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PHOSPHORUS AND BORON INTERACTIONS IN BLACK COTTON SOILS OF KERALA WITH RESPECT TO GROUNDNUT (*Arachis hypogaea* L.)

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(2016-11-011)

THESIS

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SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF HORTICULTURE

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KERALA, INDIA

2018

DECLARATION

I, hereby declare that the thesis entitled "**Phosphorus and boron interactions in black cotton soils of Kerala with respect to groundnut (*Arachis hypogaea* L.)**" 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.

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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
SSP	Single super phosphate
Zn	Zinc

Introduction

1. INTRODUCTION

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 depend on interaction between nutrients. When the supply of one of the nutrients affects absorption and utilization of 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).

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). Except for available P and B, all other soil nutrients are present either in medium level or adequate level. 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 thirds of world production is used for oil production. The nut (kernel) 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.

Boron is the most limiting micronutrient for groundnut production, as it has a role in kernel quality and flavor. Boron deficiency results in "hollow-heart" in groundnut kernels. B is involved in sugar transport, cell wall synthesis, and IAA synthesis. Boron deficiency causes low pod filling, shriveled seeds and hollow darkening or off-color in the center of the seed. Plants respond to B deficiency by slowing down growth. Boron deficiency inhibits root elongation by limiting cell enlargement and cell division. Severe B deficiency, leads to the death of root tips. Low B inhibits leaf expansion and thereby reduces photosynthetic capacity of plants. The early inhibition of root growth, compared to shoot growth, increases the shoot: root ratio, which may enhance the susceptibility of plants to environmental stresses such as deficient supplies of other nutrients and water deficit in soil.

In this context present study entitled "Phosphorus and boron interactions in black cotton soils of Kerala with respect to groundnut (*Arachis hypogaea* L.)" was carried out with following objectives:

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

Review of Literature

2. REVIEW OF LITERATURE

Literature on nutritional requirement of groundnut, nutrient uptake and interactions between nutrients are reviewed in this chapter

2.1 NUTRITIONAL REQUIREMENTS OF GROUNDNUT

2.1.1 Nitrogen

2.1.1.1 Influence of nitrogen on growth parameters

Groundnut is a leguminous crop, which can fix atmospheric nitrogen in its root nodule at the rate of 200-260 kg N ha^{-1}, which reduces the demand for applied N. Even though it fixes atmospheric N, it responds well to N fertilizer application (York and Colwell, 1951 and Williams, 1979). Application of N in early stages has beneficial effect on growth characters of groundnut (Reddy and Rao 1965).

Application of N increased the number of leaves, branches and height of groundnut plant (Punnoose, 1968). Nitrogen (N) is the structural constituent of the plant cell and plays an important role in plant metabolism (Mahapatra *et al.*, 1985). Singh and Ahuja (1985) opined that application of N at 25 kg ha^{-1} increased the growth of groundnut.

2.1.1.2 Influence of nitrogen on yield parameters

Reddy and Rao (1965) observed a decrease in yield of groundnut by application of 40 kg N ha^{-1}. Nijhawan and Maini (1966) observed increased yield of groundnut at small doses of N. Puntamkar and Bathkal (1967) viewed that application of 20 kg N resulted in significant increase in weight of pods and number of pods per plant in groundnut. Saini and Tripathi (1973) observed that application of 15 kg N ha^{-1} resulted in highest pod yield and better oil content.

Jadhar and Narkhende (1980) observed that N has significant role on number of pods per plant and number of filled pods per plant. About 86-92 per cent of N uptake by groundnut was through biological nitrogen fixation (BNF) which is equivalent to 125-178 kg N ha^{-1} (Dart *et al.,* 1983).

Higher doses of N produced more number of flowers and pegs (Saradhi *et al.,* 1990).N is required by plants in comparatively larger amounts than other elements. As a crop of *leguminosae* family, groundnut can fix as much as 40-80 kg N ha^{-1} yr^{-1} (Islam and Noor, 1992).

Application of 10-30 kg N ha^{-1} produced higher pod yield in groundnut and after that there was a decrease in pod yield (Pant and Katiyar, 1996; Patel *et al.,* 1994) whereas, Reddy *et al.* (1984) reported that application of N at the rate of 40-60 kg ha^{-1} increased number of pods per plant.

2.1.2 Phosphorus

2.1.2.1 Influence of phosphorus on growth parameters

Phosphorus (P) is the second major essential nutrient element for crop growth. The most obvious effect of P is on the plant root system. 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 nitrogen (Brady and Weil, 2002). Application of P at 132 kg ha^{-1} increased haulm yield in groundnut (York and Colwell, 1951). Punnoose (1968) studied effect of P on growth, yield and quality of groundnut and found that P application increased the number of leaves, branches, height of plant and weight of nodules per plant.

Shelke and Khuspe (1980) reported that dry matter production and P uptake by groundnut cv. Latur No.33 was highest with the application of 17.5 kg P_2O_5 ha^{-1}. Basha and Rao (1980) observed decrease in shoot length and number of leaves in groundnut under P deficiency. Change in the rate of P application from 30 to 90 kg ha^{-1} enhanced the growth of plant (Singh and Ahuja, 1985). Sebale and Khuspe (1986) reported that plant height, number of leaves, branches and dry weight per plant were increased by application of P at the rate of 60 kg ha^{-1}. Juan *et al*. (1986) reported that P application increased the plant height and dry matter yield.

Phosphorus is essential for energy storage and transfer. Adenosine di and tri phosphate (ADP and ATP) are known as energy currency of plants. (Tisdale *et al*., 1993). Higher dose of P increased the number of root nodules the number and weight of nodules, nitrogenase activity, leghaemoglobin content, leaf area and dry matter production increased by enhancing P_2O_5 rate from 0 to 30, 60 and 90 kg ha^{-1} (Patel *et al.,* 1994). Higher levels of P significantly increased root and shoot growth (Patel *et al.,* 1994). Plants meet their P requirement by uptake of phosphate anions from soil solution. P is important for root growth, root formation and N fixation (Lakshmamma and Raj, 1997).

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.

2.1.2.2 Influence of phosphorus on yield parameters

Banerjee *et al.* (1967) observed 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) reported a significant response of groundnut to superphosphate application. Choudhary (1979) viewed that pod yield of irrigated groundnut variety, TMV-2 was higher 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} increased pod yield from 1.42 to 2.5 t ha^{-1} and seed yield from 0.91 to1.58 t ha^{-1}. P application increased seed size and 100 pod weight. Application of P above 60 kg ha^{-1} had no effect on number of pods and it depended on soil fertility status (Rao *et al.,* 1984). Shelling per cent was increased by application of moderate to high level of P (Chauhan *et al.,* 1987).

Agasimani and Hosmani (1989) reported that response of P could be obtained when available soil P is less than 35 kg ha^{-1}. Balasubramanian and Palaniappan (1991) reported that higher the concentration of phosphorus, higher will be the amount of nitrogen fixed.

Total nitrogen uptake and proportion of nitrogen present in kernel is greatly influenced by phosphorus level and interaction between phosphorus and potassium had significant influence on kernel yield (Balasubramanian and Palaniappan, 1991). Samtana *et al.* (1994) observed improvement in yield attributes by addition of P. This was due to formation and proliferation of new roots and improvement in their functional activity. Ae *et al.* (1996) reported that groundnut showed superior ability to take up P from a soil with low P fertility compared with sorghum and soybean in acid soils. Root cell walls of groundnut showed higher P-solubilizing activity than those of soybean or sorghum. Response of crop to P application depends on initial available P in the soil.

There is higher requirement for P in legumes in comparison to non-legume crops because of its role in nodule formation and fixation of atmospheric nitrogen (Brady and Weil, 2002). Bala *et al.* (2011) reported that increased pod and seed index and shelling per cent of groundnut was due to early and greater availability of nitrogen and phosphorus to plants which favorably influenced the kernel development and kernel size..

2.1.3 Potassium

2.1.3.1 Influence of potassium on growth parameters

Dry matter production increased with higher levels of K in groundnut cv. TMV-2 (Rao, 1979). Mathew *et al.* (1983) observed that growth characters like plant height, number of branches, leaves per plant and LAI were increased with K application.

2.1.3.2 Influence of potassium on yield **parameters**

York and Colwell (1951) observed that groundnut grew well even in K deficient soil where other crops could not. High levels of soil K in the pod zone were undesirable as they resulted in pod rot and interfered with uptake of Ca by pegs and pods, which resulted in a higher per cent of pops and Ca deficiency in the seeds (Hallock and Garren, 1968; Csinos and Gaines, 1986).

Potassium nutrition has favorable effect on photosynthesis and translocation of food reserves from leaves to developing pods (Koch and Mengal, 1977). Number of pods per plant and seed test weight increased with higher level of K in groundnut variety, TMV-2 (Rao, 1979). There was an increase in pod yield and yield contributing characters with increase in K level (Loganathan and Krisnamoorthy, 1980). Loganathan and Krishnamoorthy (1980) reported that optimum dose of K for groundnut was 52 kg ha^{-1} for irrigated crop and 26 kg ha^{-1} for rainfed crop. Nair *et al.* (1981) reported that application of K fertilizer @ the rate of 80 kg ha^{-1} increased number of pods per plant. According to Ramanathan *et al.* (1982) application K fertilizer at 50 kg ha^{-1} yielded maximum number of pods per plant and test weight of seed. Chavan and Kalra (1983) observed that dry pod yield, shelling per cent, 1000 grain weight and oil content of groundnut cv. TG-1 were higher with 50 kg ha^{-1} than with 25 kg ha^{-1}.

Groundnut is a heavy feeder of K and adequate supply of this nutrient must be provided to obtain a better yield (Geetalakshmi *et al.,* 1993). Yakadri *et al.* (1992) viewed that 40-60 kg K_2O ha^{-1} was the optimum dose of K for groundnut. Hadwani and Gundalia (2005) reported that yield of pod and haulm was increased with K fertilizer application.

2.1.4 Secondary nutrients

2.1.4.1 Influence of Ca on growth and yield parameters

In order to avoid Ca deficiency, application of soluble source of Ca at early flowering stage is advocated. The developing pods require high Ca level in surrounding soil, because Ca absorbed by root did not translocate into pods and Ca required for pod development is absorbed directly from soil solution (Skelton and Shear, 1971). Calcium deficiency resulted in lower yield, darkened plumule in the seed, empty pods and sometimes plants remained green and continued to produce flowers and pegs without pods, which might be infertile (Sulhiram *et al.,* 1974).

Calcium (Ca) is required by groundnut plants from the time pegs began to appear for fruit formation, until the pods mature (Walker, 1975). Calcium is essential for proper development of pod and for production of high quality seed (Cox *et al.,* 1982). Ca requirement varied with seed size and smaller seeded cultivars required less Ca than larger seeded type, because of larger surface to volume ratio. Soil characters like soil water content, soluble Ca, exchangeable Ca and type of soil mineral present affected Ca uptake by groundnut (Keisling *et al.,* 1983).

For production of good quality groundnut kernel, soil Ca level must be in the range of 600-800 mg kg^{-1} (Kvien *et al.,* 1988; Sumner *et al.,* 1986). Morphological characters of pod like pod surface area, pod volume, number of days for maturation of pods and shell thickness influenced Ca uptake by pods (Kvien *et al.,* 1988). 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) observed that gypsum application for summer and rainy season groundnut in sandy loam soils of West Bengal @ the rate of 400 kg ha^{-1} recorded highest plant height (65.1cm).

2.1.4.2 Influence of magnesium on growth and yield parameters

Dowood (1982) indicated that application of three levels of Mg (0,120 and 240 kg $MgSO_4.7H_2O$ ha^{-1}) caused significant increase in phosphorus uptake by plant. Al-lami (1999) showed that increase in adding of $MgSO_4.7H_2O$ from 0 to 80 kg ha^{-1} caused a significant increase in available phosphorus in the soil from 0.23 to 0.25 c mol kg^{-1}.

2.1.4.3 Influence of sulphur on growth and yield parameters

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}. Babu *et al.* (2007) reported that application of S through gypsum @ of 40 kg ha^{-1} recorded highest pod and haulm yield. 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.

Rao *et al.* (2013) found that application of S at 45 kg ha^{-1} through 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 (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}. 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).

2.1.6 Micronutrients

2.1.6.1 Influence of micronutrients on growth and yield parameters

Mahajan *et al.* (1994) recorded that boron at 0.5 kg ha^{-1} applied through boronated super phosphate or borax increased dry pod yield (3200 kg ha^{-1}) followed by boron spray of 0.5 ppm (2 sprays, first at 30 days after germination and second at the time of flowering) gave higher yield than control. Subrahmaniyan *et al.* (2001) noticed that combined application of $ZnSO_4$ at 5 kg ha^{-1}, borax at 5 kg ha^{-1}, ferrous sulphate at 10 kg ha^{-1} recorded maximum number of pods per plant. Mahamoud *et al.* (2006) observed that foliar application of B at 25-50 ppm increased plant height, leaf area, total dry matter, number of pods and seed yield. Availability of micronutrients in soils is governed by soil pH, cation and anion exchange capacity and nutrient interactions. The application of B also promoted absorption of N by groundnut and increased plant height, plant dry weight and the total number of pods.

Singh *et al.* (2009) reported that soil application of boron at 1 kg ha^{-1} as agricol, solubor and borosol increased pod yield by 23, 18 and 12 per cent, respectively, compared to the spray of 9 per cent as borax and 5 per cent as boric acid.

Barthi *et al.* (2010) reported that application of micronutrients (Fe, Zn, B) along with recommended fertilizers improved growth parameters and chlorophyll content of groundnut. They observed highest pod yield and dry matter content on application of 20 kg ha^{-1} $ZnSO_4$ and 5 kg borax. . Reddy *et al.* (2011) reported 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} enhanced number of pods per plant. Kamalakannan and Ravichandran (2013) observed that application of 100 per cent NPK, $ZnSO_4$ at 25 kg ha^{-1}, B at 10 kg ha^{-1} and FYM at 12.5 t ha^{-1} recorded highest plant height at all critical stages of groundnut

Ravichandra *et al.* (2015) viewed that application of boron as foliar spray along with rhizobium at flowering and pod formation stage had positive effect on growth and yield of groundnut with increased plant height, number of branches, plant dry weight, number of pods per plant, 100 pod weight, seed index and pod yield. Excess spray of boron as foliar nutrition led to decrease in the above mentioned parameters.

2.1.7 Response of groundnut to combined application of N, P and K

Das (1982) reported that growth components were increased by applying NPK. Venkateswaralu and Nath (1989) reported the importance of balanced fertilizer schedule and its influence on groundnut. Combined application of NPK at the rate of 20: 40: 40 kg ha^{-1} produced highest yield (Pradhan and Das, 1989). Yadav (1990) found that the application of NPK at 20: 60: 40 kg ha^{-1} resulted in highest yield.

Whereas Balasubramaniam and Palaniappan (1991) reported that the application rate of 150 kg N and 50 kg K_2O ha^{-1} produced higher yield.

Patel *et al.* (1994) reported that application of 25 kg N + 50 kg P_2O_5 ha^{-1} increased the pod and haulm yield of groundnut *cv.* GAUG-1. Kachot *et al.* (1984) observed higher number of pegs per plant, number of pods per plant, pod weight per plant and test weight when 12.5 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1} was applied. Rana *et al.* (1984) reported that higher pod yield of 23.19 q ha^{-1} was obtained at 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} the increased the number of branches per plant significantly (Dholaria *et al.*, 1972).

Ghadekar *et al.* (1993) reported that pod yield was higher at the fertilizer rate of 40 kg N, 80 kg P_2O_5 and 30 kg K_2O ha^{-1} . NPK application @ the rate of 25 kg N + 75 kg P_2O_5 + 37.5 kg K_2O ha^{-1} gave mean pod yield of 3.55, 4.10 and 4.99 t ha^{-1} respectively (Thimmegowda, 1993).

Dahatonde (1982) revealed that combined application of inorganic fertilizer and organic manure recorded favorable effects on various growth characters and yield attributes of groundnut. They reported that application of 25:50 kg N and P_2O_5 ha^{-1} + 5 t FYM ha^{-1} recorded highest plant height, plant 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) reported that nitrogen and phosphorus uptake was highest with combination of 25:50 kg N and P_2O_5 ha^{-1} respectively. Dubey (1997) reported that, application of SSP at 60 kg P_2O_5 ha^{-1} was 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) reported that application of 80:60:20 kg ha^{-1} N, P_2O_5 and K_2O respectively showed maximum nutrient content as well as highest nitrogen, phosphorus and potassium uptake by kernel and haulm of groundnut. Sanchez and Owen (1978) reported that application 150 kg P_2O_5 ha^{-1} along with N and K increased pod yield from 0.75 to 2.07 t ha^{-1}.

Babu *et al.* (2007) reported that uptake of NPK by groundnut was higher in highly fertilized plots. 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 high fertility condition (50: 100: 50 kg NPK ha^{-1}).

2.2 NUTRIENT CONTENT AND UPTAKE

2.2.1 Influence of nitrogen on nutrient content and uptake

Uptake of nitrogen is more intensive during flowering and pod formation stages. During reproductive stages, there is continuous mobilization of N from leaves to the developing fruit, and this sometimes resulted in appearance of N deficiency symptoms (Kvien *et al.*, 1986). Chahal *et al.* (1983) observed that shoot N content was high at early and mid-flowering stages. Reddy *et al.* (1984) studied N uptake of 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) viewed that during seed filling stage leaf N declined from 4.01 to 2.85 per cent and stem N from 1.65 to 1.13 per cent and 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 as crop grew older.

2.2.2 Influence of phosphorus on nutrient content and uptake

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

Application of 60 kg P_2O_5 ha^{-1} increased N and P uptake and content 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.

