, Mn, Zn, Cu, and B) were analyzed. The methods followed to determine the nutrients in samples are given in the table below.

Table 5: Methods of plant analysis

Parameter	Method	Reference
Nitrogen	Micro kjeldahl distillation	Jackson (1973)
Phosphorus	Vanado – molybdo – phosphoric (Bartons reagent) yellow color method	Jackson (1973)
Potassium	Nitric acid digestion and estimation by flame photometer	
Calcium and magnesium	Nitric acid digestion and estimation by ICP- OES	Piper (1966)
Sulphur	Nitric acid digestion and estimation by turbidimetry	Black (1965)
Boron	Nitric acid digestion and estimation by ICP- OES	Page *et al.*, (1982)
Micro nutrients (Fe, Mn, Zn, Cu)	Nitric acid digestion and estimation by ICP- OES	Piper (1966)

3.5.4 Uptake of nutrients

Uptake of major, secondary, and micro nutrients were calculated by using the formula,

$$\text{Uptake of nutrient (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%) x biomass (kg ha}^{-1}\text{)}}{100}$$

Plate 7: Harvested groundnut pods

3.6 Quality parameters

3.6.1 Protein content of kernels

Per cent of nitrogen was estimated by micro-kjeldahl method. Crude protein content was calculated by multiplying nitrogen content of kernels with the constant 6.25.

3.6.2 Oil content

Oil extraction was done in soxhlet apparatus using petroleum benzene as solvent. The weight difference of round bottom flask gave the amount of oil extracted (Pearson, 1981).

3.7 Statistical analysis

Statistical analysis of experimental data was done by Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984).

Results

4. RESULTS

The results of the experiment entitled "Interaction of phosphorus and sulphur in black cotton soils of Palakkad (AEU: 23) under groundnut (*Arachis hypogaea* L.) cultivation" are presented in this chapter.

4.1 GROWTH AND YIELD ATTRIBUTES OF GROUNDNUT

The effect of different levels of P and S application on growth parameters of groundnut such as plant height, number of leaves and yield parameters such as number of pods at flowering, pegging, pod formation and harvesting stages are given.

4.1.1 Growth parameters

4.1.1.1 Plant height

Plant heights at flowering, pegging, pod development and harvest stages are shown in table 6, 7, 8, 9 respectively. The treatment, P_3S_3 (P,90 kg ha^{-1} and S,30 kg ha^{-1}) showed highest plant height at flowering (22.13 cm) stage. . At pegging stage (35.00 cm) and harvesting stage (41.47 cm) the treatment T_{16}, P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest plant height. Whereas, during pod formation stage, both the treatments T_{16} and T_{17} recorded highest (36.67 cm) plant height. Plant heights at different stages were found to be significantly influenced due to main effect and interaction effect. Plant height was enhanced by increased doses of P as well as S. F statistic for treatments Vs control was calculated and was found to be significantly different at flowering, pegging and harvesting stages and was on par at pod formation stage.

Table 6: Effect of application of P and S on plant height at flowering stage (cm)

T_1: 20.00

	S_0	S_1	S_2	S_3	Mean
P_0	18.03	18.07	18.17	18.13	**18.10**
P_1	18.63	18.43	18.47	18.63	**18.54**
P_2	18.83	18.93	19.83	19.27	**19.22**
P_3	19.73	21.43	21.63	22.13	**21.23**
Mean	**18.81**	**19.22**	**19.53**	**19.54**	
CD (0.05) P; 0.074		**CD (0.05) S; 0.074**		**CD (0.05) PxS; 0.147**	
SE (m) P; 0.025		**SE (m) S; 0.025**		**SE (m) PxS; 0.051**	

Table 7: Effect of application of P and S on plant height at pegging stage (cm)

T_1: 32.00

	S_0	S_1	S_2	S_3	Mean
P_0	26.33	26.30	26.53	26.27	**26.36**
P_1	28.60	28.43	28.30	28.27	**28.40**
P_2	32.27	32.90	32.63	31.97	**32.44**
P_3	34.47	34.50	35.00	34.27	**34.56**
Mean	**30.42**	**30.53**	**30.62**	**30.19**	
CD (0.05) P; 0.343		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.118		**SE (m) S; 0.118**		**SE (m) PxS; 0.237**	

Table 8: Effect of application of P and S on plant height at pod formation stage (cm)

T_1: 36.00

	S_0	S_1	S_2	S_3	Mean
P_0	31.30	31.07	31.40	31.80	**31.39**
P_1	33.60	33.63	33.30	33.50	**33.51**
P_2	35.60	35.63	35.30	35.60	**35.53**
P_3	36.27	36.30	36.67	36.67	**36.48**
Mean	**34.19**	**34.16**	**34.17**	**34.39**	
CD (0.05) P; 0.311		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.107		**SE (m) S; 0.107**		**SE (m) PxS; 0.214**	

Table 9: Effect of application of P and S on plant height at harvest stage (cm)

T_1: 37.60

	S_0	S_1	S_2	S_3	Mean
P_0	34.67	34.30	34.67	34.67	**34.58**
P_1	36.33	36.37	36.33	36.47	**36.38**
P_2	38.40	38.70	38.07	39.00	**38.54**
P_3	41.33	41.47	41.17	41.30	**41.32**
Mean	**37.68**	**37.71**	**37.56**	**37.86**	
CD (0.05) P; 0.283		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.097		**SE (m) S; 0.097**		**SE (m) PxS; 0.195**	

4.1.1.2 Number of leaves

Number of leaves at flowering, pegging, pod development and harvest stages are shown in the tables 10, 11, 12, 13 respectively. Both the main effect and interaction effect of treatments significantly influenced the number of leaves at pegging, pod formation and harvesting stages, whereas at flowering stage the interaction effect was found to be non significant. In flowering stage, the number of leaves in treatments P_2S_3 (P, 75 kg ha^{-1} and S, 30 kg ha^{-1}) and P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) were found to be on par. Treatment P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest number of leaves at pegging, (53.81), pod development (60.06) and harvesting (55.06) stages. F statistic for treatments Vs control was calculated and was found to be significantly different at flowering, pegging, pod formation and harvesting stages.

Table 10: Effect of application of P and S on number of leaves at flowering stage

T_1: 41.98

	S_0	S_1	S_2	S_3	Mean
P_0	37.30	42.87	43.67	47.40	**42.81**
P_1	37.80	44.30	46.70	47.67	**44.12**
P_2	39.20	45.07	45.30	48.80	**44.59**
P_3	42.70	45.33	45.30	49.33	**45.67**
Mean	**39.25**	**44.39**	**45.24**	**48.30**	
CD (0.05) P; 1.5		**CD (0.05) S; 1.5**		**CD (0.05) PxS; NS**	
SE (m) P; 0.517		**SE (m) S; 0.517**		**SE (m) PxS; 1.303**	

Table 11: Effect of application of P and S on number of leaves at pegging stage

T_1: 45.55

	S_0	S_1	S_2	S_3	Mean
P_0	41.93	46.63	47.30	51.33	**46.80**
P_1	41.67	48.60	50.93	52.44	**48.41**
P_2	43.13	49.19	49.51	52.87	**48.67**
P_3	46.37	49.23	49.60	53.81	**49.75**
Mean	**43.27**	**48.41**	**49.34**	**52.61**	
CD (0.05) P; 0.573		**CD (0.05) S; 0.573**		**CD (0.05) PxS; 1.146**	
SE (m) P; 0.197		**SE (m) S; 0.197**		**SE (m) PxS; 0.395**	

Table 12: Effect of application of P and S on number of leaves at pod formation stage

T_1: 50.55

	S_0	S_1	S_2	S_3	Mean
P_0	46.94	51.64	52.30	56.34	**51.80**
P_1	46.67	53.60	55.94	57.44	**53.41**
P_2	48.13	54.19	54.52	57.87	**53.68**
P_3	51.37	54.23	54.61	60.06	**55.07**
Mean	**48.28**	**53.42**	**54.34**	**57.93**	
CD (0.05) P; 0.489		CD (0.05) S; 0.489		CD (0.05) PxS; 0.978	
SE (m) P; 0.168		SE (m) S; 0.168		SE (m) PxS; 0.337	

Table 13: Effect of application of P and S on number of leaves at harvest stage

T_1: 45.56

	S_0	S_1	S_2	S_3	Mean
P_0	41.94	46.64	47.30	51.34	**46.80**
P_1	41.67	48.60	50.94	52.44	**48.41**
P_2	43.13	49.19	49.52	52.87	**48.68**
P_3	46.37	49.23	49.61	55.06	**50.07**
Mean	**43.28**	**48.42**	**49.34**	**52.93**	
CD (0.05) P; 0.489		CD (0.05) S; 0.489		CD (0.05) PxS; 0.977	
SE (m) P; 0.168		SE (m) S; 0.168		SE (m) PxS; 0.337	

4.1.2 Yield parameters

4.1.2.1 Number of pods per plant

Number of pods per plant is significantly influenced by different levels of P and S. Increase in pod number per plant can be observed with increased dose of P and S application (table 14). The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1})

produced the highest number of pods per plant. Number of pods increased with increased dose of P and S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.1.2.2 Yield

The data given in table 15 indicates that yield was significantly influenced by application of different doses of P and S fertilizers. The highest yield (3.68 t ha^{-1}) was recorded in P_3 S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). The lowest yield (3.07 t ha^{-1}) was in P_0 S_0 (P, 0 kg ha^{-1} and S, 0 kg ha^{-1}). Yield was increased with increased dose of P and S fertilizer. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.2 PHYSICO – CHEMICAL CHARACTERISTICS OF SOIL

4.2.1 Soil pH

The effect of application of different levels of P and S on soil pH is given in the table 16. Data showed that none of main effects and interaction effect had significant influence on the pH. There was only a slight change in pH after the harvest. pH varied from 7.73 to 7.85. F statistic for treatments Vs control was calculated and was found to be on par.

4.2.2 Electrical conductivity

The effect of application of different levels of P and S on soil EC is given in the table 17. Data showed that both main effects and interaction effect has no significant influence on EC. F statistic for treatments Vs control was calculated and was found to be on par.

4.2.3 Organic carbon

The data on effect of application of different levels of P and S on soil OC is given in the table 18. Data showed that both main effects and interaction effect has no significant influence on OC content. F statistic for treatments Vs control was calculated and was found to be on par.

Table 14: Effect of application of P and S on number of pods per plant

T_1: 15.33

	S_0	S_1	S_2	S_3	Mean
P_0	9.33	10.20	10.28	10.37	**10.05**
P_1	12.00	12.67	12.70	13.10	**12.62**
P_2	14.33	14.83	14.87	15.13	**14.79**
P_3	15.41	16.67	17.00	18.17	**16.81**
Mean	**12.77**	**13.59**	**13.71**	**14.19**	
CD (0.05) P; 0.745		**CD (0.05) S; 0.745**		**CD (0.05) PxS; NS**	
SE (m) P; 0.257		**SE (m) S; 0.257**		**SE (m) PxS; 0.513**	

Table 15: Effect of application of P and S on groundnut yield (t ha^{-1})

T_1: 3.37

	S_0	S_1	S_2	S_3	Mean
P_0	3.07	3.12	3.19	3.23	**3.15**
P_1	3.16	3.21	3.25	3.29	**3.23**
P_2	3.24	3.29	3.31	3.42	**3.31**
P_3	3.35	3.46	3.59	3.68	**3.52**
Mean	**3.21**	**3.27**	**3.34**	**3.40**	
CD (0.05) P; 0.054		**CD (0.05) S; 0.054**		**CD (0.05) PxS; 0.108**	
SE (m) P; 0.001		**SE (m) S; 0.001**		**SE (m) PxS; 0.002**	

Table 16: Effect of application of P and S on pH of soil

T_1: 7.73

	S_0	S_1	S_2	S_3	Mean
P_0	7.79	7.78	7.77	7.74	**7.77**
P_1	7.85	7.84	7.83	7.82	**7.91**
P_2	7.83	7.82	7.82	7.81	**7.82**
P_3	7.80	7.79	7.79	7.73	**7.78**
Mean	**7.82**	**7.81**	**7.80**	**7.77**	
CD (0.05) P; NS		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.044		**SE (m) S; 0.044**		**SE (m) PxS; 0.087**	

Table 17: Effect of application of P and S on EC of soil (dS m^{-1})

T_1: 0.25

	S_0	S_1	S_2	S_3	Mean
P_0	0.28	0.28	0.28	0.29	**0.28**
P_1	0.29	0.27	0.27	0.25	**0.27**
P_2	0.28	0.28	0.28	0.28	**0.28**
P_3	0.28	0.29	0.28	0.28	**0.28**
Mean	**0.28**	**0.28**	**0.28**	**0.27**	
CD (0.05) P; NS		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.011		**SE (m) S; 0.011**		**SE (m) PxS; 0.022**	

Table 18: Effect of application of P and S on organic carbon in soil (%)

T_1: 1.03

	S_0	S_1	S_2	S_3	Mean
P_0	1.10	1.06	1.08	1.02	**1.07**
P_1	1.07	1.08	0.99	1.01	**1.04**
P_2	1.02	1.08	1.02	1.01	**1.03**
P_3	1.06	1.02	1.11	1.02	**1.05**
Mean	**1.06**	**1.06**	**1.05**	**1.01**	
CD (0.05) P; NS		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.015		**SE (m) S; 0.015**		**SE (m) PxS; 0.030**	

4.3 NUTRIENT STATUS OF SOIL

4.3.1 Available nitrogen

The effects of application of different levels of P and S on available N are given in the table 19. Data showed that main effect, and interaction effect were significantly influenced the available nitrogen in the soil. N increased with increased dose of P and S application. The treatment, T_{17} , P_3S_3 showed highest soil available N (293.22 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.2 Available phosphorus

The influence of application of different levels of P and S on available P is given in the table 20. Data showed that main effect of P and S and interaction effects were found to be significant. In comparison with initial P status, available P increased in all treatments due to fertilizer application. Treatment, P_3 S_3 (P, 90 kg $ha^{-1}$and S, 30 kg ha^{-1}) showed highest available P (29.11 kg ha^{-1}). An increase in available P with increased dose of S can be observed among treatments.

Table 19: Effect of application of P and S on available nitrogen in soil (kg ha^{-1})

T_1: 284.91

	S_0	S_1	S_2	S_3	Mean
P_0	284.84	285.54	286.78	287.57	**286.18**
P_1	286.63	287.18	286.99	287.68	**287.12**
P_2	286.97	288.43	288.34	288.77	**288.13**
P_3	287.53	288.81	289.35	293.22	**289.73**
Mean	**286.49**	**287.49**	**287.87**	**289.31**	
CD (0.05) P; 0.267		**CD (0.05) S; 0.267**		**CD (0.05) PxS; 0.533**	
SE (m) P; 0.092		**SE (m) S; 0.092**		**SE (m) PxS; 0.184**	

Table 20: Effect of application of P and S on available phosphorus in soil (kg ha^{1})

T_1: 13.33

	S_0	S_1	S_2	S_3	Mean
P_0	6.73	10.93	11.01	11.76	**10.11**
P_1	12.21	12.43	13.63	17.88	**14.04**
P_2	20.13	20.28	20.55	24.27	**21.31**
P_3	25.03	25.76	28.59	29.11	**27.12**
Mean	**16.03**	**17.35**	**18.45**	**20.75**	
CD (0.05) P; 0.093		**CD (0.05) S; 0.093**		**CD (0.05) PxS; 0.185**	
SE (m) P; 0.032		**SE (m) S; 0.032**		**SE (m) PxS; 0.064**	

4.3.3 Available potassium

The influence of application of different levels of P and S on available K is given in the table 21. The main effect of P and S and interaction effects were found to be significant. Treatment, P_1S_0 (P, 60 kg ha $^{-1}$ and S, 0 kg ha $^{-1}$) showed highest K content (298.72 kg ha $^{-1}$). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.4 Available calcium

The influence of application of different levels of P and S on available Ca is given in the table 22. With increased dose of P application available Ca content in soil decreased. Highest available calcium was in treatment, P_1S_0 (1700.87 mg kg^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.5 Available magnesium

The influence of application of different levels of P and S on available Mg is given in the table 23. Data showed that available Mg content in soil significantly varied among different treatments due to main effects and interaction effects of P and S. Treatment, P_3S_3 had highest available Mg (796.40 mg kg^{-1}). Mg showed positive interaction with P and S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.6 Available sulphur

The influence of application of different levels of P and S on available S is given in the table 24. There was a noticeable change in available S due to different levels of fertilizer application. Available S content increased in every treatments as compared to initial sample due to S fertilizer application. Highest available S was noticed in treatment, P_2S_3 (10.95 mg kg^{-1}). Available S was influenced by both main effects and interaction effect of P and S. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 21: Effect of application of P and S on available potassium in soil (kg ha^{-1})

T_1: 232.80

	S_0	S_1	S_2	S_3	Mean
P_0	284.21	297.53	296.27	279.12	**289.28**
P_1	298.72	283.47	283.76	283.58	**287.38**
P_2	247.61	245.46	244.90	242.84	**245.20**
P_3	210.76	213.80	211.98	212.59	**212.28**
Mean	**260.32**	**260.07**	**259.23**	**254.53**	
CD (0.05) P; 4.188		CD (0.05) S; 4.188		CD (0.05) PxS; 8.376	
SE (m) P; 1.443		SE (m) S; 1.443		SE (m) PxS; 2.886	

Table 22: Effect of application of P and S on available calcium in soil (mg kg^{-1})

T_1: 1613.23

	S_0	S_1	S_2	S_3	Mean
P_0	1,666.30	1,618.93	1,664.37	1,694.17	**1,660.94**
P_1	1,700.87	1,661.23	1,611.20	1,612.20	**1,646.38**
P_2	1,605.17	1,601.70	1,608.20	1,578.17	**1,598.31**
P_3	1,567.90	1,589.40	1,577.63	1,598.53	**1,583.37**
Mean	**1,635.06**	**1,617.82**	**1,615.35**	**1,620.77**	
CD (0.05) P; 0.77		CD (0.05) S; 0.77		CD (0.05) PxS; 1.54	
SE (m) P; 0.265		SE (m) S; 0.265		SE (m) PxS; 0.531	

Table 23: Effect of application of P and S on available magnesium in soil (mg kg^{-1})

T_1: 735.43

	S_0	S_1	S_2	S_3	Mean
P_0	516.50	407.30	465.57	546.50	**483.97**
P_1	573.53	574.50	609.47	626.43	**595.98**
P_2	632.07	660.67	639.60	746.33	**669.67**
P_3	666.33	685.22	707.77	796.40	**713.93**
Mean	**597.11**	**581.92**	**605.60**	**678.92**	
CD (0.05) P; 4.029		**CD (0.05) S; 4.029**		**CD (0.05) PxS; 8.059**	
SE (m) P; 1.388		**SE (m) S; 1.388**		**SE (m) PxS; 2.777**	

Table 24: Effect of application of P and S on available sulphur in soil (mg kg^{-1})

T_1: 6.06

	S_0	S_1	S_2	S_3	Mean
P_0	3.51	6.37	9.99	10.35	**7.55**
P_1	3.53	6.70	9.58	10.55	**7.59**
P_2	3.63	6.78	9.22	10.95	**7.65**
P_3	3.40	6.29	9.86	10.56	**7.53**
Mean	**3.52**	**6.53**	**9.66**	**10.60**	
CD (0.05) P; NS		**CD (0.05) S; 0.285**		**CD (0.05) PxS; NS**	
SE (m) P; 0.098		**SE (m) S; 0.098**		**SE (m) PxS; 0.197**	

4.3.7 Available iron

The influence of application of different levels of P and S on available Fe is given in the table 25. Highest available Fe was in treatment, P_0S_3 (21.63 mg kg^{-1}). Available Fe was low in soil treated with high dose of P. The available Fe content in soil varied significantly due to the main effect of different doses of P and S and interaction effect. Fe content decreased with increased dose of P application and increased with increased dose of S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.8 Available manganese

The influence of application of different levels of P and S on available Mn is given in the table 26. Data showed that main effects of P and S and interaction effects affect the available Mn in soil. Treatment, P_0S_3 showed highest available Mn (7.84 mg kg^{-1}). Available Mn decreased with increased dose of P application. Mn content decreased with increased dose of P application and increased with increased dose of S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.9 Available zinc

The effect of application of different levels of P and S on available Zn is given in the table 27. Data showed that main effects of P and S and interaction effects affect the available Zn in the soil. Highest Zn was observed in treatment, P_0 S_3 (3.04 mg kg^{-1}). Zn content was decreased with increased dose of P application. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.3.10 Available copper

The influence of application of different levels of P and S on available Cu is given in the table 28. Both main effects and interaction effect were found to have no significant effect on available Cu in soil. F statistic for treatments Vs control was calculated and was found to be on par.

Table 25: Effect of application of P and S on available iron in soil (mg kg^{-1})

T_1: 17.00

	S_0	S_1	S_2	S_3	Mean
P_0	19.56	19.57	21.27	21.63	**20.51**
P_1	18.46	18.58	19.17	19.33	**18.88**
P_2	17.26	17.34	17.45	17.88	**17.48**
P_3	11.87	12.58	15.34	17.05	**14.21**
Mean	**16.79**	**17.02**	**18.31**	**18.97**	
CD (0.05) P; 0.107		**CD (0.05) S; 0.107**		**CD (0.05) PxS; 0.214**	
SE (m) P; 0.037		**SE (m) S; 0.037**		**SE (m) PxS; 0.074**	

Table 26: Effect of application of P and S on available manganese in soil (mg kg^{-1})

T_1: 7.580

	S_0	S_1	S_2	S_3	Mean
P_0	7.78	7.79	7.80	7.84	**7.80**
P_1	7.62	7.66	7.67	7.69	**7.66**
P_2	7.52	7.56	7.57	7.60	**7.56**
P_3	7.25	7.29	7.31	7.34	**7.30**
Mean	**7.54**	**7.58**	**7.59**	**7.62**	
CD (0.05) P; 0.049		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.017		**SE (m) S; 0.017**		**SE (m) PxS; 0.034**	

Table 27: Effect of application of P and S on available zinc in soil (mg kg^{-1})

T_1: 1.22

	S_0	S_1	S_2	S_3	Mean
P_0	1.18	1.35	2.12	3.04	**1.92**
P_1	1.01	1.18	2.18	2.24	**1.65**
P_2	0.88	1.03	1.20	2.23	**1.34**
P_3	0.78	1.14	1.23	1.24	**1.10**
Mean	**0.96**	**1.18**	**1.68**	**2.19**	
CD (0.05) P; 0.003		**CD (0.05) S; 0.003**		**CD (0.05) PxS; 0.007**	
SE (m) P; 0.011		**SE (m) S; 0.011**		**SE (m) PxS; 0.022**	

Table 28: Effect of application of P and S on available copper in soil (mg kg^{-1})

T_1: 2.03

	S_0	S_1	S_2	S_3	Mean
P_0	2.04	2.08	2.07	2.04	**2.06**
P_1	2.02	2.01	2.02	2.03	**2.02**
P_2	2.02	2.07	2.04	2.06	**2.05**
P_3	2.02	2.04	2.01	2.05	**2.03**
Mean	**2.02**	**2.05**	**2.04**	**2.04**	
CD (0.05) P; NS		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.011		**SE (m) S; 0.011**		**SE (m) PxS; 0.022**	

4.3.11 Water soluble boron

Data showed (table 29) that water soluble B in soil significantly varied due to application of different levels of P and S in the soil. B in soil decreased with application of increased dose of P. The treatment, P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest B (4.04 mg kg^{-1}) among treatments. B content decreased with increased dose of P application and increased with increased dose of S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 29: Effect of application of P and S on water soluble boron (mg kg^{-1})

T_1: 1.32

	S_0	S_1	S_2	S_3	Mean
P_0	1.14	1.45	2.50	4.04	**2.28**
P_1	1.18	1.45	1.54	1.73	**1.48**
P_2	0.77	0.86	1.74	2.32	**1.42**
P_3	0.73	0.77	0.86	1.23	**0.90**
Mean	**0.96**	**1.13**	**1.66**	**2.33**	
CD (0.05) P; 0.006		**CD (0.05) S; 0.006**		**CD (0.05) PxS; 0.012**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.004**	

4.4 ANALYSIS OF PLANT SAMPLES

4.4.1 Nitrogen content in groundnut plant

Nitrogen content of plant samples at flowering, pegging, pod development and harvest stages are given in the tables 30, 31, 32 and 33 respectively. Nitrogen content of plant during pegging and pod formation stages was significantly influenced due to main effect and interaction effect of treatments, whereas, the interaction effect was found to be non-significant at flowering and harvesting stages. Plants showed highest nitrogen content at flowering stage, there after nitrogen content decreased with plant growth. Nitrogen content in plant increased with application of increased dose of phosphorus as well as S. Highest nitrogen (2.39 per cent) was in the treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) at flowering, pegging (2.207 per cent), pod formation (2.117 per cent) and harvesting (1.78 per cent) stages. F statistic for treatments Vs control was calculated and found to be significantly different at flowering, pegging, pod formation and harvesting stages.

Table 30: Effect of application of P and S on nitrogen content in plant samples at flowering stage (%)

T_1: 2.12

	S_0	S_1	S_2	S_3	Mean
P_0	2.18	2.22	2.25	2.29	**2.24**
P_1	2.21	2.25	2.27	2.30	**2.26**
P_2	2.22	2.25	2.30	2.34	**2.28**
P_3	2.25	2.30	2.31	2.39	**2.31**
Mean	**2.21**	**2.26**	**2.28**	**2.33**	
CD (0.05) P; 0.015		**CD (0.05) S; 0.015**		**CD (0.05) PxS; NS**	
SE (m) P; 0.005		**SE (m) S; 0.005**		**SE (m) PxS; 0.010**	

Table 31: Effect of application of P and S on nitrogen content in plant samples at pegging stage (%)

T_1: 1.79

	S_0	S_1	S_2	S_3	Mean
P_0	1.813	1.840	1.893	1.923	**1.868**
P_1	1.830	1.877	1.850	1.960	**1.879**
P_2	1.897	1.903	1.953	2.050	**1.951**
P_3	1.927	1.927	2.053	2.207	**2.028**
Mean	**1.867**	**1.887**	**1.938**	**2.035**	
CD (0.05) P; 0.04		**CD (0.05) S; 0.04**		**CD (0.05) PxS; 0.079**	
SE (m) P; 0.014		**SE (m) S; 0.014**		**SE (m) PxS; 0.027**	

Table 32: Effect of application of P and S on nitrogen content in plant samples at pod setting stage (%)

T_1: 1.69

	S_0	S_1	S_2	S_3	Mean
P_0	1.717	1.747	1.770	1.810	**1.761**
P_1	1.703	1.767	1.773	1.827	**1.768**
P_2	1.770	1.760	1.793	1.860	**1.796**
P_3	1.817	1.843	1.833	2.117	**1.903**
Mean	**1.752**	**1.779**	**1.793**	**1.903**	
CD (0.05) P; 0.015		CD (0.05) S; 0.015		CD (0.05) PxS; 0.031	
SE (m) P; 0.005		SE (m) S; 0.005		SE (m) PxS; 0.011	

Table 33: Effect of application of P and S on nitrogen content in plant samples at harvest stage (%)

T_1: 1.60

	S_0	S_1	S_2	S_3	Mean
P_0	1.52	1.53	1.56	1.56	**1.54**
P_1	1.56	1.57	1.59	1.59	**1.58**
P_2	1.64	1.67	1.68	1.71	**1.67**
P_3	1.72	1.74	1.76	1.78	**1.75**
Mean	**1.61**	**1.63**	**1.65**	**1.66**	
CD (0.05) P; 0.014		CD (0.05) S; 0.014		CD (0.05) PxS; NS	
SE (m) P; 0.005		SE (m) S; 0.005		SE (m) PxS; 0.010	

4.4.2 Phosphorus content in plant

Phosphorus content in plant sample at flowering, pegging, pod development and harvest stages are given in the tables 34, 35, 36 and 37 respectively. P content in plant was increased with increased dose of P and S fertilizer application. P content in all the stages significantly varied due to main effect and interaction effect. The treatment, P_3 S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest P content (0.37 per cent at flowering stage, 0.34 per cent at pegging stage, 0.32 per cent at pod formation stage and 0.27 per cent at harvesting stage). F statistic for treatments Vs control was calculated and were found to be significantly different in all stages.

Table 34: Effect of application of P and S on phosphorus content in plant samples at flowering stage (%)

T_1: 0.31

	S_0	S_1	S_2	S_3	Mean
P_0	0.23	0.27	0.31	0.31	**0.28**
P_1	0.25	0.29	0.32	0.34	**0.30**
P_2	0.27	0.32	0.34	0.36	**0.32**
P_3	0.31	0.35	0.35	0.37	**0.34**
Mean	**0.27**	**0.31**	**0.33**	**0.34**	
CD (0.05) P; 0.013		**CD (0.05) S; 0.013**		**CD (0.05) PxS; 0.025**	
SE (m) P; 0.011		**SE (m) S; 0.011**		**SE (m) PxS; 0.023**	

Table 35: Effect of application of P and S on phosphorus content in plant samples at pegging stage (%)

T_1: 0.30

	S_0	S_1	S_2	S_3	Mean
P_0	0.21	0.21	0.26	0.28	**0.24**
P_1	0.22	0.22	0.28	0.31	**0.26**
P_2	0.23	0.25	0.30	0.32	**0.28**
P_3	0.25	0.27	0.31	0.34	**0.29**
Mean	**0.23**	**0.24**	**0.29**	**0.31**	
CD (0.05) P; 0.002		**CD (0.05) S; 0.002**		**CD (0.05) PxS; 0.004**	
SE (m) P; 0.022		**SE (m) S; 0.022**		**SE (m) PxS; 0.044**	

Table 36: Effect of application of P and S on phosphorus content in plant samples at pod formation stage (%)

T_1: 0.26

	S_0	S_1	S_2	S_3	Mean
P_0	0.18	0.18	0.22	0.23	**0.20**
P_1	0.18	0.21	0.24	0.25	**0.22**
P_2	0.20	0.23	0.25	0.27	**0.24**
P_3	0.22	0.25	0.27	0.32	**0.26**
Mean	**0.20**	**0.22**	**0.25**	**0.27**	
CD (0.05) P; 0.005		**CD (0.05) S; 0.005**		**CD (0.05) PxS; 0.010**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.005**	

Table 37: Effect of application of P and S on phosphorus content in plant samples at harvest stage (%)

T_1: 0.18

	S_0	S_1	S_2	S_3	Mean
P_0	0.12	0.15	0.18	0.22	**0.17**
P_1	0.14	0.17	0.21	0.22	**0.19**
P_2	0.16	0.20	0.21	0.25	**0.21**
P_3	0.18	0.22	0.24	0.27	**0.23**
Mean	**0.15**	**0.19**	**0.21**	**0.24**	
CD (0.05) P; 0.006		**CD (0.05) S; 0.006**		**CD (0.05) PxS; 0.013**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.004**	

4.4.3 Potassium content in plant

Potassium content in plant samples was significantly influenced by application of P and S (table no.s 38, 39, 40 and 41). The treatment, P_0S_3 (P, 0 kg ha $^{-1}$ and S, 30 kg ha^{-1}) had highest K content at flowering (2.23 per cent), pegging

(2.12 per cent), pod formation (2.01 per cent) and harvesting (1.96 per cent) stages. K content in plants decreased with increased dose of P and increased with increased dose of S fertilizers. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 38: Effect of application of P and S on potassium content in plant at flowering stage (%)

T_1: 1.96

	S_0	S_1	S_2	S_3	Mean
P_0	1.39	1.66	1.83	2.23	**1.78**
P_1	1.32	1.59	1.80	2.06	**1.69**
P_2	1.23	1.59	1.69	1.93	**1.61**
P_3	1.23	1.45	1.69	1.91	**1.57**
Mean	**1.29**	**1.57**	**1.76**	**2.03**	
CD (0.05) P; 0.028		**CD (0.05) S; 0.028**		**CD (0.05) PxS; 0.057**	
SE (m) P; 0.010		**SE (m) S; 0.010**		**SE (m) PxS; 0.020**	

Table 39: Effect of application of P and S on potassium content in plant at pegging stage (%)

T_1: 1.95

	S_0	S_1	S_2	S_3	Mean
P_0	1.35	1.64	1.81	2.12	**1.73**
P_1	1.27	1.51	1.72	2.01	**1.63**
P_2	1.21	1.48	1.59	1.96	**1.56**
P_3	1.21	1.42	1.63	1.84	**1.52**
Mean	**1.26**	**1.51**	**1.69**	**1.98**	
CD (0.05) P; 0.026		**CD (0.05) S; 0.026**		**CD (0.05) PxS; 0.052**	
SE (m) P; 0.009		**SE (m) S; 0.009**		**SE (m) PxS; 0.018**	

Table 40: Effect of application of P and S on potassium content in plant at pod setting stage (%)

T_1: 1.92

	S_0	S_1	S_2	S_3	Mean
P_0	1.33	1.60	1.74	2.01	**1.67**
P_1	1.23	1.42	1.69	1.95	**1.57**
P_2	1.13	1.42	1.53	1.86	**1.49**
P_3	1.12	1.37	1.56	1.75	**1.45**
Mean	**1.21**	**1.45**	**1.63**	**1.89**	
CD (0.05) P; 0.021		**CD (0.05) S; 0.021**		**CD (0.05) PxS; 0.042**	
SE (m) P; 0.007		**SE (m) S; 0.007**		**SE (m) PxS; 0.014**	

Table 41: Effect of application of P and S on potassium content in plant at harvest stage (%)

T_1: 1.89

	S_0	S_1	S_2	S_3	Mean
P_0	1.30	1.57	1.72	1.96	**1.64**
P_1	1.22	1.38	1.62	1.90	**1.53**
P_2	1.07	1.37	1.48	1.84	**1.44**
P_3	1.09	1.33	1.47	1.70	**1.40**
Mean	**1.17**	**1.42**	**1.57**	**1.85**	
CD (0.05) P; 0.011		**CD (0.05) S; 0.011**		**CD (0.05) PxS; 0.023**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.008**	

4.4.4 Calcium content in plant

Calcium content in plant samples at all the four stages were found to be significantly varied due to application of different levels of fertilizers (tables 42, 43,44 and 45). Ca content was highest in treatment, P_1S_0 (P, 60 kg ha^{-1} and S, 0 kg ha^{-1} at flowering (1.99 per cent) stage. At pegging stage, treatment P_0 S_0 showed high Ca content (1.617 per cent). At pod formation (1.21 per cent) and harvest (1.03 per cent) stages P_0S_3 showed highest Ca content. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 42: Effect of application of P and S on calcium content in plant at flowering stage (%)

T_1: 1.68

	S_0	S_1	S_2	S_3	Mean
P_0	1.967	1.717	1.887	1.673	**1.811**
P_1	1.990	1.847	1.637	1.597	**1.768**
P_2	1.877	1.737	1.567	1.557	**1.684**
P_3	1.847	1.710	1.560	1.517	**1.658**
Mean	**1.920**	**1.753**	**1.663**	**1.586**	
CD (0.05) P; 0.012		**CD (0.05) S; 0.012**		**CD (0.05) PxS; 0.023**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.008**	

Table 43: Effect of application of P and S on calcium content in plant at pegging stage (%)

T_1: 1.450

	S_0	S_1	S_2	S_3	Mean
P_0	1.617	1.593	1.477	1.503	**1.548**
P_1	1.543	1.583	1.480	1.437	**1.511**
P_2	1.553	1.527	1.447	1.417	**1.486**
P_3	1.500	1.520	1.383	1.237	**1.410**
Mean	**1.553**	**1.556**	**1.447**	**1.398**	
CD (0.05) P; 0.010		**CD (0.05) S; 0.010**		**CD (0.05) PxS; 0.019**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.007**	

Table 44: Effect of application of P and S on calcium content in plant at pod formation stage (%)

T_1: 0.78

	S_0	S_1	S_2	S_3	Mean
P_0	0.85	1.05	1.15	1.21	**1.07**
P_1	0.82	0.91	1.09	1.18	**1.00**
P_2	0.78	0.86	1.03	1.13	**0.95**
P_3	0.68	0.77	0.91	1.07	**0.86**
Mean	**0.78**	**0.90**	**1.05**	**1.15**	
CD (0.05) P; 0.011		**CD (0.05) S; 0.011**		**CD (0.05) PxS; 0.021**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.007**	

Table 45: Effect of application of P and S on calcium content in plant at harvest stage (%)

T_1: 0.51

	S_0	S_1	S_2	S_3	Mean
P_0	0.78	0.84	0.94	1.03	**0.90**
P_1	0.75	0.80	0.89	1.02	**0.87**
P_2	0.68	0.75	0.82	0.87	**0.78**
P_3	0.62	0.70	0.72	0.82	**0.72**
Mean	**0.71**	**0.77**	**0.84**	**0.94**	
CD (0.05) P; 0.017		**CD (0.05) S; 0.017**		**CD (0.05) PxS; 0.034**	
SE (m) P; 0.006		**SE (m) S; 0.006**		**SE (m) PxS; 0.012**	