2.2.3 Influence of potassium on nutrient content and uptake

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

2.2.4 Influence of secondary nutrients on nutrient content and uptake

Giri *et al.* (2014) reported that uptake of nutrients (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 application of S at 75 kg ha^{-1} recorded highest uptake of 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}) by groundnut. Singh *et al.* (2005) observed that S uptake by pods of groundnut increased significantly with increased levels of S up to 60 kg ha^{-1} (10.89 kg ha^{-1}). Patel *et al.* (2009) viewed that successive increase in S application up to 40 kg ha^{-1} improved NPS uptake by groundnut. The maximum uptake of nutrients was recorded at S application at 15 kg ha^{-1}. The minimum uptake of nutrients was recorded in no S treatment.

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

Veerabhadrappa and Yeledhalli (2005) revealed that foliar spray (N, P, K, Ca and S - commercial formulation of urea, SSP and MOP at 1 per cent level each) at 60 DAS along with 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 S (31.4kg ha^{-1}) uptake by groundnut.

2.2.5 Influence of micronutrients on nutrient content and uptake

Mahajan *et al.* (1994) reported that soil application of boron at 0.5 kg ha^{-1} through boronated superphosphate recorded higher uptake of nitrogen (127.4 kg ha^{-1}) and phosphorus (11.7 kg ha^{-1}) in clayey soils. Kamalakannan and Ravichandran (2013) reported that application of 100 per cent NPK, zinc sulphate at 25 kgha^{-1}, borox at 10 kg ha^{-1} and FYM at 12.5 t ha^{-1} showed highest NPK uptake at all the growth stages of crop. Nadaf and Chidanandappa (2015) observed 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}).

2.3 PROTEIN CONTENT

Nijhawan (1962) reported beneficial effect of application of nitrogen in increasing the protein content. Punnoose (1968) found that graded doses of P enhanced protein content in kernels. Basha and Rao (1980) observed that P deficiency decreased protein content in groundnut. Nair and Sadanandan (1981) found that protein content was increased with increased P application at 50-100 kg ha^{-1}. Nair and Sadanandan (1981) found that the protein content was decreased with increased dose of K from 25 to 75 kg ha^{-1}.

2.4 INTERACTIONS BETWEEN NUTRIENTS

2.4.1 P and B interaction

The effects of phosphorus deficiency like reduction in dry matter, soluble protein, DNA, activity of ribonuclease and increase in the activities of peroxidase, acid phosphatase and polyphenol oxidase were intensified by combined deficiency of boron and phosphorus in maize (Chatterjee *et al.*, 1990). The excessive application of P reduced uptake of B in citrus (Bingham *et al.*, 1958) and in strawberry (May and Pritts, 1993).

Gunes and Alpaslan (2000) reported that application of B resulted in increased B uptake and a decreased P uptake in all genotypes of maize. Similar way, application of P resulted in decreased B uptake and increased P uptake of the genotypes. B application caused decrease in dry weight of all genotypes where as dry weight of all genotypes was increased by application of P.

B is more toxic in the absence of P rather than the presence of P, and this toxicity could be alleviated by applications of P in the calcareous soils of semiarid areas. Pollard *et al.* (1976) reported that capacity for absorption of phosphate was shown to be reduced in *Zea mays* and *Vicia faba* suffering from boron deficiency. Tavajjoh *et al.* (2016) found that application of P and B fertilizers increased the concentration and total uptake of P and B in the seeds of rapeseed cultivars and there is a synergistic interaction between P and B. Kabir *et al.* (2013) reported that fertilizer level for P, Ca and B should be 50 kg ha^{-1}, 110 kg ha^{-1} and 2.5 kg ha^{-1} to attain maximum yield.

Adams and Winsor (1974) observed that boron content of the foliage was reduced by lime addition and high phosphate content in tomato. Kaya *et al.* (2009) showed that interaction between P and B had an effect on biomass of tomato. Fruit yield, number of fruits and average fruit weight decreased in the plants grown under high boron conditions.

2.4.2 Interaction of P with other nutrients

Phosphorus deficiency is a main yield limiting variable for crop production in acid and alkaline soils (Fageria *et al.,* 1983). Assessing the interaction of phosphorus with other nutrient is critical to keep up a balanced nutrient supply for enhancing crop yield. Phosphorus has a positive interaction with nitrogen and plant development (Sumner and Farina, 1986). Sumner and Farina (1986) viewed that increased growth required more of both N and P, the mutually synergistic effects resulted in growth stimulation and enhanced uptake of N and P.

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

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

Heavy application of P resulted in Fe deficiency. P interactions with Fe form Fe- phosphates which led to Fe chlorosis in plants (Ayed, 1970). P inhibits Fe absorption by roots and Fe transport from roots to shoots and inactivates plant Fe (Elliott and Lauchli, 1985; Moraghan and Mascagni, 1991).

Interaction between Ca and P was complex; it had both synergistic and antagonistic effect. 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. Fageria (1983) reported decreased uptake of P and Ca with increased concentration of K in rice. Lundergardh (1934) reported a higher absorption of P and

Ca at lower concentration of K. Acidifying effect of S application was important in mobilization of Fe, Mn, Zn and P in calcareous soil (Soliman *et al.,* 1992).

2.4.3 Interaction of B with nutrients

Hosseini *et al.* (2007) showed that Zn application increased plant height and dry matter yield where as high levels of B decreased plant height and dry matter yield. In grape, increased Zn concentration decreased B toxicity Similarly, B toxicity symptoms were severe in Zn deficient orange (Swietlik, 1995).

Mahmoud *et al.* (2006) reported synergistic interaction between B and N. The foliar application of B (25-50ppm) in combination with 40 kg N ha^{-1} has significantly increased plant height, leaf area, total dry weight, number of pods and seed yield. Daliparthy *et al.* (2008) reported that application of K led to decrease in B level and caused B deficiency.

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Phosphorus and boron interactions in black cotton soils of Kerala with respect to groundnut (*Arachis hypogaea* L.)" was carried out in College of Horticulture, Vellanikkara during 2016-18. Study consists of a field experiment with groundnut in black cotton soils of Chittur, Palakkad followed by laboratory analysis of soil, plant and pod samples taken from experimental field. The materials used and methods followed in the study are described in this chapter.

3.1 COLLECTION AND ANALYSIS SOIL SAMPLE

Soil samples were collected from different locations of Chittur and analyzed for available P and B. Three to four samples were collected from each location from 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 B. Available P and B status of samples collected from different locations are given below.

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

Sl. no.	Place	Available P (kg ha^{-1})	Water soluble B (mg kg^{-1})
1	Erimedu	32.00	0.30
2	Kochikkadu	22.67	0.48
3	Kammalathara	15.74	0.50
4	Malayampallam	25.65	0.37
5	Nellimedu	8.70	0.30

Plate 1: Initial soil sample collection from experimental field

Plate 2: View of field before experiment

The experiment was carried out where deficiencies of both P and B were noticed. The techniques followed for estimation of physico – chemical properties of soil are given below.

Table 2: Methods followed in soil analysis

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 mehod	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: Initial physico – chemical properties of soil in the experimental site

Parameter	Value
Bulk density (Mg m^{-3})	1.35
Texture	Sandy clay loam
Coarse sand (%)	31.85
Fine sand (%)	27.30
Silt (%)	18.60
Clay (%)	22.25
pH	7.83
Electrical conductivity (dS m^{-1})	0.242
Organic carbon (%)	1.40
Available nitrogen (kg ha^{-1})	288.50
Available phosphorus (kg ha^{-1})	8.70
Available potassium (kg ha^{-1})	384.48
Available calcium (mg kg^{-1})	4454.50
Available magnesium (mg kg^{-1})	812.54
Available sulphur (mg kg^{-1})	6.05
Available B (mg kg^{-1})	0.31
Available Fe (mg kg^{-1})	8.39
Available Mn (mg kg^{-1})	7.18
Available Zn (mg kg^{-1})	1.03
Available Cu (mg kg^{-1})	1.24

3.2 GENERAL DETAILS OF FIELD EXPERIMENT

3.2.1 Experimental site

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

3.2.2 Climate and weather

The experimental site has humid tropical climate.

3.2.3 Cropping season

Experiment was conducted during May to August, 2017.

3.2.4 Cropping history of field

Maize was cultivated in 2015 and then field was left fallow for one year.

3.2.5 Crop variety

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

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	: 4

Spacing : 15cm x 15cm.

Plot size : 4 x 2 m^2

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

Seeds were collected from National Seed Cooperation (NSC), Palakkad.

3.3.1 Treatment details

Different combinations of P and B at different doses were the treatments. Treatment combinations are made with four levels of P and four levels of B and soil test based recommendation is taken as control.

Factor A

Levels of phosphorus (P) – 4

P_0 -Control

P_1 -60 kg ha^{-1}

P_2 -75 kg ha^{-1}

P_3 -90 kg ha^{-1}

Factor B

Levels of boron (B) – 4

B_0 - Control

B_1 – 5 kg ha^{-1}

B_2 – 10 kg ha^{-1}

B_3 – 15 kg ha^{-1}

Plate 3: View of field at flowering stage of groundnut crop

Treatment combinations

T_1 : Soil test based recommendations

Treatment	Notation	Treatment	Notation
T_2	$P_0 B_0$	T_{10}	$P_2 B_0$
T_3	$P_0 B_1$	T_{11}	$P_2 B_1$
T_4	$P_0 B_2$	T_{12}	$P_2 B_2$
T_5	$P_0 B_3$	T_{13}	$P_2 B_3$
T_6	$P_1 B_0$	T_{14}	$P_3 B_0$
T_7	$P_1 B_1$	T_{15}	$P_3 B_1$
T_8	$P_1 B_2$	T_{16}	$P_3 B_2$
T_9	$P_1 B_3$	T_{17}	$P_3 B_3$

Nitrogen and potassium levels are kept same (based on POP recommendations of KAU) for all treatments except for the first treatment where soil test based recommendations were given.

3.4.1 Land preparation

Land was ploughed thoroughly using tractor and made into fine tilth. Gross area of field was 17 cents and net area was 13.6 cents. The selected field was divided into four blocks and each block was further divided into 17 treatment plots. Furrow of 1m width was taken in between blocks for drainage.

4 m	4 m	4 m	4 m
T15	T7	T4	T3
T8	T4	T12	T9
T11	T15	T8	T15
T17	T13	T10	T4
T1	T11	T6	T16
T12	T10	T17	T10
T14	T6	T1	T17
T2	T16	T13	T14
T9	T14	T9	T11
T5	T2	T3	T7
T13	T3	T14	T6
T16	T1	T5	T13
T7	T5	T16	T1
T6	T9	T2	T8
T4	T17	T15	T12
T3	T8	T11	T5
T10	T12	T7	T2

0.5-1m

Plate 4: View of field at pegging stage of groundnut crop

Plate 5: View of field at pod setting stage of groundnut crop

3.4.2 Application of manures and fertilizers

Fertilizers were applied as basal dose at the time of sowing. Farm yard manure was applied in all the plots equally. Urea and MOP were also applied in equal quantity based on POP except in T_1 where soil test based recommendations were given. Different levels of SSP and borax were given based on treatment requirements.

Table 3: Rate of application of fertilizers in the experimental field

Treatments	Urea (kg ha^{-1})	SSP (kg ha^{-1})	MOP (kg ha^{-1})	Borax (kg ha^{-1})
T_1	21.74	416.67	150	10
T_2	`21.74	0	150	0
T_3	21.74	0	150	5
T_4	21.74	0	150	10
T_5	21.74	0	150	15
T_6	21.74	333.33	150	0
T_7	21.74	333.33	150	5
T_8	21.74	333.33	150	10
T_9	21.74	333.33	150	15
T_{10}	21.74	416.67	150	0
T_{11}	21.74	416.67	150	5
T_{12}	21.74	416.67	150	10
T_{13}	21.74	416.67	150	15
T_{14}	21.74	500	150	0
T_{15}	21.74	500	150	5
T_{16}	21.74	500	150	10
T_{17}	21.74	500	150	15

3.4.3 Irrigation

Furrow irrigation was done once in 7 days.

3.4.4 Weed management

Hand weeding was done at 15 days interval. At the time of flowering, earthing up was done along with weeding. Field was kept without any disturbance after 45 days of sowing.

3.4.5 Plant protection

Pest and disease incidence was very meager in the field. Peacock menace was controlled by using colored reflecting papers across the field.

3.4.6 Harvesting

Harvesting was done when leaves started yellowing and began to dry up. Plants were ready for harvest at 80 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 and tagged for taking biometric observations. The following biometric observations were recorded from these plants at flowering, peg development, pod setting and harvesting stages and mean values were computed.

Plant height

Plant height was recorded at flowering, peg development, pod setting and harvesting stages and mean values were recorded.

Plate 6: Harvesting of groundnut crop

Number of leaves

Number of leaves was taken at flowering, peg development, pod setting and harvesting stages and mean values were recorded.

No.of pods/plant

No. of pods/plant were recorded at harvesting stage and mean values were recorded.

Yield

Fresh weight of pods and haulm were taken at harvesting stage and mean values were noteded.

3.5.2 Soil analysis

Soil samples were collected from a depth of 0-15 cm and analyzed for 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 analysis are given in table no. 2.

3.5.3 Plant analysis

Collection of samples

Plant samples were collected at flowering, peg development, pod setting and harvesting stages. Plant samples were first washed with tap water to remove dirt and soil. These were then washed with single and double distilled water, and shade dried for a week. The shade dried samples were kept in an oven @ 60 ^{0}C and dry weight was recorded. The samples were powdered 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) of these samples were analyzed. The methods followed to determine the nutrients are given in the table below.

Table 4: Method 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 Nutrient uptake

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 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 "Phosphorus and boron interactions in black cotton soils of Kerala with respect to groundnut (*Arachis hypogaea* L.)" are presented in this chapter.

4.1 GROWTH AND YIELD PARAMETERS OF GROUNDNUT

The effect of P and B application on growth parameters of groundnut like plant height and number of leaves, yield parameters like number of pods and yield at flowering, pegging, pod development and harvest stages under different doses of phosphorus and boron 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_3B_0 (P, 90kg ha^{-1} and B,0 kg ha^{-1}) showed highest plant height at flowering (15.42 cm), pegging (24.21 cm) and pod development (32.99 cm)stage. At harvest stage, the treatment P_1B_1 (P, 60 kg ha^{-1} and B, 10 kg ha^{-1}) showed highest plant height (37.15 cm). Plant heights at different stages were found to be significantly influenced due to main effect and interaction effect. Plant height was enhanced by increased dose of P but decreased with increased dose of B.

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

T_1: 11.07

	B_0	B_1	B_2	B_3	Mean
P_0	12.44	10.65	8.88	8.55	**10.13**
P_1	12.66	12.06	11.59	12.31	**12.15**
P_2	14.72	13.67	11.03	9.38	**12.2**
P_3	15.42	13.87	13.01	12.9	**13.8**
Mean	**13.81**	**12.56**	**11.13**	**10.78**	
CD (0.05) P; 0.104		**CD (0.05) B; 0.104**		**CD (0.05) PxB; 0.209**	
SE (m) P; 0.037		**SE (m) B; 0.037**		**SE (m) PxB; 0.073**	

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

T_1: 20.10

	B_0	B_1	B_2	B_3	Mean
P_0	21.43	19.59	17.34	16.98	**18.83**
P_1	21.96	21.12	20.72	21.37	**21.29**
P_2	23.11	22.57	19.93	17.72	**20.83**
P_3	24.21	23.34	22.8	22.39	**23.18**
Mean	**22.68**	**21.65**	**20.19**	**19.61**	
CD (0.05) P; 0.058		**CD (0.05) B; 0.058**		**CD (0.05) PxB; 0.117**	
SE (m) P; 0.02		**SE (m) B; 0.02**		**SE (m) PxB; 0.041**	

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

T_1: 30.85

	B_0	B_1	B_2	B_3	Mean
P_0	30.42	28.53	25.79	25.41	**27.53**
P_1	31.26	30.17	29.84	30.43	**30.43**
P_2	31.49	31.46	28.83	26.06	**29.46**
P_3	32.99	32.8	32.59	31.87	**32.56**
Mean	**31.54**	**30.74**	**29.26**	**28.44**	
CD (0.05) P; 0.05		**CD (0.05) B; 0.05**		**CD (0.05) PxB; 0.1**	
SE (m) P; 0.018		**SE (m) B; 0.018**		**SE (m) PxB; 0.035**	

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

T_1: 35.75

	B_0	B_1	B_2	B_3	Mean
P_0	33.6	30.93	35.4	34.68	**33.65**
P_1	35.43	33.23	37.15	34.55	**35.09**
P_2	31.23	34	35.83	32.95	**33.5**
P_3	31.95	34.15	36.23	34.95	**34.32**
Mean	**33.05**	**33.08**	**36.15**	**34.28**	
CD (0.05) P; 0.865		**CD (0.05) B; 0.865**		**CD (0.05) PxB; 1.731**	
SE (m) P; 0.303		**SE (m) B; 0.303**		**SE (m) PxB; 0.606**	

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. The treatment, P_3B_0 (P, 90kg ha^{-1} B, 0 kg ha^{-1}) showed highest number of leaves at flowering stage (39.64), pegging stage (60.58) and pod development stage (81.53).

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

T_1: 29.6

	B_0	B_1	B_2	B_3	Mean
P_0	34.44	29.26	28.65	25.62	**29.49**
P_1	34.63	30.40	30.42	30.66	**31.53**
P_2	39.25	36.45	29.22	28.82	**33.43**
P_3	39.64	39.13	35.24	34.79	**37.19**
Mean	**36.99**	**33.81**	**30.88**	**29.97**	
CD (0.05) P; 0.083		**CD (0.05) B; 0.083**		**CD (0.05) PxB; 0.165**	
SE (m) P; 0.029		**SE (m) B; 0.029**		**SE (m) PxB; 0.058**	

Table 12: Effect of P and B application on number of leaves at pod setting

T_1: 49.5

	B_0	B_1	B_2	B_3	Mean
P_0	52.05	48.26	43.11	53.74	**49.29**
P_1	48.14	45.47	52.43	47.63	**48.42**
P_2	50.45	54.99	51.30	53.21	**52.49**
P_3	60.58	58.6	47.79	53.79	**55.19**
Mean	**52.81**	**51.83**	**48.66**	**52.09**	
CD (0.05) P; 0.089		**CD (0.05) B; 0.089**		**CD (0.05) PxB; 0.178**	
SE (m) P; 0.031		**SE (m) B; 0.031**		**SE (m) PxB; 0.062**	

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

T_1: 68.00

	B_0	B_1	B_2	B_3	Mean
P_0	69.65	67.25	57.57	82.02	**69.12**
P_1	61.60	60.37	74.45	64.60	**65.26**
P_2	61.65	73.53	73.43	77.60	**71.55**
P_3	81.52	78.07	60.34	72.77	**73.18**
Mean	**68.61**	**69.81**	**66.45**	**74.25**	
CD (0.05) P; 0.126		**CD (0.05) B; 0.126**		**CD (0.05) PxB; 0.252**	
SE (m) P; 0.044		**SE (m) B; 0.044**		**SE (m) PxB; 0.088**	

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

T_1: 55.95

	B_0	B_1	B_2	B_3	Mean
P_0	59.65	54.25	47.58	62.03	**55.88**
P_1	51.60	40.38	54.45	54.60	**50.26**
P_2	41.65	67.53	63.43	70.60	**60.80**
P_3	68.53	70.08	50.34	52.78	**60.43**
Mean	**55.36**	**58.06**	**53.95**	**60.00**	
CD (0.05) P; 0.130		**CD (0.05) B; 0.130**		**CD (0.05) PxB; 0.261**	
SE (m) P; 0.046		**SE (m) B; 0.046**		**SE (m) PxB; 0.091**	

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 B. Increase in pod number per plant can be observed with increased dose of P application (table 14). The treatment, P_3B_2 (P, 90 kg ha^{-1} and B, 5 kg ha^{-1}) produced highest number of pods per plant. Number of pods increased with increased dose of P application.

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 B fertilizer application. The highest yield (3.66 t ha^{-1}) was recorded in P_3 B_1 (P, 90 kg ha^{-1} and B, 5 kg ha^{-1}). The lowest yield (3.17 t ha^{-1}) was in P_0 B_3 (P, 0 kg ha^{-1} and B, 15 kg ha^{-1}). Yield was increased with increased dose of P application.

4.2 PHYSICO – CHEMICAL CHARACTERISTICS OF SOIL

4.2.1 Soil pH

The effect of application of different levels of P and B on soil pH is given in the table 16. Data showed that none of main effects and interaction effect has significant influence on the pH. There was only a slight change in pH after the harvest. pH varied from 7.80 to 7.85.

4.2.2 Electrical conductivity

The effect of application of different levels of P and B on soil EC is given in the table 17. The main effect of different levels of P and B has no effect on EC, whereas the interaction effects were found to be significant. EC of soil was maximum in treatment, P_1 B_0 (0.298 dS m^{-1}).

4.2.3 Organic carbon

The data on effect of application of different levels of P and B 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.

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

T_1: 16.35

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	13.33	13.25	12.93	12.38	**12.97**
P_1	15.35	15.08	14.48	14.30	**14.80**
P_2	19.48	19.08	18.53	18.23	**18.83**
P_3	21.53	22.35	23.33	21.38	**22.14**
Mean	**17.42**	**17.44**	**17.31**	**16.57**	
CD (0.05) P; 0.103		**CD (0.05) B; 0.103**		**CD (0.05) PxB; 0.207**	
SE (m) P; 0.036		**SE (m) B; 0.036**		**SE (m) PxB; 0.072**	

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

T_1: 3.40

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	3.28	3.22	3.17	3.02	**3.17**
P_1	3.34	3.33	3.30	3.40	**3.34**
P_2	3.45	3.52	3.52	3.43	**3.48**
P_3	3.57	3.66	3.64	3.54	**3.60**
Mean	**3.41**	**3.43**	**3.41**	**3.35**	
CD (0.05) P; 0.056		**CD (0.05) B; 0.056**		**CD (0.05) PxB; 0.113**	
SE (m) P; 0.02		**SE (m) B; 0.02**		**SE (m) PxB; 0.039**	

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

T_1:7.80

	B_0	B_1	B_2	B_3	Mean
P_0	7.85	7.85	7.84	7.84	**7.84**
P_1	7.84	7.84	7.84	7.81	**7.83**
P_2	7.84	7.85	7.83	7.84	**7.84**
P_3	7.82	7.84	7.85	7.84	**7.84**
Mean	**7.84**	**7.85**	**7.84**	**7.83**	
CD (0.05) P; NS		**CD (0.05) B; NS**		**CD (0.05) PxB; NS**	
SE (m) P; 0.005		**SE (m) B; 0.005**		**SE (m) PxB; 0.010**	

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

T_1: 0.281

	B_0	B_1	B_2	B_3	Mean
P_0	0.285	0.285	0.278	0.286	**0.283**
P_1	0.298	0.259	0.294	0.251	**0.275**
P_2	0.290	0.290	0.289	0.290	**0.290**
P_3	0.285	0.293	0.291	0.288	**0.289**
Mean	**0.289**	**0.282**	**0.288**	**0.279**	
CD (0.05) P; NS		**CD (0.05) B; NS**		**CD (0.05)PxB; 0.023**	
SE (m) P; 0.004		**SE (m) B; 0.004**		**SE (m) PxB; 0.008**	

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

T_1: 1.041

	B_0	B_1	B_2	B_3	Mean
P_0	1.005	1.040	1.074	1.005	**1.031**
P_1	1.043	1.020	1.055	1.009	**1.032**
P_2	1.055	1.055	1.005	1.063	**1.044**
P_3	1.082	1.013	1.090	1.086	**1.067**
Mean	**1.046**	**1.032**	**1.056**	**1.040**	
CD (0.05) P; NS		**CD (0.05) B; NS**		**CD (0.05)PxB; NS**	
SE (m) P; 0.015		**SE (m) B; 0.015**		**SE (m) PxB; 0.030**	

4.3 NUTRIENT STATUS OF SOIL

4.3.1 Available nitrogen

The effects of application of different levels of P and B on available N are given in the table 19. Data showed that main effect, different levels of P and B have an influence on available nitrogen in the soil. N increased with increased dose of P application. However the interaction effect has no significant influence on available nitrogen.

4.3.2 Available phosphorus

The influence of application of different levels of P and B on available P is given in the table 20. Data showed that main effect of P and B and interaction effects were found to be significant. In comparison with initial P, available P was increased in all treatments due to fertilizer application. Treatment, P_3 B_0 (P, 90 kg $ha^{-1}$and B, 0 kg ha^{-1}) showed highest available P (51.31 kg ha^{-1}). A decrease in available P with increased dose of B can be observed among treatments.

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

T_1: 254.02

	B_0	B_1	B_2	B_3	Mean
P_0	260.29	257.15	257.15	250.88	**256.37**
P_1	260.29	257.15	254.02	254.02	**256.37**
P_2	285.38	282.24	279.10	266.56	**278.32**
P_3	291.65	288.51	285.38	282.24	**286.94**
Mean	**274.40**	**271.26**	**268.91**	**263.42**	
CD (0.05) P; 5.793		**CD (0.05) B; 5.793**		**CD (0.05) PxB; NS**	
SE (m) P; 2.027		**SE (m) B; 2.027**		**SE (m) PxB; 4.054**	

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

T_1: 34.75

	B_0	B_1	B_2	B_3	Mean
P_0	18.93	15.66	15.10	12.75	**15.61**
P_1	32.89	29.68	28.40	23.90	**28.72**
P_2	40.98	36.53	36.29	28.08	**35.47**
P_3	51.31	50.36	38.15	35.36	**43.80**
Mean	**36.03**	**33.06**	**29.49**	**25.02**	
CD (0.05) P; 0.794		**CD (0.05) B; 0.794**		**CD (0.05) PxB; 1.588**	
SE (m) P; 0.278		**SE (m) B; 0.278**		**SE (m) PxB; 0.556**	

4.3.3 Available potassium

The influence of application of different levels of P and B on available K is given in the table 21. The main effect of P and B and interaction effects were found to be significant. Treatment, P_1B_3 (P, 60 kg ha $^{-1}$ and B, 15 kg ha $^{-1}$) showed highest K content (454.72 kg ha $^{-1}$)

4.3.4Available calcium

The influence of application of different levels of P and B on available Ca is given in the table 22. Available Ca significantly varied due to main effects of P and B and interaction effects. Available Ca in soil increased compared to initial sample due to fertilizer application. All the treatments had high available Ca. Highest available calcium was in treatment, P_0B_3 (4,975.31 mg kg^{-1}).

4.3.5Available magnesium

The influence of application of different levels of P and B 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 B. Treatment, P_3B_1 had highest available Mg (730.56 mg kg^{-1}). Mg showed positive interaction with P application.

4.3.6 Available sulphur

The influence of application of different levels of P and B on available S is given in the table 24. There was a noticeable change in available S due to different levels of fertilizer application. Highest available S was in treatment, P_3B_3 (20.76 mg kg^{-1}). Available S is influenced by both main effects and interaction effect of P and B.

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

T_1: 374.00

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	409.36	445.48	438.76	442.96	**434.14**
P_1	448.28	447.44	369.6	454.72	**430.01**
P_2	428.12	451.08	306.88	321.72	**376.95**
P_3	319.20	365.96	372.4	427.56	**371.28**
Mean	**401.24**	**427.49**	**371.91**	**411.74**	
CD (0.05) P; 3.759		**CD (0.05) B; 3.759**		**CD (0.05) PxB;7.518**	
SE (m) P; 1.315		**SE (m) B; 1.315**		**SE (m) PxB; 2.631**	

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

T_1: 4,325.31

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	4573.44	4574.69	4615.31	4675.31	**4609.69**
P_1	4314.38	4396.25	4464.06	4555.94	**4432.66**
P_2	4399.06	4540.00	4523.44	4554.38	**4504.22**
P_3	4447.81	4640.00	4650.00	4705.00	**4610.70**
Mean	**4433.67**	**4537.73**	**4563.20**	**4622.66**	
CD (0.05); P 33.948		**CD (0.05); B 23.948**		**CD (0.05) PxB; 67.897**	
SE (m) P; 11.879		**SE (m) B; 11.879**		**SE (m) PxB; 23.759**	

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

T_1: 687.46

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	715.84	694.28	681.56	697.78	**697.37**
P_1	663.25	675.47	720.00	646.41	**676.28**
P_2	702.16	650.72	718.56	726.22	**699.41**
P_3	728.06	725.59	730.56	711.75	**723.99**
Mean	**702.33**	**686.52**	**712.67**	**695.54**	
CD (0.05) P; 6.443		**CD (0.05) B; 6.443**		**CD (0.05) PxB; 12.887**	
SE (m) P; 2.255		**SE (m) B; 2.225**		**SE (m) PxB; 4.509**	

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

T_1:12.15

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	8.85	7.86	7.56	7.39	**7.91**
P_1	8.63	11.74	12.02	13.20	**11.40**
P_2	13.72	14.76	14.91	16.51	**14.97**
P_3	18.92	19.41	20.49	20.76	**19.89**
Mean	**12.53**	**13.44**	**13.74**	**14.46**	
CD (0.05) P; 0.538		**CD (0.05) B; 0.538**		**CD (0.05) PxB; 1.076**	
SE (m) P; 0.188		**SE (m) B; 0.188**		**SE (m) PxB; 0.376**	

4.3.7Available iron

The influence of application of different levels of P and B on available Fe is given in the table 25. Highest available Fe was in treatment, P_0B_3 (8.27 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 effect of different doses of P and B. Interaction effect has no significant effect on Fe content. Fe content decreased with increased dose of P application and increased with increased dose of B application.

4.3.8 Available manganese

The influence of application of different levels of P and B on available Mn is given in the table 26.Data showed that main effects of P and B and interaction effects affect the available Mn in soil. Treatment, P_2B_3 showed highest available Mn (8.91 mg kg^{-1}). Available Mn decreased with increased dose of P application. Mn increased with increased dose of B application.

4.3.9 Available zinc

The effect of application of different levels of P and B on available Zn is given in the table 27. Data showed that main effects of P and B and interaction effects affect the available Zn in the soil. Highest Zn was observed in treatment, P_0 B_0 (1.07 mg kg^{-1}). Zn was decreased with increased dose of P application.

4.3.10 Available copper

The influence of application of different levels of P and B 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.

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

T_1: 7.36

	B_0	B_1	B_2	B_3	Mean
P_0	8.01	8.02	8.15	8.27	**8.11**
P_1	7.69	7.71	7.75	7.97	**7.78**
P_2	7.33	7.40	7.49	7.82	**7.51**
P_3	7.15	7.19	7.25	7.55	**7.28**
Mean	**7.54**	**7.58**	**7.66**	**7.90**	
CD (0.05) P; 0.143		**CD (0.05) B; 0.143**		**CD (0.05) PxB; NS**	
SE (m) P; 0.050		**SE (m) B; 0.050**		**SE (m) PxB; 0.010**	

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

T_1:7.79

	B_0	B_1	B_2	B_3	Mean
P_0	7.99	8.01	8.39	8.91	**8.32**
P_1	7.37	7.45	7.50	7.51	**7.46**
P_2	7.63	7.65	7.67	7.78	**7.68**
P_3	6.84	6.91	7.24	7.36	**7.09**
Mean	**7.46**	**7.51**	**7.70**	**7.89**	
CD (0.05) P; 0.099		**CD (0.05) B; 0.099**		**CD (0.05) PxB; 0.199**	
SE (m) P; 0.035		**SE (m) B; 0.035**		**SE (m) PxB; 0.069**	

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

T_1: 0.89

	B_0	B_1	B_2	B_3	Mean
P_0	1.07	0.93	0.99	0.87	**0.97**
P_1	0.89	0.83	0.90	0.88	**0.88**
P_2	1.02	0.90	0.94	1.03	**0.97**
P_3	0.77	0.64	0.76	0.79	**0.75**
Mean	**0.94**	**0.83**	**0.90**	**0.89**	
CD (0.05) P; 0.044	**CD (0.05) B; 0.044**		**CD (0.05) PxB; 0.088**		
SE (m) P; 0.015	**SE (m) B; 0.015**		**SE (m) PxB; 0.031**		

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

T_1: 2.15

	B_0	B_1	B_2	B_3	Mean
P_0	2.10	2.18	2.15	2.10	**2.13**
P_1	2.13	2.16	2.10	2.14	**2.13**
P_2	2.11	2.09	2.13	2.10	**2.11**
P_3	2.10	2.21	2.11	2.08	**2.13**
Mean	**2.11**	**2.16**	**2.12**	**2.11**	
CD (0.05) P; NS	**CD (0.05) B; NS**		**CD (0.05) PxB; NS**		
SE (m) P; 0.018	**SE (m) B; 0.018**		**SE (m) PxB; 0.037**		

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 B in the soil. B in soil decreased with application of increased dose of P. The treatment, P_0B_3 (P, 90 kg ha^{-1} and B, 0 kg ha^{-1}) showed highest B (0.80 mg kg^{-1}) among treatments. B content decreased with increased dose of P application.

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

T_1: 0.57

	B_0	B_1	B_2	B_3	Mean
P_0	0.64	0.66	0.74	0.80	**0.71**
P_1	0.61	0.62	0.62	0.62	**0.62**
P_2	0.55	0.56	0.57	0.62	**0.58**
P_3	0.49	0.51	0.56	0.59	**0.54**
Mean	**0.57**	**0.59**	**0.62**	**0.66**	
CD (0.05) P; 0.025		**CD (0.05) B; 0.025**		**CD (0.05) PxB; 0.049**	
SE (m) P; 0.009		**SE (m) B; 0.009**		**SE (m) P xB; 0.017**	

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, 33 respectively. Nitrogen content of plant in all the stages was significantly influenced due to main effect and interaction effect of treatments. 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. Highest nitrogen (2.62 per cent) was in the treatment, P_3B_0 (P, 90kg ha^{-1} and B, 0 kg ha^{-1}).

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

T_1: 2.18

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	2.23	2.14	1.98	1.97	**2.08**
P_1	2.23	2.21	2.21	2.21	**2.21**
P_2	2.44	2.36	2.17	2.01	**2.25**
P_3	2.62	2.42	2.30	2.25	**2.40**
Mean	**2.38**	**2.28**	**2.16**	**2.11**	
CD (0.05) P; 0.012		**CD (0.05) B; 0.012**		**CD (0.05) PxB; 0.023**	
SE (m) P; 0.004		**SE (m) B; 0.004**		**SE (m) PxB; 0.008**	

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

T_1: 2.00

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	1.98	1.93	1.82	1.81	**1.88**
P_1	1.97	1.93	1.98	1.93	**1.95**
P_2	2.15	2.07	1.94	1.82	**1.99**
P_3	2.31	2.21	2.06	2.01	**2.15**
Mean	**2.10**	**2.04**	**1.95**	**1.89**	
CD (0.05) P; 0.008		**CD (0.05) B; 0.008**		**CD (0.05) PxB; 0.015**	
SE (m) P; 0.003		**SE (m) B; 0.003**		**SE (m) PxB; 0.005**	

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

T_1: 1.79

	B_0	B_1	B_2	B_3	Mean
P_0	1.73	1.73	1.66	1.65	**1.69**
P_1	1.72	1.65	1.76	1.65	**1.69**
P_2	1.86	1.79	1.70	1.62	**1.74**
P_3	2.00	2.00	1.82	1.78	**1.90**
Mean	**1.83**	**1.79**	**1.73**	**1.68**	
CD (0.05) P; 0.012		**CD (0.05) B; 0.012**		**CD (0.05) PxB; 0.023**	
SE (m) P; 0.004		**SE (m) B; 0.004**		**SE (m) PxB; 0.008**	

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

T_1: 1.61

	B_0	B_1	B_2	B_3	Mean
P_0	1.53	1.53	1.50	1.51	**1.52**
P_1	1.53	1.49	1.53	1.49	**1.51**
P_2	1.64	1.55	1.51	1.47	**1.54**
P_3	1.75	1.75	1.61	1.55	**1.66**
Mean	**1.61**	**1.58**	**1.54**	**1.50**	
CD (0.05) P; 0.009		**CD (0.05) B; 0.009**		**CD (0.05) PxB; 0.018**	
SE (m) P; 0.003		**SE (m) B; 0.003**		**SE (m) PxB; 0.006**	

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, 37 respectively. P content in plant was increased with increased dose of fertilizer application. P content in all the stages significantly varied due to main effect and interaction effect. The treatment, P_3 B_1 (P, 90kg ha^{-1} and B, 5 kg ha^{-1}) showed highest P content (0.37 per cent at flowering stage, 0.34 per cent at pegging stage, 0.30 per cent at pod development stage and 0.27 per cent at harvest stage).