4.4.5 Magnesium content in plant

Magnesium content in plant samples was significantly influenced by application of P and S(tables 46, 47, 48 and 49). The treatment, P_3S_3 (P, 90 kg ha $^{-1}$ and S, 30 kg ha $^{-1}$) had highest Mg content at flowering (2.98 per cent), pegging (1.98 per cent), pod formation (1.08 per cent) and harvesting (1.04 per cent) stages. Mg content in plant samples increased with increased dose of both P and S fertilizer application. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 46: Effect of application of P and S on magnesium content in plant at flowering stage (%)

T_1: 2.51

	S_0	S_1	S_2	S_3	Mean
P_0	2.47	2.62	2.72	2.80	**2.65**
P_1	2.53	2.69	2.70	2.85	**2.69**
P_2	2.59	2.74	2.83	2.93	**2.77**
P_3	2.64	2.89	2.67	2.98	**2.82**
Mean	**2.56**	**2.18**	**2.73**	**2.89**	
CD (0.05) P; 0.008		**CD (0.05) S; 0.008**		**CD (0.05) PxS; 0.016**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.006**	

Table 47: Effect of application of P and S on magnesium content in plant at pegging stage (%)

T_1: 1.67

	S_0	S_1	S_2	S_3	Mean
P_0	1.67	1.70	1.75	1.78	**1.72**
P_1	1.68	1.74	1.82	1.88	**1.78**
P_2	1.77	1.81	1.88	1.92	**1.85**
P_3	1.82	1.87	1.92	1.98	**1.90**
Mean	**1.74**	**1.78**	**1.84**	**1.89**	
CD (0.05) P; 0.010		**CD (0.05) S; 0.010**		**CD (0.05) PxS; 0.020**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.007**	

Table 48: Effect of application of P and S on magnesium content in plant at pod formation stage (%)

T_1: 0.96

	S_0	S_1	S_2	S_3	Mean
P_0	0.72	0.72	0.82	0.87	**0.78**
P_1	0.69	0.78	0.88	0.91	**0.82**
P_2	0.78	0.85	0.94	1.05	**0.90**
P_3	0.82	0.94	1.03	1.08	**0.97**
Mean	**0.75**	**0.82**	**0.92**	**0.98**	
CD (0.05) P; 0.009		**CD (0.05) S; 0.009**		**CD (0.05) PxS; 0.018**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.006**	

Table 49: Effect of application of P and S on magnesium content in plant at harvest stage (%)

T_1: 0.74

	S_0	S_1	S_2	S_3	Mean
P_0	0.67	0.71	0.80	0.85	**0.76**
P_1	0.67	0.78	0.86	0.89	**0.80**
P_2	0.77	0.83	0.94	1.02	**0.89**
P_3	0.80	0.91	0.98	1.04	**0.94**
Mean	**0.73**	**0.81**	**0.90**	**0.95**	
CD (0.05) P; 0.008		**CD (0.05) S; 0.008**		**CD (0.05) PxS; 0.015**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.005**	

4.4.6 Sulphur content in plant

Sulphur content of plant at different stages varied significantly due to main effect and interaction effect (tables 50, 51, 52 and 53). S content at all the stages were influenced by treatments. The treatment, P_3S_3 produced high S content. Treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest S content at flowering (0.64 per cent), pegging (0.51 per cent), pod formation (0.34 per cent) and harvest stages (0.123 per cent). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 50: Effect of application of P and S on sulphur content in plant at flowering stage (%)

T_1: 0.22

	S_0	S_1	S_2	S_3	Mean
P_0	0.11	0.21	0.24	0.29	**0.21**
P_1	0.13	0.22	0.27	0.33	**0.24**
P_2	0.18	0.22	0.25	0.34	**0.25**
P_3	0.18	0.23	0.32	0.64	**0.34**
Mean	**0.15**	**0.22**	**0.27**	**0.40**	
CD (0.05) P; 0.005		**CD (0.05) S; 0.005**		**CD (0.05) PxS; 0.010**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.003**	

Table 51: Effect of application of P and S on sulphur content in plant at pegging stage (%)

T_1: 0.18

	S_0	S_1	S_2	S_3	Mean
P_0	0.08	0.14	0.17	0.18	**0.14**
P_1	0.09	0.14	0.16	0.24	**0.16**
P_2	0.11	0.15	0.17	0.25	**0.17**
P_3	0.12	0.17	0.24	0.51	**0.26**
Mean	**0.10**	**0.15**	**0.19**	**0.30**	
CD (0.05) P; 0.006		**CD (0.05) S; 0.006**		**CD (0.05) PxS; 0.012**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.004**	

Table 52: Effect of application of P and S on sulphur content in plant at pod formation stage (%)

T_1: 0.16

	S_0	S_1	S_2	S_3	Mean
P_0	0.06	0.07	0.10	0.10	**0.08**
P_1	0.07	0.08	0.11	0.12	**0.09**
P_2	0.08	0.09	0.12	0.16	**0.11**
P_3	0.09	0.14	0.16	0.34	**0.18**
Mean	**0.08**	**0.09**	**0.12**	**0.18**	
CD (0.05) P; 0.004		**CD (0.05) S; 0.004**		**CD (0.05) PxS; 0.008**	
SE (m) P; 0.001		**SE (m) S; 0.001**		**SE (m) PxS; 0.002**	

Table 53: Effect of application of P and S on sulphur content in plant at harvest stage (%)

T_1: 0.030

	S_0	S_1	S_2	S_3	Mean
P_0	0.019	0.019	0.028	0.092	**0.039**
P_1	0.015	0.019	0.019	0.025	**0.019**
P_2	0.022	0.028	0.031	0.058	**0.035**
P_3	0.043	0.052	0.095	0.123	**0.079**
Mean	**0.025**	**0.029**	**0.043**	**0.075**	
CD (0.05) P; 0.001		**CD (0.05) S; 0.001**		**CD (0.05) PxS; 0.002**	
SE (m) P; 0.011		**SE (m) S; 0.011**		**SE (m) PxS; 0.023**	

4.4.7 Iron content in plant

Iron content in plant at all stages was significantly affected by main effect and interaction effect (tables 54, 55, 56 and 57). P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Fe content at flowering stage (799.00 mg kg^{-1}), pegging (707.23 mg kg^{-1}), pod formation (687.83 mg kg^{-1}) and harvesting stages (663.20 mg kg^{-1}). Fe content in plant samples decreased with increased dose of P fertilizer application and increased with increased dose of S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 54: Effect of application of P and S on iron content in plant at flowering stage (mg kg^{-1})

T_1: 488.50

	S_0	S_1	S_2	S_3	Mean
P_0	504.33	621.00	664.33	799.00	**647.17**
P_1	395.50	618.50	661.83	741.50	**604.33**
P_2	366.50	564.00	639.50	720.83	**572.71**
P_3	303.00	524.50	637.00	706.95	**542.86**
Mean	**392.33**	**582.00**	**650.67**	**742.07**	
CD (0.05) P; 0.972		**CD (0.05) S; 0.972**		**CD (0.05) PxS; 1.944**	
SE (m) P; 0.335		**SE (m) S; 0.335**		**SE (m) PxS; 0.670**	

Table 55: Effect of application of P and S on iron content in plant at pegging stage (mg kg^{-1})

T_1: 472.10

	S_0	S_1	S_2	S_3	Mean
P_0	498.63	604.43	611.43	707.23	**605.43**
P_1	324.43	593.83	623.70	703.30	**561.32**
P_2	362.83	523.10	617.60	701.43	**551.24**
P_3	302.37	511.87	604.83	697.43	**529.13**
Mean	**372.07**	**558.31**	**614.39**	**702.35**	
CD (0.05) P; 0.204		**CD (0.05) S; 0.204**		**CD (0.05) PxS; 0.407**	
SE (m) P; 0.070		**SE (m) S; 0.070**		**SE (m) PxS; 0.014**	

Table 56: Effect of application of P and S on iron content in plant at pod formation stage (mg kg^{-1})

T_1: 454.50

	S_0	S_1	S_2	S_3	Mean
P_0	472.13	582.77	590.63	687.83	**583.34**
P_1	321.67	570.57	587.53	672.10	**537.97**
P_2	319.27	519.03	553.53	650.87	**510.68**
P_3	300.73	504.43	543.87	622.03	**492.77**
Mean	**353.45**	**544.20**	**568.89**	**658.21**	
CD (0.05) P; 0.188		**CD (0.05) S; 0.188**		**CD (0.05) PxS; 0.376**	
SE (m) P; 0.065		**SE (m) S; 0.065**		**SE (m) PxS; 0.130**	

Table 57: Effect of application of P and S on iron content in plant at harvest stage (mg kg^{-1})

T_1: 421.70

	S_0	S_1	S_2	S_3	Mean
P_0	439.50	554.63	567.10	663.20	**556.11**
P_1	317.60	543.20	553.30	657.43	**517.88**
P_2	312.20	509.00	541.10	638.20	**500.13**
P_3	297.63	497.20	522.13	608.03	**481.25**
Mean	**341.73**	**526.01**	**545.91**	**641.72**	
CD (0.05) P; 0.048		**CD (0.05) S; 0.048**		**CD (0.05) PxS; 0.097**	
SE (m) P; 0.017		**SE (m) S; 0.017**		**SE (m) PxS; 0.033**	

4.4.8 Manganese content in plant

Manganese content in plant samples at flowering, pegging, pod development and harvest stages are given in the tables 58, 59, 60 and 61 respectively. Mn content was high in treatment having low P and high S. The treatment, P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Mn content at flowering (87.50 mg kg^{-1}), pegging (85.30 mg kg^{-1}), pod setting (83.10 mg kg^{-1}) and harvest (80.90 mg kg^{-1}) stages. Mn content was found to be significantly different in all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 58: Effect of application of P and S on manganese content in plant at flowering stage (mg kg^{-1})

T_1: 73.50

	S_0	S_1	S_2	S_3	Mean
P_0	40.83	53.00	69.50	87.50	**62.71**
P_1	40.83	50.00	68.00	85.50	**61.08**
P_2	38.70	46.00	65.00	80.17	**57.47**
P_3	36.10	45.00	53.00	71.42	**51.38**
Mean	**39.12**	**48.50**	**63.88**	**81.15**	
CD (0.05) P; 0.191		**CD (0.05) S; 0.191**		**CD (0.05) PxS; 0.381**	
SE (m) P; 0.066		**SE (m) S; 0.066**		**SE (m) PxS; 0.131**	

Table 59: Effect of application of P and S on manganese content in plant at pegging stage (mg kg^{-1})

T_1: 70.10

	S_0	S_1	S_2	S_3	Mean
P_0	38.90	51.53	67.10	85.30	**60.71**
P_1	39.20	48.30	66.03	83.60	**59.28**
P_2	35.10	43.70	63.10	78.30	**55.05**
P_3	35.50	43.20	49.83	68.60	**49.28**
Mean	**37.18**	**46.68**	**61.52**	**78.95**	
CD (0.05) P; 0.123		**CD (0.05) S; 0.123**		**CD (0.05) PxS; 0.246**	
SE (m) P; 0.042		**SE (m) S; 0.042**		**SE (m) PxS; 0.085**	

Table 60: Effect of application of P and S on manganese content in plant at pod setting stage (mg kg^{-1})

T_1: 67.70

	S_0	S_1	S_2	S_3	Mean
P_0	37.43	48.80	65.70	83.10	**58.76**
P_1	38.03	46.70	63.53	80.90	**57.29**
P_2	33.07	40.20	60.73	75.10	**52.28**
P_3	33.80	40.70	47.70	65.73	**46.98**
Mean	**35.58**	**44.10**	**59.42**	**76.21**	
CD (0.05) P; 0.246		**CD (0.05) S; 0.246**		**CD (0.05) PxS; 0.491**	
SE (m) P; 0.085		**SE (m) S; 0.085**		**SE (m) PxS; 0.169**	

Table 61: Effect of application of P and S on manganese content in plant at harvest stage (mg kg^{-1})

T_1: 65.20

	S_0	S_1	S_2	S_3	Mean
P_0	36.13	46.30	63.20	80.90	**56.63**
P_1	35.90	44.43	62.30	78.40	**55.26**
P_2	30.90	38.43	57.60	70.30	**49.31**
P_3	32.30	38.23	45.30	61.53	**44.34**
Mean	**33.81**	**41.85**	**57.10**	**72.78**	
CD (0.05) P; 0.279		**CD (0.05) S; 0.279**		**CD (0.05) PxS; 0.559**	
SE (m) P; 0.096		**SE (m) S; 0.096**		**SE (m) PxS; 0.193**	

4.4.9 Zinc content in plant

Zinc content in plant samples at flowering, pegging, pod development and harvesting stages were significantly influenced by main effect and interaction effect. Whereas, at pegging stage, interaction effect was found to be non-significant. Zn content was highest in treatment having low P. Treatment P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Zn content in all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 62: Effect of application of P and S on zinc content in plant at flowering stage (mg kg^{-1})

T_1: 48.78

	S_0	S_1	S_2	S_3	Mean
P_0	50.10	52.30	50.80	53.43	**51.66**
P_1	49.10	49.50	51.10	52.70	**50.60**
P_2	47.70	47.20	50.10	51.63	**49.16**
P_3	45.60	46.10	49.23	50.20	**47.78**
Mean	**48.13**	**48.78**	**50.31**	**51.99**	
CD (0.05) P; 0.216		**CD (0.05) S; 0.216**		**CD (0.05) PxS; 0.432**	
SE (m) P; 0.075		**SE (m) S; 0.075**		**SE (m) PxS; 0.149**	

Table 63: Effect of application of P and S on zinc content in plant at pegging stage (mg kg^{-1})

T_1: 46.70

	S_0	S_1	S_2	S_3	Mean
P_0	47.10	48.70	51.50	52.53	**49.96**
P_1	47.30	46.63	50.40	51.70	**49.01**
P_2	44.63	45.50	49.10	50.20	**47.36**
P_3	43.20	44.63	47.20	48.80	**45.96**
Mean	**45.56**	**46.37**	**49.55**	**50.81**	
CD (0.05) P; 0.249		**CD (0.05) S; 0.249**		**CD (0.05) PxS; NS**	
SE (m) P; 0.086		**SE (m) S; 0.086**		**SE (m) PxS; 0.171**	

Table 64: Effect of application of P and S on zinc content in plant at pod setting stage (mg kg^{-1})

T_1: 45.30

	S_0	S_1	S_2	S_3	Mean
P_0	47.40	45.80	48.60	51.43	**48.31**
P_1	45.10	46.07	47.20	48.10	**46.62**
P_2	44.70	43.50	46.10	47.20	**45.38**
P_3	43.43	42.40	45.30	46.40	**44.38**
Mean	**45.16**	**44.44**	**46.80**	**48.28**	
CD (0.05) P; 0.164		**CD (0.05) S; 0.164**		**CD (0.05) PxS; 0.327**	
SE (m) P; 0.056		**SE (m) S; 0.056**		**SE (m) PxS; 0.113**	

Table 65: Effect of application of P and S on zinc content in plant at harvest stage (mg kg^{-1})

T_1: 44.10

	S_0	S_1	S_2	S_3	Mean
P_0	44.40	47.30	46.20	49.03	**46.73**
P_1	43.10	42.70	45.40	46.50	**44.43**
P_2	41.60	42.60	44.73	45.30	**43.56**
P_3	41.70	39.53	43.10	44.30	**42.16**
Mean	**42.70**	**43.03**	**44.86**	**46.28**	
CD (0.05) P; 0.209		**CD (0.05) S; 0.209**		**CD (0.05) PxS; 0.419**	
SE (m) P; 0.072		**SE (m) S; 0.072**		**SE (m) PxS; 0.144**	

4.4.10 Copper content in plant

Copper content in plant samples at flowering, pegging, pod development and harvest stages are given in the tables 66, 67, 68 and 69 respectively. Cu content at flowering, pegging and pod formation stages was significant due to main effect of P and S and interaction effect. During flowering stage, Cu content in plants was highest in treatment P_0 S_0 (P, 0 kg ha^{-1} and S, 0 kg ha^{-1}. During pegging and pod formation stages Cu content was highest in treatments P_0 S_3 (P,0 kg ha^{-1} and S,30 kg ha^{-1}). At harvest stage Cu content was non-significant due to main effect of S and interaction effect. F statistic for treatments Vs control was calculated and was found to be significant at flowering, pegging and pod formation stages, whereas, at harvesting stage it was found to be non-significant .

Table 66: Effect of application of P and S on copper content in plant at flowering stage (mg kg^{-1})

T_1: 17.20

	S_0	S_1	S_2	S_3	Mean
P_0	19.63	18.70	19.20	18.80	**19.08**
P_1	17.30	16.80	16.90	17.80	**17.20**
P_2	15.63	14.70	14.90	15.20	**15.11**
P_3	14.10	14.50	14.73	15.10	**14.61**
Mean	**16.67**	**16.18**	**16.43**	**16.73**	
CD (0.05) P; 0.209		**CD (0.05) S; 0.209**		**CD (0.05) PxS; 0.419**	
SE (m) P; 0.072		**SE (m) S; 0.072**		**SE (m) PxS; 0.144**	

Table 67: Effect of application of P and S on copper content in plant at pegging stage (mg kg^{-1})

T_1: 16 .70

	S_0	S_1	S_2	S_3	Mean
P_0	16.53	17.30	18.10	18.30	**17.56**
P_1	16.80	15.60	15.40	16.20	**16.00**
P_2	15.43	14.30	14.10	15.00	**14.71**
P_3	12.90	13.50	13.40	14.07	**13.47**
Mean	**15.42**	**15.18**	**15.25**	**15.89**	
CD (0.05) P; 0.175		CD (0.05) S; 0.175		CD (0.05) PxS; 0.351	
SE (m) P; 0.060		SE (m) S; 0.060		SE (m) PxS; 0.121	

Table 68: Effect of application of P and S on copper content at in plant pod setting stage (mg kg^{-1})

T_1: 14.30

	S_0	S_1	S_2	S_3	Mean
P_0	14.43	15.30	15.10	15.40	**15.06**
P_1	14.20	14.40	14.10	14.07	**14.19**
P_2	13.70	13.50	13.03	13.30	**13.38**
P_3	12.50	12.20	12.10	12.13	**12.23**
Mean	**13.71**	**13.85**	**13.58**	**13.73**	
CD (0.05) P; 0.124		CD (0.05) S; 0.124		CD (0.05) PxS; 0.249	
SE (m) P; 0.043		SE (m) S; 0.043		SE (m) PxS; 0.086	

Table 69: Effect of application of P and S on copper content in plant at harvest stage (mg kg^{-1})

T_1: 11.73

	S_0	S_1	S_2	S_3	Mean
P_0	11.93	11.90	11.80	11.90	**11.88**
P_1	11.50	11.70	11.70	11.60	**11.63**
P_2	11.63	11.50	11.60	11.20	**11.48**
P_3	11.20	11.40	11.73	11.10	**11.36**
Mean	**11.57**	**11.63**	**11.71**	**11.45**	
CD (0.05) P; NS		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.072		**SE (m) S; 0.072**		**SE (m) PxS; 0.144**	

4.4.11 Boron content in plant

Boron content at flowering, pegging, pod development and harvest stages are given in the tables 70, 71, 72 and 73 respectively. The B content was significantly influenced by different levels of P application. The treatment with higher dose of P significantly reduced the B content. Application of S was not found to cause significant difference between treatments. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 70: Effect of application of P and S on boron content in plant at flowering stage (mg kg^{-1})

T_1: 16.30

	S_0	S_1	S_2	S_3	Mean
P_0	18.13	18.17	18.00	18.07	**18.09**
P_1	17.27	17.20	17.43	17.33	**17.31**
P_2	16.43	16.30	16.10	16.13	**16.24**
P_3	15.33	15.30	15.10	15.23	**15.24**
Mean	**16.79**	**16.74**	**16.66**	**16.69**	
CD (0.05) P; 0.277		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.095		**SE (m) S; 0.095**		**SE (m) PxS; 0.191**	

Table 71: Effect of application of P and S on boron content in plant at pegging stage (mg kg^{-1})

T_1: 15.02

	S_0	S_1	S_2	S_3	Mean
P_0	16.20	16.27	16.23	16.23	**16.23**
P_1	15.47	15.40	15.30	15.43	**15.40**
P_2	14.67	14.51	14.61	14.63	**14.60**
P_3	13.47	13.70	13.26	13.42	**13.46**
Mean	**14.95**	**14.97**	**14.85**	**14.93**	
CD (0.05) P; 0.439		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.151		**SE (m) S; 0.151**		**SE (m) PxS; 0.303**	

Table 72: Effect of application of P and S on boron content at in plant pod setting stage (mg kg^{-1})

T_1: 13.04

	S_0	S_1	S_2	S_3	Mean
P_0	14.35	14.24	14.13	14.15	**14.22**
P_1	13.14	13.37	13.29	13.25	**13.26**
P_2	13.10	13.08	13.05	13.07	**13.08**
P_3	12.30	12.24	12.18	12.16	**12.22**
Mean	**13.22**	**13.23**	**13.16**	**13.16**	
CD (0.05) P; 0.232		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.08		**SE (m) S; 0.08**		**SE (m) PxS; 0.16**	

Table 73: Effect of P and B application on boron content in plant at harvest stage (mg kg^{-1})

T_1: 11.70

	S_0	S_1	S_2	S_3	Mean
P_0	12.27	12.34	12.36	12.27	**12.31**
P_1	11.26	11.34	11.21	11.23	**11.26**
P_2	11.04	11.02	11.03	11.04	**11.03**
P_3	10.42	10.21	10.40	10.42	**10.36**
Mean	**11.25**	**11.23**	**11.25**	**11.24**	
CD (0.05) P; 0.149		**CD (0.05) S; NS**		**CD (0.05) PxS; NS**	
SE (m) P; 0.052		**SE (m) S; 0.052**		**SE (m) PxS; 0.103**	

4.5 NUTRIENT CONTENT IN POD SAMPLES

4.5.1 Nitrogen content in kernels

Nitrogen content in kernels varied significantly due to main effect and interaction effect. N content was increased with increased dose of P and S application (table 74). Highest N content was observed in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) which had 3.83 per cent N. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.2 Phosphorus content in kernels

Data (table 75) on P content in kernels showed that treatments varied significantly due to main effect and interaction effect. Treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest P content (0.414 per cent). P content in kernel increased with increased dose of P and S application. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.3 Potassium content in kernels

Effect of application of P and S on K content in kernels is shown in the table 76. The K content varied significantly due to main effect whereas interaction effect was found to be non-significant. Treatment, P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest K content (1.631 per cent). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 74: Effect of application of P and S on nitrogen content in kernel (%)

T_1: 3.24

	S_0	S_1	S_2	S_3	Mean
P_0	3.15	3.25	3.49	3.60	**3.37**
P_1	3.28	3.44	3.49	3.69	**3.48**
P_2	3.37	3.48	3.65	3.66	**3.54**
P_3	3.47	3.57	3.68	3.83	**3.64**
Mean	**3.32**	**3.44**	**3.58**	**3.69**	
CD (0.05) P; 0.054		**CD (0.05) S; 0.054**		**CD (0.05) PxS; NS**	
SE (m) P; 0.019		**SE (m) S; 0.019**		**SE (m) PxS; 0.037**	

Table 75: Effect of application of P and S on phosphorus content in kernel (%)

T_1: 0.35

	S_0	S_1	S_2	S_3	Mean
P_0	0.332	0.344	0.353	0.363	**0.348**
P_1	0.342	0.346	0.352	0.382	**0.356**
P_2	0.351	0.355	0.377	0.393	**0.369**
P_3	0.351	0.366	0.392	0.414	**0.381**
Mean	**0.344**	**0.353**	**0.368**	**0.388**	
CD (0.05) P; 0.003		**CD (0.05) S; 0.003**		**CD (0.05) PxS; 0.005**	
SE (m) P; 0.001		**SE (m) S; 0.001**		**SE (m) PxS; 0.002**	

Table 76: Effect of application of P and S on potassium content in kernel (%)

T_1: 1.43

	S_0	S_1	S_2	S_3	Mean
P_0	1.338	1.463	1.543	1.631	**1.494**
P_1	1.283	1.393	1.430	1.531	**1.409**
P_2	1.243	1.283	1.320	1.413	**1.315**
P_3	1.193	1.223	1.253	1.377	**1.262**
Mean	**1.265**	**1.341**	**1.387**	**1.488**	
CD (0.05) P; 0.034		**CD (0.05) S; 0.034**		**CD (0.05) PxS; NS**	
SE (m) P; 0.012		**SE (m) S 0.012**		**SE (m) PxS; 0.023**	

4.5.4 Calcium content in kernels

Effect of application of P and S on Ca content in pod is shown in the table 77. Calcium content varied significantly due to the application of P and S fertilizers. Ca showed a synergistic interaction with P. Ca content increased with increased dose of P application. Highest Ca content was noted in P_3S_1 (P, 90 kg ha^{-1} and S, 10 kg ha^{-1}), where the Ca content was 0.245 per cent. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.5 Magnesium content in kernels

Effect of application of P and S on Mg content in kernel is shown in the table 78. Mg content varied significantly due to the application of P and S fertilizers. Highest Mg content was observed in P_2S_3 (P, 75 kg ha^{-1} and S, 30 kg ha^{-1}) (0.351 per cent). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.6 Sulphur content in kernels

Sulphur content varied significantly due to the application of P and S fertilizers. The S content showed a synergistic interaction with P upto medium dose of P (75 kg ha^{-1}). S content increased with increased dose of P application (table 79).

Highest S content was noted in P_2S_3 (P, 75 kg ha^{-1} and S, 30 kg ha^{-1}) and it was recorded as 0.224 per cent S. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 77: Effect of application of P and S on calcium content in kernel (%)

T_1: 0.132

	S_0	S_1	S_2	S_3	Mean
P_0	0.113	0.138	0.148	0.134	**0.133**
P_1	0.147	0.155	0.155	0.156	**0.153**
P_2	0.152	0.166	0.186	0.191	**0.174**
P_3	0.197	0.254	0.219	0.214	**0.221**
Mean	**0.152**	**0.178**	**0.177**	**0.174**	
CD (0.05) P; 0.013		CD (0.05) S; 0.013		CD (0.05) PxS; 0.026	
SE (m) P; 0.005		SE (m) S; 0.005		SE (m) PxS; 0.009	

Table 78: Effect of application of P and S on magnesium content in kernel (%)

T_1: 0.25

	S_0	S_1	S_2	S_3	Mean
P_0	0.231	0.291	0.321	0.341	**0.296**
P_1	0.231	0.291	0.313	0.340	**0.294**
P_2	0.241	0.261	0.281	0.351	**0.283**
P_3	0.241	0.241	0.250	0.331	**0.266**
Mean	**0.236**	**0.271**	**0.291**	**0.341**	
CD (0.05) P; 0.002		CD (0.05) S; 0.002		CD (0.05) PxS; 0.003	
SE (m) P; 0.001		SE (m) S; 0.001		SE (m) PxS; 0.001	

Table 79: Effect of application of P and S on sulphur content in kernel (%)

T_1: 0.152

	S_0	S_1	S_2	S_3	Mean
P_0	0.149	0.174	0.195	0.222	**0.186**
P_1	0.152	0.175	0.194	0.218	**0.185**
P_2	0.167	0.182	0.193	0.224	**0.192**
P_3	0.152	0.163	0.188	0.219	**0.181**
Mean	**0.155**	**0.174**	**0.193**	**0.222**	
CD (0.05) P; 0.001		**CD (0.05) S; 0.001**		**CD (0.05) PxS; 0.002**	
SE (m) P; 0.011		**SE (m) S; 0.011**		**SE (m) PxS; 0.022**	

4.5.7 Iron content in kernels

Effect of application of P and S on Fe content in kernel is shown in the table 80. Fe content was influenced by both main effect and interaction effect. Highest Fe content was noted in P_0S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.8 Manganese content in kernels

Manganese content varied significantly due to main effect and interaction effect. Mn content decreased with increased dose of P application (table 81). The highest Mn content was observed in P_0S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.9 Zinc content in kernels

Data (table 82) on Zn content showed that Zn was influenced by P and S application. Zn content decreased with increased dose of P application. Highest Zn was noted in P_0 S_3 (P, 0 kg ha^{-1} and S, 0 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.10 Copper content in kernels

Copper content was found to be significant due to main effect and interaction effect (table 83). Highest Cu content was observed in P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.11 Boron content in kernels

Data (table 84) on B content showed that B was significantly influenced by P and S application. B content decreased with increased dose of P application. Highest B was noted in P_0S_2 (P, 0 kg ha^{-1} and S, 20 kg ha^{-1}). It was on par with treatment, P_0 S_0 (P, 0 kg ha^{-1} and S, 0 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 80: Effect of application of P and S on iron content in kernel (mg kg^{-1})

T_1: 123.00

	S_0	S_1	S_2	S_3	Mean
P_0	206.00	274.00	343.00	399.33	305.58
P_1	182.00	215.00	281.00	354.33	258.08
P_2	167.00	186.00	245.33	313.00	227.83
P_3	117.33	156.00	197.00	276.00	186.58
Mean	168.08	207.75	266.58	335.67	
CD (0.05) P; 0.248		CD (0.05) S; 0.248		CD (0.05) PxS; 0.496	
SE (m) P; 0.085		SE (m) S; 0.085		SE (m) PxS; 0.171	

Table 81: Effect of application of P and S on manganese content in kernel (mg kg^{-1})

T_1: 20.64

	S_0	S_1	S_2	S_3	Mean
P_0	19.96	21.95	24.30	26.75	**23.24**
P_1	18.00	20.00	22.50	24.00	**21.13**
P_2	17.03	17.95	18.75	21.35	**18.77**
P_3	15.00	16.25	17.55	19.07	**16.97**
Mean	**17.50**	**19.04**	**20.78**	**22.79**	
CD (0.05) P; 0.027		**CD (0.05) S; 0.027**		**CD (0.05) PxS; 0.053**	
SE (m) P; 0.009		**SE (m) S; 0.009**		**SE (m) PxS; 0.018**	

Table 82: Effect of application of P and S on zinc content in kernel (mg kg^{-1})

T_1: 52.21

	S_0	S_1	S_2	S_3	Mean
P_0	53.00	55.00	57.65	60.83	**56.62**
P_1	53.25	54.25	53.75	56.00	**54.31**
P_2	47.25	48.00	49.07	51.25	**48.89**
P_3	45.50	46.75	47.25	46.10	**46.40**
Mean	**49.75**	**51.00**	**51.93**	**53.55**	
CD (0.05) P; 0.130		**CD (0.05) S; 0.130**		**CD (0.05) PxS; 0.260**	
SE (m) P; 0.045		**SE (m) S; 0.045**		**SE (m) PxS; 0.090**	

Table 83: Effect of application of P and S on copper content in kernel (mg kg^{-1})

T_1: 13.75

	S_0	S_1	S_2	S_3	Mean
P_0	13.57	13.00	13.75	14.00	**13.58**
P_1	12.75	12.27	12.50	12.00	**12.38**
P_2	10.75	11.25	10.50	11.50	**11.00**
P_3	10.13	10.25	9.50	10.07	**9.99**
Mean	**11.80**	**11.69**	**11.56**	**11.89**	
CD (0.05) P; 0.117		**CD (0.05) S; 0.117**		**CD (0.05) PxS; 0.233**	
SE (m) P; 0.040		**SE (m) S; 0.040**		**SE (m) PxS; 0.080**	

Table 84: Effect of application of P and S on boron content in kernel (mg kg^{-1})

T_1: 17.50

	S_0	S_1	S_2	S_3	Mean
P_0	20.23	20.07	20.24	20.16	**20.18**
P_1	19.03	17.50	18.25	19.50	**18.57**
P_2	16.13	17.00	16.25	17.25	**16.66**
P_3	15.07	15.25	14.97	14.99	**15.07**
Mean	**17.62**	**17.45**	**17.43**	**17.98**	
CD (0.05) P; 0.060		**CD (0.05) S; 0.060**		**CD (0.05) PxS; 0.121**	
SE (m) P; 0.021		**SE (m) S; 0.021**		**SE (m) PxS; 0.042**	

4.5.12 Nitrogen content in shell

Nitrogen content in shell varied significantly due to main effect and interaction effect. N content was increased with increased dose of P and S application (table 85). Highest N content was observed in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) which had 1.193 per cent. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.13 Phosphorus content in shell

Data (table 86) on P content in shell showed that treatments varied significantly due to main effect and interaction effect. P content in shell increased with increased dose of P and S application. Treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest P content (0.223%). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.14 Potassium content in shell

Effect of application of P and S on K content in shell is shown in the table 87. The K content varied significantly due to main effect whereas interaction effect was found to be non-significant. Treatment, P_0 S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest K content (0.769%). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.15 Calcium content in shell

Effect of application of P and S on Ca content in shell is shown in the table 88. Calcium content varied significantly due to the application of P and S fertilizers. Ca showed a synergistic interaction with P. Ca content increased with increased dose of P application. Highest Ca content was noted in P_3S_0 (P, 90 kg ha^{-1} and S, 0 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.16 Magnesium content in shell

Effect of application of P and S on Mg content in shell is shown in the table 89. Mg content varied significantly due to the application of P and S fertilizers. Highest Mg content was observed in P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.17 Sulphur content in shell

Sulphur content varied significantly due to the application of P and S fertilizers. The S showed a synergistic interaction with P upto medium dose of P (P, 75 kg ha^{-1}). S content increased with increased dose of P application (table 90). Highest S content was noted in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.18 Iron content in shell

Effect of application of P and S on Fe content in shell is shown in the table 91. Fe content was influenced by both main effect and interaction effect. Highest Fe content was noted in P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.19 Manganese content in shell

Manganese content varied significantly due to main effect and interaction effect. Mn content decreased with increased dose of P application (table 92). The highest Mn content was observed in P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.20 Zinc content in shell

Data (table 93) showed that Zn content was influenced by P and S application. Zn content decreased with increased dose of P application. Highest Zn was noted in P_0 S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.21 Copper content in shell

Copper content was found to be significant due to main effect and interaction effect (table 94). Highest Cu content was observed in P_0S_2 (P, 0 kg ha^{-1} and S, 20 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.5.22 Boron content in shell

Data (table 95) on B content showed that B was influenced by P and S application. B content decreased with increased dose of P application. Highest B (15.35 mg kg^{-1}) was noted in P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 85: Effect of application of P and S on nitrogen content in shell (%)

T_1: 1.020

	S_0	S_1	S_2	S_3	**Mean**
P_0	0.973	0.983	1.043	1.073	**1.018**
P_1	0.983	1.073	1.083	1.083	**1.056**
P_2	1.057	1.103	1.123	1.163	**1.112**
P_3	1.093	1.123	1.173	1.193	**1.146**
Mean	**1.027**	**1.071**	**1.106**	**1.128**	
CD (0.05) P; 0.043		**CD (0.05) S; 0.043**		**CD (0.05) PxS; NS**	
SE (m) P; 0.015		**SE (m) S; 0.015**		**SE (m) PxS; 0.029**	

Table 86: Effect of application of P and S on phosphorus content in shell (%)

T_1: 0.150

	S_0	S_1	S_2	S_3	**Mean**
P_0	0.077	0.093	0.103	0.123	**0.099**
P_1	0.093	0.123	0.143	0.163	**0.131**
P_2	0.073	0.124	0.163	0.173	**0.134**
P_3	0.133	0.153	0.183	0.223	**0.173**
Mean	**0.094**	**0.124**	**0.148**	**0.171**	
CD (0.05) P; 0.005		**CD (0.05) S; 0.005**		**CD (0.05) PxS; 0.01**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.004**	

Table 87: Effect of application of P and S on potassium content in shell (%)

T_1: 0.548

	S_0	S_1	S_2	S_3	Mean
P_0	0.453	0.479	0.517	0.769	**0.555**
P_1	0.417	0.469	0.497	0.617	**0.500**
P_2	0.417	0.465	0.490	0.565	**0.484**
P_3	0.407	0.459	0.486	0.531	**0.471**
Mean	**0.424**	**0.468**	**0.497**	**0.621**	
CD (0.05) P; 0.006		**CD (0.05) S; 0.006**		**CD (0.05) PxS; 0.012**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.004**	

Table 88: Effect of application of P and S on calcium content in shell (%)

T_1: 1.91

	S_0	S_1	S_2	S_3	Mean
P_0	1.52	1.78	1.78	1.97	**1.76**
P_1	1.93	2.12	2.02	2.17	**2.06**
P_2	2.10	2.02	2.09	2.21	**2.11**
P_3	2.50	2.39	2.43	2.22	**2.39**
Mean	**2.01**	**2.08**	**2.08**	**2.14**	
CD (0.05) P; 0.012		**CD (0.05) S; 0.012**		**CD (0.05) PxS; 0.024**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.008**	

Table 89: Effect of application of P and S on magnesium content in shell (%)

T_1: 1.304

	S_0	S_1	S_2	S_3	Mean
P_0	1.297	1.413	1.583	1.733	**1.507**
P_1	1.123	1.263	1.473	1.643	**1.376**
P_2	1.023	1.163	1.384	1.590	**1.290**
P_3	0.907	1.010	1.245	1.486	**1.162**
Mean	**1.088**	**1.213**	**1.421**	**1.613**	
CD (0.05) P; 0.012		**CD (0.05) S; 0.012**		**CD (0.05) PxS; 0.023**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.008**	