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

T_1: 0.33

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	0.27	0.25	0.24	0.21	**0.24**
P_1	0.30	0.30	0.30	0.30	**0.30**
P_2	0.33	0.32	0.32	0.32	**0.32**
P_3	0.36	0.37	0.33	0.34	**0.35**
Mean	**0.31**	**0.31**	**0.30**	**0.29**	
CD (0.05) P; 0.011		**CD (0.05) B; 0.011**		**CD (0.05) PxB; 0.021**	
SE (m) P; 0.004		**SE (m) B; 0.004**		**SE (m) PxB; 0.007**	

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

T_1: 0.33

	B_0	B_1	B_2	B_3	Mean
P_0	0.23	0.22	0.20	0.18	**0.21**
P_1	0.25	0.25	0.26	0.27	**0.26**
P_2	0.31	0.29	0.28	0.27	**0.29**
P_3	0.33	0.34	0.31	0.31	**0.32**
Mean	**0.28**	**0.27**	**0.26**	**0.26**	
CD (0.05) P; 0.005		**CD (0.05) B; 0.005**		**CD (0.05) PxB; 0.011**	
SE (m) P; 0.002		**SE (m) B; 0.002**		**SE (m) PxB; 0.004**	

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

T_1:0.29

	B_0	B_1	B_2	B_3	Mean
P_0	0.20	0.19	0.17	0.14	**0.17**
P_1	0.21	0.21	0.22	0.24	**0.22**
P_2	0.28	0.27	0.24	0.22	**0.25**
P_3	0.29	0.30	0.29	0.29	**0.29**
Mean	**0.24**	**0.24**	**0.23**	**0.22**	
CD (0.05) P; 0.006		**CD (0.05) B; 0.006**		**CD (0.05) PxB; 0.011**	
SE (m) P; 0.002		**SE (m) B; 0.002**		**SE (m) PxB; 0.004**	

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

T_1: 0.26

	B_0	B_1	B_2	B_3	Mean
P_0	0.17	0.16	0.14	0.12	**0.15**
P_1	0.18	0.18	0.19	0.19	**0.18**
P_2	0.24	0.23	0.21	0.19	**0.22**
P_3	0.26	0.27	0.2	0.2	**0.26**
Mean	**0.21**	**0.20**	**0.19**	**0.19**	
CD (0.05) P; 0.007		**CD (0.05) B; 0.007**		**CD (0.05) PxB; 0.013**	
SE (m) P; 0.002		**SE (m) B; 0.002**		**SE (m) PxB; 0.005**	

4.4.3 Potassium content in plant

Potassium content in plant samples was significantly influenced by application of P and B. The treatment, P_2B_3 (P, 75kg ha $^{-1}$ and B, 15 kg ha $^{-1}$) had highest K content at flowering (2.21 per cent). At pegging, pod development and harvesting stages treatment, P_2B_0 (P, 75kg ha $^{-1}$ and B, 0 kg ha $^{-1}$) showed highest K content.

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

T_1: 2.18

	B_0	B_1	B_2	B_3	Mean
P_0	2.06	2.08	1.95	1.65	**1.94**
P_1	2.00	1.87	1.99	1.86	**1.93**
P_2	2.10	1.81	2.01	2.21	**2.03**
P_3	1.96	2.19	1.81	2.03	**2.00**
Mean	**2.03**	**1.99**	**1.94**	**1.94**	
CD (0.05) P; 0.039		**CD (0.05) B; 0.039**		**CD (0.05) PxB; 0.077**	
SE (m) P; 0.014		**SE (m) B; 0.014**		**SE (m) PxB; 0.028**	

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

T_1: 1.88

	B_0	B_1	B_2	B_3	Mean
P_0	1.70	1.83	1.59	1.67	**1.70**
P_1	1.85	1.77	1.85	1.82	**1.82**
P_2	1.95	1.73	1.90	1.93	**1.88**
P_3	1.72	1.78	1.72	1.85	**1.77**
Mean	**1.81**	**1.78**	**1.76**	**1.82**	
CD (0.05) P; 0.023		**CD (0.05) B; 0.023**		**CD (0.05) PxB; 0.046**	
SE (m) P; 0.008		**SE (m) B; 0.008**		**SE (m) PxB; 0.016**	

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

T_1: 1.58

	B_0	B_1	B_2	B_3	Mean
P_0	1.34	1.59	1.38	1.53	**1.46**
P_1	1.71	1.66	1.71	1.78	**1.71**
P_2	1.80	1.65	1.79	1.64	**1.72**
P_3	1.48	1.37	1.63	1.68	**1.54**
Mean	**1.58**	**1.57**	**1.63**	**1.66**	
CD (0.05) P; 0.025		**CD (0.05) B; 0.025**		**CD (0.05) PxB; 0.051**	
SE (m) P; 0.009		**SE (m) B; 0.009**		**SE (m) P xB; 0.018**	

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

T_1: 1.49

	B_0	B_1	B_2	B_3	Mean
P_0	1.26	1.50	1.27	1.46	**1.37**
P_1	1.62	1.54	1.59	1.66	**1.60**
P_2	1.69	1.54	1.66	1.54	**1.61**
P_3	1.35	1.31	1.54	1.58	**1.44**
Mean	**1.48**	**1.47**	**1.51**	**1.56**	
CD (0.05) P; 0.029		**CD (0.05) B; 0.029**		**CD (0.05) PxB; 0.059**	
SE (m) P; 0.010		**SE (m) B; 0.010**		**SE (m) PxB; 0.021**	

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. Ca content was highest in treatment having low P. P_0B_3 (P, 0 kg ha^{-1} and B, 15 kg ha^{-1}) showed highest Ca content at flowering (1.98 per cent), pegging (1.61 per cent), pod setting (1.24 per cent) and harvest(1.01 per cent) stages.

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

T_1: 1.51

	B_0	B_1	B_2	B_3	Mean
P_0	1.84	1.87	1.98	1.98	**1.91**
P_1	1.52	1.53	1.63	1.73	**1.60**
P_2	1.55	1.70	1.70	1.72	**1.67**
P_3	1.56	1.76	1.79	1.83	**1.73**
Mean	**1.62**	**1.71**	**1.77**	**1.81**	
CD (0.05) P; 0.029		**CD (0.05) B; 0.029**		**CD (0.05) PxB; 0.058**	
SE (m) P; 0.010		**SE (m) B; 0.010**		**SE (m) PxB; 0.020**	

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

T_1: 1.14

	B_0	B_1	B_2	B_3	Mean
P_0	1.50	1.52	1.60	1.61	**1.56**
P_1	1.09	1.16	1.24	1.34	**1.21**
P_2	1.18	1.30	1.28	1.31	**1.27**
P_3	1.20	1.39	1.43	1.45	**1.37**
Mean	**1.24**	**1.34**	**1.38**	**1.43**	
CD (0.05) P; 0.018		**CD (0.05) B; 0.018**		**CD (0.05)PxB; 0.037**	
SE (m) P; 0.006		**SE (m) B; 0.006**		**SE (m) PxB; 0.012**	

Table 44: Effect of P and B application on plant calcium content at pod setting stage (%)

T_1: 0.76

	B_0	B_1	B_2	B_3	Mean
P_0	1.15	1.18	1.22	1.24	**1.20**
P_1	0.66	0.80	0.84	0.95	**0.81**
P_2	0.81	0.90	0.85	0.90	**0.86**
P_3	0.84	1.02	1.07	1.07	**1.00**
Mean	**0.87**	**0.97**	**1.00**	**1.04**	
CD (0.05) P; 0.023		**CD (0.05) B;0.023**		**CD (0.05) PXB; 0.045**	
SE (m) P; 0.008		**SE (m) B; 0.008**		**SE (m) PxB; 0.016**	

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

T_1: 0.48

	B_0	B_1	B_2	B_3	Mean
P_0	0.87	0.89	0.99	1.01	0.94
P_1	0.46	0.55	0.64	0.69	0.58
P_2	0.62	0.70	0.66	0.70	0.67
P_3	0.65	0.81	0.81	0.83	0.77
Mean	0.65	0.74	0.78	0.81	
CD (0.05) P; 0.029		**CD (0.05) B;0.029**		**CD (0.05) PxB; 0.058**	
SE (m) P; 0.010		**SE (m) B; 0.010**		**SE (m) PxB; 0.020**	

4.4.5 Magnesium content in plant

Magnesium content in plant samples was significantly influenced by application of P and B. The treatment, P_0B_1 (P, 0 kg ha $^{-1}$ and B, 10 kg ha $^{-1}$) had highest Mg content at flowering (2.97 per cent). At pegging stage, treatment, P_1B_1 (P, 60 kg ha $^{-1}$ and B, 10 kg ha $^{-1}$) had highest Mg content (2.02 per cent). pod development and harvesting stages treatment, P_2B_0 (P, 75kg ha $^{-1}$ and B, 0 kg ha $^{-1}$) showed highest Mg content.

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

T_1: 2.41

	B_0	B_1	B_2	B_3	Mean
P_0	2.79	2.97	2.73	3.39	**2.97**
P_1	2.46	2.62	2.97	2.67	**2.68**
P_2	2.80	2.73	2.92	2.64	**2.77**
P_3	2.53	2.85	2.38	2.63	**2.59**
Mean	**2.65**	**2.79**	**2.75**	**2.83**	
CD (0.05) P; 0.060		**CD (0.05) B; 0.060**		**CD (0.05) PxB; 0.120**	
SE (m) P; 0.020		**SE (m) B; 0.020**		**SE (m) PxB; 0.039**	

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

T_1: 1.68

	B_0	B_1	B_2	B_3	Mean
P_0	1.95	2.02	1.86	2.18	**2.00**
P_1	1.66	1.82	1.97	1.83	**1.82**
P_2	1.85	1.84	1.92	1.84	**1.86**
P_3	1.79	1.98	1.72	1.75	**1.81**
Mean	**1.81**	**1.91**	**1.86**	**1.89**	
CD (0.05) P; 0.031		**CD (0.05) B; 0.031**		**CD (0.05) PxB; 0.061**	
SE (m) P; 0.010		**SE (m) B; 0.010**		**SE (m) PxB; 0.020**	

Table 48: Effect of P and B application on plant magnesium content at pod setting stage (%)

T_1: 0.97

	B_0	B_1	B_2	B_3	Mean
P_0	1.09	1.07	0.98	0.97	**1.03**
P_1	0.85	1.03	0.97	0.97	**0.95**
P_2	0.89	0.94	0.91	1.03	**0.94**
P_3	1.05	1.09	1.06	0.87	**1.01**
Mean	**0.97**	**1.03**	**0.98**	**0.96**	
CD (0.05) P; 0.024		**CD (0.05) B; 0.024**		**CD (0.05) PxB; 0.048**	
SE (m) P; 0.008		**SE (m) B; 0.008**		**SE (m) PxB; 0.016**	

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

T_1: 0.86

	B_0	B_1	B_2	B_3	Mean
P_0	1.03	0.98	0.88	0.86	**0.94**
P_1	0.75	0.91	0.86	0.86	**0.84**
P_2	0.79	0.84	0.81	0.92	**0.84**
P_3	0.94	0.99	0.91	0.79	**0.90**
Mean	**0.88**	**0.93**	**0.86**	**0.86**	
CD (0.05) P; 0.022		**CD (0.05) B; 0.022**		**CD (0.05) PxB; 0.044**	
SE (m) P; 0.007		**SE (m) B; 0.007**		**SE (m) PxB; 0.014**	

4.4.6 Sulphur content in plant

Sulphur content of plant at different stages varied significantly due to main effect and interaction effect. S content at all the stages were influenced by treatments. The treatment having high P produced high S content. Treatment, P_3 B_3 (P, 90 kg ha^{-1} and B, 15 kg ha^{-1}) showed highest S content at flowering (0.83 per cent) and pegging (0.60 per cent) stages and P_3B_2 (P, 90 kg ha^{-1} and B 10 kg ha^{-1}) showed highest S content at pod setting(0.44 per cent) and harvest stages (0.39 per cent).

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

T_1: 0.53

	B_0	B_1	B_2	B_3	Mean
P_0	0.46	0.43	0.39	0.38	**0.41**
P_1	0.41	0.47	0.49	0.51	**0.47**
P_2	0.52	0.53	0.54	0.58	**0.54**
P_3	0.57	0.61	0.62	0.83	**0.66**
Mean	**0.49**	**0.51**	**0.51**	**0.57**	
CD (0.05) P; 0.009		**CD (0.05) B; 0.009**		**CD (0.05) PxB; 0.019**	
SE (m) P; 0.003		**SE (m) B; 0.003**		**SE (m) PxB; 0.007**	

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

T_1: 0.29

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	0.34	0.32	0.30	0.29	**0.31**
P_1	0.32	0.35	0.37	0.40	**0.36**
P_2	0.40	0.43	0.42	0.44	**0.42**
P_3	0.44	0.47	0.53	0.60	**0.51**
Mean	**0.37**	**0.39**	**0.40**	**0.43**	
CD (0.05) P; 0.007		**CD (0.05) B;0.007**		**CD (0.05) PxB; 0.014**	
SE (m) P; 0.002		**SE (m) B; 0.002**		**SE (m) PxB; 0.005**	

Table 52: Effect of P and B application on plant sulphur content at pod setting stage (%)

T_1: 0.20

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	0.22	0.21	0.21	0.20	**0.21**
P_1	0.22	0.24	0.25	0.28	**0.25**
P_2	0.27	0.28	0.30	0.31	**0.29**
P_3	0.32	0.34	0.44	0.36	**0.36**
Mean	**0.26**	**0.27**	**0.30**	**0.29**	
CD (0.05) P;0.016		**CD (0.05) B;0.016**		**CD (0.05) PxB; 0.031**	
SE (m) P; 0.005		**SE (m) B; 0.005**		**SE (m) PxB; 0.011**	

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

T_1: 0.27

	B_0	B_1	B_2	B_3	Mean
P_0	0.19	0.18	0.18	0.18	**0.18**
P_1	0.19	0.21	0.22	0.26	**0.22**
P_2	0.24	0.27	0.26	0.28	**0.26**
P_3	0.28	0.30	0.39	0.33	**0.33**
Mean	**0.23**	**0.24**	**0.26**	**0.26**	
CD (0.05) P; 0.011		**CD (0.05) B; 0.011**		**CD (0.05) PxB; 0.023**	
SE (m) P; 0.004		**SE (m) B; 0.004**		**SE (m) PxB; 0.008**	

4.4.7 Iron content in groundnut plant

Iron content at all stages was significantly affected by main effect and interaction effect. P_0B_3 (P, 0kg ha^{-1} and B, 15 kg ha^{-1}) showed highest Fe content at flowering stage (497.50 mg kg^{-1}). At pegging and harvesting stage treatment, P_0B_0 (P, 0 kg ha^{-1} and B, 0 kg ha^{-1}) showed highest Fe content. At pod development stage treatment P_0B_2 (P, 0 kg ha^{-1} and B, 10 kg ha^{-1}) showed highest Fe content.

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

T_1: 425.52

	B_0	B_1	B_2	B_3	Mean
P_0	424.63	366.04	388.41	497.50	**419.14**
P_1	458.54	417.13	390.60	376.47	**410.68**
P_2	383.75	380.63	312.00	418.66	**373.76**
P_3	359.28	336.13	451.85	454.41	**400.42**
Mean	**406.55**	**374.98**	**385.71**	**436.76**	
CD (0.05) P; 14.021		**CD (0.05) B;14.021**		**CD (0.05) PxB; 28.041**	
SE (m) P; 4.906		**SE (m) B; 4.906**		**SE (m) PxB; 9.812**	

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

T_1: 414.98

	B_0	B_1	B_2	B_3	Mean
P_0	400.69	306.65	382.65	395.82	**371.45**
P_1	375.30	371.13	314.96	355.49	**354.22**
P_2	352.12	345.99	304.02	340.77	**335.72**
P_3	327.71	332.22	388.08	331.33	**344.84**
Mean	**363.95**	**339.00**	**347.43**	**355.85**	
CD (0.05) P; 9.533		**CD (0.05) B; 9.533**		**CD (0.05) PxB; 19.066**	
SE (m) P; 3.336		**SE (m) B; 3.336**		**SE (m) PxB; 6.672**	

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

T_1: 378.56

	B_0	B_1	B_2	B_3	Mean
P_0	376.75	247.25	376.88	294.13	**323.75**
P_1	292.06	325.13	239.31	334.50	**297.75**
P_2	320.47	311.35	296.04	262.88	**297.68**
P_3	296.13	328.32	324.31	208.25	**289.25**
Mean	**321.35**	**303.01**	**309.13**	**274.94**	
CD (0.05) P; 13.267		**CD (0.05) B;13.267**		**CD (0.05) PxB; 26.534**	
SE (m) P; 4.643		**SE (m) B; 4.643**		**SE (m) PxB; 9.285**	

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

T_1: 348.36

	B_0	B_1	B_2	B_3	Mean
P_0	359.28	233.42	357.76	275.89	**306.59**
P_1	272.96	308.51	229.29	325.70	**284.11**
P_2	315.31	305.39	292.31	247.68	**290.17**
P_3	276.76	326.81	304.48	199.31	**276.84**
Mean	**306.08**	**293.53**	**295.96**	**262.15**	
CD (0.05) P; 9.327		**CD (0.05) B;9.327**		**CD (0.05) PxB; 18.654**	
SE (m) P; 3.264		**SE (m) B; 3.264**		**SE (m) PxB; 6.528**	

4.4.8 Manganese content in groundnut plant

Manganese content in plant sample at flowering, pegging, pod development and harvest stages are given in the tables 58, 59, 60, 61 respectively. Mn content was high in treatment having low P. The treatment, P_1B_3 (P, 0 kg ha^{-1} and B, 15 kg ha^{-1}) showed highest Mn content at flowering (82.25 mg kg^{-1}), pegging (74.38 mg kg^{-1}), pod setting (66.5 mg kg^{-1}) and harvest (62.38 mg kg^{-1}) stage. Mn content was found to be significantly different in all stages. But interaction effect at harvest stage was non-significant.