Table 90: Effect of application of P and S on sulphur content in shell (%)

T_1: 0.05

	S_0	S_1	S_2	S_3	Mean
P_0	0.045	0.121	0.162	0.193	**0.130**
P_1	0.034	0.140	0.135	0.156	**0.116**
P_2	0.102	0.109	0.172	0.163	**0.136**
P_3	0.102	0.108	0.172	0.200	**0.145**
Mean	**0.071**	**0.119**	**0.160**	**0.178**	
CD (0.05) P; 0.019		**CD (0.05) S; 0.019**		**CD (0.05) PxS; 0.037**	
SE (m) P; 0.008		**SE (m) S; 0.008**		**SE (m) PxS; 0.016**	

Table 91: Effect of application of P and S on iron content in shell (mg kg^{-1})

T_1: 124.00

	S_0	S_1	S_2	S_3	Mean
P_0	176.00	227.00	253.00	274.00	**232.50**
P_1	155.00	204.00	237.00	258.00	**213.50**
P_2	137.00	184.00	221.00	234.33	**194.08**
P_3	109.33	143.00	182.00	217.00	**162.83**
Mean	**144.33**	**189.50**	**223.25**	**245.83**	
CD (0.05) P; 0.174		**CD (0.05) S; 0.174**		**CD (0.05) PxS; 0.348**	
SE (m) P; 0.060		**SE (m) S; 0.060**		**SE (m) PxS; 0.120**	

Table 92: Effect of application of P and S on manganese content in shell (mg kg^{-1})

T_1: 20.12

	S_0	S_1	S_2	S_3	Mean
P_0	19.23	20.33	22.75	24.00	**19.23**
P_1	17.44	18.64	20.45	22.35	**17.44**
P_2	15.01	16.39	18.65	20.58	**15.01**
P_3	11.23	15.97	16.28	19.34	**11.23**
Mean	**15.73**	**17.83**	**19.53**	**21.57**	**15.73**
CD (0.05) P; 0.021		**CD (0.05) S; 0.021**		**CD (0.05) PxS; 0.042**	
SE (m) P; 0.007		**SE (m) S; 0.007**		**SE (m) PxS; 0.014**	

Table 93: Effect of application of P and S on zinc content in shell (mg kg^{-1})

T_1: 41.30

	S_0	S_1	S_2	S_3	Mean
P_0	38.20	41.60	42.70	45.33	**41.96**
P_1	35.40	40.17	41.30	43.20	**40.02**
P_2	32.53	38.20	39.20	41.70	**37.91**
P_3	29.30	34.30	37.40	39.60	**35.15**
Mean	**33.86**	**38.57**	**40.15**	**42.46**	
CD (0.05) P; 0.125		**CD (0.05) S; 0.125**		**CD (0.05) PxS; 0.250**	
SE (m) P; 0.043		**SE (m) S; 0.043**		**SE (m) PxS; 0.086**	

Table 94: Effect of application of P and S on copper content in shell (mg kg^{-1})

T_1: 11.20

	S_0	S_1	S_2	S_3	Mean
P_0	11.73	11.50	12.00	11.40	**11.66**
P_1	11.20	11.10	10.80	10.90	**11.00**
P_2	10.80	10.70	10.90	10.60	**10.75**
P_3	9.80	9.17	9.10	9.30	**9.34**
Mean	**10.88**	**10.62**	**10.70**	**10.55**	
CD (0.05) P; 0.062		**CD (0.05) S; 0.062**		**CD (0.05) PxS; 0.123**	
SE (m) P; 0.021		**SE (m) S; 0.021**		**SE (m) PxS; 0.042**	

Table 95: Effect of application of P and S on boron content in shell (mg kg^{-1})

T_1: 10.50

	S_0	S_1	S_2	S_3	**Mean**
P_0	15.29	15.10	15.10	15.35	**15.21**
P_1	14.17	14.25	13.95	13.50	**13.97**
P_2	12.15	12.30	11.85	11.50	**11.95**
P_3	9.75	9.20	9.25	8.85	**9.27**
Mean	**12.84**	**12.71**	**12.54**	**12.30**	
CD (0.05) P; 0.054		**CD (0.05) S; 0.054**		**CD (0.05) PxS; 0.108**	
SE (m) P; 0.019		**SE (m) S; 0.019**		**SE (m) PxS; 0.037**	

4.6 UPTAKE OF NUTRIENTS BY PLANT

4.6.1 Nitrogen uptake by plant

Uptake of N by plant varied significantly due to different levels of fertilizer application (table no.s 96, 97, 98 and 99). Significantly the highest N uptake by plant was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) at all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 96: Effect of application of P and S on nitrogen uptake by plant at flowering stage (kg ha^{-1})

T_1: 12.11

	S_0	S_1	S_2	S_3	**Mean**
P_0	6.91	12.72	14.70	18.45	**13.19**
P_1	7.95	12.34	18.33	21.25	**14.97**
P_2	8.54	13.37	20.04	22.96	**16.23**
P_3	9.76	14.96	23.67	25.05	**18.36**
Mean	**8.29**	**13.35**	**19.19**	**21.93**	
CD (0.05) P; 0.244		**CD (0.05) S; 0.244**		**CD (0.05) PxS; 0.488**	
SE (m) P; 0.084		**SE (m) S; 0.084**		**SE (m) PxS; 0.168**	

Table 97: Effect of application of P and S on nitrogen uptake by plant at pegging stage (kg ha^{-1})

T_1: 34.22

	S_0	S_1	S_2	S_3	Mean
P_0	27.12	31.81	34.40	37.42	**32.69**
P_1	30.38	35.05	36.65	39.76	**35.46**
P_2	33.25	38.82	39.58	45.97	**39.40**
P_3	38.15	40.70	48.45	52.29	**44.90**
Mean	**32.23**	**36.60**	**39.77**	**43.86**	
CD (0.05) P; 0.842		**CD (0.05) S; 0.842**		**CD (0.05) PxS; 1.685**	
SE (m) P; 0.29		**SE (m) S; 0.29**		**SE (m) PxS; 0.581**	

Table 98: Effect of application of P and S on nitrogen uptake by plant at pod setting stage (kg ha^{-1})

T_1: 41.34

	S_0	S_1	S_2	S_3	Mean
P_0	38.85	40.33	45.43	51.36	**43.99**
P_1	41.97	45.20	50.55	56.98	**48.68**
P_2	45.54	48.94	52.55	61.70	**52.18**
P_3	50.38	56.00	68.00	77.19	**62.89**
Mean	**44.18**	**47.62**	**54.13**	**61.81**	
CD (0.05) P; 0.384		**CD (0.05) S; 0.384**		**CD (0.05) PxS; 0.769**	
SE (m) P; 0.132		**SE (m) S; 0.132**		**SE (m) PxS; 0.265**	

Table 99: Effect of application of P and S on nitrogen uptake by plant at harvest stage (kg ha^{-1})

T_1: 46.33

	S_0	S_1	S_2	S_3	Mean
P_0	44.46	48.34	53.82	61.02	**51.91**
P_1	48.14	55.48	62.20	65.87	**57.92**
P_2	56.62	63.51	68.13	73.23	**65.37**
P_3	63.67	68.34	74.98	78.39	**71.35**
Mean	**53.22**	**58.92**	**64.78**	**69.63**	
CD (0.05) P; 0.934		**CD (0.05) S; 0.934**		**CD (0.05) PxS; 1.868**	
SE (m) P; 0.322		**SE (m) S; 0.322**		**SE (m) PxS; 0.644**	

4.6.2 Phosphorus uptake by plant

Uptake of P by plant varied significantly due to different levels of fertilizer application (table no.s 100, 101, 102 and 103). Significantly highest P uptake by plant was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) at all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 100: Effect of application of P and S on phosphorus uptake by plant at flowering stage (kg ha^{-1})

T_1: 1.72

	S_0	S_1	S_2	S_3	Mean
P_0	0.73	1.56	2.05	2.58	**1.73**
P_1	0.90	1.61	2.58	3.14	**2.06**
P_2	1.04	1.88	2.92	3.57	**2.35**
P_3	1.36	2.26	3.59	3.87	**2.77**
Mean	**1.01**	**1.83**	**2.78**	**3.29**	
CD (0.05) P; 0.011		**CD (0.05) S; 0.011**		**CD (0.05) PxS; 0.022**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.007**	

Table 101: Effect of application of P and S on phosphorus uptake by plant at pegging stage (kg ha^{-1})

T_1: 5.23

	S_0	S_1	S_2	S_3	Mean
P_0	3.18	3.66	4.76	5.47	**4.27**
P_1	3.69	4.15	5.41	6.34	**4.90**
P_2	4.07	5.14	6.15	7.23	**5.65**
P_3	5.33	5.73	7.35	8.09	**6.62**
Mean	**4.07**	**4.67**	**5.92**	**6.78**	
CD (0.05) P; 0.048		**CD (0.05) S; 0.048**		**CD (0.05) PxS; 0.097**	
SE (m) P; 0.017		**SE (m) S; 0.017**		**SE (m) PxS; 0.033**	

Table 102: Effect of application of P and S on phosphorus uptake by plant at pod setting stage (kg ha^{-1})

T_1: 7.34

	S_0	S_1	S_2	S_3	Mean
P_0	3.66	4.15	5.69	6.23	**4.93**
P_1	4.33	5.62	6.86	7.48	**6.07**
P_2	4.89	6.40	7.18	8.96	**6.86**
P_3	6.10	7.28	9.79	11.29	**8.62**
Mean	**4.75**	**5.86**	**7.38**	**8.49**	
CD (0.05) P; 0.027		**CD (0.05) S; 0.027**		**CD (0.05) PxS; 0.053**	
SE (m) P; 0.009		**SE (m) S; 0.009**		**SE (m) PxS; 0.018**	

Table 103: Effect of application of P and S on phosphorus uptake by plant at harvest stage (kg ha^{-1})

T_1: 7.81

	S_0	S_1	S_2	S_3	**Mean**
P_0	3.26	5.05	6.61	8.21	**5.78**
P_1	4.06	6.02	8.65	9.49	**7.05**
P_2	5.56	7.60	8.50	10.76	**8.10**
P_3	6.31	8.66	10.27	11.74	**9.24**
Mean	**4.79**	**6.83**	**8.51**	**10.05**	
CD (0.05) P; 0.034		**CD (0.05) S; 0.034**		**CD (0.05) PxS; 0.069**	
SE (m) P; 0.012		**SE (m) S; 0.012**		**SE (m) PxS; 0.024**	

4.6.3 Potassium uptake by plant

Potassium uptake by plant was found to be significant in all treatments due to main effect and interaction effect. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest K uptake at flowering stage (20.17 kg ha^{-1}) and pod formation stage (64.48 kg ha^{-1}). At pegging stage P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest K uptake (21.93 kg ha^{-1}). At harvesting stage P_2S_3 (P, 75 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest K uptake (79.40 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 104: Effect of application of P and S on potassium uptake by plant at flowering stage (kg ha^{-1})

T_1: 12.5

	S_0	S_1	S_2	S_3	Mean
P_0	4.38	9.60	11.93	17.91	**10.96**
P_1	4.77	9.17	14.27	18.69	**11.72**
P_2	4.80	9.18	14.41	19.19	**11.89**
P_3	5.44	9.62	17.94	20.17	**13.29**
Mean	**4.85**	**9.39**	**14.64**	**18.99**	
CD (0.05) P; 0.125		**CD (0.05) S; 0.125**		**CD (0.05) PxS; 0.25**	
SE (m) P; 0.043		**SE (m) S; 0.043**		**SE (m) PxS; 0.086**	

Table 105: Effect of application of P and S on potassium uptake by plant at pegging stage (kg ha^{-1})

T_1: 33.18

	S_0	S_1	S_2	S_3	Mean
P_0	13.64	15.65	16.36	17.30	**15.74**
P_1	15.36	17.19	17.49	18.32	**17.09**
P_2	16.35	18.97	18.78	20.58	**18.67**
P_3	19.18	19.68	21.93	21.86	**20.66**
Mean	**16.13**	**17.87**	**18.64**	**19.52**	
CD (0.05) P; 0.001		**CD (0.05) S; 0.001**		**CD (0.05) PxS; 0.003**	
SE (m) P; NS		**SE (m) S;NS**		**SE (m) PxS; 0.001**	

Table 106: Effect of application of P and S on potassium uptake by plant at pod setting stage (kg ha^{-1})

T_1: 41.1

	S_0	S_1	S_2	S_3	Mean
P_0	29.90	37.15	45.37	57.23	**42.41**
P_1	28.84	36.55	47.56	61.11	**43.52**
P_2	29.61	38.93	45.01	62.08	**43.91**
P_3	31.34	40.66	56.94	64.48	**48.35**
Mean	**29.92**	**38.32**	**48.72**	**61.23**	
CD (0.05) P; 0.025		**CD (0.05) S; 0.025**		**CD (0.05) PxS; 0.049**	
SE (m) P; 0.009		**SE (m) S; 0.009**		**SE (m) PxS; 0.017**	

Table 107: Effect of application of P and S on potassium uptake by plant at harvest stage (kg ha^{-1})

T_1: 45.52

	S_0	S_1	S_2	S_3	Mean
P_0	38.03	50.23	59.86	77.36	**56.37**
P_1	37.44	49.21	64.39	78.77	**57.45**
P_2	36.27	52.76	60.29	79.40	**57.18**
P_3	40.39	52.72	63.14	76.08	**58.08**
Mean	**38.03**	**51.23**	**61.92**	**77.90**	
CD (0.05) P; 0.297		**CD (0.05) S; 0.297**		**CD (0.05) PxS; 0.595**	
SE (m) P; 0.102		**SE (m) S; 0.102**		**SE (m) PxS; 0.205**	

4.6.4 Calcium uptake by plant

Calcium uptake by plant varied significantly due to main effect and interaction effect. Highest Ca uptake was noted in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) during flowering, pegging, and pod formation stages. Whereas at harvesting stage highest Ca uptake was noted in P_1S_3 (P, 60 kg ha^{-1} and S, 30 kg ha^{-1}). Ca uptake increased with plant growth and there was a slight decrease at harvest stage. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 108: Effect of application of P and S on calcium uptake by plant at flowering stage (kg ha^{-1})

T_1: 10.03

	S_0	S_1	S_2	S_3	Mean
P_0	5.31	9.88	12.26	15.94	**10.85**
P_1	5.81	9.03	14.83	18.16	**11.96**
P_2	5.98	9.29	14.84	18.49	**12.15**
P_3	6.60	10.52	17.43	19.27	**13.45**
Mean	**5.93**	**9.68**	**14.84**	**17.96**	
CD (0.05) P; 0.029		**CD (0.05) S; 0.029**		**CD (0.05) PxS; 0.058**	
SE (m) P; 0.01		**SE (m) S; 0.01**		**SE (m) PxS; 0.02**	

Table 109: Effect of application of P and S on calcium uptake by plant at pegging stage (kg ha^{-1})

T_1: 24.74

	S_0	S_1	S_2	S_3	Mean
P_0	22.50	25.94	28.87	31.28	**27.15**
P_1	24.13	27.86	29.55	32.12	**28.42**
P_2	24.75	29.84	31.31	34.84	**30.19**
P_3	25.06	29.32	35.16	35.77	**31.33**
Mean	**24.11**	**28.24**	**31.23**	**33.51**	
CD (0.05) P; 0.015		**CD (0.05) S; 0.015**		**CD (0.05) PxS; 0.03**	
SE (m) P; 0.005		**SE (m) S; 0.005**		**SE (m) PxS; 0.01**	

Table 110: Effect of application of P and S on calcium uptake by plant at pod setting stage (kg ha^{-1})

T_1: 27.67

	S_0	S_1	S_2	S_3	Mean
P_0	19.48	24.00	29.22	34.28	**26.74**
P_1	19.95	23.00	31.04	36.79	**27.70**
P_2	20.34	23.64	29.82	37.18	**27.75**
P_3	19.13	23.36	32.64	38.62	**28.44**
Mean	**19.73**	**23.50**	**30.68**	**36.72**	
CD (0.05) P; 0.016		**CD (0.05) S; 0.016**		**CD (0.05) PxS; 0.031**	
SE (m) P; 0.005		**SE (m) S; 0.005**		**SE (m) PxS; 0.011**	

Table 111: Effect of application of P and S on calcium uptake by plant at harvest stage (kg ha^{-1})

T_1: 24.79

	S_0	S_1	S_2	S_3	Mean
P_0	23.08	26.21	32.18	39.88	**30.34**
P_1	23.82	27.97	34.98	40.42	**31.80**
P_2	23.83	28.11	32.77	37.34	**30.52**
P_3	23.37	27.15	30.72	36.92	**29.54**
Mean	**23.53**	**27.36**	**32.66**	**38.64**	
CD (0.05) P; 0.015		**CD (0.05) S; 0.015**		**CD (0.05) PxS; 0.030**	
SE (m) P; 0.005		**SE (m) S; 0.005**		**SE (m) PxS; 0.010**	

4.6.5 Magnesium uptake by plant

Application of P and S fertilizers significantly affected Mg uptake by plant. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) had highest Mg uptake during flowering, pegging, pod formation and harvesting stages. The main effect and interaction effect was found to be significant at all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 112: Effect of application of P and S on magnesium uptake by plant at flowering stage (kg ha^{-1})

T_1: 16.69

	S_0	S_1	S_2	S_3	Mean
P_0	7.79	15.03	17.67	22.54	**15.76**
P_1	9.17	14.85	22.33	26.31	**18.16**
P_2	10.04	16.05	24.28	28.88	**19.81**
P_3	11.66	18.38	29.62	31.20	**22.72**
Mean	**9.66**	**16.08**	**23.48**	**27.23**	
CD (0.05) P; 0.005		**CD (0.05) S; 0.005**		**CD (0.05) PxS; 0.009**	
SE (m) P; 0.002		**SE (m) S; 0.002**		**SE (m) PxS; 0.003**	

Table 113: Effect of application of P and S on magnesium uptake by plant at pegging stage (kg ha^{-1})

T_1: 33.26

	S_0	S_1	S_2	S_3	Mean
P_0	24.87	29.22	31.60	34.78	**30.12**
P_1	27.96	32.35	34.73	38.42	**33.37**
P_2	31.06	36.79	38.31	43.39	**37.39**
P_3	36.87	39.44	45.08	47.14	**42.13**
Mean	**30.19**	**34.45**	**37.43**	**40.93**	
CD (0.05) P; 0.263		**CD (0.05) S; 0.263**		**CD (0.05) PxS; 0.526**	
SE (m) P; 0.091		**SE (m) S; 0.091**		**SE (m) PxS; 0.181**	

Table 114: Effect of application of P and S on magnesium uptake by plant at pod setting stage (kg ha^{-1})

T_1: 24.74

	S_0	S_1	S_2	S_3	Mean
P_0	15.86	16.61	21.27	24.65	**19.60**
P_1	16.58	20.19	25.06	28.06	**22.47**
P_2	19.83	23.36	27.77	34.20	**26.29**
P_3	22.46	28.22	38.08	39.34	**32.03**
Mean	**18.68**	**22.10**	**28.05**	**31.56**	
CD (0.05) P; 0.008		**CD (0.05) S; 0.008**		**CD (0.05) PxS; 0.016**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.006**	

Table 115: Effect of application of P and S on magnesium uptake by plant at harvest stage (kg ha^{-1})

T_1: 33.71

	S_0	S_1	S_2	S_3	Mean
P_0	19.54	22.11	27.33	33.24	**25.55**
P_1	20.42	27.59	33.80	36.70	**29.63**
P_2	26.94	31.53	38.03	43.68	**35.05**
P_3	29.67	36.13	41.81	47.60	**38.80**
Mean	**24.14**	**29.34**	**35.24**	**40.31**	
CD (0.05) P; 0.263		**CD (0.05) S; 0.263**		**CD (0.05) PxS; 0.526**	
SE (m) P; 0.091		**SE (m) S; 0.091**		**SE (m) PxS; 0.181**	

4.6.6 Sulphur uptake by plant

Application of P and S fertilizers significantly affected S uptake by plant. The treatment, P_0S_3 (P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) had highest S uptake during flowering stage. At pegging, pod setting and harvesting stages, highest S uptake was noted in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). The main effect and interaction effect was found to be significant at all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 116: Effect of application of P and S on sulphur uptake by plant at flowering stage (kg ha^{-1})

T_1: 0.724

	S_0	S_1	S_2	S_3	Mean
P_0	0.597	1.267	2.088	5.152	**2.276**
P_1	0.686	1.219	2.176	3.047	**1.782**
P_2	0.463	1.352	2.059	2.868	**1.686**
P_3	0.619	1.399	2.565	3.560	**2.036**
Mean	**0.591**	**1.309**	**2.222**	**3.657**	
CD (0.05) P; 0.002		**CD (0.05) S; 0.002**		**CD (0.05) PxS; 0.004**	
SE (m) P; 0.001		**SE (m) S; 0.001**		**SE (m) PxS; 0.001**	

Table 117: Effect of application of P and S on sulphur uptake by plant at pegging stage (kg ha^{-1})

T_1: 2.13

	S_0	S_1	S_2	S_3	Mean
P_0	1.914	2.906	3.325	6.124	**3.567**
P_1	1.963	2.666	3.052	3.915	**2.899**
P_2	1.499	2.903	3.073	3.875	**2.838**
P_3	1.955	2.513	4.042	6.178	**3.672**
Mean	**1.833**	**2.747**	**3.373**	**5.023**	
CD (0.05) P; 0.045		**CD (0.05) S; 0.045**		**CD (0.05) PxS; 0.09**	
SE (m) P; 0.015		**SE (m) S; 0.015**		**SE (m) PxS; 0.031**	

Table 118: Effect of application of P and S on sulphur uptake by plant at pod setting stage (kg ha^{-1})

T_1: 3.140

	S_0	S_1	S_2	S_3	Mean
P_0	2.092	3.261	4.137	6.676	**4.042**
P_1	1.560	1.696	3.160	4.275	**2.673**
P_2	2.265	3.242	3.810	4.249	**3.391**
P_3	2.335	2.552	5.323	6.862	**4.268**
Mean	**2.063**	**2.688**	**4.108**	**5.515**	
CD (0.05) P; 0.274		**CD (0.05) S; 0.274**		**CD (0.05) PxS; 0.547**	
SE (m) P; 0.094		**SE (m) S; 0.094**		**SE (m) PxS; 0.189**	

Table 119: Effect of application of P and S on sulphur uptake by plant at harvest stage (kg ha^{-1})

T_1: 3.04

	S_0	S_1	S_2	S_3	Mean
P_0	0.54	0.58	0.96	3.64	**1.43**
P_1	0.48	0.66	0.73	1.07	**0.73**
P_2	0.76	1.05	1.25	2.50	**1.39**
P_3	1.60	2.05	4.08	5.85	**3.39**
Mean	**0.84**	**1.09**	**1.75**	**3.27**	
CD (0.05) P; 0.009		**CD (0.05) S; 0.009**		**CD (0.05) PxS; 0.018**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.006**	

4.6.7 Iron uptake by plant

Uptake of Fe by plant at different stages is shown in the tables 120, 121, 122 and 123. Uptake of Fe varied significantly due to interaction effect and main effect.

P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Fe uptake in all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 120: Effect of application of P and S on iron uptake by plant at flowering stage (g ha^{-1})

T_1: 310.02

	S_0	S_1	S_2	S_3	Mean
P_0	201.67	317.33	372.50	511.69	**350.80**
P_1	190.17	364.92	423.69	506.45	**371.31**
P_2	216.24	383.52	454.05	533.50	**396.83**
P_3	190.89	382.89	529.04	617.60	**430.10**
Mean	**199.74**	**362.16**	**444.82**	**542.31**	
CD (0.05) P; 0.181		**CD (0.05) S; 0.181**		**CD (0.05) PxS; 0.362**	
SE (m) P; 0.062		**SE (m) S; 0.062**		**SE (m) PxS; 0.125**	

Table 121: Effect of application of P and S on iron uptake by plant at pegging stage (g ha^{-1})

T_1: 425.12

	S_0	S_1	S_2	S_3	Mean
P_0	219.69	339.57	377.30	497.87	**358.61**
P_1	171.65	385.18	439.09	529.14	**381.27**
P_2	235.26	391.28	482.35	570.70	**419.90**
P_3	209.08	412.10	552.82	667.13	**460.28**
Mean	**208.92**	**382.03**	**462.89**	**566.21**	
CD (0.05) P; 0.294		**CD (0.05) S; 0.294**		**CD (0.05) PxS; 0.587**	
SE (m) P; 0.101		**SE (m) S; 0.101**		**SE (m) PxS; 0.202**	

Table 122: Effect of application of P and S on iron uptake by plant at pod setting stage (g ha^{-1})

T_1: 547.32

	S_0	S_1	S_2	S_3	Mean
P_0	229.17	360.35	401.38	532.97	**380.97**
P_1	186.61	407.85	454.39	555.28	**401.03**
P_2	227.88	427.12	475.25	582.46	**428.18**
P_3	230.76	445.27	547.21	655.85	**469.77**
Mean	**218.60**	**410.15**	**469.56**	**581.64**	
CD (0.05) P; 0.227		CD (0.05) S; 0.227		CD (0.05) PxS; 0.454	
SE (m) P; 0.078		SE (m) S; 0.078		SE (m) PxS; 0.157	

Table 123: Effect of application of P and S on iron uptake by plant at harvest stage (g ha^{-1})

T_1: 697.30

	S_0	S_1	S_2	S_3	Mean
P_0	264.03	424.87	477.22	636.67	**450.70**
P_1	228.67	480.73	531.50	674.22	**478.78**
P_2	276.30	519.18	576.27	708.40	**520.04**
P_3	281.62	544.43	649.64	794.35	**567.51**
Mean	**262.65**	**492.30**	**558.66**	**703.41**	
CD (0.05) P; 0.233		CD (0.05) S; 0.233		CD (0.05) PxS; 0.465	
SE (m) P; 0.08		SE (m) S; 0.08		SE (m) PxS; 0.16	

4.6.8 Manganese uptake by plants

Manganese uptake was significantly influenced by main effect and interaction effect. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Mn uptake in all stages. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 124: Effect of application of P and S on manganese uptake by plant at flowering stage (g ha^{-1})

T_1: 26.33

	S_0	S_1	S_2	S_3	Mean
P_0	16.60	27.08	38.99	56.00	**34.67**
P_1	19.44	29.50	43.52	58.40	**37.71**
P_2	22.83	31.28	46.15	59.20	**39.87**
P_3	22.74	32.85	43.99	61.99	**40.39**
Mean	**20.40**	**30.18**	**43.16**	**58.90**	
CD (0.05) P; 0.021		**CD (0.05) S; 0.021**		**CD (0.05) PxS; 0.042**	
SE (m) P; 0.007		**SE (m) S; 0.007**		**SE (m) PxS; 0.014**	

Table 125: Effect of application of P and S on manganese uptake by plant at pegging stage (g ha^{-1})

T_1: 27.15

	S_0	S_1	S_2	S_3	Mean
P_0	17.16	28.80	41.41	60.05	**36.86**
P_1	20.70	31.35	46.57	62.81	**40.36**
P_2	22.81	32.69	49.28	63.74	**42.13**
P_3	24.62	34.69	45.47	65.67	**42.61**
Mean	**21.323**	**31.882**	**45.682**	**63.066**	
CD (0.05) P; 0.023		**CD (0.05) S; 0.023**		**CD (0.05) PxS; 0.046**	
SE (m) P; 0.008		**SE (m) S; 0.008**		**SE (m) PxS; 0.016**	

Table 126: Effect of application of P and S on manganese uptake by plant at pod setting stage (g ha^{-1})

T_1 : 29.98

	S_0	S_1	S_2	S_3	Mean
P_0	18.29	30.17	44.60	64.69	**39.44**
P_1	21.90	33.34	49.72	66.86	**42.95**
P_2	23.56	33.08	52.23	67.58	**44.11**
P_3	25.77	35.95	47.91	68.85	**44.62**
Mean	**22.38**	**33.14**	**48.61**	**66.99**	
CD (0.05) P; 0.216		CD (0.05) S; 0.216		CD (0.05) PxS; 0.432	
SE (m) P; 0.074		SE (m) S; 0.074		SE (m) PxS; 0.0149	

Table 127: Effect of application of P and S on manganese uptake by plant at harvest stage (g ha^{-1})

T_1: 34.56

	S_0	S_1	S_2	S_3	Mean
P_0	21.51	35.49	53.18	77.66	**46.96**
P_1	25.85	39.03	59.81	80.35	**51.26**
P_2	27.35	39.88	61.34	78.03	**51.65**
P_3	30.52	41.83	56.40	81.50	**52.57**
Mean	**26.31**	**39.06**	**57.68**	**79.39**	
CD (0.05) P; 0.172		CD (0.05) S; 0.172		CD (0.05) PxS; 0.344	
SE (m) P; 0.059		SE (m) S; 0.059		SE (m) PxS; 0.118	

4.6.9 Zinc uptake by plants

Zinc uptake varied significantly due to application of P and S fertilizers. The treatment P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest zinc uptake at flowering and pod formation stages. Whereas at pegging and harvest stages, P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest Zn uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 128: Effect of application of P and S on zinc uptake by plant at flowering stage (g ha^{-1})

T_1: 27.64

	S_0	S_1	S_2	S_3	Mean
P_0	21.27	26.73	28.50	32.06	**27.14**
P_1	25.30	30.15	31.68	33.54	**30.17**
P_2	30.60	34.07	33.87	34.93	**33.37**
P_3	31.63	36.43	38.60	39.67	**36.58**
Mean	**27.20**	**31.84**	**33.16**	**35.05**	
CD (0.05) P; 0.173		**CD (0.05) S; 0.173**		**CD (0.05) PxS; 0.346**	
SE (m) P; 0.06		**SE (m) S; 0.06**		**SE (m) PxS; 0.119**	

Table 129: Effect of application of P and S on zinc uptake by plant at pegging stage (g ha^{-1})

T_1: 29.23

	S_0	S_1	S_2	S_3	Mean
P_0	23.00	28.95	30.05	33.16	**28.79**
P_1	27.30	32.71	33.30	35.54	**32.21**
P_2	32.58	36.76	35.54	36.06	**35.23**
P_3	33.82	37.90	41.76	41.68	**38.69**
Mean	**29.17**	**34.08**	**35.06**	**36.61**	
CD (0.05) P; 0.121		**CD (0.05) S; 0.121**		**CD (0.05) PxS; 0.243**	
SE (m) P; 0.042		**SE (m) S; 0.042**		**SE (m) PxS; 0.084**	

Table 130: Effect of application of P and S on zinc uptake by plant at pod setting stage (g ha^{-1})

T_1 : 29.56

	S_0	S_1	S_2	S_3	Mean
P_0	25.22	30.05	32.18	35.47	**30.73**
P_1	27.94	33.70	35.62	37.27	**33.63**
P_2	33.70	37.93	38.40	38.95	**37.25**
P_3	35.37	40.01	44.29	44.63	**41.08**
Mean	**30.56**	**35.42**	**37.62**	**39.08**	
CD (0.05) P; 0.026		**CD (0.05) S; 0.026**		**CD (0.05) PxS; 0.052**	
SE (m) P; 0.009		**SE (m) S; 0.009**		**SE (m) PxS; 0.018**	

Table 131: Effect of application of P and S on zinc uptake by plant at harvest stage (g ha^{-1})

T_1 : 34.56

	S_0	S_1	S_2	S_3	Mean
P_0	29.92	36.26	38.88	42.62	**36.92**
P_1	33.48	40.18	41.38	43.75	**39.70**
P_2	40.42	45.29	45.37	46.18	**44.31**
P_3	41.86	47.20	52.92	52.79	**48.44**
Mean	**36.42**	**42.23**	**44.39**	**46.34**	
CD (0.05) P; 0.178		**CD (0.05) S; 0.178**		**CD (0.05) PxS; 0.355**	
SE (m) P; 0.061		**SE (m) S; 0.061**		**SE (m) PxS; 0.122**	

4.6.10 Copper uptake by groundnut plant

Uptake of Cu was significant at all the stages. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest uptake at flowering, pegging and pod setting stages. Highest uptake during harvest stage was noted in P_3S_2 (P, 90 kg ha^{-1}

and S, 20 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 132: Effect of application of P and S on copper uptake by plant at flowering stage (g ha^{-1})

T_1 : 9.53

	S_0	S_1	S_2	S_3	**Mean**
P_0	8.15	9.56	10.77	12.03	**10.13**
P_1	8.30	9.91	10.85	12.16	**10.31**
P_2	9.03	10.00	10.58	11.25	**10.21**
P_3	8.88	10.59	12.78	13.47	**11.43**
Mean	**8.59**	**10.01**	**11.25**	**12.23**	
CD (0.05) P; 0.123		**CD (0.05) S; 0.123**		**CD (0.05) PxS; 0.246**	
SE (m) P; 0.042		**SE (m) S; 0.042**		**SE (m) PxS; 0.085**	

Table 133: Effect of application of P and S on copper uptake by plant at pegging stage (g ha^{-1})

T_1 : 9.77

	S_0	S_1	S_2	S_3	**Mean**
P_0	7.57	9.72	11.17	12.88	**10.34**
P_1	8.87	10.12	10.84	12.17	**10.50**
P_2	9.80	10.70	11.01	12.21	**10.93**
P_3	8.94	10.84	12.23	13.59	**11.40**
Mean	**8.80**	**10.35**	**11.31**	**12.71**	
CD (0.05) P; 0.003		**CD (0.05) S; 0.003**		**CD (0.05) PxS; 0.006**	
SE (m) P; 0.001		**SE (m) S; 0.001**		**SE (m) PxS; 0.002**	

Table 134: Effect of application of P and S on copper uptake by plant at pod setting stage (g ha^{-1})

T_1 : 9.89

	S_0	S_1	S_2	S_3	Mean
P_0	7.37	9.46	10.25	11.93	**9.75**
P_1	8.25	10.28	10.92	11.57	**10.25**
P_2	9.78	11.44	11.25	11.91	**11.10**
P_3	9.53	10.78	12.15	13.07	**11.38**
Mean	**8.73**	**10.49**	**11.14**	**12.12**	
CD (0.05) P; 0.175		**CD (0.05) S; 0.175**		**CD (0.05) PxS; 0.349**	
SE (m) P; 0.060		**SE (m) S; 0.060**		**SE (m) PxS; 0.120**	

Table 135: Effect of application of P and S on copper uptake by plant at harvest stage (g ha^{-1})

T_1 : 10.11

	S_0	S_1	S_2	S_3	Mean
P_0	7.59	9.12	9.93	11.42	**9.52**
P_1	8.28	10.36	11.57	11.88	**10.52**
P_2	10.00	11.73	12.35	12.43	**11.63**
P_3	10.58	12.48	15.44	14.82	**13.33**
Mean	**9.11**	**10.92**	**12.32**	**12.64**	
CD (0.05) P; 0.175		**CD (0.05) S; 0.175**		**CD (0.05) PxS; 0.349**	
SE (m) P; 0.060		**SE (m) S; 0.060**		**SE (m) PxS; 0.120**	

4.6.11 Boron uptake by plant

Uptake of B was significantly influenced by main effect and interaction effect. Treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest uptake at flowering, pegging and pod formation stages. Treatment, P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest uptake at harvesting stage. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 136: Effect of application of P and S on boron uptake by plant at flowering stage (g ha^{-1})

T_1: 11.31

	S_0	S_1	S_2	S_3	Mean
P_0	7.25	9.31	10.13	11.59	**9.57**
P_1	8.30	10.18	11.20	11.89	**10.39**
P_2	9.70	11.08	11.43	11.96	**11.04**
P_3	9.70	11.17	12.60	13.31	**11.70**
Mean	**8.74**	**10.44**	**11.34**	**12.19**	
CD (0.05) P; 0.245		**CD (0.05) S; 0.245**		**CD (0.05) PxS; 0.490**	
SE (m) P; 0.084		**SE (m) S; 0.084**		**SE (m) PxS; 0.169**	

Table 137: Effect of application of P and S on boron uptake by plant at pegging stage (g ha^{-1})

T_1 : 11.22

	S_0	S_1	S_2	S_3	Mean
P_0	7.18	9.17	10.05	11.47	**9.46**
P_1	8.18	10.00	10.77	11.62	**10.14**
P_2	9.52	10.86	11.42	11.94	**10.94**
P_3	9.34	11.00	12.11	12.86	**11.33**
Mean	**8.56**	**10.26**	**11.09**	**11.97**	
CD (0.05) P; 0.03		**CD (0.05) S; 0.03**		**CD (0.05) PxS; 0.06**	
SE (m) P; 0.01		**SE (m) S; 0.01**		**SE (m) PxS; 0.021**	

Table 138: Effect of application of P and S on boron uptake by plant at pod setting stage (g ha^{-1})

T_1 : 10.84

	S_0	S_1	S_2	S_3	**Mean**
P_0	6.95	8.81	9.59	10.96	**9.08**
P_1	7.63	9.55	10.29	10.95	**9.61**
P_2	9.35	10.76	11.21	11.70	**10.76**
P_3	9.38	10.81	12.23	12.80	**11.30**
Mean	**8.33**	**9.98**	**10.83**	**11.60**	
CD (0.05) P; 0.008		**CD (0.05) S; 0.008**		**CD (0.05) PxS; 0.016**	
SE (m) P; 0.003		**SE (m) S; 0.003**		**SE (m) PxS; 0.005**	