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

T_1: 74.25

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	66.00	71.19	72.69	74.25	**71.03**
P_1	77.63	78.88	81.63	82.25	**80.09**
P_2	60.94	64.69	65.06	74.81	**66.38**
P_3	58.06	58.81	59.25	60.56	**59.17**
Mean	**65.66**	**68.39**	**69.66**	**72.97**	
CD (0.05) P; 2.054		**CD (0.05) B; 2.054**		**CD (0.05) PxB; 4.109**	
SE (m) P; 0.719		**SE (m) B; 0.719**		**SE (m) PxB; 1.438**	

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

T_1: 70.00

	B_0	B_1	B_2	B_3	Mean
P_0	62.25	64.97	66.09	67.50	**65.20**
P_1	70.69	72.13	73.81	74.38	**72.75**
P_2	54.16	57.91	61.28	65.41	**59.69**
P_3	50.34	50.97	52.19	52.91	**51.60**
Mean	**59.36**	**61.49**	**63.35**	**65.05**	
CD (0.05) P; 1.197		**CD (0.05) B; 1.197**		**CD (0.05) PxB; 2.394**	
SE (m) P; 0.419		**SE (m) B; 0.419**		**SE (m) PxB; 0.838**	

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

T_1: 67.16

	B_0	B_1	B_2	B_3	Mean
P_0	58.50	58.75	59.50	60.75	**59.38**
P_1	63.75	65.38	66.00	66.50	**65.41**
P_2	47.38	51.13	57.50	56.00	**53.00**
P_3	42.63	43.13	45.14	45.25	**44.03**
Mean	**53.06**	**54.59**	**57.03**	**57.13**	
CD (0.05) P; 1.725		**CD (0.05) B; 1.725**		**CD (0.05) PxB; 3.451**	
SE (m) P; 0.604		**SE (m) B; 0.604**		**SE (m) PxB; 1.208**	

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

T_1: 65.81

	B_0	B_1	B_2	B_3	Mean
P_0	55.06	55.50	57.44	56.75	**56.19**
P_1	60.88	61.44	62.13	62.38	**61.70**
P_2	44.38	48.13	53.50	52.00	**49.50**
P_3	39.25	40.56	41.56	42.00	**40.84**
Mean	**49.89**	**51.41**	**53.66**	**53.28**	
CD (0.05) P; 1.596		**CD (0.05) B; 1.596**		**CD (0.05)PxB; NS**	
SE (m) P; 0.558		**SE (m) B; 0.558**		**SE (m) PxB; 1.117**	

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. Zn content was highest in treatment having low P. At flowering stage, P_0B_3 (P, 0 kg ha^{-1} and B, 15 kg ha^{-1}) showed highest Zn content (53.06 mg kg^{-1}). Treatment, P_0B_2 (P, 0 kg ha^{-1} and B, 10 kg ha^{-1}) showed highest Zn at pegging (50.00 mg kg^{-1}), pod setting (47.63 mg kg^{-1}) and harvest (43.48 mg kg^{-1}) stages.

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

T_1: 50.50

	B_0	B_1	B_2	B_3	Mean
P_0	49.13	46.88	52.38	53.06	**50.36**
P_1	41.44	41.38	42.25	41.88	**41.73**
P_2	40.56	41.81	41.63	44.13	**42.03**
P_3	39.75	38.31	37.63	37.06	**38.19**
Mean	**42.72**	**42.09**	**43.47**	**44.03**	
CD (0.05) P; 0.914		**CD (0.05) B; 0.914**		**CD (0.05) PxB; 1.827**	
SE (m) P; 0.320		**SE (m) B; 0.320**		**SE (m) PxB; 0.639**	

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

T_1: 42.38

	B_0	B_1	B_2	B_3	Mean
P_0	47.82	46.19	50.00	48.03	**48.01**
P_1	40.13	40.57	39.76	39.75	**40.05**
P_2	37.32	38.41	37.38	36.88	**37.50**
P_3	34.44	35.72	35.00	34.35	**34.88**
Mean	**39.92**	**40.22**	**40.54**	**39.75**	
CD (0.05) P; 0.559		**CD (0.05) B; 0.559**		**CD (0.05) PxB; 1.119**	
SE (m) P; 0.196		**SE (m) B; 0.196**		**SE (m) PxB; 0.391**	

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

T_1: 33.00

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	46.50	45.50	47.63	43.00	**45.66**
P_1	38.81	39.75	37.25	37.63	**38.36**
P_2	34.06	35.00	33.13	29.63	**32.95**
P_3	29.13	33.13	32.38	31.63	**31.56**
Mean	**37.13**	**38.34**	**37.59**	**35.47**	
CD (0.05) P; 0.712		**CD (0.05) B; 0.712**		**CD (0.05) PxB; 1.424**	
SE (m) P; 0.249		**SE (m) B; 0.249**		**SE (m) PxB; 0.498**	

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

T_1: 30.30

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	41.94	41.00	43.48	39.81	**41.56**
P_1	35.56	36.00	33.75	33.56	**34.72**
P_2	30.81	30.94	30.06	26.69	**29.63**
P_3	26.19	30.13	28.35	28.13	**28.20**
Mean	**33.63**	**34.52**	**33.91**	**32.05**	
CD (0.05) P; 0.393		**CD (0.05) B; 0.393**		**CD (0.05) PxB; 0.785**	
SE (m) P; 0.137		**SE (m) B; 0.137**		**SE (m) PxB; 0.275**	

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, 69 respectively. Cu content at flowering and pegging stage was significant due to main effect of P and interaction effect and the main effect of B had no significant influence on Cu content at all these stages. At pod development stage and harvest stage Cu content was non-significant due to both main effects

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

T_1: 20.00

	B_0	B_1	B_2	B_3	Mean
P_0	18.38	18.38	19.25	17.63	**18.41**
P_1	17.25	17.25	16.25	19.75	**17.63**
P_2	19.63	18.38	19.50	17.00	**18.63**
P_3	15.63	15.75	16.38	18.13	**16.47**
Mean	**17.72**	**17.44**	**17.84**	**18.13**	
CD (0.05) P; 1.100		**CD (0.05) B; NS**		**CD (0.05) PxB; 2.199**	
SE (m) P; 0.385		**SE (m) B; 0.385**		**SE (m) PxB; 0.770**	

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

T_1: 18.84

	B_0	B_1	B_2	B_3	Mean
P_0	16.13	16.06	15.88	15.41	**15.87**
P_1	15.47	15.50	14.72	16.22	**15.48**
P_2	16.72	16.13	16.31	15.06	**16.06**
P_3	14.00	14.44	15.16	15.97	**14.89**
Mean	**15.58**	**15.53**	**15.52**	**15.66**	
CD (0.05) P; 0.658		**CD (0.05) B; NS**		**CD (0.05) PxB; 1.315**	
SE (m) P; 0.230		**SE (m) B; 0.230**		**SE (m) PxB; 0.460**	

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

T_1: 14.19

	B_0	B_1	B_2	B_3	Mean
P_0	13.88	13.75	12.50	13.19	**13.33**
P_1	13.69	13.75	13.19	12.69	**13.33**
P_2	13.81	13.88	13.13	13.13	**13.48**
P_3	12.38	13.13	13.94	13.81	**13.31**
Mean	**13.44**	**13.63**	**13.19**	**13.20**	
CD (0.05) P; NS		**CD (0.05) B; NS**		**CD (0.05) PxB; 0.985**	
SE (m) P; 0.172		**SE (m) B; 0.172**		**SE (m) PxB; 0.345**	

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

T_1: 11.69

	B_0	B_1	B_2	B_3	Mean
P_0	11.63	11.81	10.50	10.94	**11.22**
P_1	11.69	11.75	11.19	10.69	**11.33**
P_2	11.81	11.89	11.01	10.85	**11.39**
P_3	10.43	11.12	11.90	11.91	**11.34**
Mean	**11.39**	**11.64**	**11.15**	**11.10**	
CD (0.05) P; NS		**CD (0.05) B; NS**		**CD (0.05) PxB; 1.006**	
SE (m) P; 0.176		**SE (m) B; 0.176**		**SE (m) PxB; 0.352**	

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 73 respectively. The B content was significantly influenced by different levels of P and B application. The treatment, P_0B_3 (P, 0 kg ha^{-1} and B, 15 kg ha^{-1}) produced highest B content at flowering (21.47 mg kg^{-1}), pegging (17.43 mg kg^{-1}), pod development (13.38 mg kg^{-1}) and at harvest (11.45 mg kg^{-1}) stages.

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

T_1: 20.66

	B_0	B_1	B_2	B_3	Mean
P_0	19.82	20.26	20.63	21.47	**20.54**
P_1	18.60	19.07	19.41	19.47	**19.13**
P_2	17.41	18.19	18.35	19.22	**18.29**
P_3	16.01	17.10	17.78	18.38	**17.31**
Mean	**17.96**	**18.65**	**19.04**	**19.63**	
CD (0.05) P; 0.205		**CD (0.05) B; 0.205**		**CD (0.05) PxB; 0.410**	
SE (m) P; 0.072		**SE (m) B; 0.072**		**SE (m) PxB; 0.144**	

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

T_1:16.96

	B_0	B_1	B_2	B_3	Mean
P_0	16.07	16.55	16.80	17.43	**16.71**
P_1	15.10	15.38	15.71	15.74	**15.48**
P_2	13.83	14.55	14.73	15.51	**14.65**
P_3	13.24	13.27	14.22	14.77	**13.88**
Mean	**14.56**	**14.94**	**15.36**	**15.86**	
CD (0.05) P; 0.131		**CD (0.05) B; 0.131**		**CD (0.05) PxB; 0.261**	
SE (m) P; 0.046		**SE (m) B; 0.046**		**SE (m) PxB; 0.091**	

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

T_1:13.00

	B_0	B_1	B_2	B_3	Mean
P_0	12.32	12.85	12.97	13.38	**12.88**
P_1	11.60	11.69	12.00	12.00	**11.82**
P_2	10.25	10.91	11.10	11.78	**11.01**
P_3	10.47	9.44	10.66	11.16	**10.43**
Mean	**11.16**	**11.22**	**11.68**	**12.08**	
CD (0.05) P; 0.156		**CD (0.05) B; 0.156**		**CD (0.05) PxB; 0.313**	
SE (m) P; 0.055		**SE (m) B; 0.055**		**SE (m) PxB; 0.109**	

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

T_1: 10.76

	B_0	B_1	B_2	B_3	Mean
P_0	10.36	10.83	10.98	11.45	**10.90**
P_1	9.69	9.64	10.10	10.00	**9.86**
P_2	8.25	8.94	9.12	10.12	**9.11**
P_3	8.44	8.09	8.68	9.18	**8.60**
Mean	**9.18**	**9.37**	**9.72**	**10.19**	
CD (0.05) P; 0.142		**CD (0.05) B; 0.142**		**CD (0.05) PxB; 0.285**	
SE (m) P; 0.050		**SE (m) B; 0.050**		**SE (m) PxB; 0.100**	

4.5 NUTRIENT CONTENT IN POD

4.5.1 Nitrogen content in pod

Nitrogen content in pod varied significantly due to main effect and interaction effect. N content was increased with increased dose of P application (table 74). Highest N content was observed in P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) which had 3.89 per cent.

4.5.2 Phosphorus content in pod

Data (table 75) on P content in pod showed that treatments varied significantly due to main effect and interaction effect. Treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest P content. P content in pod increased with increased dose of P application.

4.5.3 Potassium content in pod

Effect of application of P and B on K content in pod is shown in the table 76. The K content varied significantly due to main effect and interaction effect. Treatment, P_2 B_3 (P, 75 kg ha^{-1} B, 15 kg ha^{-1}) showed highest K content.

Table 74: Effect of P and B application on nitrogen content in pod (%)

T_1: 3.47

	B_0	B_1	B_2	B_3	Mean
P_0	3.60	3.41	3.38	3.35	**3.43**
P_1	3.66	3.51	3.49	3.57	**3.55**
P_2	3.89	3.82	3.41	3.39	**3.63**
P_3	3.91	3.87	3.78	3.71	**3.81**
Mean	**3.76**	**3.65**	**3.51**	**3.50**	
CD (0.05) P; 0.009		**CD (0.05) B; 0.009**		**CD (0.05) PxB; 0.017**	
SE (m) P; 0.003		**SE (m) B; 0.003**		**SE (m) PxB; 0.006**	

Table 75: Effect of P and B application on phosphorus content in pod (%)

T_1: 0.40

	B_0	B_1	B_2	B_3	Mean
P_0	0.35	0.35	0.35	0.34	**0.35**
P_1	0.36	0.37	0.36	0.37	**0.36**
P_2	0.40	0.38	0.39	0.39	**0.39**
P_3	0.42	0.42	0.40	0.41	**0.41**
Mean	**0.38**	**0.38**	**0.38**	**0.38**	
CD (0.05) P; 0.002		**CD (0.05) B; 0.002**		**CD (0.05) PxB; 0.003**	
SE (m) P; 0.001		**SE (m) B; 0.001**		**SE (m) PxB; 0.001**	

Table 76: Effect of P and B application on potassium content in pod (%)

T_1: 0.99

	B_0	B_1	B_2	B_3	Mean
P_0	0.98	0.99	0.93	0.90	**0.95**
P_1	0.95	0.93	0.96	0.91	**0.94**
P_2	0.98	0.91	0.96	1.00	**0.96**
P_3	0.93	0.99	0.92	0.97	**0.95**
Mean	**0.96**	**0.95**	**0.94**	**0.95**	
CD (0.05) P; 0.001		**CD (0.05) B; 0.001**		**CD (0.05) PxB; 0.002**	
SE (m) P; 0.00		**SE (m) B; 0.00**		**SE (m) PxB; 0.001**	

4.5.4 Calcium content in pod

Effect of application of P and B on Ca content in pod is shown in the table 77. Calcium content varied significantly due to the application of P and B fertilizers. Ca showed a synergistic interaction with P. Ca content increased with increased dose of P application. Highest Ca content was noted in P_3B_3 (P, 90 kg ha^{-1} B, 15 kg ha^{-1}).

4.5.5 Magnesium content in pod

Effect of application of P and B on Mg content in pod is shown in the table 78. Mg content varied significantly due to the application of P and B fertilizers. Highest Mg content was observed in P_0B_2 (P, 0 kg ha^{-1} B, 10 kg ha^{-1}).

4.5.6 Sulphur content in pod

Sulphur content varied significantly due to the application of P and B fertilizers. The S showed a synergistic interaction with P. S content increased with increased dose of P application (table 79). Highest S content was noted in P_3B_3 (P, 90 kg ha^{-1} B, 15 kg ha^{-1}).

Table 77: Effect of P and B application on calcium content in pod (%)

T_1: 0.18

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	0.145	0.130	0.140	0.120	**0.134**
P_1	0.150	0.120	0.150	0.150	**0.143**
P_2	0.180	0.160	0.170	0.160	**0.168**
P_3	0.200	0.220	0.190	0.210	**0.205**
Mean	**0.169**	**0.158**	**0.163**	**0.160**	
CD (0.05) P; 0.003		**CD (0.05) B; 0.003**		**CD (0.05) PxB; 0.006**	
SE (m) P; 0.001		**SE (m) B; 0.001**		**SE (m) PxB; 0.002**	

Table 78: Effect of P and B application on magnesium content in pod (%)

T_1: 0.25

	B_0	B_1	B_2	B_3	Mean
P_0	0.22	0.25	0.28	0.25	**0.25**
P_1	0.27	0.24	0.26	0.24	**0.25**
P_2	0.26	0.25	0.27	0.30	**0.27**
P_3	0.22	0.26	0.24	0.27	**0.25**
Mean	**0.24**	**0.25**	**0.26**	**0.27**	
CD (0.05) P; 0.006		**CD (0.05) B; 0.006**		**CD (0.05) PxB; 0.011**	
SE (m) P; 0.002		**SE (m) B; 0.002**		**SE (m) PxB; 0.004**	

Table 79: Effect of P and B application on sulphur content in pod (%)

T_1: 0.44

	B_0	B_1	B_2	B_3	Mean
P_0	0.38	0.36	0.39	0.45	**0.40**
P_1	0.41	0.43	0.46	0.47	**0.44**
P_2	0.44	0.48	0.48	0.50	**0.47**
P_3	0.53	0.65	0.55	0.66	**0.60**
Mean	**0.44**	**0.48**	**0.47**	**0.52**	
CD (0.05) P; 0.002		**CD (0.05) B; 0.002**		**CD (0.05) PxB; 0.004**	
SE (m) P; 0.001		**SE (m) B; 0.001**		**SE (m) PxB; 0.001**	

4.5.7 Iron content in pod

Effect of application of P and B on Fe content in pod is shown in the table 80. Fe content was influenced by both main effect and interaction effect. Highest Fe content was noted in P_0B_2 (P, 0 kg ha^{-1} B, 15 kg ha^{-1}).