Table 139: Effect of application of P and S on boron uptake by plant at harvest stage (g ha^{-1})

T_1: 11.26

	S_0	S_1	S_2	S_3	**Mean**
P_0	7.40	9.49	10.43	11.81	**9.78**
P_1	8.14	10.07	10.80	11.54	**10.14**
P_2	9.80	11.30	11.81	12.32	**11.31**
P_3	9.88	11.25	12.96	12.66	**11.94**
Mean	**8.81**	**10.53**	**11.50**	**12.33**	
CD (0.05) P; 0.056		**CD (0.05) S; 0.056**		**CD (0.05) PxS; 0.113**	
SE (m) P; 0.019		**SE (m) S; 0.019**		**SE (m) PxS; 0.039**	

4.7 NUTRIENT UPTAKE BY POD

4.7.1 Nitrogen uptake by kernel

Data (table 140) on N uptake by kernels showed that, N uptake varied significantly due to application of different levels of P and S. The treatment, P_0S_2 (P, 0 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest N uptake (42.97 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.2 Phosphorus uptake by kernel

Uptake of P by kernal was shown in the table 141. P uptake by kernel varied significantly due to application of different levels of P and S. The treatment, P_3S_2 (P, 30 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest P uptake (4.33 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 140: Effect of application of P and S on nitrogen uptake by kernel (kg ha^{-1})

T_1: 33.41

	S_0	S_1	S_2	S_3	Mean
P_0	31.09	40.18	42.97	41.18	**38.86**
P_1	38.28	41.32	39.82	37.86	**39.32**
P_2	34.71	34.76	37.12	37.48	**36.02**
P_3	36.02	37.56	40.59	39.18	**38.34**
Mean	**35.02**	**38.46**	**40.13**	**38.93**	
CD (0.05) P; 0.559		**CD (0.05) S; 0.559**		**CD (0.05) PxS; 1.117**	
SE (m) P; 0.192		**SE (m) S; 0.192**		**SE (m) PxS; 0.385**	

Table 141: Effect of application of P and S on phosphorus uptake by kernel (kg ha^{-1})

`T_1: 4.01

	S_0	S_1	S_2	S_3	Mean
P_0	3.28	4.24	4.32	4.16	**4.01**
P_1	3.99	4.15	4.01	3.92	**4.02**
P_2	3.62	3.54	3.83	4.03	**3.75**
P_3	3.64	3.85	4.33	4.24	**4.01**
Mean	**3.63**	**3.95**	**4.13**	**4.09**	
CD (0.05) P; 0.028		**CD (0.05) S; 0.028**		**CD (0.05) PxS; 0.056**	
SE (m) P; 0.01		**SE (m) S; 0.01**		**SE (m) PxS; 0.019**	

4.7.3 Potassium uptake by kernel

Potassium uptake varied significantly due to main effect and interaction effect (table 142). The treatment, P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest K uptake (18.94 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.4 Calcium uptake by kernel

Calcium uptake varied significantly due to main effect and interaction effect (table 143). The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Ca uptake . F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.5 Magnesium uptake by kernel

Uptake of Mg by plant varied significantly due to different levels of fertilizer application (table 144). Significantly highest Mg uptake by kernel was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.6 Sulphur uptake by kernel

Uptake of S by pod varied significantly due to different levels of fertilizer application (table 145). Significantly highest S uptake by kernel was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 142: Effect of application of P and S on potassium uptake by kernel (kg ha^{-1})

T_1: 14.65

	S_0	S_1	S_2	S_3	Mean
P_0	12.03	12.51	12.80	12.48	**12.45**
P_1	13.23	13.32	14.35	13.47	**13.59**
P_2	14.02	14.94	15.54	16.19	**15.17**
P_3	16.32	17.66	18.94	18.56	**17.87**
Mean	**13.90**	**14.61**	**15.41**	**15.17**	
CD (0.05) P; 0.121		**CD (0.05) S; 0.121**		**CD (0.05) PxS; 0.242**	
SE (m) P; 0.085		**SE (m) S; 0.085**		**SE (m) PxS; 0.171**	

Table 143: Effect of application of P and S on Ca uptake by kernel (kg ha[-1])

T_1: 2.12

	S_0	S_1	S_2	S_3	Mean
P_0	1.48	2.04	2.40	2.52	**2.11**
P_1	1.68	2.19	2.39	2.82	**2.27**
P_2	1.72	2.45	3.10	3.06	**2.58**
P_3	2.00	2.46	3.56	4.87	**3.22**
Mean	**1.72**	**2.28**	**2.86**	**3.32**	
CD (0.05) P; 0.659		**CD (0.05) S; 0.659**		**CD (0.05) PxS; NS**	
SE (m) P; 0.227		**SE (m) S; 0.227**		**SE (m) PxS; 0.454**	

Table 144: Effect of application of P and S on Mg uptake by kernel (kg ha[-1])

T_1: 2.47

	S_0	S_1	S_2	S_3	Mean
P_0	2.27	2.49	2.47	2.52	**2.44**
P_1	2.60	2.68	2.76	2.85	**2.72**
P_2	3.62	3.38	3.42	3.48	**3.47**
P_3	3.49	3.58	3.89	3.94	**3.72**
Mean	**2.99**	**3.03**	**3.14**	**3.20**	
CD (0.05) P; 0.012		**CD (0.05) S; 0.012**		**CD (0.05) PxS; 0.024**	
SE (m) P; 0.004		**SE (m) S; 0.004**		**SE (m) PxS; 0.008**	

Table 145: Effect of application of P and S on S uptake by kernel (kg ha^{-1})

T_1: 3.45

	S_0	S_1	S_2	S_3	Mean
P_0	1.45	5.41	7.20	7.15	**5.30**
P_1	1.28	3.70	6.40	7.46	**4.71**
P_2	1.63	3.90	6.28	7.49	**4.82**
P_3	3.88	3.20	6.49	8.16	**5.43**
Mean	**2.06**	**4.05**	**6.59**	**7.57**	
CD (0.05) P; 0.139		**CD (0.05) S; 0.139**		**CD (0.05) PxS; 0.279**	
SE (m) P; 0.048		**SE (m) S; 0.048**		**SE (m) PxS; 0.096**	

4.7.7 Iron uptake by kernel

Iron uptake by kernel was found to be significantly different due to various levels of P and S (table no. 146). Compared to other micro nutrients Fe was present in highest amount. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Fe uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.8 Manganese uptake by kernel

Uptake of Mn by kernel varied significantly due to different levels of fertilizer application (table no. 147). Significantly highest Mn uptake by kernel was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.9 Zinc uptake by kernel

Zinc uptake varied significantly due to main effect and interaction effect (table no. 148). The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Zn uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 146: Effect of application of P and S on Fe uptake by kernel (g ha^{-1})

T_1: 308.21

	S_0	S_1	S_2	S_3	Mean
P_0	235.17	316.68	397.94	563.37	**378.29**
P_1	342.35	383.16	492.45	635.39	**463.34**
P_2	369.46	438.60	576.05	729.24	**528.34**
P_3	420.24	556.22	703.15	813.96	**623.39**
Mean	**341.81**	**423.67**	**542.40**	**685.49**	
CD (0.05) P; 0.423		**CD (0.05) S; 0.423**		**CD (0.05) PxS; 0.845**	
SE (m) P; 0.146		**SE (m) S; 0.146**		**SE (m) PxS; 0.291**	

Table 147: Effect of application of P and S on Mn uptake by kernel (g ha^{-1})

T_1: 32.78

	S_0	S_1	S_2	S_3	Mean
P_0	30.60	32.99	34.84	35.98	**33.60**
P_1	36.62	36.90	38.44	38.76	**37.68**
P_2	40.10	41.20	43.98	44.56	**42.46**
P_3	45.23	48.72	49.09	54.90	**49.48**
Mean	**38.14**	**39.95**	**41.59**	**43.55**	
CD (0.05) P; 0.161		**CD (0.05) S; 0.161**		**CD (0.05) PxS; 0.321**	
SE (m) P; 0.055		**SE (m) S; 0.055**		**SE (m) PxS; 0.111**	

Table 148: Effect of application of P and S on Zn uptake by kernel (g ha^{-1})

T_1: 99.87

	S_0	S_1	S_2	S_3	Mean
P_0	92.82	95.84	93.84	95.92	**94.60**
P_1	97.34	98.73	99.96	104.04	**100.02**
P_2	108.10	108.12	109.04	110.73	**109.00**
P_3	111.10	114.80	117.03	121.61	**116.13**
Mean	**102.34**	**104.37**	**104.97**	**108.07**	
CD (0.05) P; 0.111		**CD (0.05) S; 0.111**		**CD (0.05) PxS; 0.222**	
SE (m) P; 0.038		**SE (m) S; 0.038**		**SE (m) PxS; 0.076**	

4.7.10 Copper uptake by kernel

Copper uptake varied significantly due to main effect and interaction effect (table no. 149). The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Cu uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.11 Boron uptake by kernel

Uptake of B by kernel at different stages is shown in the table 150. B uptake by groundnut kernel varied significantly due to different treatments applied. Significantly highest uptake was noted in treatment having high P and S. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 149: Effect of application of P and S on Cu uptake by kernel (g ha^{-1})

T_1: 25.21

	S_0	S_1	S_2	S_3	Mean
P_0	19.48	20.73	20.40	20.81	**20.35**
P_1	21.53	21.82	23.69	22.95	**22.50**
P_2	24.36	24.72	25.13	26.14	**25.09**
P_3	26.39	27.14	27.78	28.56	**27.47**
Mean	**22.94**	**23.60**	**24.25**	**24.61**	
CD (0.05) P; 0.122		**CD (0.05) S; 0.122**		**CD (0.05) PxS; 0.244**	
SE (m) P; 0.042		**SE (m) S; 0.042**		**SE (m) PxS; 0.084**	

Table 150: Effect of application of P and S on B uptake by kernel (g ha^{-1})

T_1: 3.56

	S_0	S_1	S_2	S_3	Mean
P_0	3.18	3.19	3.18	3.20	**3.19**
P_1	3.35	3.50	3.58	3.71	**3.54**
P_2	3.71	3.76	3.69	3.96	**3.78**
P_3	4.65	4.16	4.77	4.92	**4.63**
Mean	**3.72**	**3.65**	**3.81**	**3.95**	
CD (0.05) P; 0.05		**CD (0.05) S; 0.05**		**CD (0.05) PxS; 0.10**	
SE (m) P; 0.017		**SE (m) S; 0.017**		**SE (m) PxS; 0.034**	

4.7.12 Nitrogen uptake by shell

Data (table 151) on N uptake by shell showed that, N uptake by shell varied significantly due to application of different levels of P and S. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest N uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.13 Phosphorus uptake by shell

Uptake of P by shell was shown in the table 152. P uptake by shell varied significantly due to application of different levels of P and S. The treatment, P_3S_3 (P, 30 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest P uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 151: Effect of application of P and S on N uptake by shell (kg ha^{-1})

T_1: 1.02

	S_0	S_1	S_2	S_3	Mean
P_0	0.97	0.98	1.04	1.07	1.02
P_1	0.98	1.07	1.08	1.08	1.05
P_2	1.06	1.10	1.12	1.16	1.11
P_3	1.09	1.12	1.17	1.19	1.14
Mean	1.03	1.07	1.10	1.13	
CD (0.05) P; 0.022		CD (0.05) S; 0.022		CD (0.05) PxS; 0.044	
SE (m) P; 0.08		SE (m) S; 0.08		SE (m) PxS; 0.15	

Table 152: Effect of application of P and S on P uptake by shell (kg ha^{-1})

T_1: 3.88

	S_0	S_1	S_2	S_3	Mean
P_0	0.25	0.41	0.45	0.45	0.39
P_1	0.38	0.44	0.64	0.70	0.54
P_2	0.29	0.51	0.63	0.71	0.54
P_3	0.54	0.60	0.78	0.94	0.71
Mean	0.37	0.49	0.63	0.70	
CD (0.05) P; 0.02		CD (0.05) S; 0.02		CD (0.05) PxS; 0.03	
SE (m) P; 0.01		SE (m) S; 0.01		SE (m) PxS; 0.01	

4.7.14 Potassium uptake by shell

Potassium uptake varied significantly due to main effect and interaction effect (table 153). The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest K uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.15 Calcium uptake by shell

Calcium uptake varied significantly due to main effect and interaction effect (table 154). The treatment, P_1S_3 (P, 60 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Ca uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.16 Magnesium uptake by shell

Uptake of Mg by shell varied significantly due to different levels of fertilizer application (table 155). Significantly highest Mg uptake by plant was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.17 Sulphur uptake by shell

Uptake of S by pod varied significantly due to different levels of fertilizer application (table 156). Significantly highest S uptake by shell was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 153: Effect of application of P and S on K uptake by shell (kg ha^{-1})

T_1: 1.95

	S_0	S_1	S_2	S_3	Mean
P_0	1.97	1.58	1.69	1.71	1.74
P_1	1.74	1.69	1.82	1.92	1.79
P_2	1.97	2.07	2.22	2.14	2.10
P_3	2.26	2.32	2.31	2.87	2.44
Mean	1.98	1.92	2.01	2.16	
CD (0.05) P; 0.13		CD (0.05) S; 0.13		CD (0.05) PxS; 0.27	
SE (m) P; 0.07		SE (m) S; 0.07		SE (m) PxS; 0.15	

Table 154: Effect of application of P and S on Ca uptake by shell (kg ha^{-1})

T_1: 5.31

	S_0	S_1	S_2	S_3	Mean
P_0	3.28	4.39	4.58	8.44	5.17
P_1	5.28	4.44	8.06	9.02	6.70
P_2	3.60	6.62	5.96	7.90	6.02
P_3	5.51	5.25	6.46	7.45	6.17
Mean	4.42	5.18	6.27	8.20	
CD (0.05) P; 0.087		CD (0.05) S; 0.087		CD (0.05) PxS; 0.175	
SE (m) P; 0.301		SE (m) S; 0.301		SE (m) PxS; 0.603	

Table 155: Effect of application of P and S on Mg uptake by shell (kg ha^{-1})

T_1: 5.24

	S_0	S_1	S_2	S_3	Mean
P_0	3.50	4.10	4.44	4.11	**4.04**
P_1	6.06	6.20	6.24	6.41	**6.23**
P_2	6.91	7.07	7.17	7.19	**7.08**
P_3	7.33	7.42	7.62	7.91	**7.57**
Mean	**5.95**	**6.20**	**6.37**	**6.40**	
CD (0.05) P; 0.05		CD (0.05) S; 0.05		CD (0.05) PxS; 0.099	
SE (m) P; 0.17		SE (m) S; 0.17		SE (m) PxS; 0.34	

Table 156: Effect of application of P and S on S uptake by shell (kg ha^{-1})

T_1: 2.25

	S_0	S_1	S_2	S_3	Mean
P_0	1.50	1.60	1.77	1.77	**1.66**
P_1	1.80	1.86	1.96	2.09	**1.93**
P_2	2.10	2.17	2.25	2.26	**2.19**
P_3	2.27	2.31	2.40	2.61	**2.40**
Mean	**1.92**	**1.99**	**2.09**	**2.18**	
CD (0.05) P; 0.048		**CD (0.05) S; 0.048**		**CD (0.05) PxS; 0.095**	
SE (m) P; 0.016		**SE (m) S; 0.016**		**SE (m) PxS; 0.033**	

4.7.18 Iron uptake by shell

Iron uptake by shell was found to be significantly influenced by different levels of P and S. Compared to other micro nutrients, Fe was present in highest amount in shell. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Fe uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.19 Manganese uptake by shell

Uptake of Mn by shell varied significantly due to different levels of fertilizer application. Significantly highest Mn uptake by pod was noticed in treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.20 Zinc uptake by shell

Zinc uptake varied significantly due to main effect and interaction effect. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) showed highest Zn uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 157: Effect of application of P and S on Fe uptake by shell (g ha^{-1})

T_1: 325.24

	S_0	S_1	S_2	S_3	Mean
P_0	219.42	290.29	367.64	442.68	**330.01**
P_1	280.85	379.37	444.21	475.02	**394.86**
P_2	314.65	416.16	485.85	531.48	**437.04**
P_3	359.04	460.81	518.98	559.29	**474.53**
Mean	**293.49**	**386.66**	**454.17**	**502.12**	
CD (0.05) P; 0.37		**CD (0.05) S; 0.37**		**CD (0.05) PxS; 0.74**	
SE (m) P; 0.13		**SE (m) S; 0.13**		**SE (m) PxS; 0.25**	

Table 158: Effect of application of P and S on Mn uptake by shell (g ha^{-1})

T_1: 40.22

	S_0	S_1	S_2	S_3	Mean
P_0	22.91	30.47	33.09	33.37	**29.96**
P_1	33.44	35.75	38.23	38.40	**36.46**
P_2	38.63	39.45	41.11	41.94	**40.28**
P_3	42.33	45.37	45.96	48.96	**45.66**
Mean	**34.33**	**37.76**	**39.59**	**40.67**	
CD (0.05) P; 0.329		**CD (0.05) S; 0.329**		**CD (0.05) PxS; 0.658**	
SE (m) P; 0.133		**SE (m) S; 0.133**		**SE (m) PxS; 0.227**	

Table 159: Effect of application of P and S on Zn uptake by shell (g ha^{-1})

T_1: 69.23

	S_0	S_1	S_2	S_3	Mean
P_0	59.77	67.16	70.32	71.86	**67.28**
P_1	77.93	75.92	78.31	79.97	**78.03**
P_2	80.60	80.78	84.03	84.65	**82.52**
P_3	85.08	86.68	88.56	90.45	**87.69**
Mean	**75.85**	**77.64**	**80.30**	**81.73**	
CD (0.05) P; 0.044		**CD (0.05) S; 0.044**		**CD (0.05) PxS; 0.088**	
SE (m) P; 0.08		**SE (m) S; 0.08**		**SE (m) PxS; 0.17**	

4.7.21 Copper uptake by shell

Copper uptake varied significantly due to main effect and interaction effect. The treatment, P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) showed highest Cu uptake. F statistic for treatments Vs control was calculated and was found to be significantly different.

4.7.22 Boron uptake by shell

Uptake of B by shell is shown in the table 161. B uptake by groundnut shell varied significantly due to different treatments applied. Significantly highest uptake was in treatment P_3 S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}) and P_3 S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 160: Effect of application of P and S on Cu uptake by shell (g ha^{-1})

T_1: 22.30

	S_0	S_1	S_2	S_3	Mean
P_0	18.27	18.66	18.97	19.99	**18.97**
P_1	21.83	21.71	21.84	21.92	**21.82**
P_2	22.13	22.87	22.35	22.96	**22.58**
P_3	23.26	23.35	23.52	23.24	**23.59**
Mean	**21.37**	**21.64**	**21.67**	**22.28**	
CD (0.05) P; 0.22		**CD (0.05) S; 0.22**		**CD (0.05) PxS; 0.43**	
SE (m) P; 0.08		**SE (m) S; 0.08**		**SE (m) PxS; 0.15**	

Table 161: Effect of application of P and S on B uptake by shell (g ha^{-1})

T_1: 2.25

	S_0	S_1	S_2	S_3	Mean
P_0	1.33	1.10	1.10	1.29	**1.21**
P_1	1.36	1.66	1.70	1.76	**1.62**
P_2	1.76	1.72	1.89	1.96	**1.83**
P_3	2.35	2.34	2.69	2.69	**2.52**
Mean	**1.71**	**1.70**	**1.84**	**1.92**	
CD (0.05) P; 0.101		**CD (0.05) S; 0.101**		**CD (0.05) PxS; 0.203**	
SE (m) P; 0.035		**SE (m) S; 0.035**		**SE (m) PxS; 0.07**	

4.8 PROTEIN CONTENT IN KERNEL

Data on protein content in groundnut kernel is shown in the table 162. Protein content was significantly influenced by main effect but interaction effect of P and S was found to be non-significant. Highest protein content was noted in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 162: Effect of application of P and S on protein content (g)

T_1: 19.69

	S_0	S_1	S_2	S_3	Mean
P_0	19.69	20.33	21.83	22.48	**21.08**
P_1	20.50	21.52	21.83	23.08	**21.73**
P_2	21.06	21.77	22.81	22.85	**22.13**
P_3	21.71	22.33	22.98	23.94	**22.74**
Mean	**20.74**	**21.49**	**22.37**	**23.09**	
CD (0.05) P; 0.34		**CD (0.05) S; 0.34**		**CD (0.05) PxS; NS**	
SE (m) P; 0.12		**SE (m) S; 0.12**		**SE (m) PxS; 0.23**	

4.9 OIL CONTENT IN KERNEL

Data on oil content in groundnut kernel is shown in the table 163. Oil content was significantly influenced by main effect and interaction effect of P and S. Oil content increased with increased dose of both P and S. Highest oil content was noted in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). It is on par with treatment P_2S_3 (P, 75 kg ha^{-1} and S, 30 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 163: Effect of application of P and S on oil content (%)

T_1: 37.66

	S_0	S_1	S_2	S_3	Mean
P_0	32.57	34.03	39.67	49.63	**38.98**
P_1	32.90	34.03	40.32	52.80	**40.01**
P_2	33.17	37.07	42.10	56.80	**42.28**
P_3	34.05	36.20	45.00	57.40	**43.16**
Mean	**33.17**	**35.33**	**41.77**	**54.16**	
CD (0.05) P; 0.41		**CD (0.05) S; 0.41**		**CD (0.05) PxS; 0.82**	
SE (m) P; 0.14		**SE (m) S; 0.14**		**SE (m) PxS; 0.28**	

4.10 ECONOMICS

4.10.1 Benefit: Cost Ratio

Application of different levels of P and S significantly influenced the benefit: cost ratio (Table 164). Highest benefit: cost ratio was noted in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}). It was on par with treatment P_3S_2 (P, 90 kg ha^{-1} and S, 20 kg ha^{-1}). F statistic for treatments Vs control was calculated and was found to be significantly different.

Table 164: Effect of application of P and S on benefit cost ratio

T_1: 2.20

	S_0	S_1	S_2	S_3	Mean
P_0	1.99	1.99	2.04	2.11	**2.03**
P_1	2.05	2.06	2.08	2.15	**2.09**
P_2	2.10	2.12	2.16	2.18	**2.14**
P_3	2.19	2.24	2.31	2.35	**2.27**
Mean	**2.08**	**2.10**	**2.15**	**2.20**	
CD (0.05) P; 0.05		**CD (0.05) S; 0.05**		**CD (0.05) PxS; NS**	
SE (m) P; 0.11		**SE (m) S; 0.11**		**SE (m) PxS; 0.22**	

Discussion

5. DISCUSSION

The results of study entitled "Interaction of phosphorus and sulphur in black cotton soils of Palakkad (AEU: 23) under groundnut (*Arachis hypogaea* L.) cultivation" presented in chapter 4 are discussed here with supporting studies conducted elsewhere and based on available literature.

5.1 GROWTH AND YIELD ATTRIBUTES OF GROUNDNUT

5.1.1 Growth parameters

5.1.1.1 Plant height and number of leaves

Plant height and number of leaves at flowering, pegging, pod formation and harvesting stages were significantly influenced by application of different levels of P and S fertilizers. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S,30 kg ha^{-1}) showed the highest plant height at flowering (22.13 cm) and harvesting stages (41.30 cm). At pegging stage (35.00cm), the treatment T_{16}, P_3S_2 (P, 90kg ha^{-1} and S,20 kg ha^{-1}) showed highest plant height. Whereas in pod formation (36.67 cm) stage, both the treatments, T_{16} and T_{17} recorded highest plant height.

The treatment, P_3S_3 (P, 90kg ha^{-1} and S, 30 kg ha^{-1}) showed highest number of leaves at pegging (53.81), pod development (57.93) and harvesting (55.06) stages, whereas during flowering stage, interaction effect was found to be non significant. Phosphorus application increased plant height and number of leaves. Application of soluble phosphorus increased the availability of soluble phosphate to plants and enhanced their root development and there by enhanced nutrient uptake and resulted in improved plant growth. Higher level of P is important for formation and growth of root and N fixation (Lakshmamma and Raj, 1997). Similar results were reported by Punnoose (1968), Sebale and Khuspe (1980), Patel *et al.* (1981) and Juan *et al.* (1986). Higher soil P content increased N fixation which in turn enhanced the plant growth (Balasubramanian and Palaniappan, 1991). This was in conformity with the findings of Punnoose (1968), Singh and Ahuja (1985) and Rayar (1986). Basha and Rao (1980) observed reduction in plant height and shoot length under P deficiency in groundnut plant.

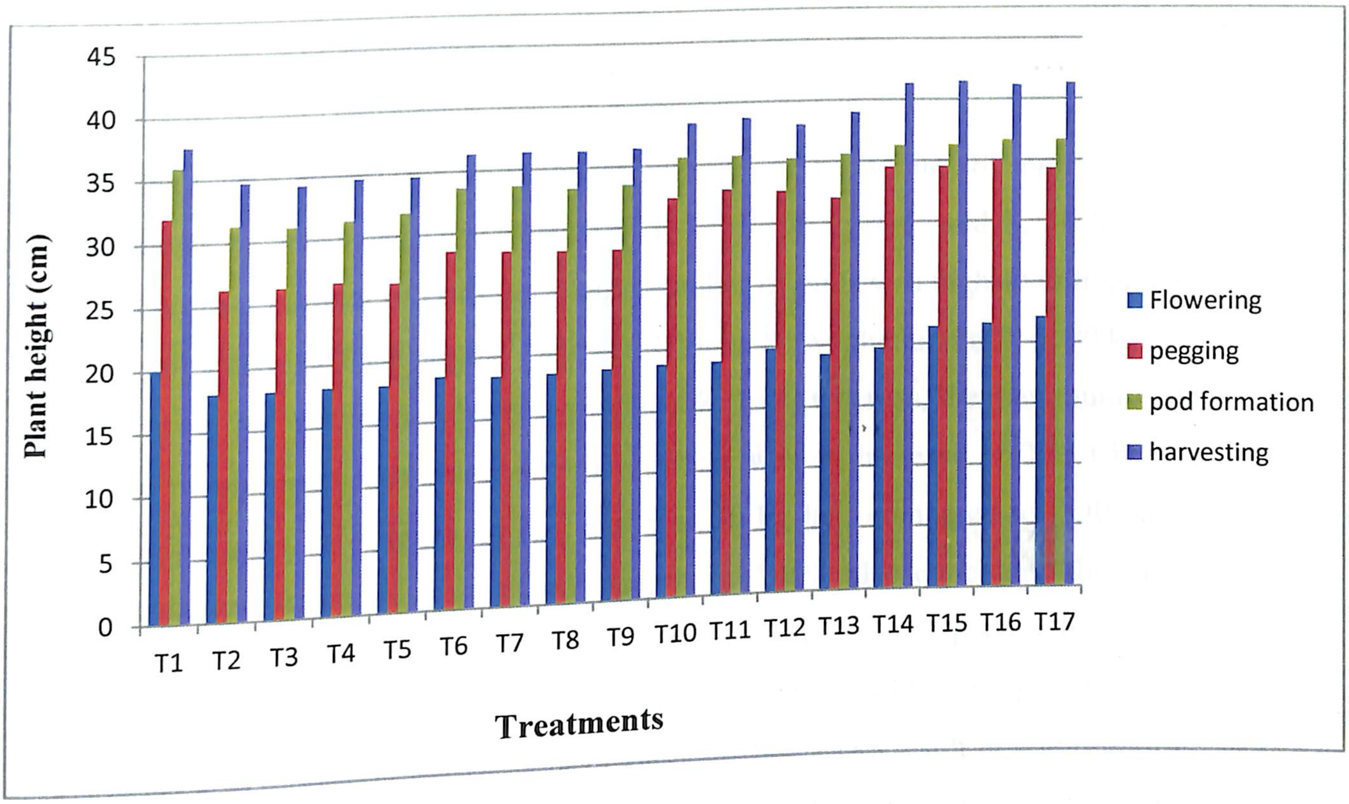

Fig 1: Effect of application of P and S on plant height at different stages

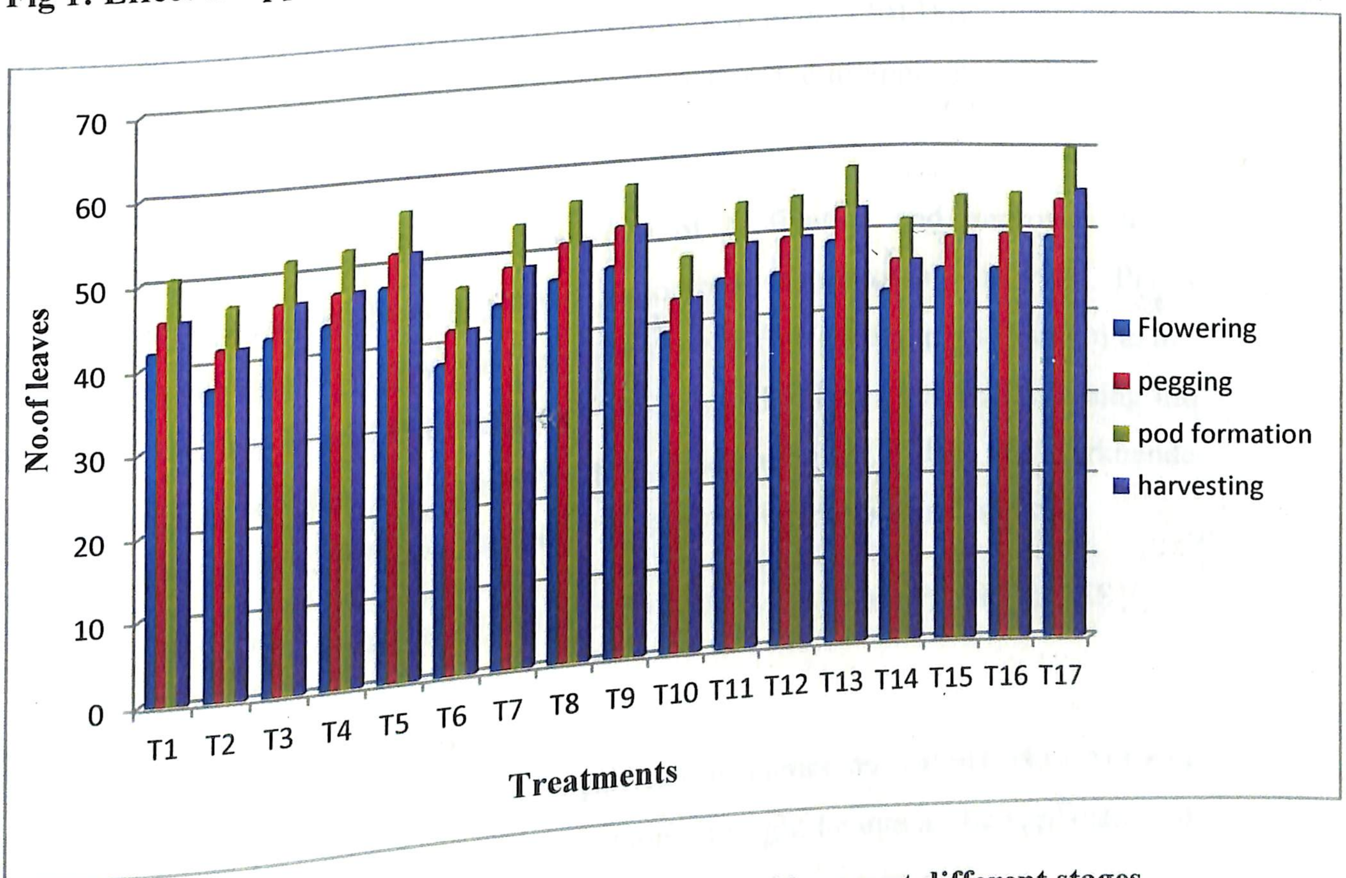

Fig 2: Effect of application of P and S on number of leaves at different stages

5.1.2 Yield parameters

5.1.2.1 Number of pods per plant and yield

There was significant variation in number of pods due to application of various levels of fertilizers. The treatment, P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) produced highest number of pods per plant. Number of pods was highest in treatment receiving high dose of P (90 kg ha^{-1}) and S (30 kg ha^{-1}). Application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} resulted in highest yield (3.68 t ha^{-1}) whereas, the maximum yield from POP recommendation was 3.45 t ha^{-1}. There was an increase of 0.23 t ha^{-1} in yield on application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} compared to POP based recommendation. Banerjee *et al.* (1967) and Puri (1969) also concluded the same. They found that application of phosphorus increased number of pods and yield in groundnut. Application of 90 kg P_2O_5 ha^{-1} recorded highest yield of dry pod. Samtana *et al.* (1994) also reported improvement in yield attributes as a result of addition of P. This was due to formation and proliferation of new roots and improvement in their functional activity. P stimulates setting of pods, decreases the number of unfilled pods (pops) and hastens the maturity of the crop. Rao *et al.*, (2013) reported that there was increase in yield and yield attributing characters due to application of elemental sulphur.

Application of P increases the rate of N fixation and improves the N availability. Increase in N also plays a major role in improving the yield. Plants having high N availability produced more number of flowers and pegs (Saradhi *et al.*, 1990) and resulted in an increased yield. N plays a significant role in increasing the number of pods per plant and number of filled pods per plant. Jadhar and Narkhende (1980), Reddy *et al.* (1984) and Patel *et al.* (1994) also concluded the same.

5.2 EFFECT OF DIFFERENT LEVELS OF P AND S ON SOIL PROPERTIES

5.2.1 Soil pH

Application of P and S had no significant influence on soil pH. However soil pH decreased slightly compared to initial status. It might be due to the application of acid forming fertilizers, urea and elemental sulphur.