4.5.8 Manganese content in pod

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_2B_2 (P, 75 kg ha^{-1} B, 15 kg ha^{-1}).

4.5.9 Zinc content in pod

Data (table 82) on Zn content showed that Zn was influenced by P and B application. Zn content decreased with increased dose of P application. Highest Zn was noted in P_0 B_3 (P, 0 kg ha^{-1} B, 15 kg ha^{-1}).

4.5.10 Copper content in pod

Copper content was found to be non- significant due to main effect and significant due to interaction effect (table 83).

4.5.11 Boron content in pod

Data (table 84) on B content showed that B had influenced by P and B application. B content decreased with increased dose of P application. Highest B was noted in P_0B_3 (P, 0 kg ha^{-1} B, 15 kg ha^{-1}).

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

T_1: 253.25

	B_0	B_1	B_2	B_3	Mean
P_0	263.00	207.75	254.25	300.75	**256.44**
P_1	295.50	198.00	212.75	228.00	**233.56**
P_2	208.25	138.75	233.00	217.50	**199.38**
P_3	256.75	114.00	128.25	186.75	**171.44**
Mean	**255.88**	**164.63**	**207.06**	**233.25**	
CD (0.05) P; 0.601		**CD (0.05) B; 0.601**		**CD (0.05) PxB; 1.201**	
SE (m) P; 0.197		**SE (m) B; 0.197**		**SE (m) PxB; 0.395**	

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

T_1: 19.00

	B_0	B_1	B_2	B_3	Mean
P_0	20.25	20.75	21.50	21.75	21.06
P_1	23.25	24.25	25.75	25.75	24.75
P_2	18.50	19.00	19.50	22.75	19.94
P_3	15.25	17.50	18.00	18.00	17.19
Mean	19.31	20.38	21.19	22.06	
CD (0.05) P; 0.277		**CD (0.05) B; 0.277**		**CD (0.05) PxB; 0.553**	
SE (m) P; 0.091		**SE (m) B; 0.091**		**SE (m) PxB; 0.182**	

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

T_1: 58.50

	B_0	B_1	B_2	B_3	Mean
P_0	55.75	56.50	59.75	61.00	**58.25**
P_1	50.50	50.00	54.00	53.50	**52.00**
P_2	49.50	52.50	50.50	54.00	**51.63**
P_3	49.00	47.50	47.75	46.50	**47.69**
Mean	**51.19**	**51.63**	**53.00**	**53.75**	
CD (0.05) P; 0.277		**CD (0.05) B; 0.277**		**CD (0.05) PxB; 0.553**	
SE (m) P; 0.091		**SE (m) B; 0.091**		**SE (m) PxB; 0.182**	

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

T_1: 14.00

	B_0	B_1	B_2	B_3	Mean
P_0	13.25	11.50	9.25	11.00	**11.25**
P_1	9.75	11.00	10.75	9.25	**10.19**
P_2	11.75	11.75	10.50	10.25	**11.06**
P_3	9.25	9.25	13.50	10.25	**10.56**
Mean	**11.00**	**10.88**	**11.00**	**10.19**	
CD (0.05) P; NS		**CD (0.05) B; NS**		**CD (0.05) PxB; 2.842**	
SE (m) P; 0.467		**SE (m) B; 0.467**		**SE (m) PxB; 0.934**	

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

T_1: 17.45

	B_0	B_1	B_2	B_3	Mean
P_0	17.13	17.54	18.38	20.27	**18.33**
P_1	16.56	17.36	17.97	19.91	**17.95**
P_2	16.68	17.15	17.65	19.14	**17.65**
P_3	15.97	16.93	17.04	17.42	**16.84**
Mean	**16.58**	**17.24**	**17.76**	**19.18**	
CD (0.05) P; 0.022		**CD (0.05) B; 0.022**		**CD (0.05) PxB; 0.045**	
SE (m) P; 0.007		**SE (m) B; 0.007**		**SE (m) PxB; 0.015**	

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. Significantly highest N uptake by plant was noticed in treatment, P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) at all stages.

Table 85: Effect of P and B application on nitrogen uptake by plant at flowering stage (kg ha^{-1})

T$_1$: 12.44					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	14.21	10.93	9.12	6.75	**10.25**
P$_1$	15.48	13.78	12.56	13.81	**13.91**
P$_2$	23.85	20.02	12.08	9.29	**16.31**
P$_3$	27.08	23.13	19.46	17.03	**21.68**
Mean	**20.16**	**16.96**	**13.30**	**11.72**	
CD (0.05) P; 0.225		**CD (0.05) B; 0.225**		**CD (0.05) PxB; 0.450**	
SE (m) P; 0.079		**SE (m) B; 0.079**		**SE (m) PxB; 0.157**	

Table 86: Effect of P and B application on nitrogen uptake by plant at pegging stage (kg ha^{-1})

T$_1$: 35.49					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	36.36	33.08	30.22	27.87	**31.88**
P$_1$	37.35	35.16	35.06	36.22	**35.94**
P$_2$	46.76	42.45	34.00	30.20	**38.35**
P$_3$	51.62	47.59	42.14	39.40	**45.19**
Mean	43.02	39.57	35.35	33.42	
CD (0.05) P; 0.340		**CD (0.05) B; 0.340**		**CD (0.05) PxB; 0.680**	
SE (m) P; 0.119		**SE (m) B; 0.119**		**SE (m) PxB; 0.238**	

Table 87: Effect of P and B application on nitrogen uptake by plant at pod setting stage (kg ha^{-1})

T_1: 47.55					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	49.12	41.40	38.77	39.34	**42.16**
P_1	49.38	43.76	43.45	43.40	**44.99**
P_2	64.52	58.63	42.49	38.84	**51.12**
P_3	78.99	68.57	54.30	51.43	**63.32**
Mean	**60.50**	**53.09**	**44.75**	**43.25**	
CD (0.05) P; 1.315		**CD (0.05) B; 1.315**		**CD (0.05) PxB; 2.630**	
SE (m) P; 0.460		**SE (m) B; 0.460**		**SE (m) PxB; 0.920**	

Table 88: Effect of P and B application on nitrogen uptake by plant at harvest stage (kg ha^{-1})

T_1: 49.15					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	52.73	47.32	44.84	44.27	**47.29**
P_1	54.76	48.74	47.40	48.49	**49.85**
P_2	67.48	60.79	46.24	43.95	**54.61**
P_3	79.43	68.70	59.21	55.51	**65.71**
Mean	**63.60**	**56.38**	**49.42**	**48.05**	
CD (0.05) P; 1.013		**CD (0.05) B; 1.013**		**CD (0.05)PxB; 2.025**	
SE (m) P; 0.354		**SE (m) B; 0.354**		**SE (m) PxB; 0.709**	

4.6.2 Phosphorus uptake by plant

Uptake of P by plant varied significantly due to different levels of fertilizer application. Significantly highest P uptake by plant was noticed in treatment, P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) at all stages.

Table 89: Effect of P and B application on phosphorus uptake by plant at flowering stage (kg ha^{-1})

T_1: 1.87					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	1.71	1.26	1.10	0.74	**1.20**
P_1	2.06	1.88	1.71	1.90	**1.89**
P_2	3.20	2.68	1.78	1.46	**2.28**
P_3	3.74	3.58	2.80	2.59	**3.17**
Mean	**2.68**	**2.35**	**1.85**	**1.67**	
CD (0.05) P; 0.076		**CD (0.05) B;0.076**		**CD (0.05);PxB 0.151**	
SE (m) P; 0.027		**SE (m) B; 0.027**		**SE (m) PxB; 0.053**	

Table 90: Effect of P and B application on phosphorus uptake by plant at pegging stage (kg ha^{-1})

T_1: 5.43					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	4.24	3.70	3.38	2.74	**3.51**
P_1	4.74	4.61	4.60	5.06	**4.75**
P_2	6.64	5.94	4.93	4.45	**5.49**
P_3	7.33	7.22	6.28	6.15	**6.74**
Mean	**5.74**	**5.37**	**4.80**	**4.60**	
CD (0.05) P;0.111		**CD (0.05) B;0.111**		**CD (0.05);PxB 0.222**	
SE (m) P; 0.039		**SE (m) B; 0.039**		**SE (m) PxB; 0.078**	

Table 91: Effect of P and B application on phosphorus uptake by plant at pod setting stage (kg ha^{-1})

T$_1$: 7.48					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	5.54	4.49	3.92	3.35	**4.32**
P$_1$	5.98	5.52	5.38	6.18	**5.76**
P$_2$	9.84	8.70	6.06	5.26	**7.47**
P$_3$	11.54	10.23	8.51	8.25	**9.63**
Mean	**8.23**	**7.23**	**5.96**	**5.76**	
CD (0.05) P; 0.273		**CD (0.05) B; 0.273**		**CD (0.05) PxB; 0.546**	
SE (m) P; 0.096		**SE (m) B; 0.096**		**SE (m) PxB; 0.191**	

Table 92: Effect of P and B application on phosphorus uptake by plant at harvest stage (kg ha^{-1})

T$_1$:7.79					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	5.93	4.95	4.19	3.45	**4.63**
P$_1$	6.35	5.82	5.81	6.11	**6.02**
P$_2$	9.91	9.05	6.53	5.62	**7.78**
P$_3$	11.93	10.43	9.48	9.52	**10.34**
Mean	**8.53**	**7.56**	**6.50**	**6.17**	
CD (0.05) P;0.263		**CD (0.05) B;0.263**		**CD (0.05);PxB 0.525**	
SE (m) P; 0.092		**CD (0.05) B;0.092**		**SE (m) PxB; 0.184**	

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$_3$B$_1$ (P, 90 kg ha^{-1} B, 5 kg ha^{-1})

showed highest K uptake at flowering stage (39.08 kg ha^{-1}). At pegging, pod setting and harvest stages, P_2B_0 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest uptake.

Table 93: Effect of P and B application on potassium uptake by plant at flowering stage (kg ha^{-1})

T_1: 12.43					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	13.17	10.65	8.99	5.66	**9.62**
P_1	13.92	11.68	11.31	11.59	**12.12**
P_2	20.49	15.35	11.20	10.23	**14.32**
P_3	20.28	20.85	15.35	15.39	**17.97**
Mean	**16.97**	**14.63**	**11.71**	**10.72**	
CD (0.05) P; 0.381		**CD (0.05) B; 0.381**		**CD (0.05) PxB; 0.762**	
SE (m) P; 0.133		**SE (m) B; 0.133**		**SE (m) PxB; 0.267**	

Table 94: Effect of P and B application on potassium uptake by plant at pegging stage (kg ha^{-1})

T_1: 33.26					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	31.26	31.37	27.73	24.50	**28.71**
P_1	35.12	32.18	32.69	34.12	**33.53**
P_2	42.33	35.44	33.33	32.05	**35.78**
P_3	38.49	38.31	35.27	36.27	**37.08**
Mean	**36.80**	**34.32**	**32.26**	**31.73**	
CD (0.05) P;0.546		**CD (0.05) B;0.546**		**CD (0.05) PxB; 1.091**	
SE (m) P; 0.191		**SE (m) B; 0.191**		**SE (m) PxB; 0.382**	

Table 95: Effect of P and B application on potassium uptake by plant at pod setting stage (kg ha^{-1})

T_1: 41.06					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	38.00	37.95	31.61	36.58	**36.04**
P_1	49.78	43.08	41.70	46.78	**45.33**
P_2	62.41	54.21	44.59	39.22	**50.11**
P_3	56.42	47.18	48.70	48.46	**50.19**
Mean	**51.65**	**45.60**	**41.65**	**42.76**	
CD (0.05) P; 1.435		**CD (0.05) B; 1.435**		**CD (0.05) PxB; 2.869**	
SE (m) P; 0.502		**SE (m) B; 0.502**		**SE (m) PxB; 1.004**	

Table 96: Effect of P and B application on potassium uptake by plant at harvest stage (kg ha^{-1})

T_1: 45.40					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	43.44	46.24	38.02	42.80	**42.62**
P_1	57.99	50.49	49.33	54.04	**52.96**
P_2	69.87	60.48	50.99	45.99	**56.83**
P_3	61.15	51.49	56.53	56.68	**56.46**
Mean	**58.11**	**52.17**	**48.72**	**49.88**	
CD (0.05) P; 1.336		**CD (0.05) B; 1.336**		**CD (0.05) PxB; 2.672**	
SE (m) P; 0.468		**SE (m) B; 0.468**		**SE (m) PxB; 0.935**	

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_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1})

during all stages. Ca uptake increased as plants grews and there was a slight decrease at harvest stage. Main effect of B was non -significant at harvest stage.

Table 97: Effect of P and B application on calcium uptake by plant at flowering stage (kg ha^{-1})

T_1: 8.62					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	11.75	9.55	9.09	6.79	**9.29**
P_1	10.56	9.52	9.28	10.77	**10.03**
P_2	15.16	14.41	9.46	7.95	**11.74**
P_3	16.14	16.78	15.15	13.87	**15.49**
Mean	**13.40**	**12.56**	**10.75**	**9.84**	
CD (0.05) P; 0.288		**CD (0.05) B; 0.288**		**CD (0.05) PxB; 0.576**	
SE (m) P; 0.101		**SE (m) B; 0.101**		**SE (m) PxB; 0.202**	

Table 98: Effect of P and B application on calcium uptake by plant at pegging stage (kg ha^{-1})

T_1: 17.04					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	27.58	26.06	26.57	24.84	**26.26**
P_1	20.66	21.24	21.94	25.17	**22.25**
P_2	25.74	26.63	22.44	21.78	**24.15**
P_3	26.87	29.95	29.28	28.44	**28.64**
Mean	**25.21**	**25.97**	**25.06**	**25.06**	
CD (0.05) P; 0.437		**CD (0.05) B; 0.437**		**CD (0.05) PxB; 0.874**	
SE (m) P; 0.153		**SE (m) B; 0.153**		**SE (m) PxB; 0.306**	

Table 99: Effect of P and B application on calcium uptake by plant at pod setting stage (kg ha^{-1})

T_1: 19.20					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	32.73	28.20	28.56	29.52	**29.75**
P_1	18.98	21.15	20.83	25.03	**21.50**
P_2	28.06	29.35	21.23	21.47	**25.03**
P_3	33.13	35.06	31.81	31.03	**32.76**
Mean	**28.22**	**28.44**	**25.61**	**26.76**	
CD (0.05) P; 0.713		**CD (0.05) B; 0.713**		**CD (0.05) PxB; 1.426**	
SE (m) P; 0.250		**SE (m) B; 0.250**		**SE (m) PxB; 0.499**	

Table 100: Effect of P and B application on calcium uptake by plant at harvest stage (kg ha^{-1})

T_1: 13.89					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	29.85	27.53	29.56	29.66	**29.15**
P_1	16.38	17.96	19.90	22.35	**19.15**
P_2	25.37	27.45	20.28	21.04	**23.53**
P_3	29.31	31.78	29.91	29.93	**30.23**
Mean	**25.23**	**26.18**	**24.91**	**25.74**	
CD (0.05) P; 1.147		**CD (0.05) B; NS**		**CD (0.05) PxB; 2.293**	
SE (m) P; 0.401		**SE (m) B; 0.401**		**SE (m) PxB; 0.802**	

4.6.5 Magnesium uptake by groundnut plant

Application of P and B fertilizers significantly affected Mg uptake by plant. The treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) had highest Mg uptake during flowering and pegging stages. During pod setting and harvest, highest Mg uptake was noted in P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}). The main effect and interaction effect was found to be significant at all stages except at harvest where, main effect of B was non- significant.

Table 101: Effect of P and B application on Magnesium uptake by plant at flowering stage (kg ha^{-1})

T_1: 16.78					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	17.78	15.00	12.40	11.41	**14.15**
P_1	17.42	16.11	17.08	16.71	**16.83**
P_2	27.39	23.05	16.15	12.41	**19.75**
P_3	25.78	27.51	20.20	20.06	**23.39**
Mean	**22.09**	**20.41**	**16.46**	**15.15**	
CD (0.05) P; 0.533		**CD (0.05) B; 0.533**		**CD (0.05) PxB; 1.065**	
SE (m) P; 0.175		**SE (m) B; 0.175**		**SE (m) PxB; 0.350**	

Table 102: Effect of P and B application on Magnesium uptake by plant at pegging stage (kg ha^{-1})

T$_1$: 33.41					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	35.71	34.44	30.66	33.36	**33.54**
P$_1$	31.53	33.05	34.89	33.24	**33.18**
P$_2$	40.13	37.46	33.57	30.64	**35.45**
P$_3$	39.66	42.65	35.19	34.30	**37.95**
Mean	**36.76**	**36.90**	**33.58**	**32.88**	
CD (0.05) P; 0.581		**CD (0.05) B; 0.581**		**CD (0.05) PxB; 1.163**	
SE (m) P; 0.191		**SE (m) B; 0.191**		**SE (m) PxB; 0.382**	

Table 103: Effect of P and B application on Magnesium uptake by plant at pod setting stage (kg ha^{-1})

T$_1$: 23.22					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	31.74	25.95	22.65	21.74	**25.52**
P$_1$	24.84	27.37	24.18	26.23	**25.65**
P$_2$	29.92	29.33	22.88	23.43	**26.39**
P$_3$	41.55	37.45	30.16	24.97	**33.53**
Mean	**32.01**	**30.02**	**24.96**	**24.09**	
CD (0.05) P; 0.849		**CD (0.05) B; 0.849**		**CD (0.05) PxB; 1.699**	
SE (m) P; 0.279		**SE (m) B; 0.279**		**SE (m) PxB; 0.559**	

Table 104: Effect of P and B application on Magnesium uptake by plant at harvest stage (kg ha^{-1})

T_1:					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	36.07	29.98	25.31	25.02	**29.09**
P_1	26.37	29.91	26.62	28.13	**27.75**
P_2	33.24	32.88	25.17	27.69	**29.74**
P_3	42.79	38.94	33.11	28.93	**35.94**
Mean	**34.61**	**32.92**	**27.55**	**27.44**	
CD (0.05) P; 0.913		**CD (0.05) B; 0.913**		**CD (0.05) PxB; 1.826**	
SE (m) P; 0.300		**SE (m) B; 0.300**		**SE (m) PxB; 0.600**	

4.6.6 Sulphur uptake by groundnut plant

Application of P and B fertilizers significantly affected S uptake by plant. The treatment, P_3B_3 (P, 90 kg ha^{-1} B, 15 kg ha^{-1}) had highest S uptake during flowering and pegging stages. During pod setting and harvest, highest S uptake was noted in P_3B_2 (P, 90 kg ha^{-1} B, 10 kg ha^{-1}). The main effect and interaction effect was found to be significant at all stages except at harvest where, main effect of B was non-significant.