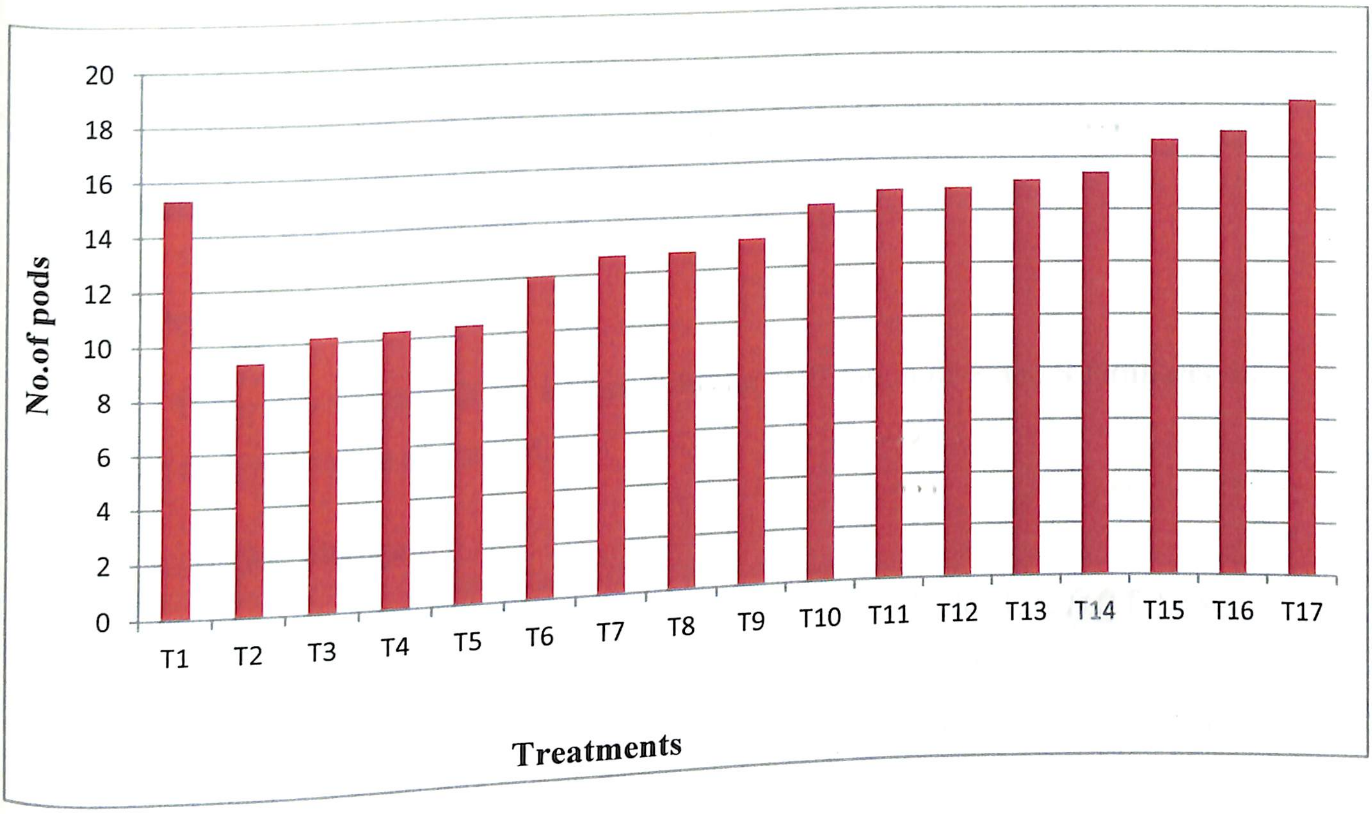

Fig 3: Effect of application of P and S on number of pods per plant

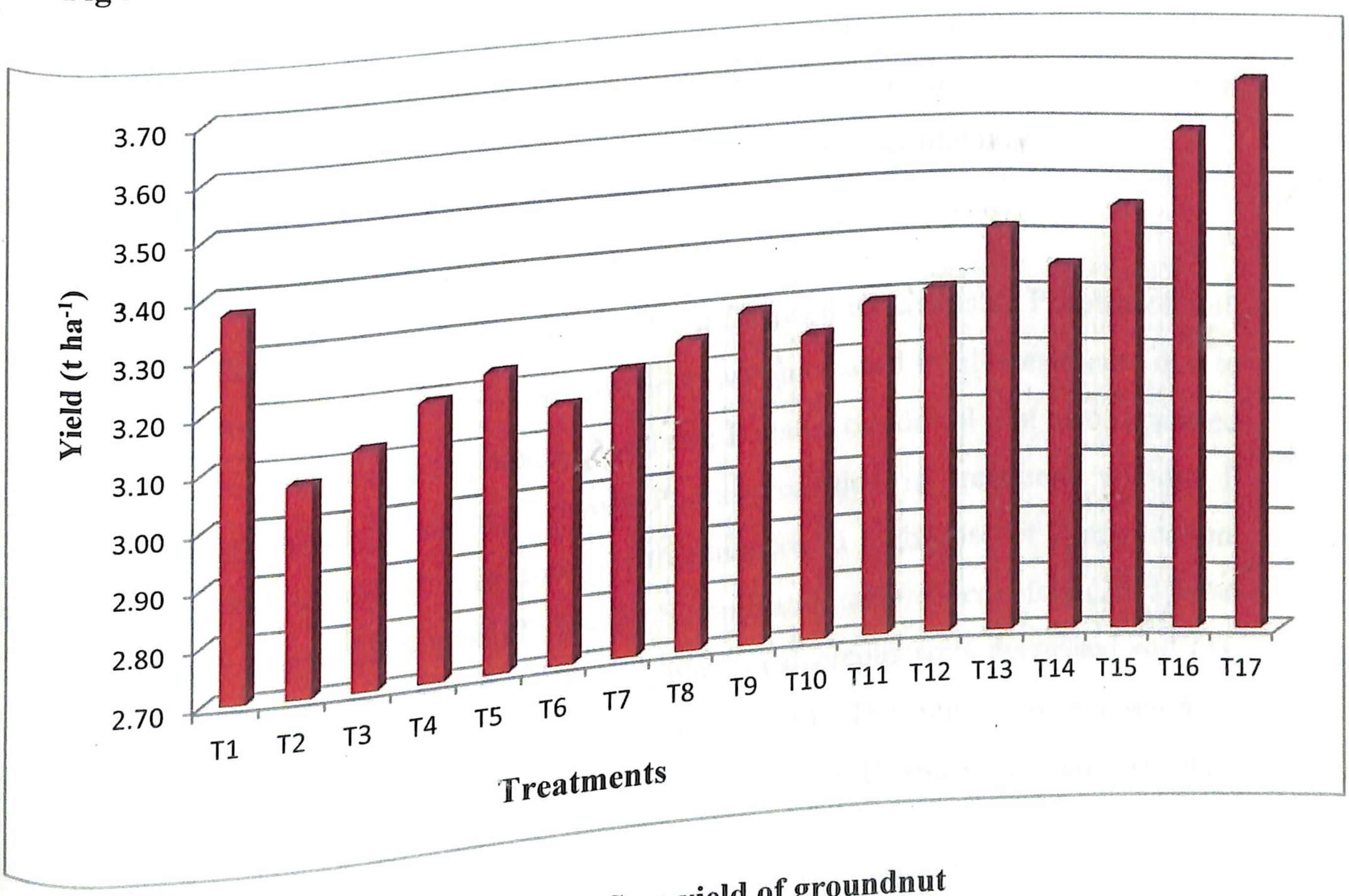

Fig 4: Effect of application of P and S on yield of groundnut

5.2.2 EC

There was a slight increase in electrical conductivity of soil due to the application of soluble fertilizers.

5.2.3 Organic carbon

There was no significant influence in the application of P and S fertilizers on organic carbon content of the soil.

5.2.4 Available nitrogen

Application of P and S significantly influenced available N status of the soil. The requirement of P in nodulating legumes is higher compared to non-nodulating crops as it plays a significant role in nodule formation and fixation of atmospheric N (Brady and Weil, 2002). Available N status of soil increased with increased dose of application of P. P has a positive interaction with N and plant development (Sumner and Farina, 1986). This might be due to the increased N fixation. Balasubramanian and Palaniappan (1991) reported that higher the concentration of P, the higher will be the amount of N fixed. Available N has increased with increased dose of S also. Fazili *et al.* (2008) reported that S addition increases the N availability.

5.2.5 Available phosphorus

Application of P and S significantly influenced the available P status of soil. Compared to initial available P. Available P was increased in all treatments due to application of phosphatic fertilizers. Available P status of control plot also increased compared to initial P status. Lowest P was recorded in treatment without P application and highest P was noted in treatment with high dose of P application. Available P status of soil was affected by S application also. Wiedenfeld (2011) also reported that application of elemental sulphur in calcareous soils decreased soil pH, thereby increasing the available P content in soil. The microbial oxidation of elemental sulphur produced protons which dissolved P and increased the plant available P.

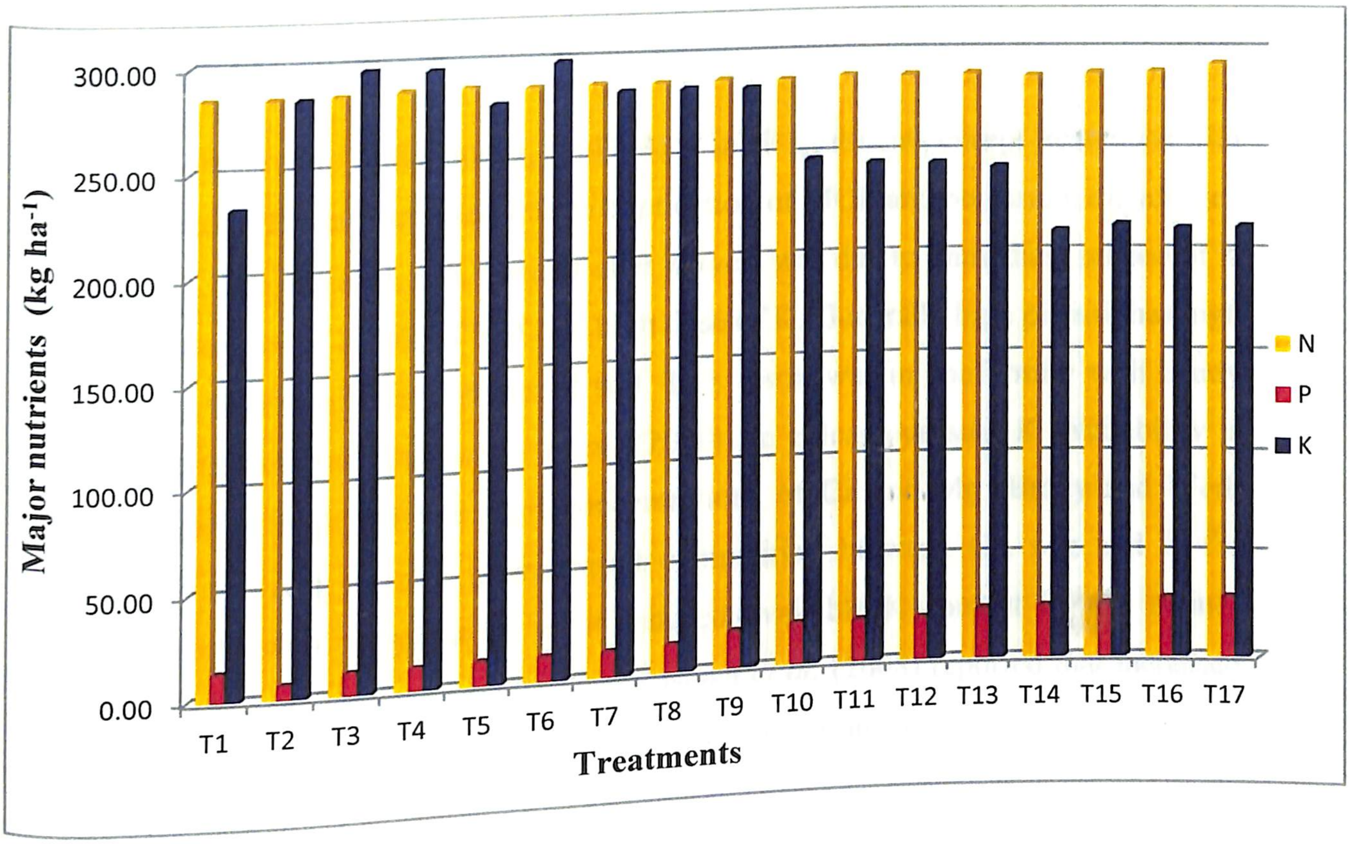

Fig 5: Effect of application of P and S on major nutrients in soil

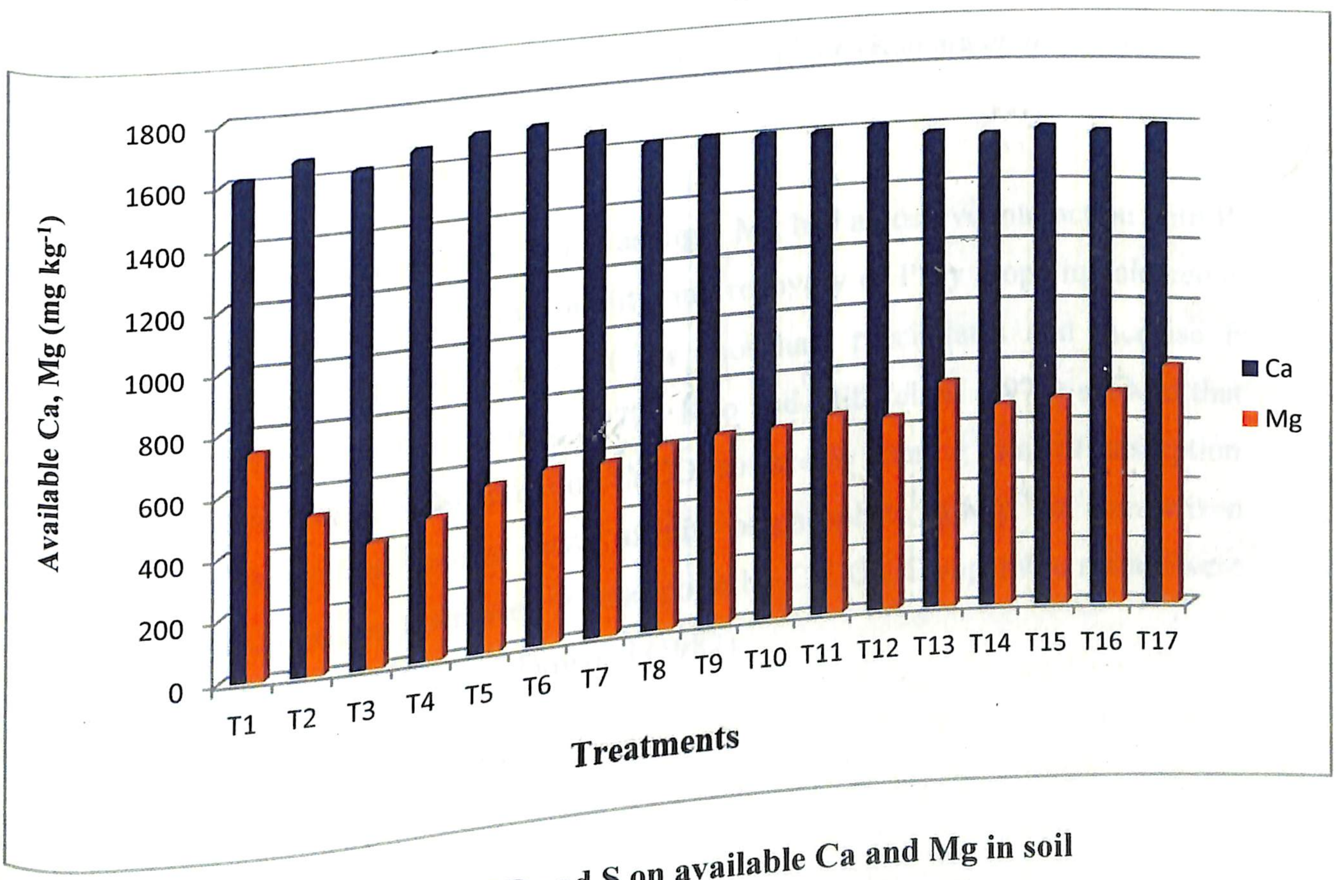

Fig 6: Effect of application of P and S on available Ca and Mg in soil

5.2.6 Available potassium

Compared to initial status, available K in all treatments except treatments with higher dose of P was increased due to application of MOP and potassium dihydrogen phosphate. The increase in K content after harvest was due to immediate release of K to available pool of K from FYM and high dose of K. Generally high pH soil has high Mg which decreases the K status of soil. This result was in conformity with Brady and Weil (2002) and Daliparthy *et al.* (2008). In calcareous soil, K availability is limited due to high pH and high concentrations of Ca and Mg (Brady and Weil, 2002). This might be due to increased competition between Ca, Mg and K for exchangeable sites. Application of P reduced available K content in soil mainly because of enhanced plant uptake. Skwierawska *et al.* (2008) reported that increased level of sulphur application reduced available K content in soil.

5.2.7 Available calcium

Experimental field had high Ca content since it is a calcareous soil with high soil pH. There was a decrease in available Ca with increased dose of P application. This might be due to the formation of calcium phosphate (Kamara *et al.*, 2011).

5.2.8 Available magnesium

The initial Mg content of soil was high. Mg had a positive interaction with P. Mg plays a positive role in P availability and recovery of P by crops in calcareous soils. Mg can alter the formation of Ca phosphate precipitates and increase P availability (Marion and Babbcock, 1977). Kuo and Milkkelsen (1979) showed that Mg may interfere with P adsorption on $CaCO_3$ surface by altering some of adsorption sites on $CaCO_3$ surface, due to lower affinity of phosphate to Mg^{2+} in comparison with Ca^{2+} which causes decreased P adsorption by $CaCO_3$. Comparable results were reported by Al-Lami (1999) and Dowood (1982).

5.2.9 Available sulphur

There was a noticeable increase in available S from T_1 to T_{17} due to increased dose of S application as elemental sulphur.

5.2.10 Available iron

Application of P and S significantly influenced Fe status of soil. Treatment having low P and high S showed highest available Fe. Heavy application of P reduced availability of Fe. This might be due to the formation of Fe-phosphate which reduced the Fe availability. This was in conformity with result of Ayed (1970). Loneragan *et al.* (1979) reported that application of large amount of P increased P: Fe ratio and led to deficiency of these nutrients.

5.2.11 Available manganese

Available Mn was high in treatment with low P. Application of P reduced available Mn status of soil. It may be due to the formation of insoluble Mn-phosphate. High available P induced the deficiency of Mn in maize (Adriano and Murphy, 1970) and in potato (Adriano *et al.*, 1971).

5.2.12 Available zinc

Application of P and S significantly affected Zn content. Highest Zn was noticed in treatment, T_4 (P_0S_2 - P, 0 kg ha^{-1} and S, 20 kg ha^{-1}) and lowest was in treatment, T_{16} (P_3S_2- P, 90 kg ha^{-1} and S, 20 kg ha^{-1}). Available Zn decreased with increase in P. P forms chemical bond with Zn at high levels of P and P binds large quantity of Zn resulting in P induced Zn deficiency that leads to reduced shoot growth. The findings of Adriano and Murphy (1970) in maize and Adriano *et al.* (1971) in potato were in conformity with the results obtained. They found that high P induced Zn deficiency. This result was in conformity with Modaihsh *et al.* (1989) in calcareous soils.

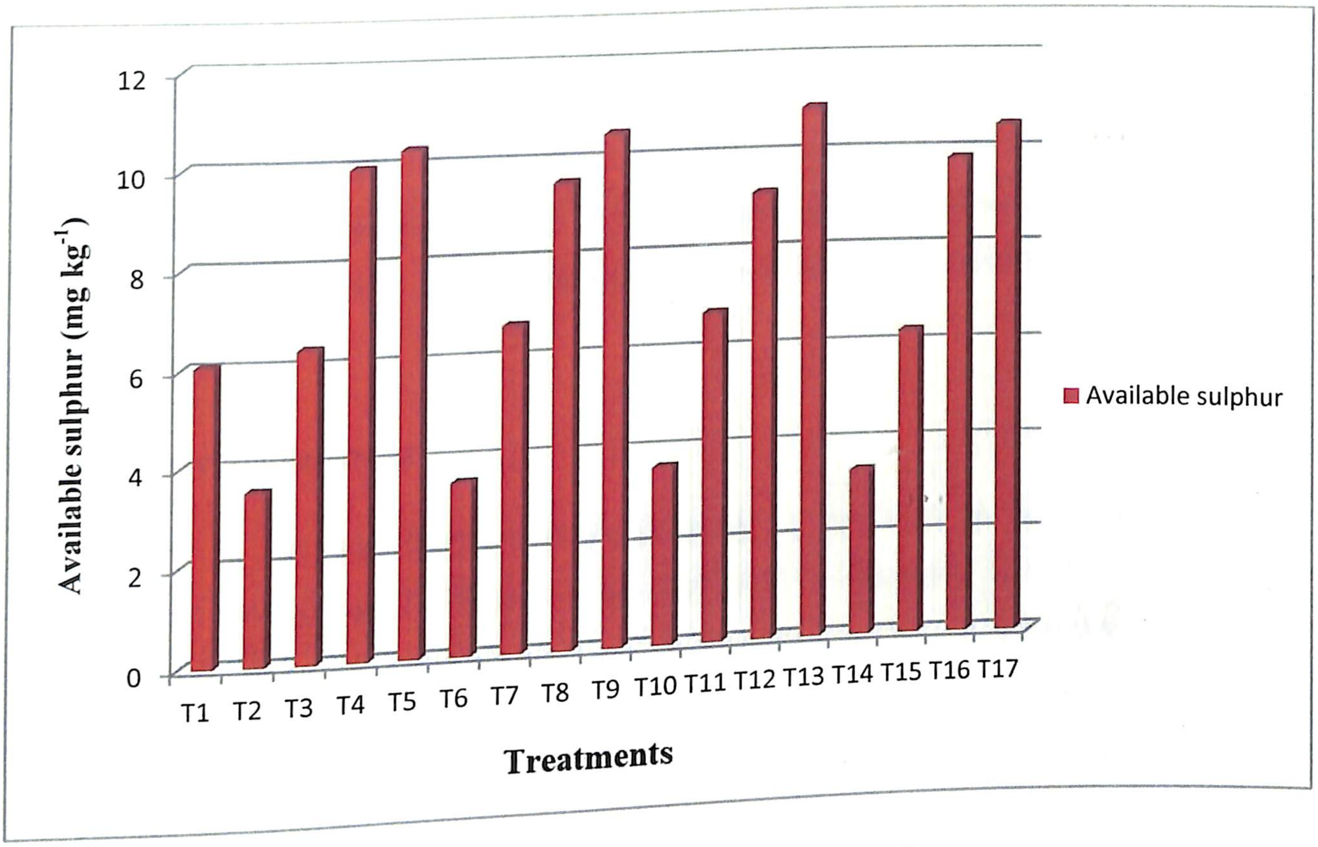

Fig 7: Effect of application of P and S on available S in soil

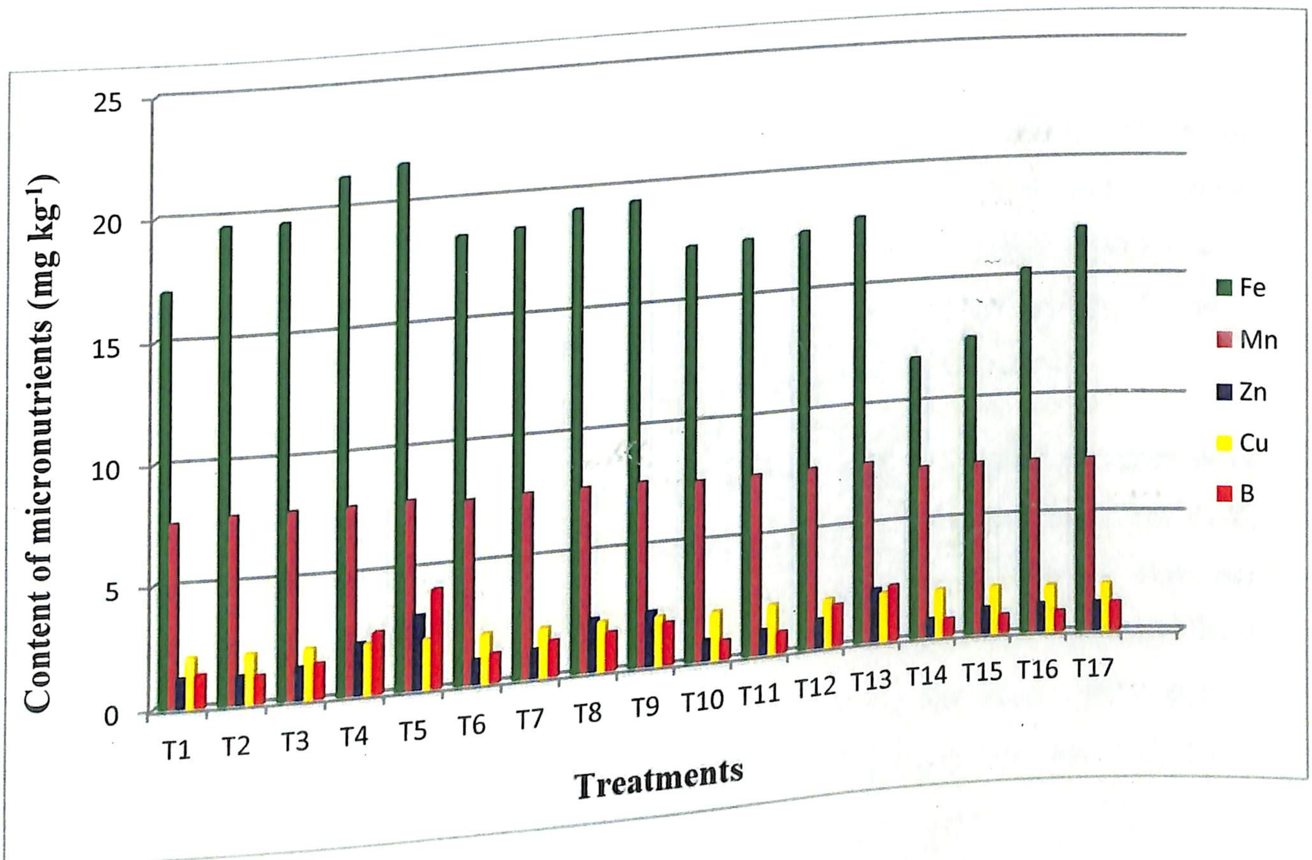

Fig 8: Effect of application of P and S on micronutrients in soil

5.2.13 Available copper

Effect of available Cu was non-significant for main effect and interaction effect. This result was in conformity with Modaihsh *et al.* (1989) in calcareous soils.

5.2.14 Available boron

A significant positive decrease in available B was noticed in treatment having high P. Highest B was observed in treatment, T_5 (P_0S_3: P, 0 kg ha^{-1} and S, 30 kg ha^{-1}) and lowest was in treatment, T_{14} (P_3S_0: P, 90 kg ha^{-1} and S, 0 kg ha^{-1}). There was antagonistic interaction between B and P. This was in conformity with results of Bingham *et al.* (1958) in citrus and May and Pritts (1993) in strawberry.

5.3 EFFECT OF APPLICATION OF P AND S ON PLANT NUTRIENT CONTENT AND UPTAKE

5.3.1 Nutrient content

Nutrient content in groundnut was significantly influenced by the application of different levels of P and S. Significantly highest N, P, and S content were observed in treatments with high dose of P (90 kg ha^{-1}) and S (30 kg ha^{-1}). Dhage *et al.* (2014) reported that application of P and S increased N, P and S contents in groundnut plant. Highest K content was noted in T_5 (P_0S_3).

P_1S_0 (P, 60 kg ha^{-1} and S, 0 kg ha^{-1}) showed highest Ca content at flowering (1.99 per cent) stage. At pegging stage (1.62 per cent) treatment P_0 S_0 showed highest Ca content. At pod formation (1.21 per cent) and harvest (1.03 per cent) stages, P_0S_3 showed highest Ca content. Low P status of soil decreased N, P and Ca contents in 30 day old groundnut plants (Basha and Rao, 1980). Higher content of N, P, S and K in these treatments helped root growth and enhanced uptake of nutrients and increased dry matter production and yield. The findings of Nakagawa *et al.* (1981) and Patel *et al.* (1981) also supported the result. Highest Mg content was observed in T_{17} (P_3S_3). Mg content in plant increased with increased dose of sulphur. This is in conformity with Barczak (2010). He also reported increase in total plant Mg content with increased dose of S application. Mg content also showed an increasing trend with increased dose of P. Mg showed positive interaction with N and P (Ranade and Malvi, 2011). The haulm retains magnesium accumulated during vegetative growth indicating its utilization for structural and developmental processes, with less translocation of magnesium towards reproductive parts; hence kernels contain least amount of magnesium compared to haulm (Babu *et al.*, 2007). Plant S content increased with increased dose of S application. Dhage *et al.* (2014) reported that S application increased the plant S content in soybean.

T_5 (P_0S_3) showed highest Fe, Mn, and Zn content. Soliman *et al.*, (1992) reported that application of sulphur increased Mn content in corn plants grown in calcareous soils. Cu content was highest in T_2 (P_0S_0) at flowering stage and in T_5 (P_0S_3) at pegging and pod formation stages. There was no significant effect for the application of P and S on plant Cu content at harvesting stage.

Nutrient content in plant decreased from flowering to harvest stage. Highest nutrient content was noticed in flowering stage and it gradually decreased towards harvest stage. The findings of Chahal *et al.* (1983) were in conformity with this result. Reddy and Murthy (1985) observed that plant N content decreased as crop grew older.

N, P and S content by the kernel increased with increased dose of P and S. The result was in conformity with Das (2017). Ca content in shell increased with increased dose of P. This result was in conformity with Amruth *et al.* (2018). The content of Fe, Mn and Zn in kernel and shell increased with increased dose of sulphur. This result was in conformity with the findings of Kharol *et al.* (2014). Jankowski *et al.* (2014) also concluded that application of S increased Zn and Mn content in rapeseed.

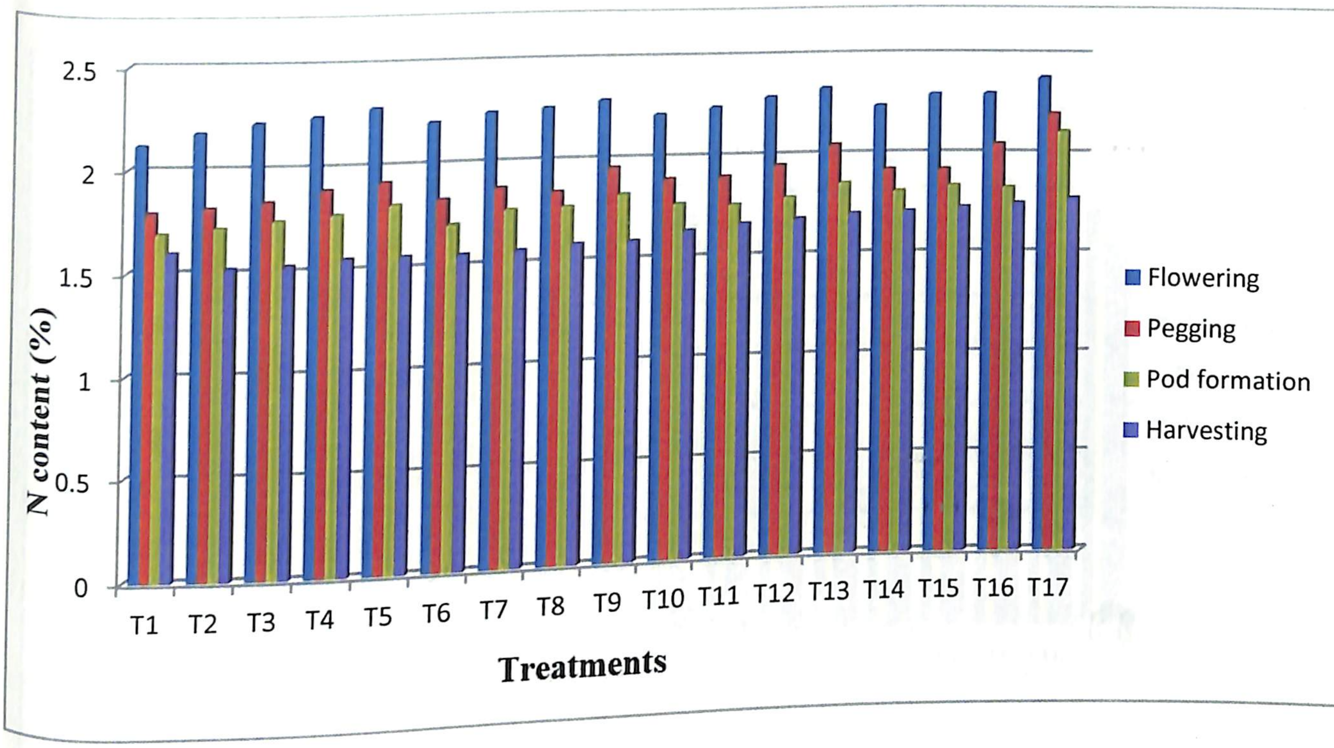

Fig 9: Effect of application of P and S on nitrogen content in plant at different stages

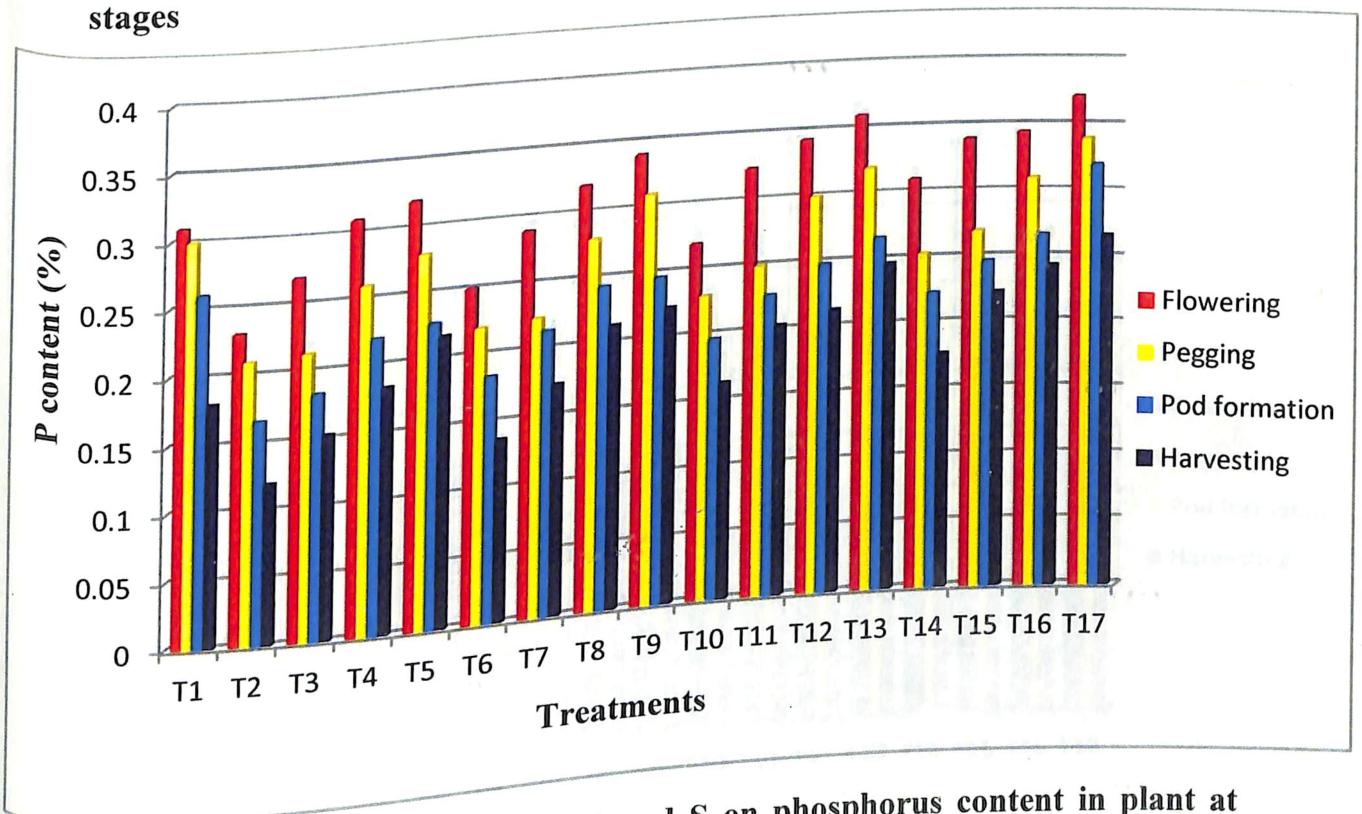

Fig 10: Effect of application of P and S on phosphorus content in plant at different stages

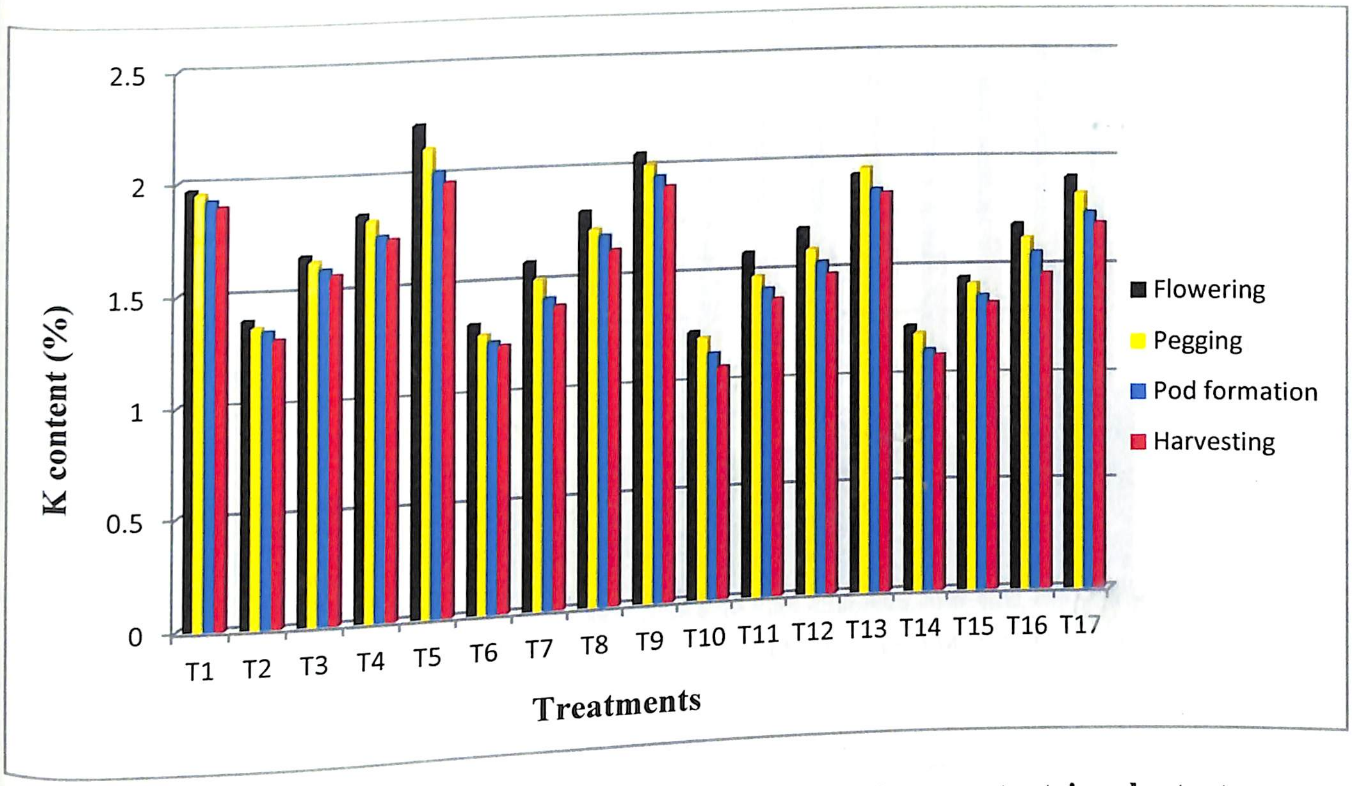

Fig 11: Effect of application of P and S on potassium content in plant at different stages

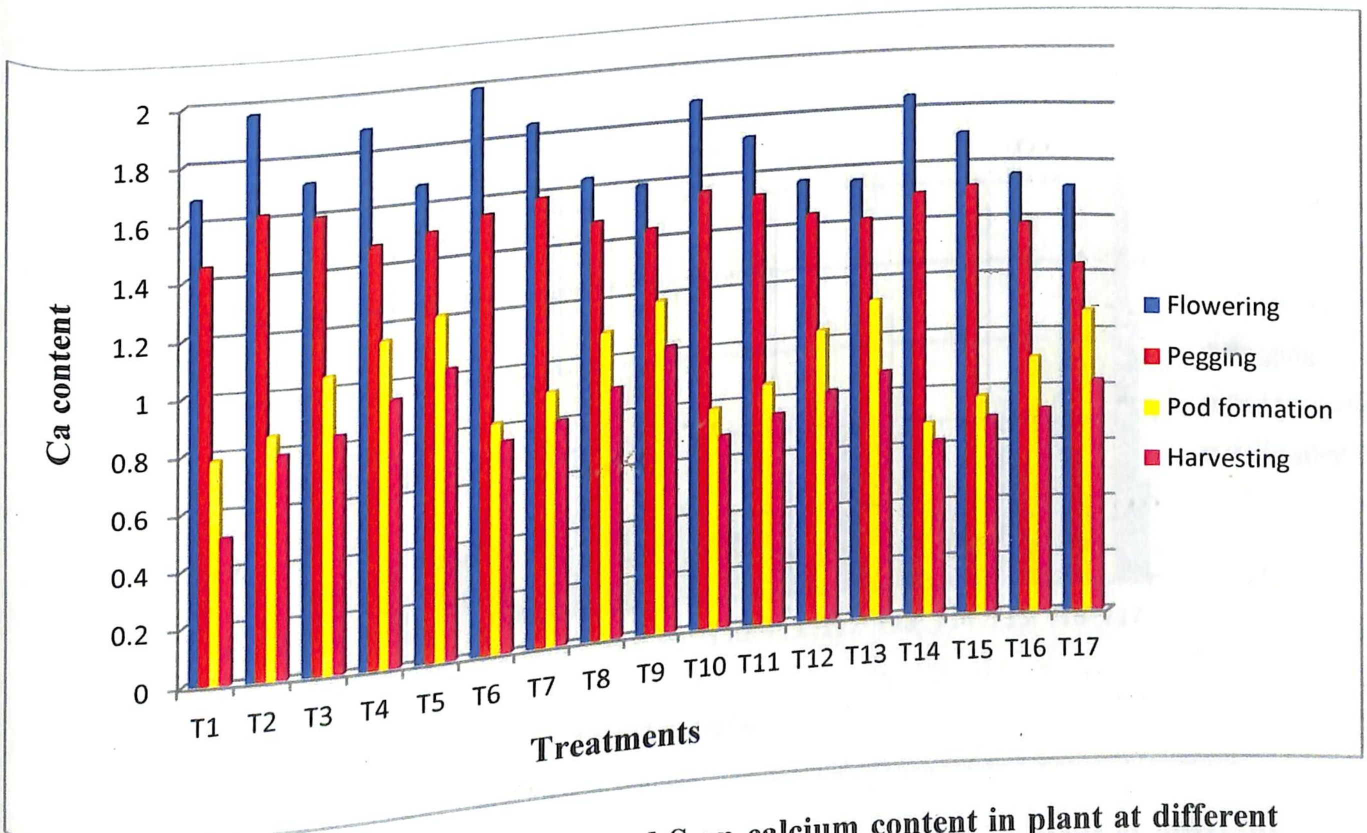

Fig 12: Effect of application of P and S on calcium content in plant at different stages

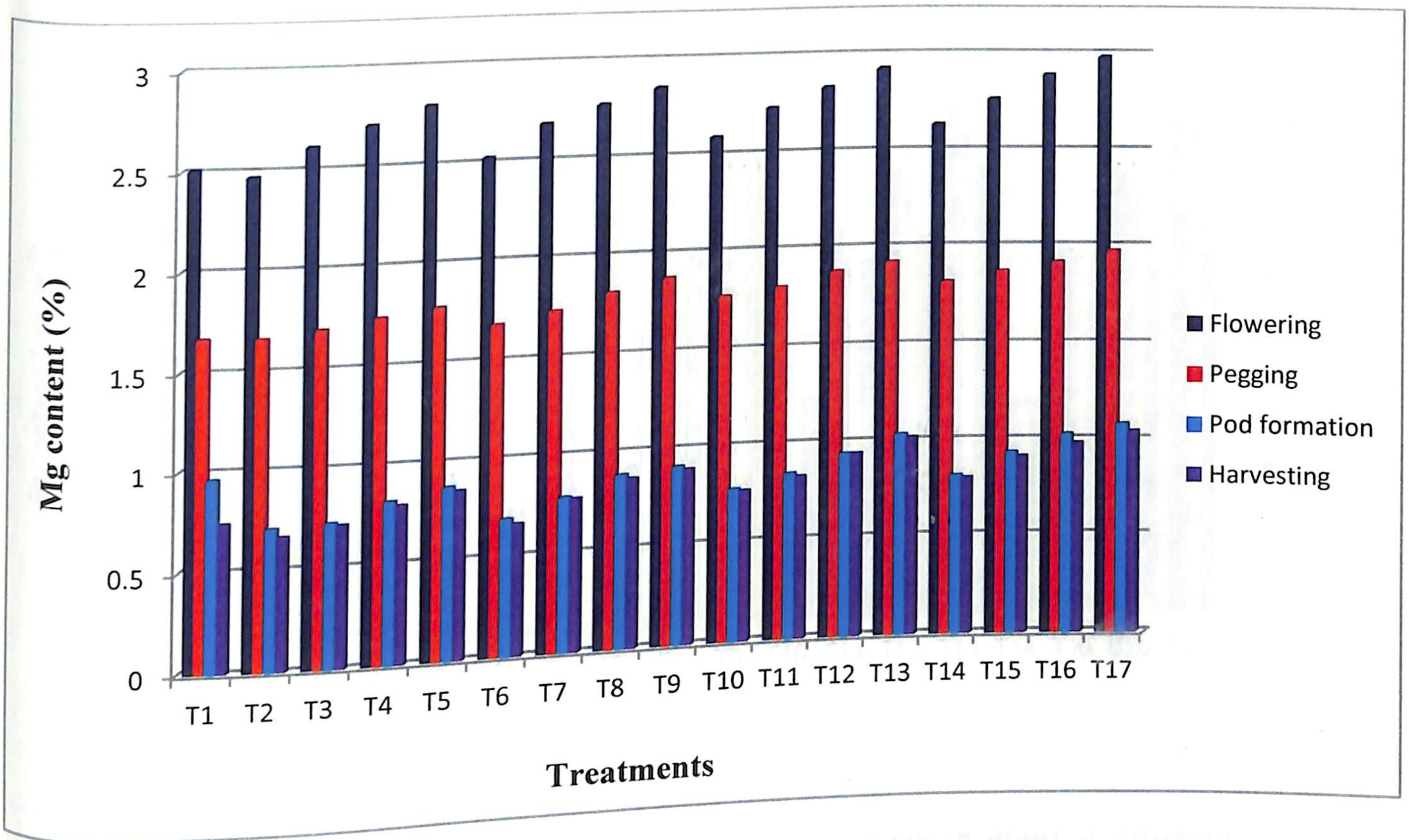

Fig 13: Effect of application of P and S on magnesium content in plant at different stages

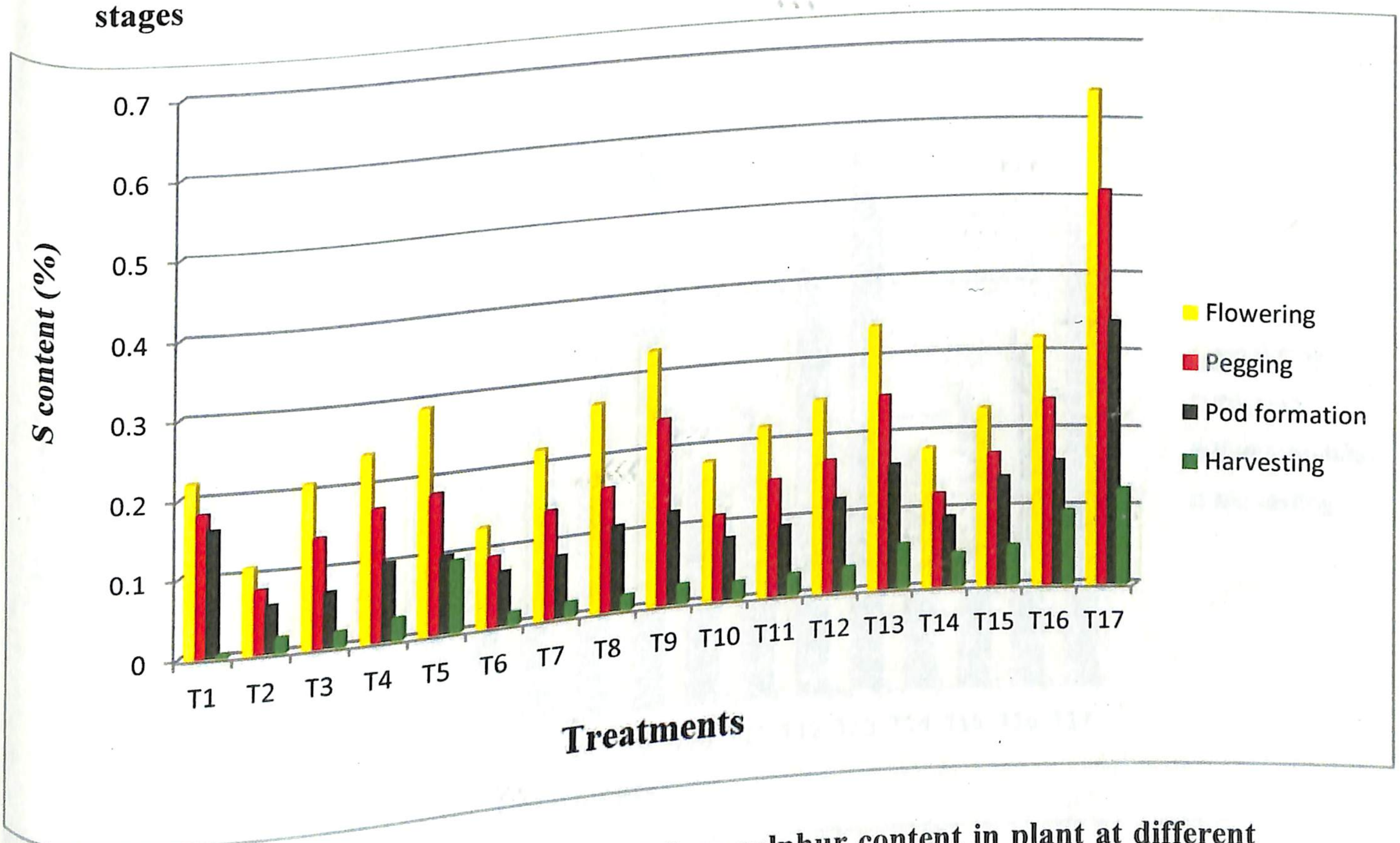

Fig 14: Effect of application of P and S on sulphur content in plant at different stages

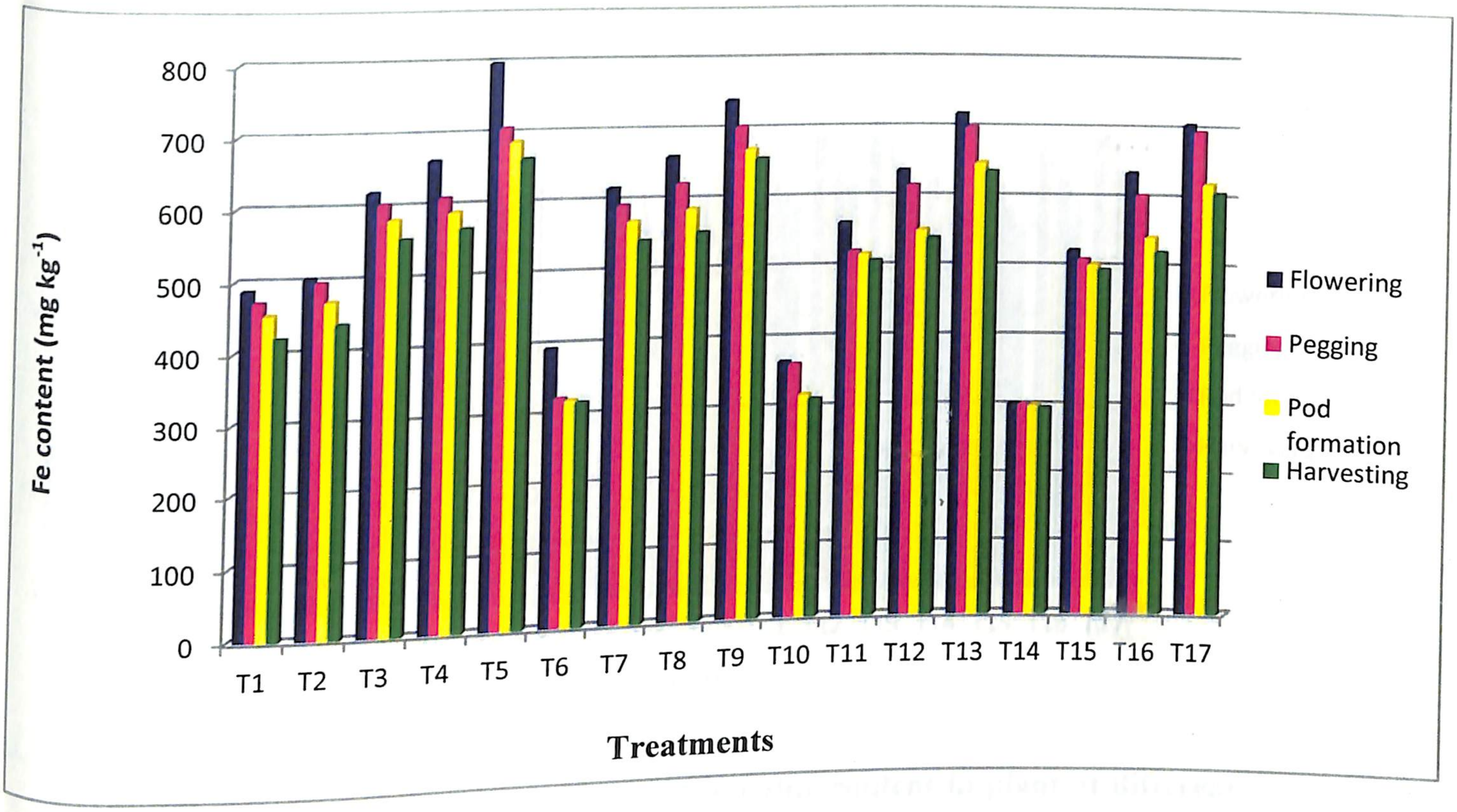

Fig 15: Effect of application of P and S on iron content in plant at different stages

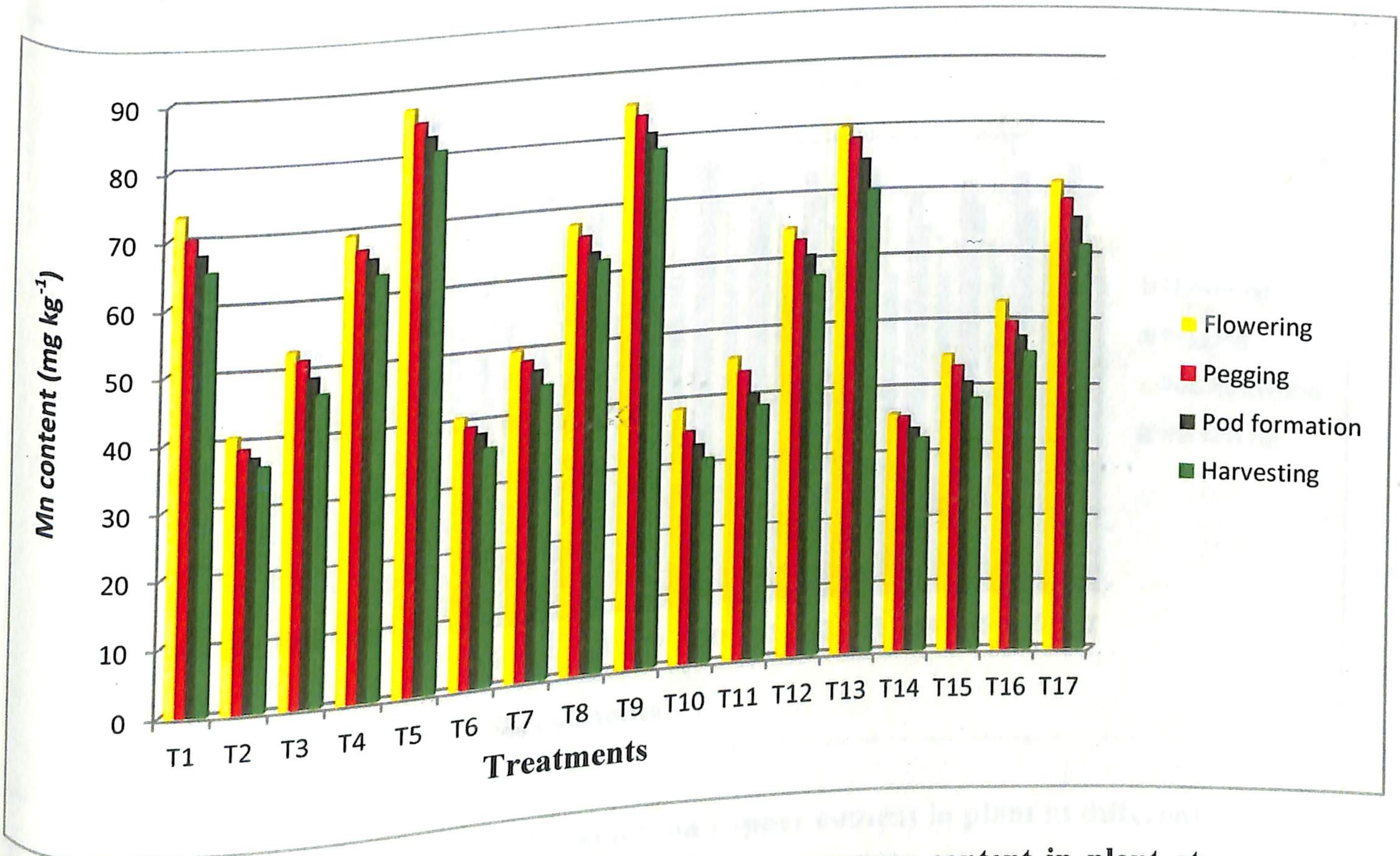

Fig 16: Effect of application of P and S on manganese content in plant at different stages

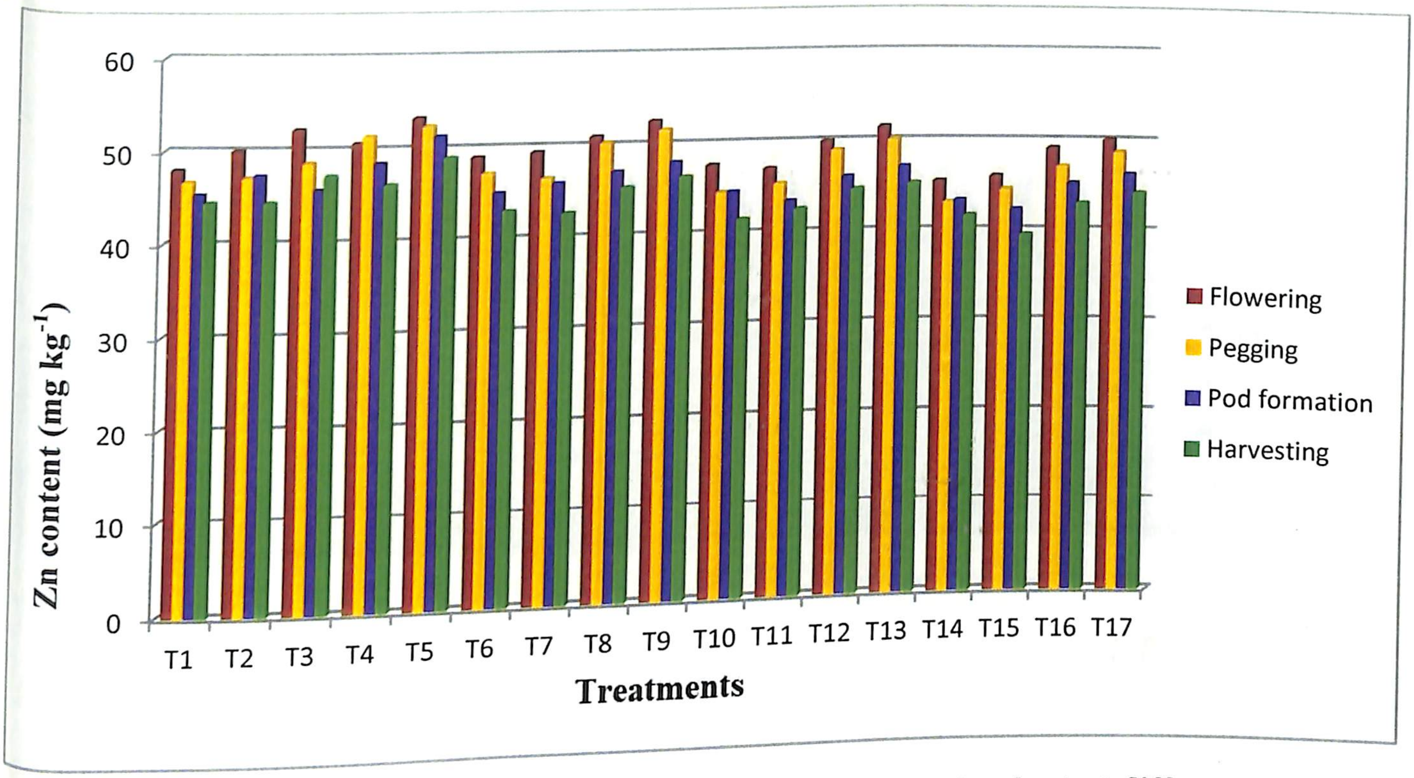

Fig 17: Effect of application of P and S on zinc content in plant at different stages

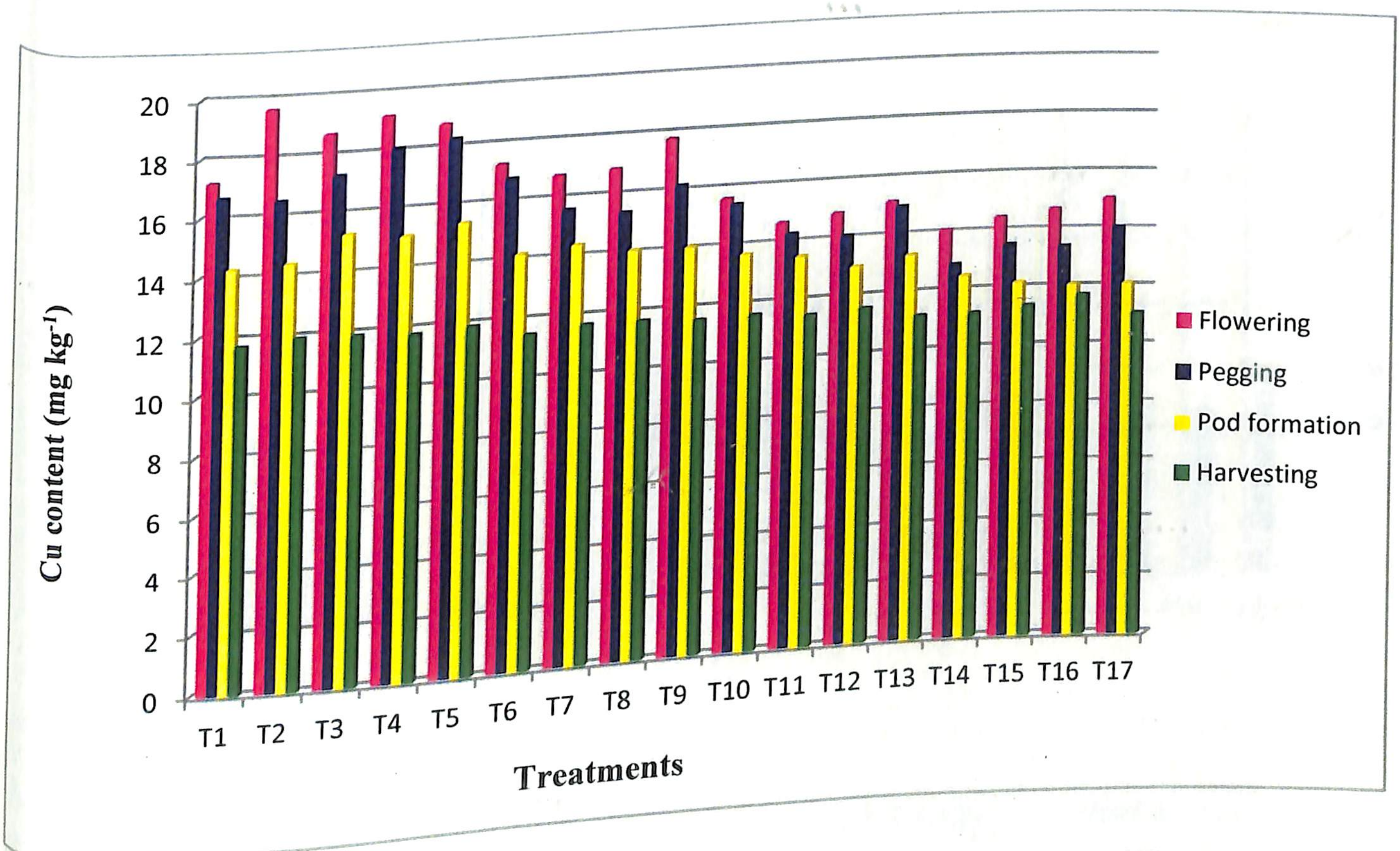

Fig 18: Effect of application of P and S on copper content in plant at different stages

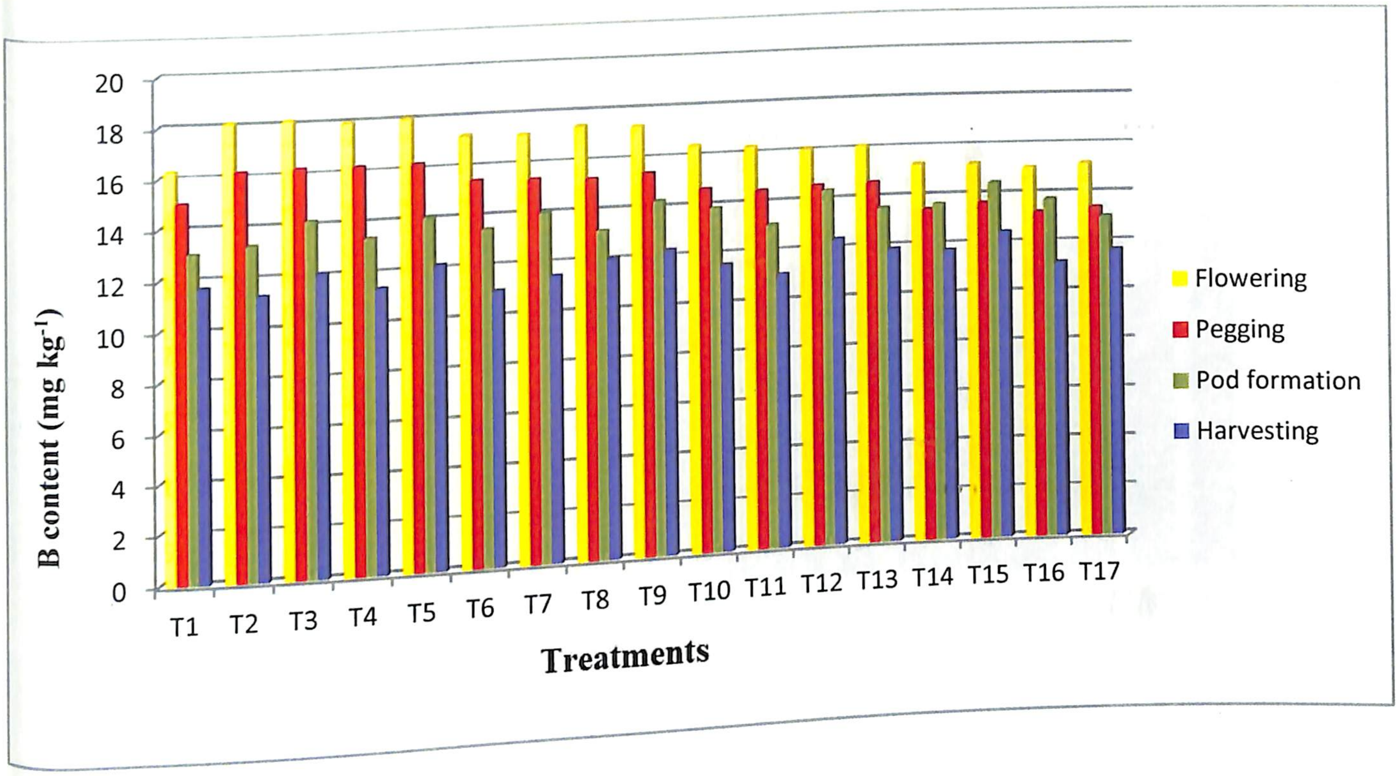

Fig 19: Effect of application of P and S on boron content in plant at different stages

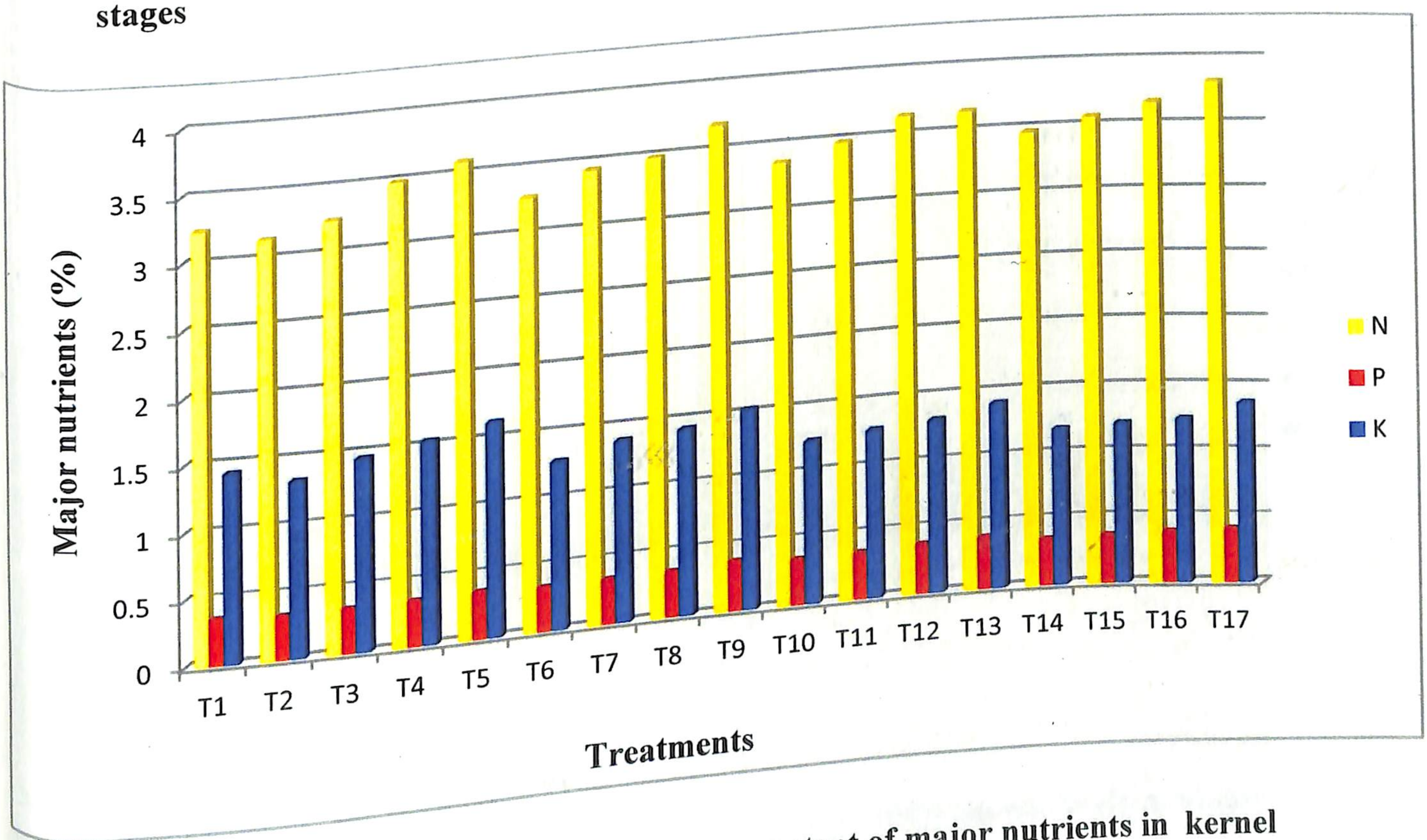

Fig 20: Effect of application of P and S on content of major nutrients in kernel

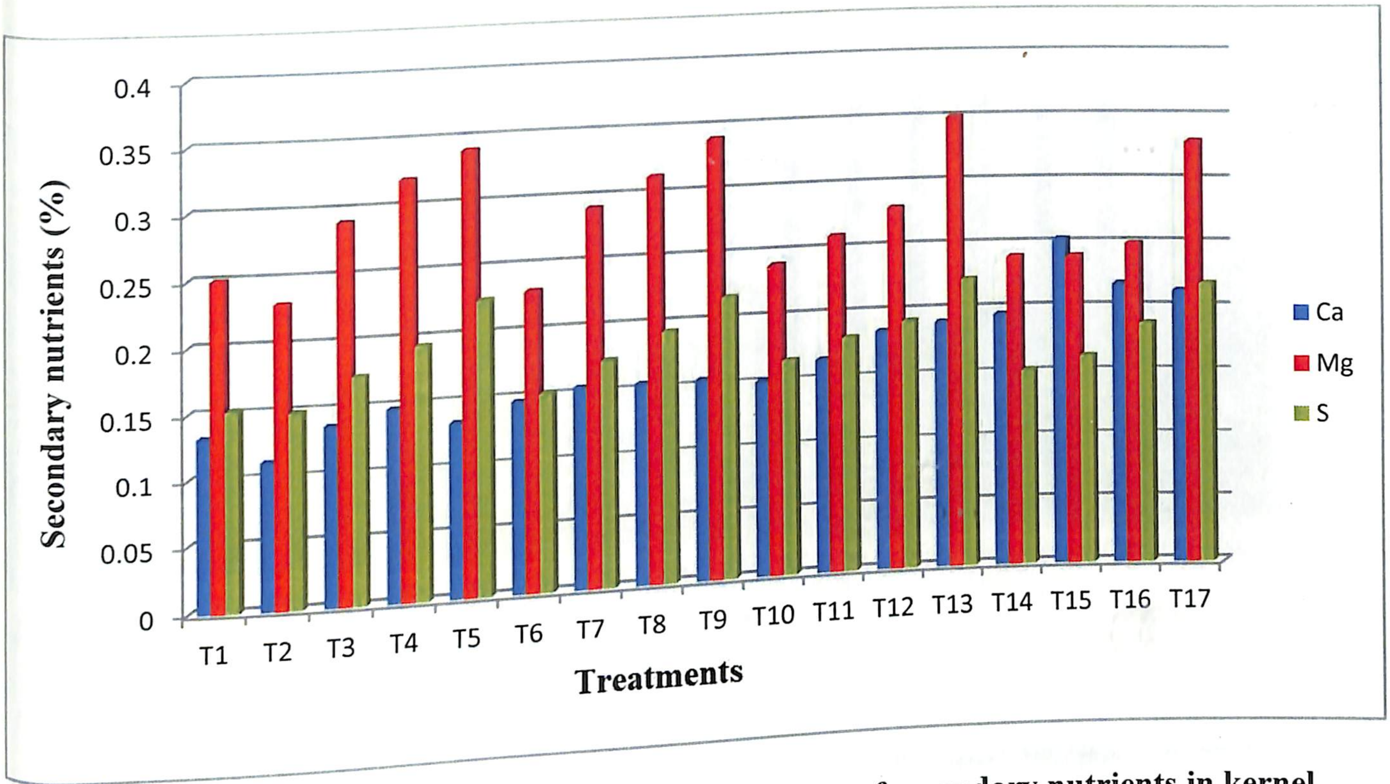

Fig 21: Effect of application of P and S on content of secondary nutrients in kernel