Table 105: Effect of P and B application on sulphur uptake by plant at flowering stage (kg ha^{-1})

T_1: 1.56					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	2.95	2.18	1.78	1.30	**2.05**
P_1	2.87	2.90	2.76	3.19	**2.93**
P_2	5.08	4.52	3.02	2.68	**3.82**
P_3	5.90	5.83	5.26	6.27	**5.81**
Mean	**4.20**	**3.85**	**3.20**	**3.36**	
CD (0.05) P; 0.089		**CD (0.05) B; 0.089**		**CD (0.05) PxB; 0.178**	
SE (m) P; 0.031		**SE (m) B; 0.031**		**SE (m) PxB; 0.062**	

Table 106: Effect of P and B application on sulphur uptake by plant at pegging stage (kg ha^{-1})

T_1:4.16					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	6.25	5.44	4.94	4.48	**5.27**
P_1	5.97	6.43	6.46	7.43	**6.57**
P_2	8.62	8.86	7.36	7.38	**8.05**
P_3	9.89	10.18	10.80	11.65	**10.63**
Mean	**7.68**	**7.73**	**7.39**	**7.73**	
CD (0.05) P; 0.169		**CD (0.05) B; 0.169**		**CD (0.05) PxB; 0.338**	
SE (m) P; 0.059		**SE (m) B; 0.059**		**SE (m) PxB; 0.118**	

Table 107: Effect of P and B application on sulphur uptake by plant at pod setting stage (kg ha^{-1})

T_1:5.08					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	6.18	5.03	4.91	4.85	**5.24**
P_1	6.26	6.39	6.06	7.42	**6.53**
P_2	9.47	9.29	7.37	7.36	**8.37**
P_3	12.43	11.52	12.97	10.49	**11.85**
Mean	**8.58**	**8.06**	**7.83**	**7.53**	
CD (0.05) P; 0.548		**CD (0.05) B; 0.548**		**CD (0.05) PxB; 1.096**	
SE (m) P; 0.192		**SE (m) B; 0.192**		**SE (m) PxB; 0.192**	

Table 108: Effect of P and B application on sulphur uptake by plant at harvest stage (kg ha^{-1})

T_1:5.13					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	6.63	5.64	5.37	5.37	**5.75**
P_1	6.72	6.89	6.66	8.31	**7.14**
P_2	10.02	10.64	7.87	8.31	**9.21**
P_3	12.83	11.72	14.36	11.96	**12.72**
Mean	**9.05**	**8.72**	**8.57**	**8.49**	
CD (0.05) P; 0.494		**CD (0.05) B; NS**		**CD (0.05) PxB; 0.988**	
SE (m) P; 0.173		**SE (m) B; 0.173**		**SE (m) PxB; 0.346**	

4.6.7 Iron uptake by plant

Uptake of Fe by plant at different stages is shown in the tables 109, 110, 111, 112. Uptake of Fe varied significantly due to interaction effect and main effect. P_3B_2 (P, 90 kg ha^{-1} B, 10 kg ha^{-1}) showed highest Fe uptake at flowering and pegging stages. P_3 B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) showed highest uptake at pod setting stage and P_2 B_0 (P, 75 kg ha^{-1} B, 0 kg ha^{-1}) showed highest uptake at harvest stage.

Table 109: Effect of P and B application on iron uptake by plant at flowering stage (g ha^{-1})

T_1:338.87					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	271.31	187.33	179.00	170.90	**202.13**
P_1	318.88	259.86	222.49	235.33	**259.14**
P_2	374.79	323.07	173.68	193.82	**266.34**
P_3	371.67	320.84	383.17	344.54	**355.05**
Mean	**334.16**	**272.77**	**239.58**	**236.15**	
CD (0.05) P; 10.217		**CD (0.05) B; 10.217**		**CD (0.05)PxB; 20.435**	
SE (m) P; 3.575		**SE (m) B; 3.575**		**SE (m) PxB; 7.151**	

Table 110: Effect of P and B application on iron uptake by plant at pegging stage (g ha^{-1})

T_1:898.44					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	736.72	524.95	635.42	610.84	**626.98**
P_1	711.39	676.53	557.28	665.79	**652.75**
P_2	766.11	708.75	534.00	566.69	**643.89**
P_3	732.27	715.86	794.72	648.77	**722.90**
Mean	**736.62**	**656.52**	**630.35**	**623.02**	
CD (0.05) P; 18.605		**CD (0.05) B; 18.605**		**CD (0.05) PxB; 37.210**	
SE (m) P; 6.510		**SE (m) B; 6.510**		**SE (m) PxB; 13.021**	

Table 111: Effect of P and B application on iron uptake by plant at pod setting stage (g ha^{-1})

T_1:1084.78					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	1070.32	591.94	880.53	703.51	**811.58**
P_1	840.87	865.24	591.74	879.08	**794.23**
P_2	1115.54	1020.52	739.44	629.08	**876.14**
P_3	1168.24	1128.65	966.25	602.18	**966.33**
Mean	**1048.74**	**901.59**	**794.49**	**703.46**	
CD (0.05) P; 44.940		**CD (0.05) B; 44.940**		**CD (0.05) PxB; 89.880**	
SE (m) P; 15.726		**SE (m) B; 15.726**		**SE (m) PxB; 31.451**	

Table 112: Effect of P and B application on iron uptake by plant at harvest stage (g ha^{-1})

T_1:1242.22					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	1236.32	721.86	1070.52	810.20	**959.72**
P_1	976.86	1012.02	710.15	1061.90	**940.23**
P_2	1298.36	1200.84	897.97	741.67	**1034.71**
P_3	1257.90	1286.78	1121.69	716.51	**1095.72**
Mean	**1192.36**	**1055.37**	**950.08**	**832.57**	
CD (0.05) P; 36.848		**CD (0.05) B; 36.848**		**CD (0.05) PxB; 73.695**	
SE (m) P; 12.894		**SE (m) B; 12.894**		**SE (m) PxB; 25.788**	

4.6.8 Manganese uptake by groundnut plants

Manganese uptake was significantly influenced by main effect and interaction effect. The treatment, P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) showed highest Mn uptake at flowering stage. At pegging highest uptake was observed in P_1B_3 (P, 60 kg ha^{-1} B, 15 kg ha^{-1}) and at pod setting and harvest, the highest Mn uptake was in treatment P_1B_0 (P, 60 kg ha^{-1} B, 0 kg ha^{-1})

Table 113: Effect of P and B application on manganese uptake by plant at flowering stage (g ha^{-1})

T_1: 35.92					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	42.14	36.45	33.49	25.48	**34.39**
P_1	53.98	49.13	46.49	51.38	**50.24**
P_2	59.47	54.89	36.22	34.59	**46.29**
P_3	60.10	56.18	50.29	45.88	**53.11**
Mean	**53.92**	**49.16**	**41.62**	**39.33**	
CD (0.05) P; 1.775		**CD (0.05) B; 1.775**		**CD (0.05) PxB; 3.551**	
SE (m) P; 0.621		**SE (m) B; 0.621**		**SE (m) PxB; 1.242**	

Table 114: Effect of P and B application on manganese uptake by plant at pegging stage (g ha^{-1})

T_1:121.51					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	114.44	111.24	109.76	104.16	**109.90**
P_1	134.00	131.49	130.63	139.40	**133.88**
P_2	117.85	118.64	107.66	108.74	**113.22**
P_3	112.51	109.85	106.90	103.58	**108.21**
Mean	**119.70**	**117.80**	**113.73**	**113.97**	
CD (0.05) P; 2.735		**CD (0.05) B; 2.735**		**CD (0.05) PxB; 5.471**	
SE (m) P; 0.957		**SE (m) B; 0.957**		**SE (m) PxB; 1.914**	

Table 115: Effect of P and B application on manganese uptake by plant at pod setting stage (g ha^{-1})

T_1:193.22					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	166.01	140.50	138.92	145.21	**147.66**
P_1	183.59	173.87	163.16	174.70	**173.83**
P_2	164.84	167.84	143.66	133.91	**152.56**
P_3	168.16	148.28	134.71	130.94	**145.52**
Mean	**170.65**	**157.62**	**145.11**	**146.19**	
CD (0.05) P; 6.009		**CD (0.05) B; 6.009**		**CD (0.05) PxB; 12.017**	
SE (m) P; 2.103		**SE (m) B; 2.103**		**SE (m) PxB; 4.205**	

Table 116: Effect of P and B application on manganese uptake by plant at harvest stage (g ha^{-1})

T_1: 213.78					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	189.31	171.66	171.75	166.64	**174.84**
P_1	217.92	201.35	192.55	203.32	**203.78**
P_2	183.30	189.29	164.32	155.71	**173.15**
P_3	178.41	159.41	153.04	150.97	**160.46**
Mean	**192.23**	**180.43**	**170.41**	**169.16**	
CD (0.05) P; 6.269		**CD (0.05) B; 6.269**		**CD (0.05) PxB; 12.538**	
SE (m) P; 2.194		**SE (m) B; 2.194**		**SE (m) PxB; 4.387**	

4.6.9 Zinc uptake by groundnut plants

Zinc uptake varied significantly due to application of P and B fertilizers. The treatment P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) showed highest zinc uptake at flowering stage. Whereas at pegging, pod setting and harvest stage, P_0B_0 (P, 0 kg ha^{-1} B, 0 kg ha^{-1}) showed highest Zn uptake.

Table 117: Effect of P and B application on zinc uptake by plant at flowering stage (g ha^{-1})

T_1: 28.05					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	29.70	23.99	24.13	18.20	**24.01**
P_1	28.83	25.29	24.07	26.14	**26.08**
P_2	39.10	35.48	23.15	20.41	**29.53**
P_3	41.12	36.58	31.88	28.10	**34.42**
Mean	**34.69**	**30.33**	**25.81**	**23.21**	
CD (0.05) P; 0.786		**CD (0.05) B; 0.786**		**CD (0.05) PxB; 1.573**	
SE (m) P; 0.275		**SE (m) B; 0.275**		**SE (m) PxB; 0.550**	

Table 118: Effect of P and B application on zinc uptake by plant at pegging stage (g ha^{-1})

T$_1$: 72.78					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	87.91	79.07	83.04	74.12	**81.03**
P_1	76.07	73.95	70.35	74.50	**73.72**
P_2	81.19	78.69	65.65	61.31	**71.71**
P_3	76.96	76.98	71.67	67.25	**73.22**
Mean	**80.53**	**77.17**	**72.68**	**69.29**	
CD (0.05) P; 1.227		**CD (0.05) B; 1.227**		**CD (0.05) PxB; 2.454**	
SE (m) P; 0.429		**SE (m) B; 0.429**		**SE (m) PxB; 0.859**	

Table 119: Effect of P and B application on zinc uptake by plant at pod setting stage (g ha^{-1})

T$_1$: 85.83					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	132.18	108.98	111.27	102.96	**113.85**
P_1	111.77	105.75	92.05	98.93	**102.12**
P_2	118.51	114.94	82.76	70.96	**96.79**
P_3	114.89	113.86	96.66	91.44	**104.21**
Mean	**119.34**	**110.88**	**95.68**	**91.07**	
CD (0.05) P; 3.804		**CD (0.05) B; 3.804**		**CD (0.05) PxB; 7.609**	
SE (m) P; 1.331		**SE (m) B; 1.331**		**SE (m) PxB; 2.662**	

Table 120: Effect of P and B application on zinc uptake by plant at harvest stage (g ha^{-1})

T_1: 91.66					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	144.32	126.82	130.08	116.92	**129.53**
P_1	127.26	117.97	104.56	109.42	**114.80**
P_2	127.24	121.71	92.36	79.91	**105.31**
P_3	119.01	118.62	104.46	101.02	**110.78**
Mean	**129.46**	**121.28**	**107.86**	**101.82**	
CD (0.05) P; 2.499		**CD (0.05) B; 2.499**		**CD (0.05) PxB; 4.998**	
SE (m) P; 0.874		**SE (m) B; 0.874**		**SE (m) PxB; 1.749**	

4.6.10 Copper uptake by groundnut plant

Uptake of Cu was significant at all the stages. The treatment, P_2B_0 (P, 75 kg ha^{-1} B, 0 kg ha^{-1}) showed highest uptake at flowering and pegging and pod setting stages. Highest uptake during harvest stage was noted in P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}). Uptake was decreased from pod setting to harvest stage.

Table 121: Effect of P and B application on copper uptake by plant at flowering stage (g ha^{-1})

T_1: 9.64					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	8.86	7.04	5.76	4.53	**6.55**
P_1	9.52	8.57	7.50	7.91	**8.37**
P_2	13.49	11.78	7.30	6.08	**9.66**
P_3	12.82	12.53	11.81	10.47	**11.91**
Mean	**11.17**	**9.98**	**8.09**	**7.25**	
CD (0.05) P; 0.412		**CD (0.05) B; 0.412**		**CD (0.05) PxB; 0.823**	
SE (m) P; 0.144		**SE (m) B; 0.144**		**SE (m) PxB; 0.288**	

Table 122: Effect of P and B application on copper uptake by plant at pegging stage (g ha^{-1})

T_1:33.34					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	29.64	27.49	26.37	23.78	**26.82**
P_1	29.33	28.26	26.05	30.44	**28.52**
P_2	36.39	33.04	28.66	25.05	**30.78**
P_3	31.29	31.12	31.04	31.27	**31.18**
Mean	**31.66**	**29.98**	**28.03**	**27.63**	
CD (0.05) P; 1.272		**CD (0.05) B;1.272**		**CD (0.05) PxB; 2.544**	
SE (m) P; 0.445		**SE (m) B; 0.445**		**SE (m) PxB; 0.890**	

Table 123: Effect of P and B application on copper uptake by plant at pod setting stage (g ha^{-1})

T_1:54.01					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	52.36	44.07	44.97	42.14	**45.88**
P_1	49.71	45.90	40.21	51.91	**46.93**
P_2	68.26	60.25	48.70	40.71	**54.48**
P_3	61.63	54.12	48.78	52.41	**54.23**
Mean	**57.99**	**51.08**	**45.66**	**46.79**	
CD (0.05) P; 3.425		**CD (0.05) B; 3.425**		**CD (0.05) PxB; 6.850**	
SE (m) P; 1.198		**SE (m) B; 1.198**		**SE (m) PxB; 2.397**	

Table 124: Effect of P and B application on copper uptake by plant at harvest stage (g ha^{-1})

T_1:44.82					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	38.37	36.34	32.02	31.95	**34.67**
P_1	41.60	38.49	36.00	36.67	**38.19**
P_2	48.25	47.01	34.85	33.23	**40.83**
P_3	49.93	45.28	43.95	42.88	**45.51**
Mean	**44.53**	**41.78**	**36.70**	**36.18**	
CD (0.05) P; 2.304		**CD (0.05) B; 2.304**		**CD (0.05) PxB; 4.609**	
SE (m) P; 0.806		**SE (m) B; 0.806**		**SE (m) PxB; 1.613**	

4.6.11 Boron uptake by groundnut plant

Uptake of B was significantly influenced by main effect and interaction effect. Treatment, P_2B_0 (P, 75 kg ha^{-1} B, 0 kg ha^{-1}) showed highest uptake at flowering and pegging stages. Treatment, P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) showed highest uptake at pod setting and harvest stages.

Table 125: Effect of P and B application on boron uptake by plant at flowering stage (g ha^{-1})

T_1: 11.91					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	12.65	10.37	9.50	7.37	**9.97**
P_1	12.93	11.88	11.06	12.16	**12.01**
P_2	16.99	15.44	10.21	8.89	**12.88**
P_3	16.56	16.33	15.07	13.93	**15.47**
Mean	**14.78**	**13.50**	**11.46**	**10.59**	
CD (0.05) P; 0.276		**CD (0.05) B; 0.276**		**CD (0.05) PxB; 0.552**	
SE (m) P; 0.096		**SE (m) B; 0.096**		**SE (m) PxB; 0.193**	

Table 126: Effect of P and B application on boron uptake by plant at pegging stage (g ha^{-1})

T$_1$: 30.01					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	29.54	28.34	27.91	26.89	**28.17**
P$_1$	28.62	28.04	27.80	29.50	**28.49**
P$_2$	30.10	29.81	25.87	25.78	**27.89**
P$_3$	29.59	28.61	29.12	28.92	**29.06**
Mean	**29.46**	**28.70**	**27.67**	**27.77**	
CD (0.05) P; 0.360		**CD (0.05) B; 0.360**		**CD (0.05) PxB; 0.721**	
SE (m) P; 0.237		**SE (m) B; 0.237**		**SE (m) PxB; 0.474**	

Table 127: Effect of P and B application on boron uptake by plant at pod setting stage (g ha^{-1})

T$_1$: 33.84					
	B$_0$	**B$_1$**	**B$_2$**	**B$_3$**	**Mean**
P$_0$	35.00	30.77	30.31	31.99	**32.01**
P$_1$	33.39	31.10	29.68	31.54	**31.43**
P$_2$	35.65	35.82	27.73	28.19	**31.85**
P$_3$	41.31	32.45	31.80	32.28	**34.46**
Mean	**36.34**	**32.53**	**29.88**	**31.00**	
CD (0.05) P; 0.938	**CD (0.05) B; 0.938**			**CD (0.05) PxB; 1.875**	
SE (m) P; 0.328	**SE (m) B; 0.328**			**SE (m) PxB; 0.656**	

Table 128: Effect of P and B application on boron uptake by plant at harvest stage (g ha^{-1})

T_1: 33.59					
	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	35.65	33.48	32.86	33.61	**33.90**
P_1	34.66	31.62	31.29	32.60	**32.54**
P_2	34.07	35.16	28.02	30.30	**31.89**
P_3	38.35	31.84	31.96	32.98	**33.78**
Mean	**35.68**	**33.02**	**31.03**	**32.37**	
CD (0.05) P; 0.764		**CD (0.05) B; 0.764**		**CD (0.05) PxB; 1.527**	
SE (m) P; 0.267		**SE (m) B; 0.267**		**SE (m) PxB; 0.534**	

4.7 NUTRIENT UPTAKE BY POD

4.7.1 Nitrogen uptake by pod

Data (table 129) on N uptake by pod showed that, N uptake by pod varied significantly due to application of different levels of P and B. The treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest N uptake.