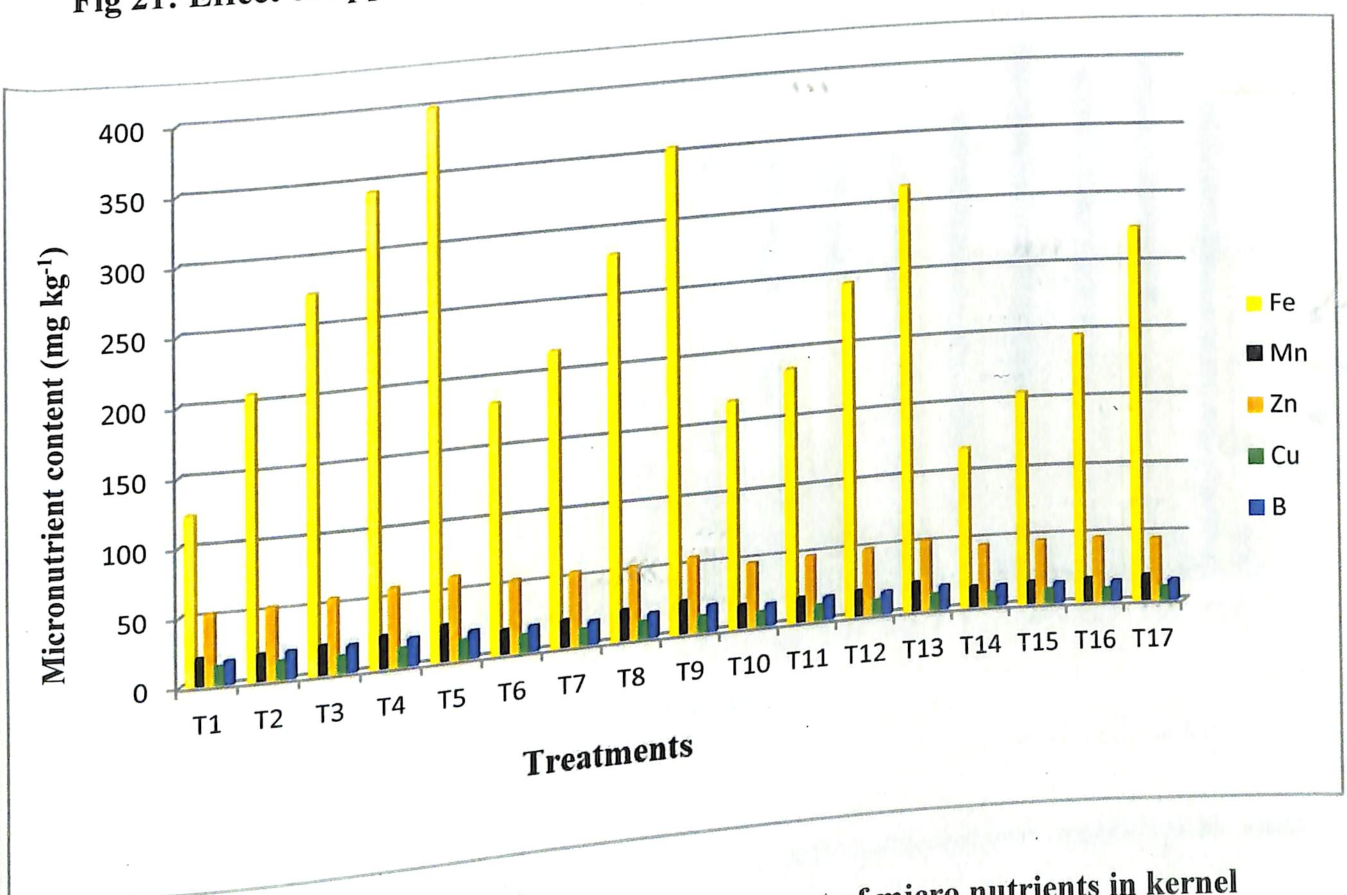

Fig 22: Effect of application of P and S on content of micro nutrients in kernel

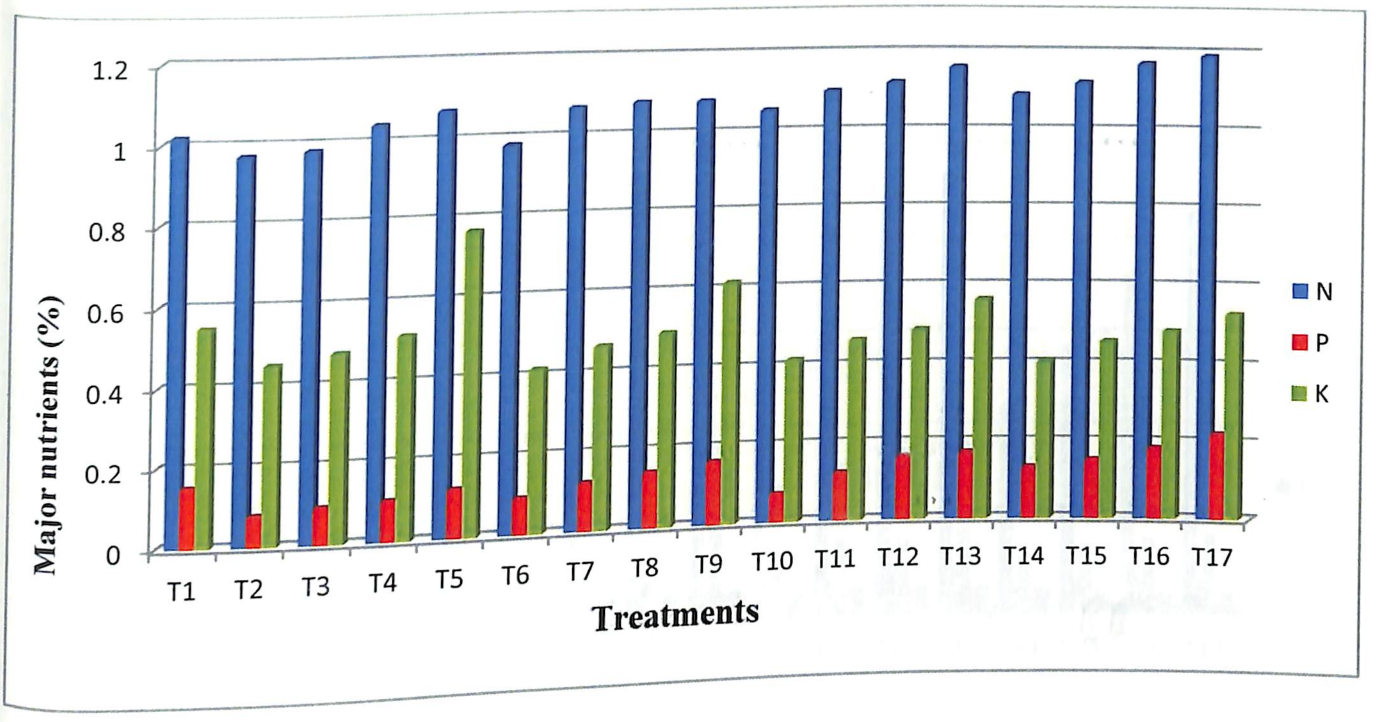

Fig 23: Effect of application of P and S on content of major nutrients in shell

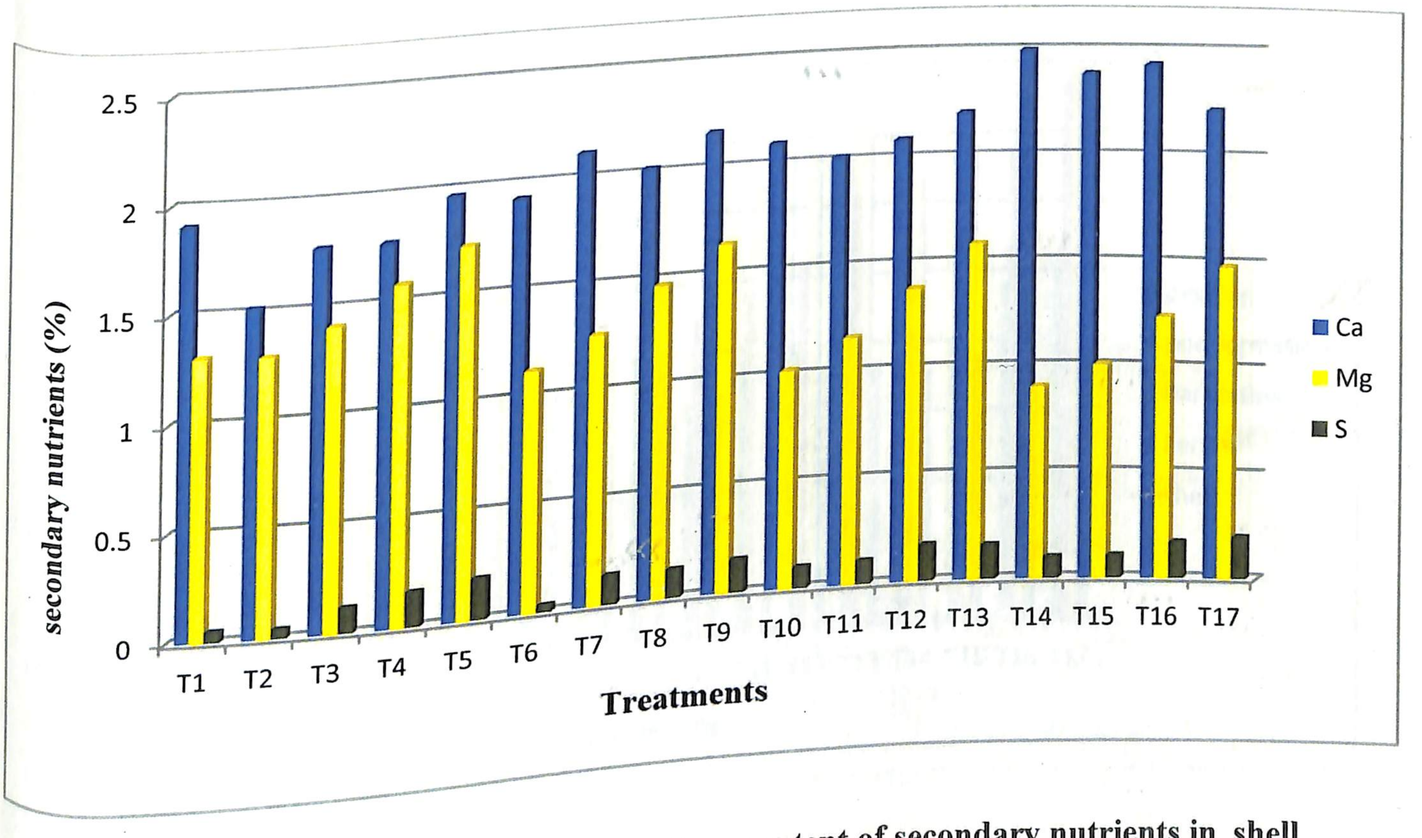

Fig 24: Effect of application of P and S on content of secondary nutrients in shell

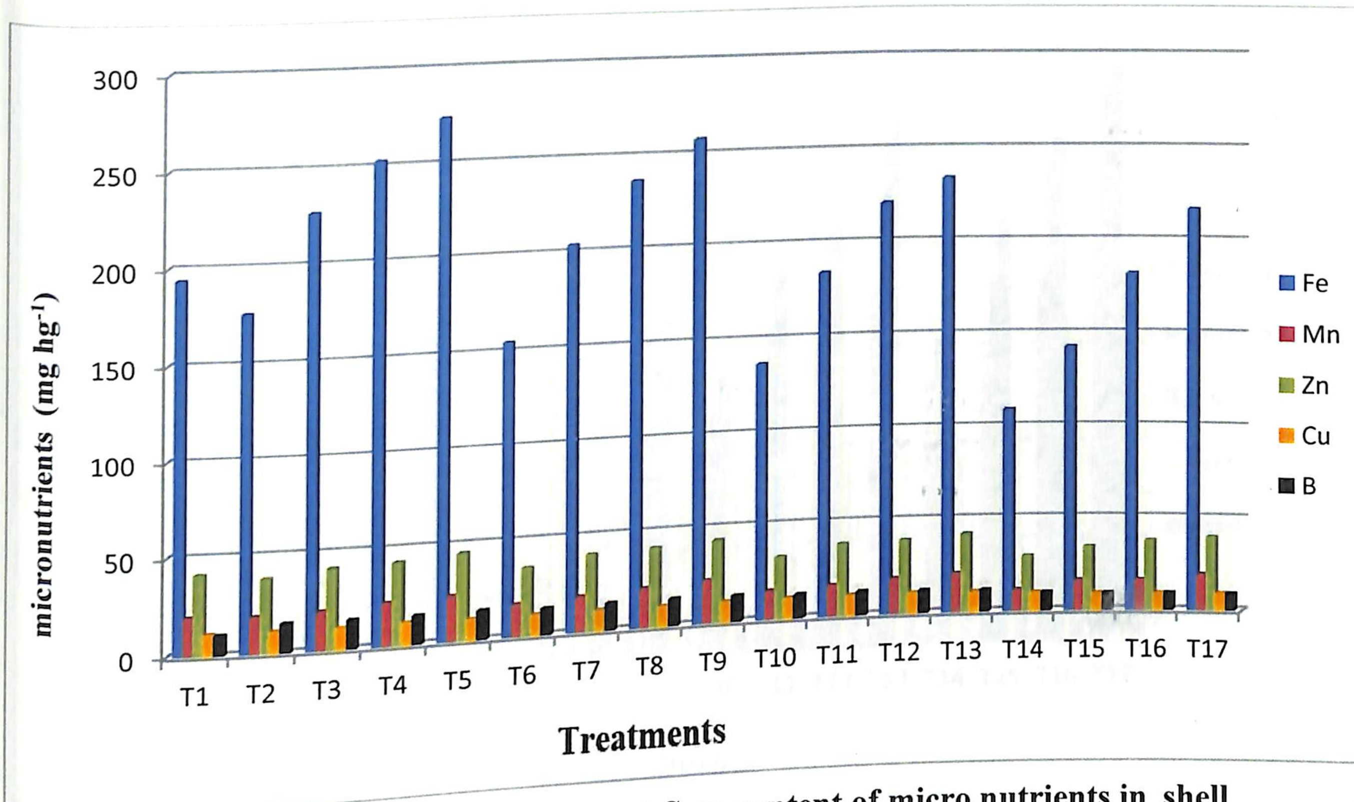

Fig 25: Effect of application of P and S on content of micro nutrients in shell

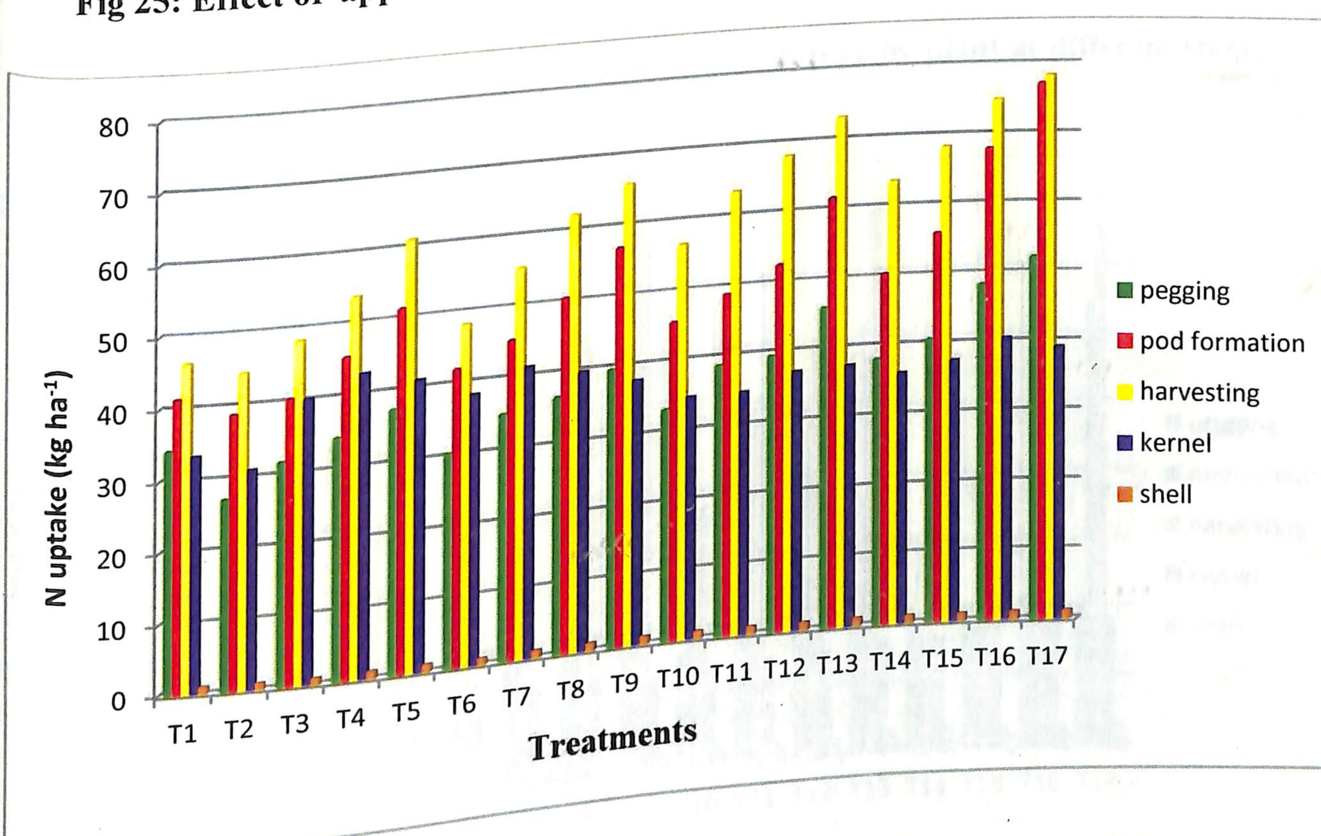

Fig 26: Effect of application of P and S on N uptake by plant at different stages and uptake by kernel and shell

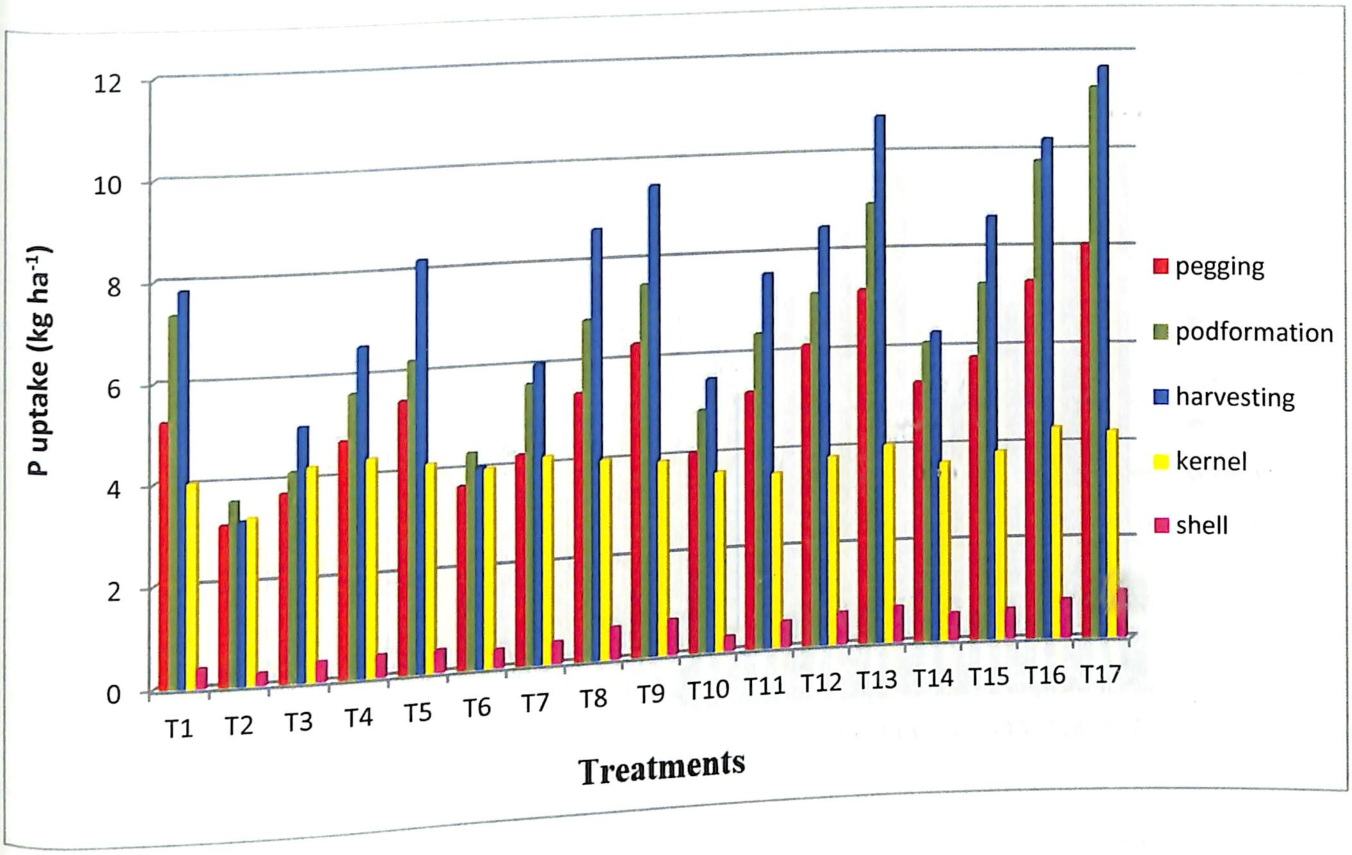

Fig 27: Effect of application of P and S on P uptake by plant at different stages and uptake by kernel and shell

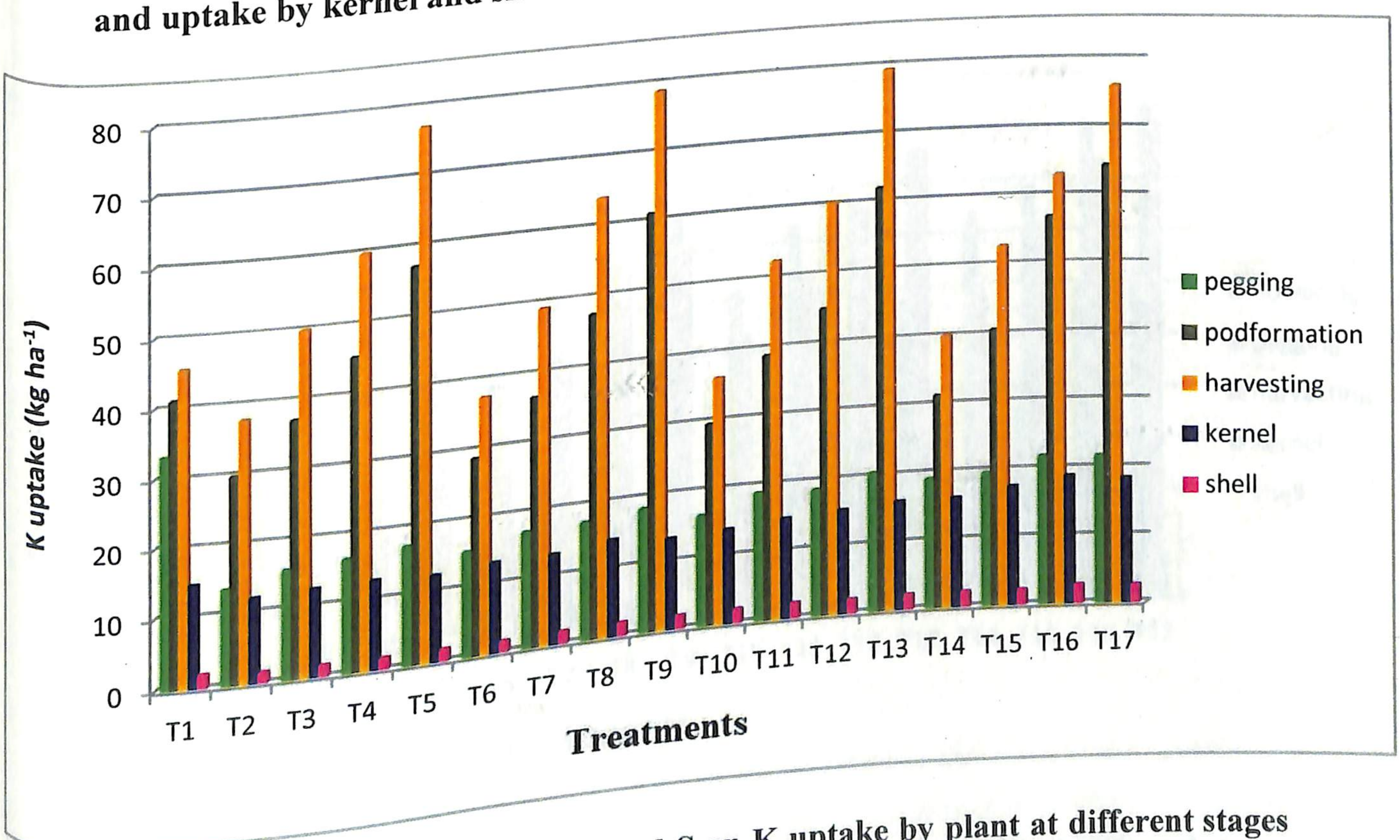

Fig 28: Effect of application of P and S on K uptake by plant at different stages and uptake by kernel and shell

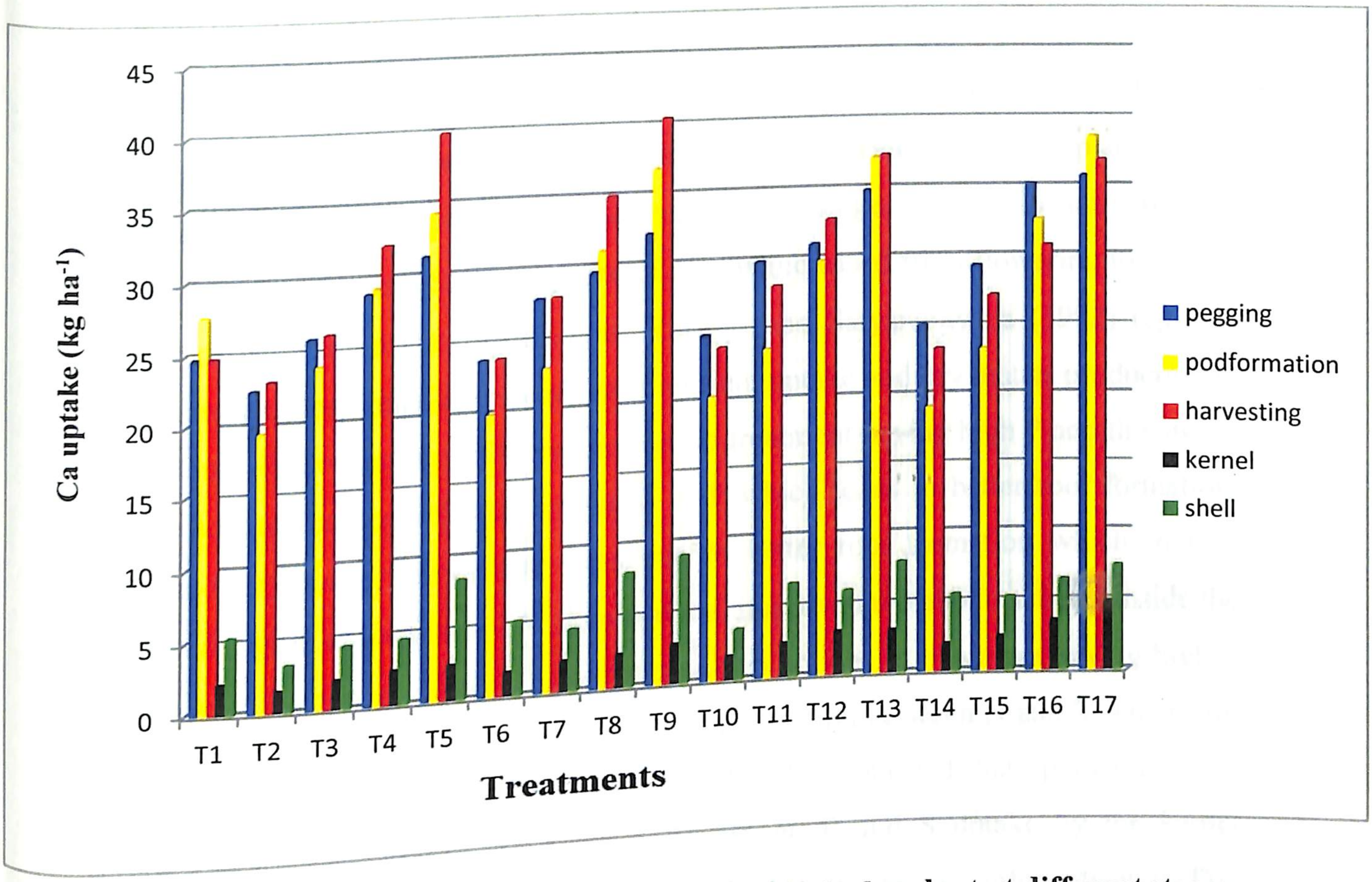

Fig 29: Effect of application of P and S on Ca uptake by plant at different stages and uptake by kernel and shell

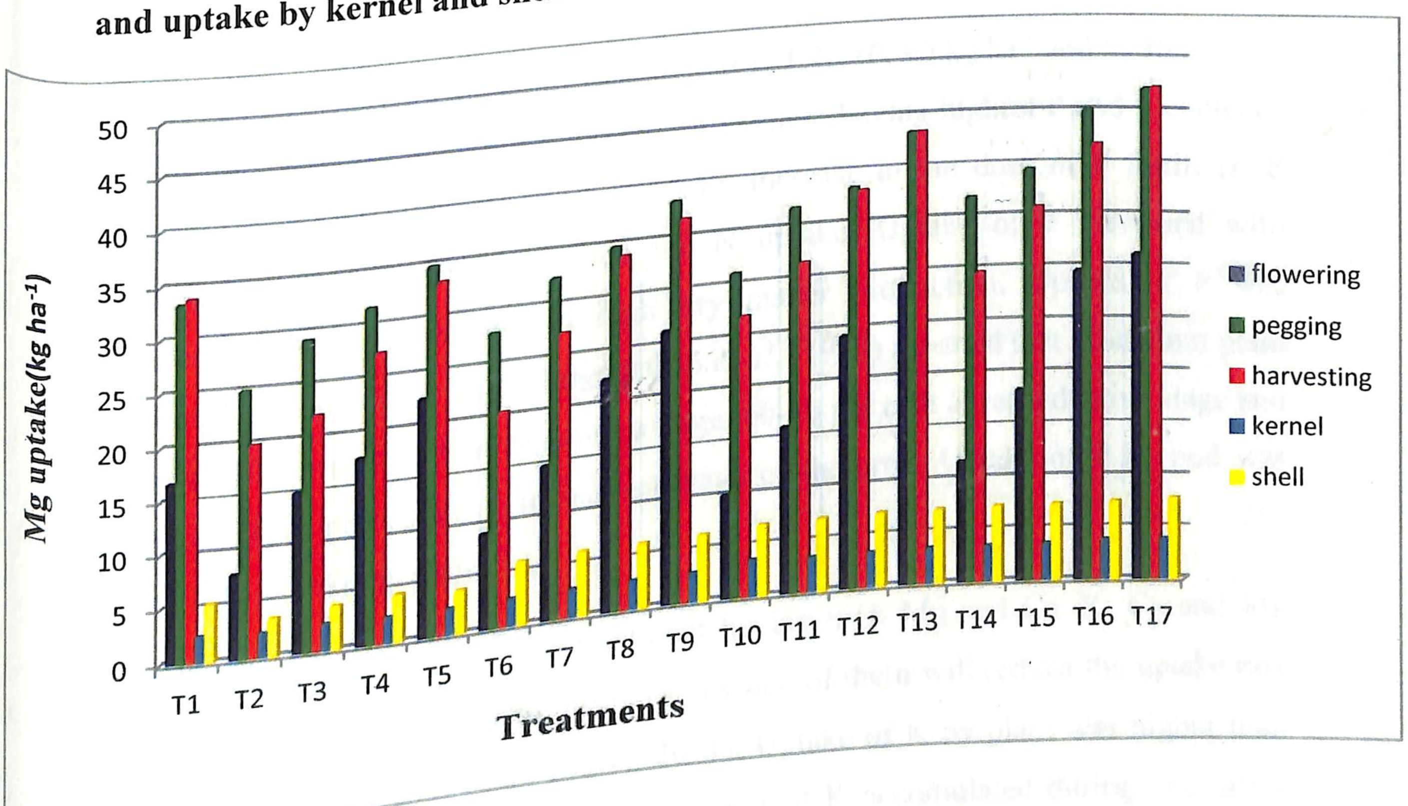

Fig 30: Effect of application of P and S on Mg uptake by plant at different stages and uptake by kernel and shell

5.3.2 Nutrient uptake

The uptake of nutrients is associated with the metabolic activities of the plant and depends on the concentration and distribution of nutrient ions in the plant system (Manasa *et al.*, 2015). Uptake of nutrients at various stages was significantly affected by application of P and S. The uptake of N was increased from flowering to harvest with increased dry matter production. Yakadri and Satyanarayana (1992) reported that there is a close relationship between nutrient uptake and dry matter production in groundnut. Higher uptake of N was noticed in treatment having high P and this might be due to the fixation of N in presence of P which leads to better root formation. Increased dry matter production was due to better root formation which in turn enhanced higher absorption of N from soil and improved metabolic activity inside the plant (Laxminarayana, 2004). Higher uptake was noticed in treatment having high S application. This might be due to synergestic interaction between N and S. The result is in conformity with Nasreen and Huq (2002). They reported that application of S significantly increased N uptake in sunflower. N, P and S uptake by the kernel increased with increased dose of P and S. The result was in conformity with Das (2017).

Uptake of P by groundnut was highest in P_3S_3 (P, 90 kg ha^{-1} and S, 30 kg ha^{-1}) at all stages. Highest uptake was noted in treatment having highest P and S contents. The availability of nutrients increased with increase in the dose of P fertilizer. P uptake by the plant was less than the N uptake. Uptake of P increased with advancement in growth due to high dry matter production. Uptake of P was maximum at pod setting stage. Loganathan *et al.* (1996) reported that groundnut plant absorbed 10 per cent of P at vegetative stage, 40-50 per cent at reproductive stage and remaining P at reproductive to harvest stage of the crop. Uptake of P by pod was higher than uptake by plant.

Uptake of K was less in treatment having high Mg and Ca. K, Ca and Mg compete with each other and addition of any one of them will reduce the uptake rate of the other two (Ranade and Malvi, 2011). Uptake of K by plant was higher than uptake by pods. The haulm retains major part of K accumulated during vegetative growth indicating its utilization for structural and developmental processes and allowed little translocation of potassium towards reproductive parts and hence kernel contains less amount of K (Yakadri and Satyanarayana, 1992).

Uptake of Ca and Mg increased with advance in the age of the crop due to the increased dry matter production. Groundnut crop was a heavy feeder of Ca. (Sarkar *et al.*, 1999). At harvest, Ca and Mg uptake was more in plant than in pod. Ca taken up by the plant will remain in the leaf tissues, and will not move from the leaves to the developing pods where its requirement was high (Ca is immobile in plant system). So the uptake by pods was lesser compared to plant (Meena *et al.*, 2007).

Dhage *et al.* (2014) reported that S application increased plant S uptake in soybean. The results revealed that the uptake of S by groundnut increased with the advancement in the age of the crop. This was mainly due to increased dry matter production. S uptake was more in pod than in plant and this might be due to role of S in amino acids, proteins and oil synthesis in pod. Uptake of Fe, Mn and Zn increased with increased dose of sulphur. This result was in conformity with the findings of Kharol *et al.* (2014).

Rate of micro nutrient uptake by plant increased from 30 to 90 DAS, but lowest uptake was noticed during harvest. At harvest, iron, zinc, copper and boron uptake was more in pod than in haulm, whereas uptake was more in haulm than in pod in case of manganese. Uptake of zinc by pod was higher than that of plant and this might be due to involvement of zinc in metabolism of amino acids and protein in pod. Since B is immobile in plant, B uptake was more by plant than pod (Mahajan *et al.*, 1994).

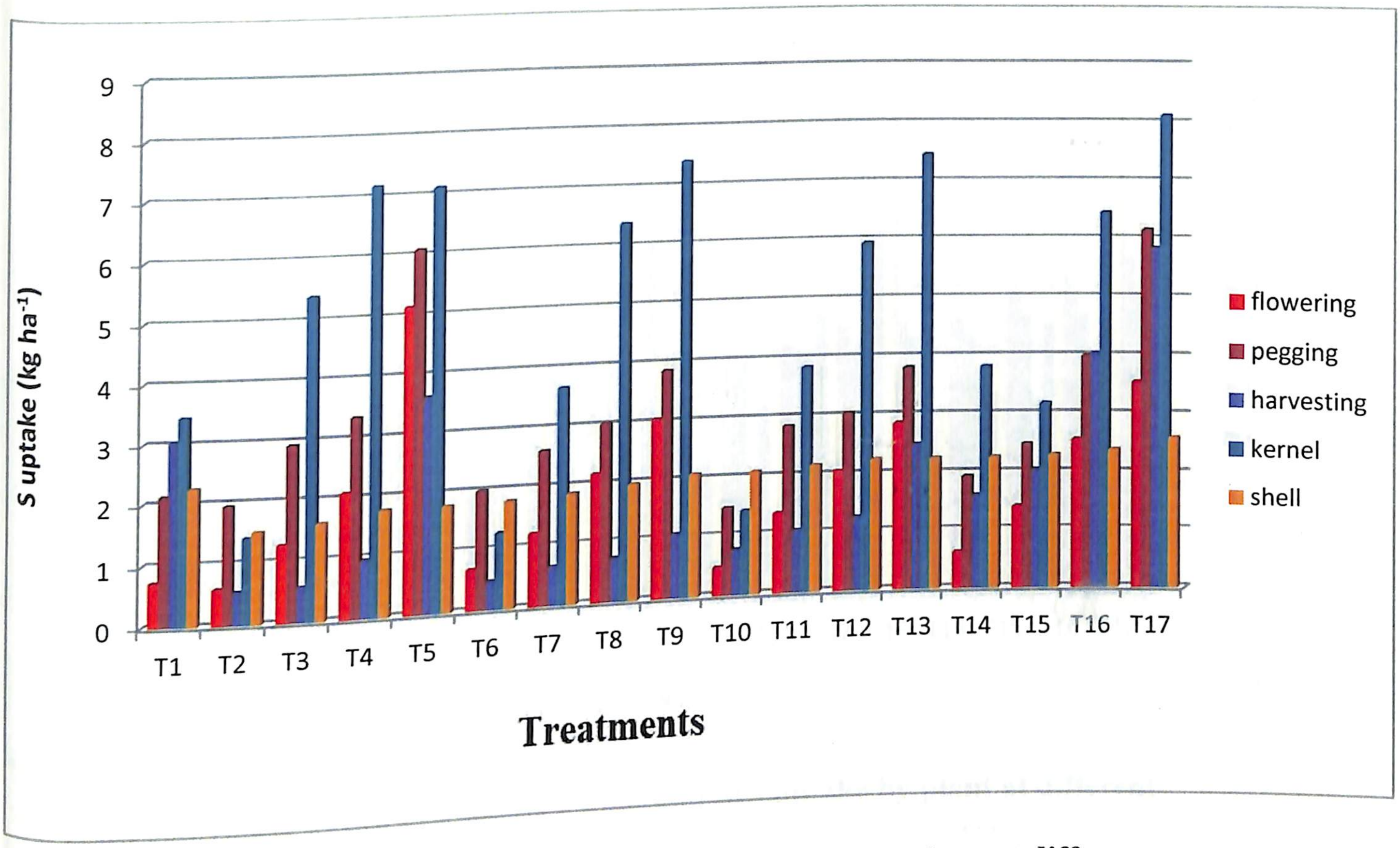

Fig 31: Effect of application of P and S on S uptake by plant at different stages and uptake by kernel and shell

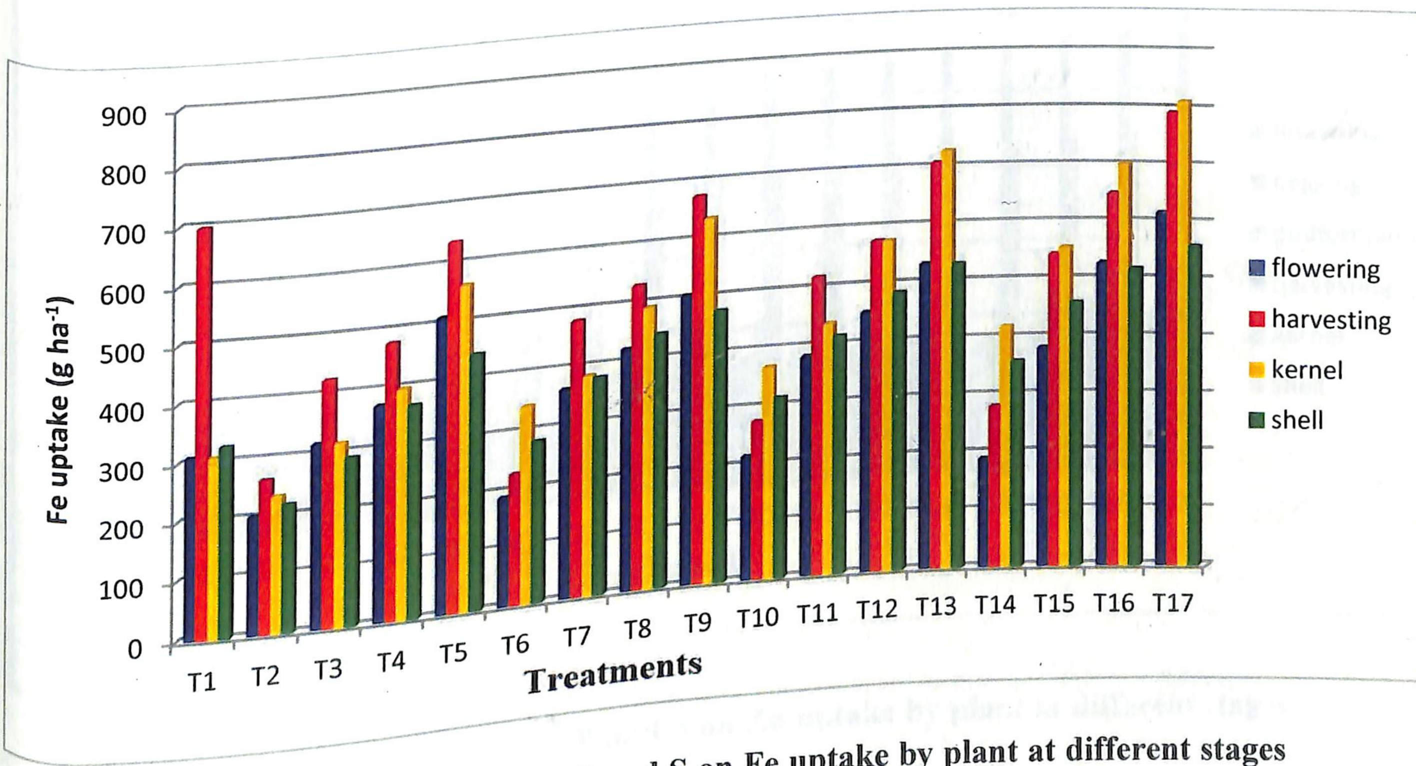

Fig 32: Effect of application of P and S on Fe uptake by plant at different stages and uptake by kernel and shell

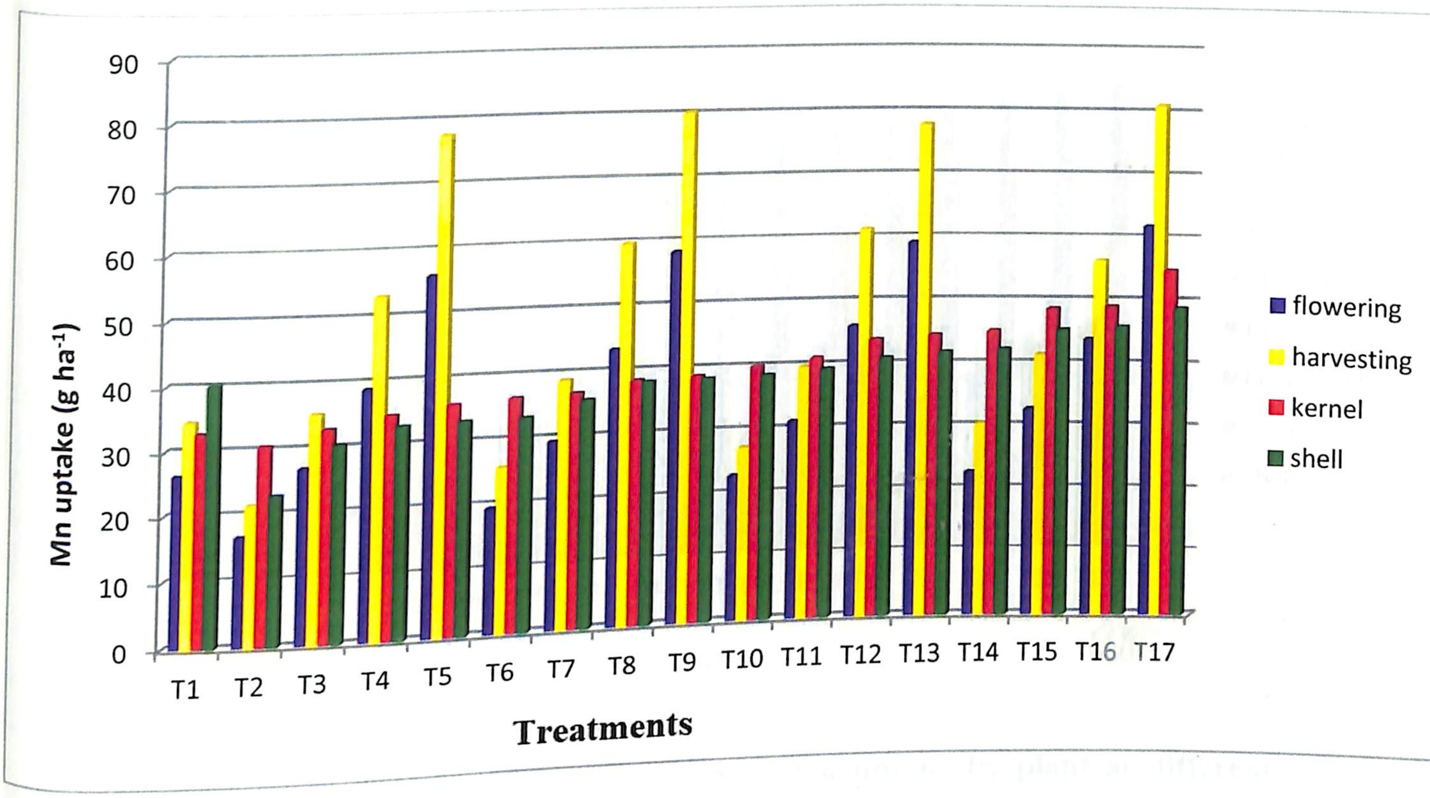

Fig 33: Effect of application of P and S on Mn uptake by plant at different stages and uptake by kernel and shell

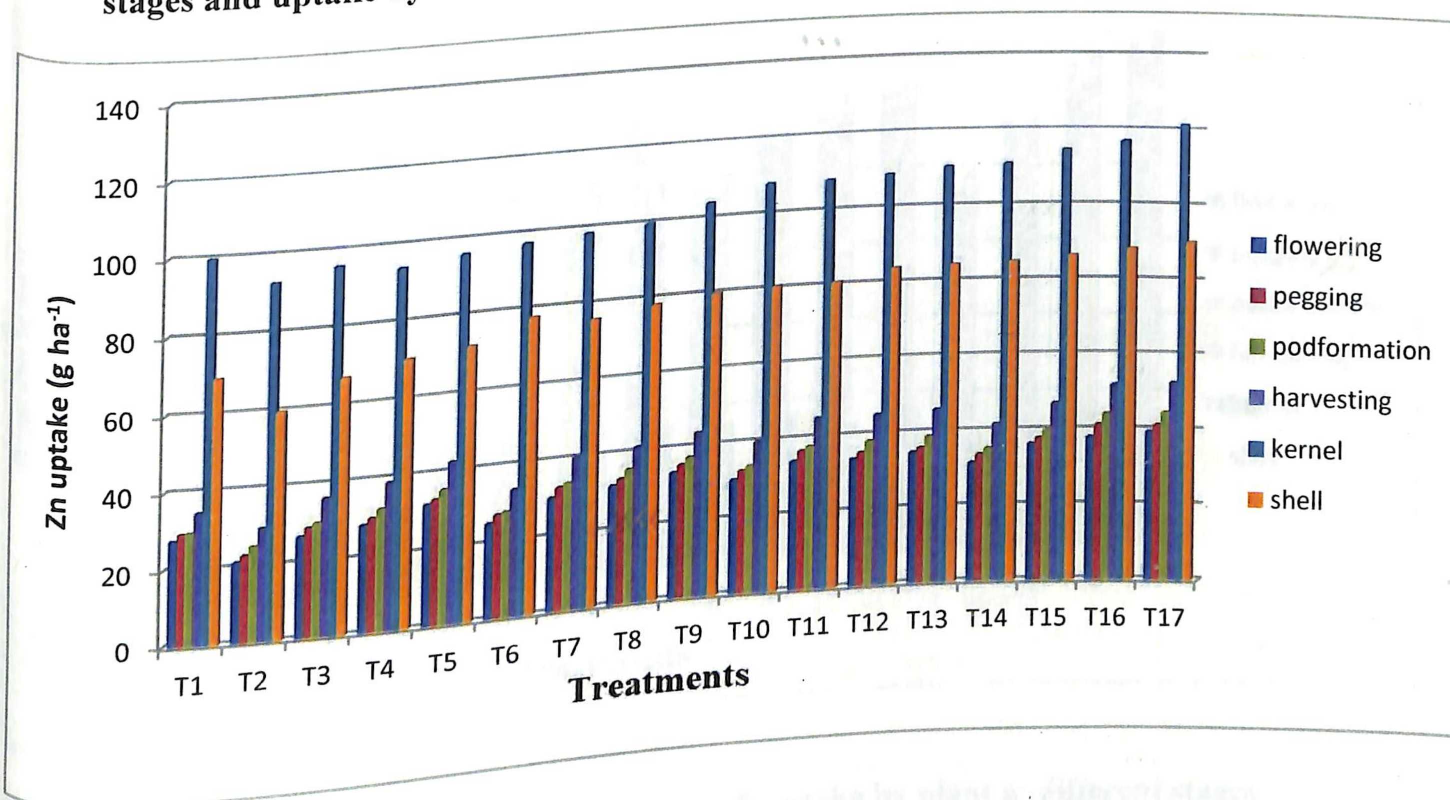

Fig 34: Effect of application of P and S on Zn uptake by plant at different stages and uptake by kernel and shell

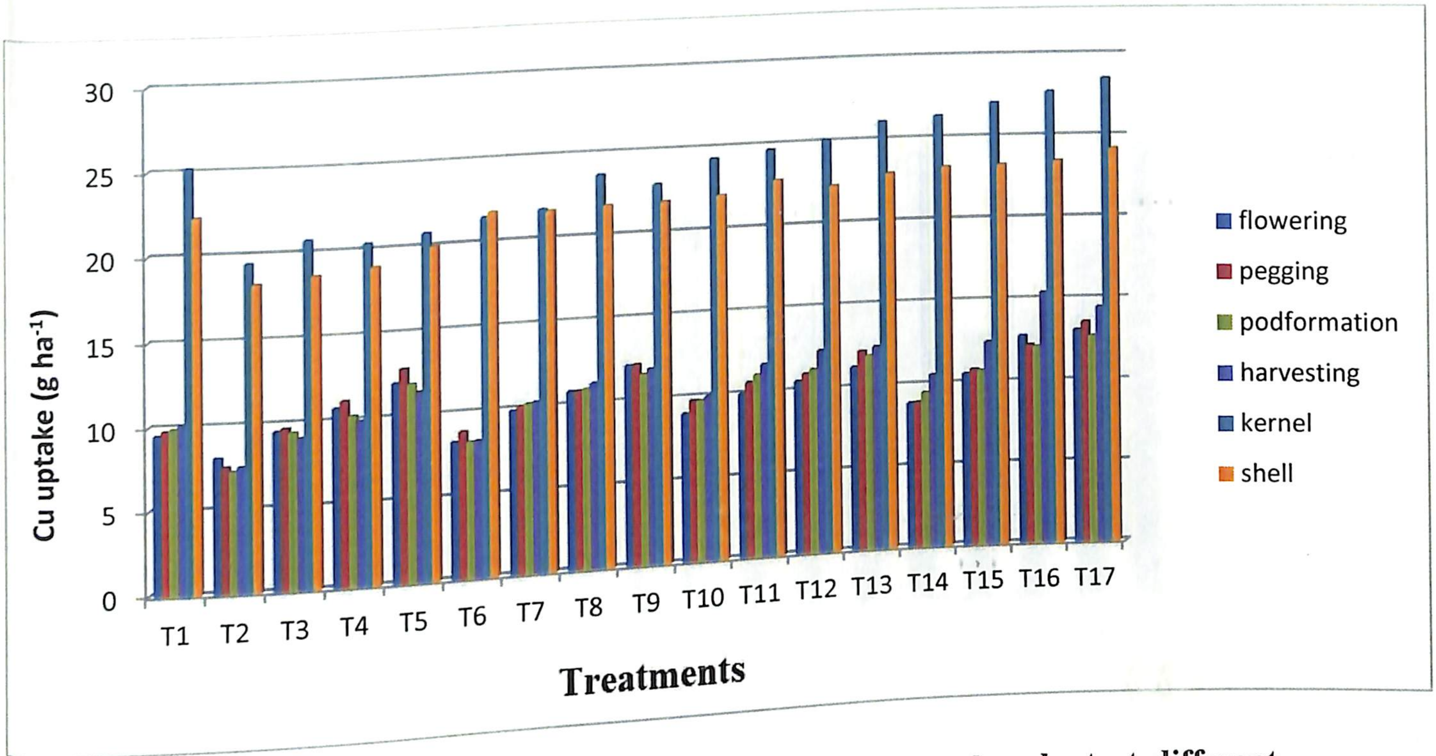

Fig 35: Effect of application of P and S on Cu uptake by plant at different stages and uptake by kernel and shell

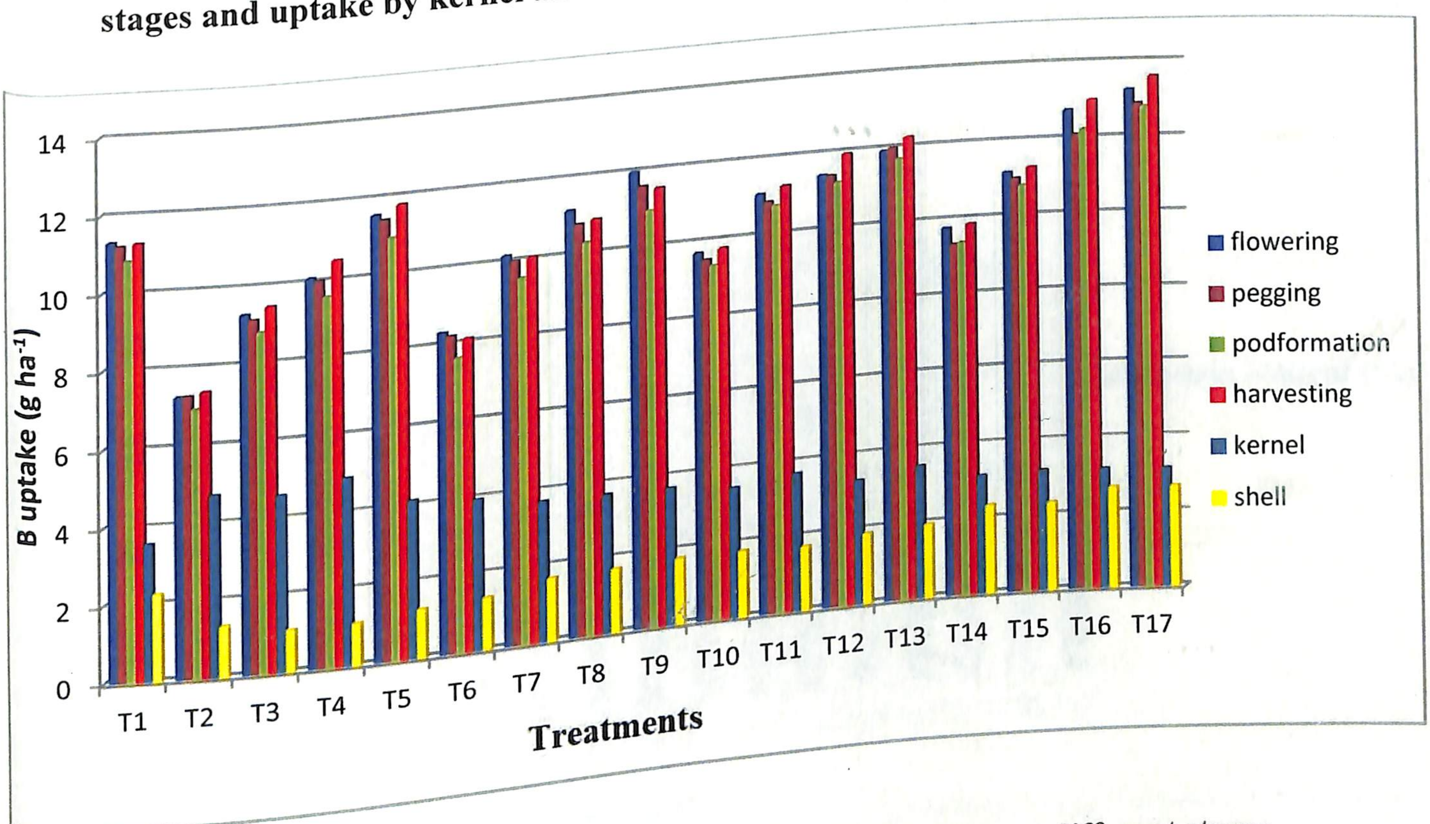

Fig 36: Effect of application of P and S on B uptake by plant at different stages and uptake by kernel and shell

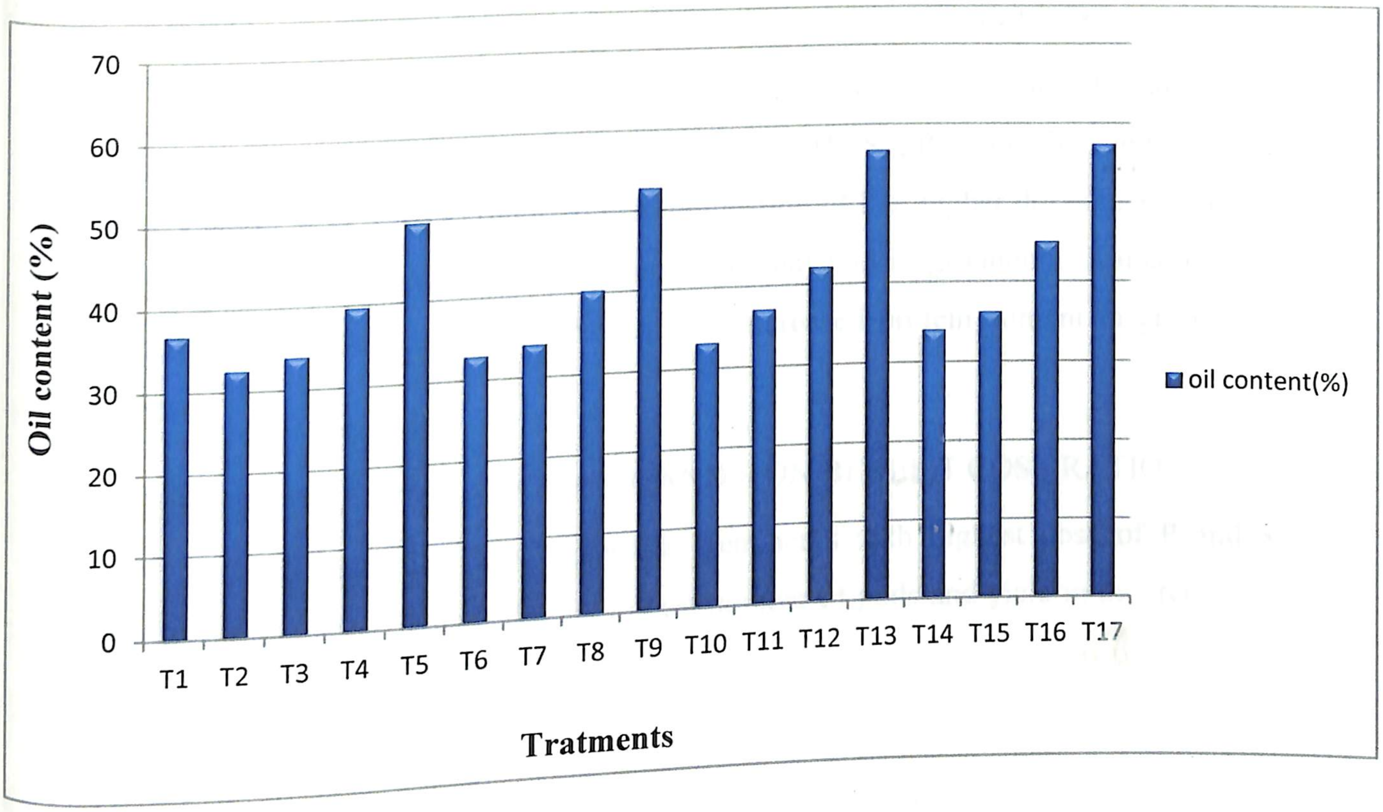

Fig 37: Effect of application of P and S on oil content (%) in groundnut kernel

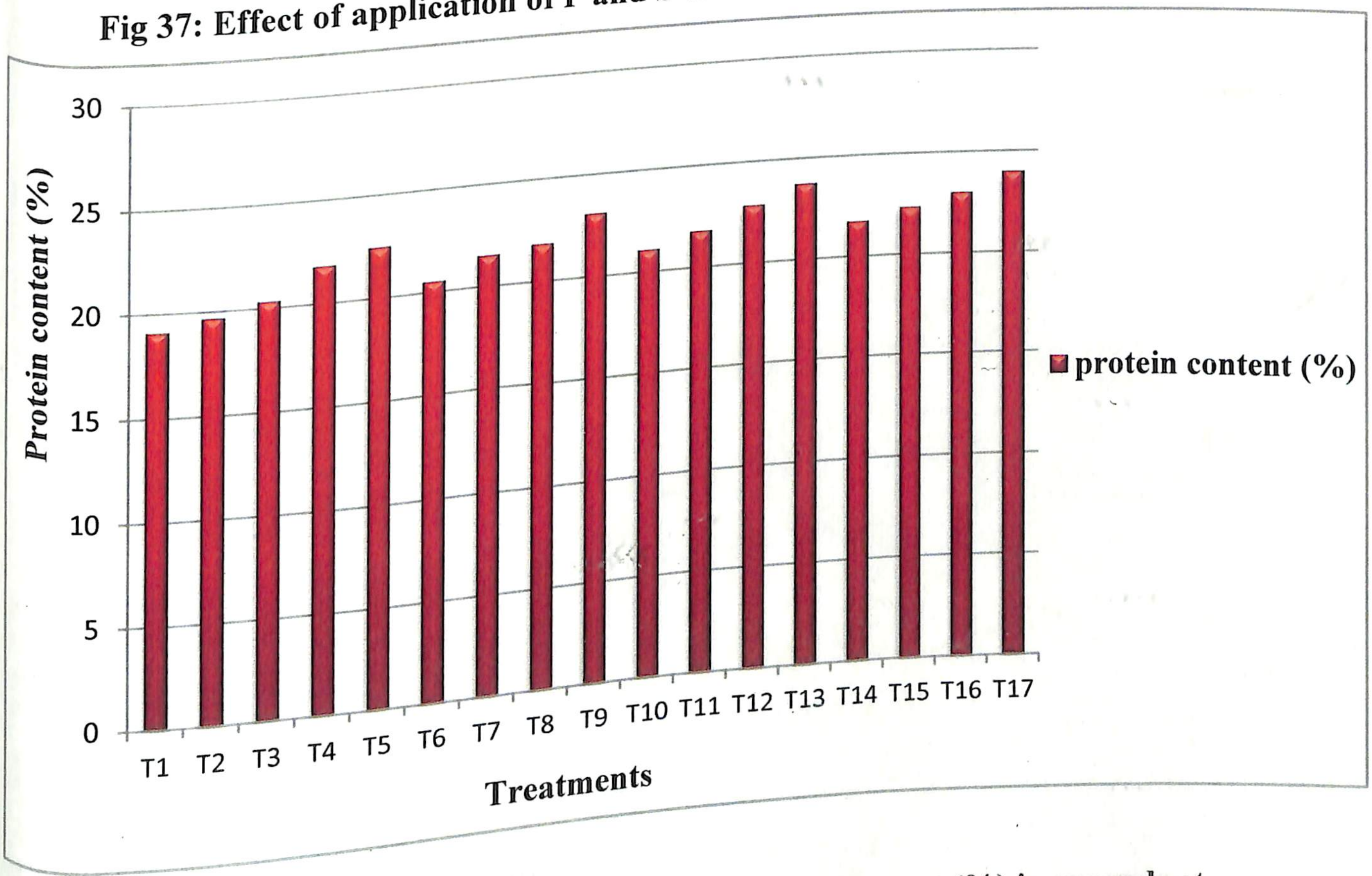

Fig 38: Effect of application of P and S on protein content (%) in groundnut kernel

5.4 EFFECT OF APPLICATION OF P AND S ON QUALITY PARAMETERS

Oil and protein content increased with increased dose of both P and S. The highest protein and oil content was recorded in T_{17} (P_3 S_3 ; P : 90 kg ha^{-1} and S: 30 kg ha^{-1}). Kadam *et al.* (2018) reported that application of P at higher doses increased the quality parameters such as oil and protein content (%) in groundnut. Kamara *et al.* (2011) also concluded that application of P increased protein content in groundnut kernels.

5.5 EFFECT OF APPLICATION OF P AND S ON BENEFIT COST RATIO

Benefit cost ratio was highest in treatments with highest dose of P and S fertilizer application. This is due to highest number of pods and yield in the treatment with highest dose of P and S.

Summary

6. SUMMARY

In Kerala, black soils are located in Chittur taluk of Palakkad district occupying an area of 2000 ha. These soils are dark, low in organic matter, calcareous, neutral to alkaline (pH 7.0 to 8.5), high in clay content and CEC. The texture of soil ranges from clay loam to clay. Even though these soils are fertile, the nutrient imbalances and poor physical conditions may adversely affect the yield of the crop These are deficient in phosphorus (P) and sulphur (S). So the availability of P and S is one of the yield limiting factors in this soil. Finding the interaction between S and P in black soils would help to understand the factors determining the availability of these nutrients to crops.

Soil samples were collected from different locations of Chittur and analyzed for available P and S. Field experiment was conducted in a field at Nellimed that is deficient in both P and S. The study consisted of a field experiment with groundnut variety, K-6 followed by analysis of soil, plant, kernel and shell. Experiment was laid out in factorial RBD with 17 treatments and 3 replications.

Treatment combinations were made with four levels of P and four levels of S with soil test based recommendations as control. N and K levels were kept same (based on POP recommendations of KAU) for all treatments except for the first treatment where soil test based recommendations was given. P_0 - 0 kg ha^{-1}, P_1 - 60 kg ha^{-1}, P_2 -75 kg ha^{-1} and P_3 -90 kg ha^{-1} were the four levels of P and S_0 - 0 kg ha^{-1}, S_1 - 10 kg ha^{-1}, S_2 - 20 kg ha^{-1} and S_3 - 30 kg ha^{-1} were the four levels of sulphur. Potassium dihydrogenphosphate was used as source of P and elemental sulphur was used as source of sulphur.

Application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} increased plant height and number of leaves per plant. Application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} resulted in highest number of pods as well as yield (3.68 t ha^{-1}). Effect of application of different doses of P and S was non-significant for pH, EC and OC. N content in soil increased by increasing levels of P and S. Application of P increased soil S and vice versa. P and S showed positive interaction. Available K content in soil decreased with increased dose of P. Ca content in soil decreased with increased levels of P due to complex formation. Mg showed synergistic interaction with P.

Application of P decreased B content in soil due to antagonistic interaction, whereas Available B content in soil increased with increased dose of S. Application of P reduced the availability of micronutrients such as Fe, Mn and Zn in soil due to the formation of insoluble compounds like Fe-P, Mn-P and Zn-P. Whereas available micronutrient content in soil increased with increased dose of S fertilizer application. Increased available micronutrient status of soil with increased dose of S may be due to slight reduction in pH of the soil as a result of application of acid forming fertilizers and also due to soluble sulphate formation. Available Cu content in soil was non-significant to the addition of different levels of P and S.

Plant nutrient content showed a decreasing trend from flowering to harvesting stage. Content of N, P, Mg and S in plant, kernel and shell was increased with increased levels of P and S due to enhanced availability of these nutrients from soil as well as increased vegetative growth and vigour of the plant. Content of K in plant, kernel and shell decreased with increased dose of P and increased with increased dose of S. Content of Ca in plants decreased with increased dose of P as a result of decreased availability in soil due to insoluble complex formation. Content of Fe, Mn, Zn, Cu and B in plants, kernel and shell decreased with increased dose of P due to reduced availability and competition and increased with increased dose of S due to increased availability in soil.

Uptake of nutrients followed increasing trend from flowering to harvesting stage. Uptake of nutrients by plant, kernel and shell increased with increased dose of P and S fertilizer application. It may be due to increased vegetative growth of plants followed by increased dry matter production. Uptake of S, Fe, Zn and Cu were higher in kernel than plant. Oil content and protein content in kernels increased with increased dose of both P and S. Application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} resulted in highest protein and oil contents. Benefit: cost ratio was calculated, and it was found that application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} resulted in highest benefit: cost ratio.

Future line of work

- Conduct OFT in different location before recommending for the farmers for adoption.
- Fractionation of phosphorus and sulphur in Vertisols of Kerala.
- Influence of phosphorus and sulphur application on soil biology of black soils of Kerala.
- Interaction study of phosphorus and sulphur in deficient black soils using different sources of nutrients.

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INTERACTION OF PHOSPHORUS AND SULPHUR IN BLACK COTTON SOILS OF PALAKKAD (AEU: 23) UNDER GROUNDNUT (*Arachis hypogaea* L.) CULTIVATION

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ABSTRACT OF THESIS

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ABSTRACT

Supply of nutrients in a balanced manner is one of the most important factors determining crop yield. Sometimes due to interaction between nutrients in soil, the applied nutrients may not be available for plant use. When the supply of one nutrient element affects the absorption and utilization of other nutrient element, the elements are said to be in interaction and interactions may be negative or positive. In Kerala, black cotton soils are seen in Chittur taluk of Palakkad district occupying an area of approximately 2000 ha. These soils are sandy clay loam, dark, calcareous, neutral to alkaline (pH 7.0 to 8.5), high in clay content and CEC. These soils are deficient in phosphorus (P) and sulphur (S). Finding the interaction between P and S in these soils will help to understand the factors determining the availability of these nutrients to crops.

The present study was carried out at Nellimed in Chittur taluk of Palakkad district during 2017-19. The objectives of the study were to find out the interaction of P and S in black cotton soils of Palakkad and to assess the treatment level of phosphorus and sulphur for maximizing the yield. The study consisted of a field experiment with groundnut variety, K-6 in black cotton soils of Chittur, Palakkad followed by analysis of soil, plant and pod samples taken from the experimental field. Soil samples were collected from different locations of Chittur and analyzed for available P and S. Field experiment was carried out in the field deficient in both P and S.

Experiment was laid out in factorial RBD with 17 treatments and 3 replications. Soil test based recommendation was taken as T_1 and treatment combinations were made with four levels of P and four levels of S. The levels of N and K applications are kept same (based on POP recommendations of KAU) for all treatments, except for the first treatment where soil test based recommendation was given. P_0 - 0 kg ha^{-1}, P_1 - 60 kg ha^{-1}, P_2 -75 kg ha^{-1} and P_3 -90 kg ha^{-1} were the four levels of P and S_0 - 0 kg ha^{-1}, S_1 - 10 kg ha^{-1}, S_2 - 20 kg ha^{-1} and S_3 - 30 kg ha^{-1} were the four levels of sulphur.

Physical characteristics of soil *viz.,* texture and bulk density were analyzed before experiment and chemical characteristics *viz.,* pH, EC, organic carbon, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B were analyzed before and after the experiment. Growth parameters such as plant height and number of leaves per plant were recorded at flowering, pegging, pod formation and

harvesting stages and yield parameters like number of pods per plant and yield were recorded at harvesting stage. The nutrient contents in plant were analyzed and uptake was computed in critical growth stages. The nutrient content, protein and oil content in pod were analyzed.

Soil nutrient status, plant nutrient content and uptake of nutrients were influenced by main effect and interaction effect of P and S. Application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} resulted in highest plant height and number of leaves per plant. Application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1} resulted in highest number of pods per plant and yield. Highest protein and oil content were recorded by application of P at 90 kg ha^{-1} and S at 30 kg ha^{-1}.

Application of increased dose of P increased the availability of S. Application of P reduced the availability of Fe, Mn and Zn in soil due to the formation of insoluble compounds like Fe-P, Mn-P and Zn-P. Application of P enhanced the availability of N. The K content in soil was reduced with increased dose of P application. Ca content in soil was reduced due to P fertilizer application.

Plant nutrient content showed a decreasing trend from flowering to harvest stage. Application of P and S enhanced content of P in plant and pod. Content of N, P, Mg and S was increased with increased levels of P and content of Fe, Mn, Zn, Cu and B was reduced with increased dose of P. The uptake of nutrients followed an increasing trend from flowering to harvest due to increased dry matter production. Uptake of S, Fe, Zn and Cu by kernel is higher compared to plant.

P and S showed a positive interaction and P at 90 kg ha^{-1} and S at 30 kg ha^{-1} was found to be the best treatment in black cotton soils of Palakkad for high yield, protein and oil content in groundnut.