4.7.2 Phosphorus uptake by pod

Uptake of P by plant at different stages was shown in the table 130. P uptake by pod varied significantly due to application of different levels of P and B. The treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest P uptake.

Table 129: Effect of P and B application on nitrogen uptake by pod (kg ha^{-1})

T_1: 67.26

	B_0	B_1	B_2	B_3	Mean
P_0	73.58	67.73	64.29	61.05	**66.66**
P_1	78.54	72.31	71.86	77.79	**75.13**
P_2	99.57	104.72	99.88	78.07	**95.56**
P_3	123.48	126.93	123.14	111.67	**121.30**
Mean	**93.79**	**92.92**	**89.79**	**82.15**	
CD (0.05) P; 0.627	**CD (0.05) B; 0.627**		**CD (0.05) PxB; 1.255**		
SE (m) P; 0.206	**SE (m) B; 0.206**		**SE (m) PxB; 0.412**		

Table 130: Effect of P and B application on phosphorus uptake by pod (kg ha^{-1})

`T_1: 7.83

	B_0	B_1	B_2	B_3	Mean
P_0	7.19	6.95	6.61	6.22	**6.74**
P_1	7.65	7.69	7.37	8.05	**7.69**
P_2	10.14	10.38	11.53	8.96	**10.25**
P_3	13.14	13.91	13.18	12.28	**13.13**
Mean	9.53	9.73	9.67	8.88	
CD (0.05) P; 0.066	**CD (0.05) B; 0.066**		**CD (0.05) PxB; 0.131**		
SE (m) P; 0.022	**SE (m) B; 0.022**		**SE (m) PxB; 0.044**		

4.7.3 Potassium uptake by pod

Potassium uptake varied significantly due to main effect and interaction effect (table 131). The treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest K uptake.

4.7.4 Calcium uptake by pod

Calcium uptake varied significantly due to main effect and interaction effect (table 132). The treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest Ca uptake.

4.7.5 Magnesium uptake by pod

Uptake of Mg by plant varied significantly due to different levels of fertilizer application (table 133). Significantly highest Mg uptake by plant was noticed in treatment, P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}).

4.7.6 Sulphur uptake by pod

Uptake of S by pod varied significantly due to different levels of fertilizer application (table 134). Significantly highest S uptake by pod was noticed in treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}).

Table 131: Effect of P and B application on potassium uptake by pod (kg ha^{-1})

T_1:19.24

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	20.01	19.67	17.72	16.46	**18.46**
P_1	20.32	19.12	19.81	19.91	**19.79**
P_2	25.13	24.90	28.24	22.94	**25.30**
P_3	29.27	32.49	29.93	29.16	**30.21**
Mean	**23.68**	**24.04**	**23.93**	**22.12**	
CD (0.05) P; 0.129		**CD (0.05) B; 0.129**		**CD (0.05) PxB; 0.257**	
SE (m) P; 0.042		**SE (m) B; 0.042**		**SE (m) PxB; 0.085**	

Table 132: Effect of P and B application on Ca uptake by pod (kg ha^{-1})

T_1: 3.25

	B_0	B_1	B_2	B_3	Mean
P_0	2.96	2.59	2.67	2.19	**2.60**
P_1	3.22	2.48	3.09	3.27	**3.02**
P_2	4.61	4.39	4.98	3.69	**4.42**
P_3	6.32	7.23	6.20	6.32	**6.52**
Mean	**4.28**	**4.17**	**4.23**	**3.87**	
CD (0.05) P; 0.048		**CD (0.05) B; 0.048**		**CD (0.05) PxB; 0.097**	
SE (m) P; 0.016		**SE (m) B; 0.016**		**SE (m) PxB; 0.032**	

Table 133: Effect of P and B application on Mg uptake by pod (kg ha^{-1})

T_1: 5.51

	B_0	B_1	B_2	B_3	Mean
P_0	4.50	4.97	5.33	4.56	**4.84**
P_1	5.79	4.95	5.36	5.24	**5.34**
P_2	6.66	6.86	7.91	6.91	**7.09**
P_3	6.80	8.54	7.83	8.13	**7.82**
Mean	**5.94**	**6.33**	**6.61**	**6.21**	
CD (0.05) P; 0.184		**CD (0.05) B; 0.184**		**CD (0.05) PxB; 0.367**	
SE (m) P; 0.060		**SE (m) B; 0.060**		**SE (m) PxB; 0.121**	

Table 134: Effect of P and B application on S uptake by pod (kg ha^{-1})

T_1: 7.94

	B_0	B_1	B_2	B_3	Mean
P_0	7.81	7.09	7.47	8.22	**7.65**
P_1	8.87	8.83	9.55	10.34	**9.40**
P_2	11.20	13.09	14.17	11.43	**12.47**
P_3	16.89	21.29	18.04	19.94	**19.04**
Mean	11.19	12.58	12.31	12.48	
CD (0.05) P; 0.086		**CD (0.05) B; 0.086**		**CD (0.05) PxB; 0.171**	
SE (m) P; 0.030		**SE (m) B; 0.030**		**SE (m) PxB; 0.059**	

4.7.7 Iron uptake by pod

Iron uptake by pod was found to be significant. Compared to other micro nutrients Fe was present in highest amount. The treatment, P_2B_2 (P, 75 kg ha^{-1} and B, 10 kg ha^{-1}) showed highest Fe uptake.

4.7.8 Manganese uptake by pod

Uptake of Mn by pod varied significantly due to different levels of fertilizer application. Significantly highest Mn uptake by pod was noticed in treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}).

4.7.9 Zinc uptake by pod

Zinc uptake varied significantly due to main effect and interaction effect. The treatment, P_3B_1 (P, 90 kg ha^{-1} B, 5 kg ha^{-1}) showed highest Zn uptake.

Table 135: Effect of P and B application on Fe uptake by pod (g ha^{-1})

T_1: 358.15

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	537.57	413.22	484.35	548.87	**496.00**
P_1	634.14	408.47	438.69	497.50	**494.70**
P_2	533.75	380.87	682.45	500.90	**524.49**
P_3	811.85	374.38	418.35	562.11	**541.67**
Mean	**629.33**	**394.23**	**505.96**	**527.35**	
CD (0.05) P; 2.779		**CD (0.05) B; 2.779**		**CD (0.05) PxB; 5.558**	
SE (m) P; 0.914		**SE (m) B; 0.914**		**SE (m) PxB; 1.827**	

Table 136: Effect of P and B application on Mn uptake by pod (g ha^{-1})

T_1: 45.13

	B_0	**B_1**	**B_2**	**B_3**	**Mean**
P_0	41.39	41.27	40.96	39.69	**40.83**
P_1	49.89	50.03	53.10	56.19	**52.30**
P_2	47.41	52.16	57.12	52.39	**52.27**
P_3	48.22	57.47	58.72	54.18	**54.65**
Mean	**46.73**	**50.23**	**52.47**	**50.61**	
CD (0.05) P; 0.662		**CD (0.05) B; 0.662**		**CD (0.05) PxB; 1.323**	
SE (m) P; 0.217		**SE (m) B; 0.217**		**SE (m) PxB; 0.435**	

Table 137: Effect of P and B application on Zn uptake by pod (g ha^{-1})

T_1: 123.76

	B_0	B_1	B_2	B_3	Mean
P_0	113.95	112.38	113.83	111.33	**112.87**
P_1	108.37	103.15	111.35	116.74	**109.90**
P_2	126.87	144.11	147.92	124.36	**135.81**
P_3	154.94	155.99	155.76	139.97	**151.66**
Mean	**126.03**	**128.91**	**132.21**	**123.10**	
CD (0.05) P; 0.973		**CD (0.05) B; 0.973**		**CD (0.05) PxB; 1.946**	
SE (m) P; 0.320		**SE (m) B; 0.320**		**SE (m) PxB; 0.640**	

4.7.10 Copper uptake by pod

Copper uptake varied significantly due to main effect of P and interaction effect and it was non- significant due to factor B. The treatment, P_3B_2 (P, 90 kg ha^{-1} B, 10 kg ha^{-1}) showed highest Cu uptake.

4.7.11 Boron uptake by pod

Uptake of B by pod at different stages is shown in the table 139. B uptake by groundnut pod varied significantly due to different treatments applied. Significantly highest uptake was in treatment having high P.

Table 138: Effect of application of P and B on Cu uptake by pod (g ha^{-1})

T_1: 28.76

	B_0	B_1	B_2	B_3	Mean
P_0	27.08	22.87	17.62	20.08	**21.91**
P_1	20.91	22.69	22.17	20.18	**21.49**
P_2	30.12	32.25	30.76	23.61	**29.18**
P_3	29.25	30.38	44.04	30.94	**33.65**
Mean	**26.84**	**27.05**	**28.64**	**23.70**	
CD (0.05) P; 3.827		**CD (0.05) B; NS**		**CD (0.05) PxB; 7.655**	
SE (m) P; 1.258		**SE (m) B; 1.258**		**SE (m) PxB; 2.516**	

Table 139: Effect of P and B application on B uptake by pod (g ha^{-1})

T_1: 42.24

	B_0	B_1	B_2	B_3	Mean
P_0	35.01	34.89	35.01	36.99	**35.48**
P_1	35.54	35.80	37.05	43.44	**37.96**
P_2	42.74	47.06	51.68	44.08	**46.39**
P_3	50.50	55.58	55.58	52.42	**53.52**
Mean	**40.95**	**43.33**	**44.83**	**44.23**	
CD (0.05) P; 0.219		**CD (0.05) B; 0.219**		**CD (0.05) PxB; 0.438**	
SE (m) P; 0.072		**SE (m) B; 0.072**		**SE (m) PxB; 0.144**	

4.8 PROTEIN CONTENT IN GROUNDNUT POD

Data on protein content in groundnut kernel is shown in the table 140. Protein content was significantly influenced by main effect and interaction effect of P and B. Highest protein content was noted in P_3B_0 (P, 90 kg ha^{-1} B, 0 kg ha^{-1}) .

Table 140: Effect of P and B application on protein content (g)

T_1:22.56

	B_0	B_1	B_2	B_3	Mean
P_0	22.50	21.28	21.09	20.91	**21.45**
P_1	22.88	21.91	21.78	22.28	**22.21**
P_2	24.28	23.84	21.31	21.19	**22.66**
P_3	24.41	24.16	23.59	23.19	**23.84**
Mean	**23.52**	**22.80**	**21.95**	**21.89**	
CD (0.05) P; 0.054		**CD (0.05) B; 0.054**		**CD (0.05) PxB; 0.108**	
SE (m) P; 0.018		**SE (m) B; 0.018**		**SE (m) PxB; 0.036**	

Discussion

5. DISCUSSION

The results of study entitled "P and B interactions in black cotton soils of Kerala with respect to groundnut (*Arachis hypogaea* L.)" presented in chapter 4 are discussed here with supporting studies conducted elsewhere and based on available literature.

5.1 GROWTH AND YIELD PARAMETERS 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 development and harvest stages were significantly affected by application of different levels of P and B fertilizers. At flowering, pegging and pod development stages, treatment T_{14} (P_3B_0: P, 90 kg ha^{-1} and B, 0 kg ha^{-1}) gave highest plant height. At harvest stage, highest plant height was noticed in T_8 (P_1B_2: P, 60 kg ha^{-1} and B, 0 kg ha^{-1}). Application of P increased plant height and number of leaves. Application of soluble P increased the availability of soluble phosphate and enhanced root development and there by enhanced nutrient uptake and resulted in improved plant growth. A higher level of P is important for root growth, root formation and N fixation (Lakshmamma and Raj, 1997). Similar results were reported by Punnoose (1968), Sabale and Khuspe (1986), Patel *et al.* (1981) and Juan *et al.* (1986). Higher content of P in soil increases the N fixation which in turn enhances 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 of groundnut plant under P deficiency.

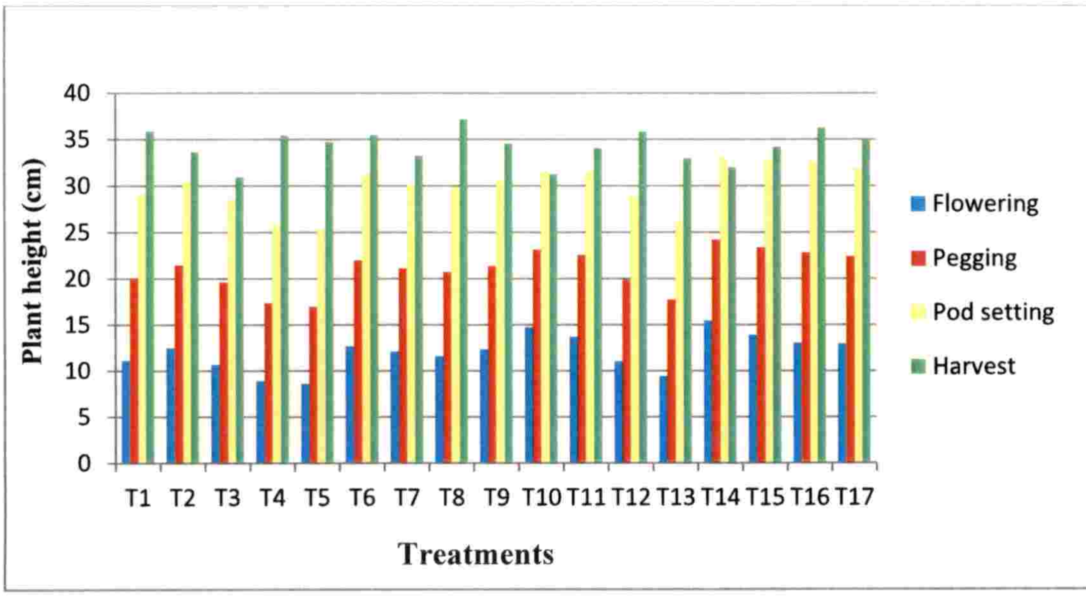

Fig 1: Effect of application of P and B on plant height

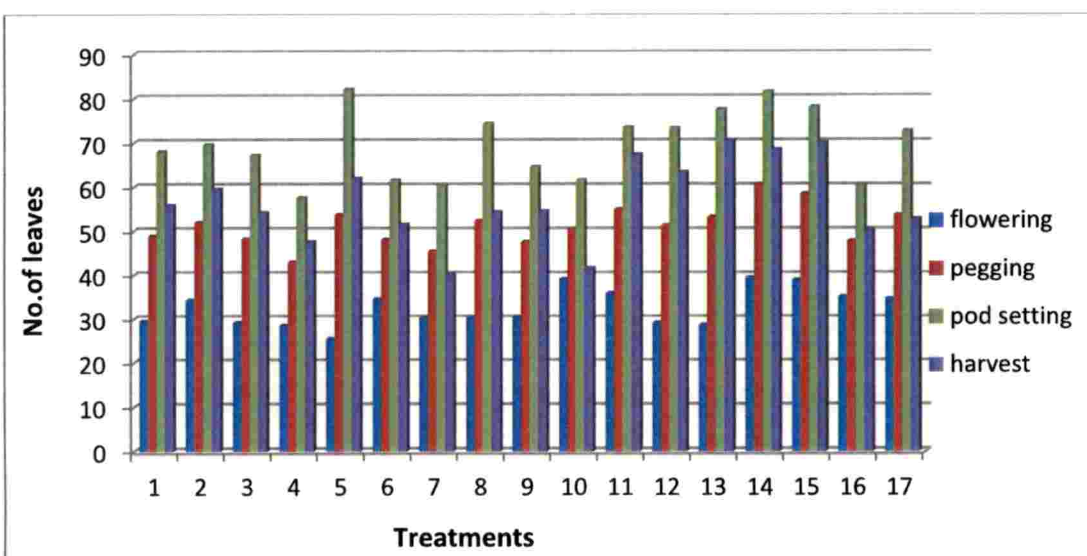

Fig 2: Effect of application of P and B on number of leaves

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. Treatment, T_{16} (P_3 B_2: P, 90 kg ha^{-1} and B, 10 kg ha^{-1}) produced maximum number of pods. Number of pods was highest in treatment receiving high dose of P (90 kg ha^{-1}). Application of P at 90 kg ha^{-1} and B at 5 kg ha^{-1} resulted in highest yield (3.66 t ha^{-1}) whereas yield from present university recommendation was 3.45 t ha^{-1}. There was an increase of 0.21 t ha^{-1} in yield on application of P at 90 kg ha^{-1} and B at 5 kg ha^{-1} than present recommendation. Banerjee *et al.* (1967) and Puri (1969) also reported the same. They reported that application of P increased number of pods and yield. 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 by 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.

Application of P increases rate of N fixation and improves the N availability. Increase in N also has a role in improved yield. Plants having high N availability produce more number of flowers and pegs (Saradhi *et al.,* 1990) and results in an improved yield. N has significant role in 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 observed the same.

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

5.2.1 Soil pH

Application of P and B 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 SSP.

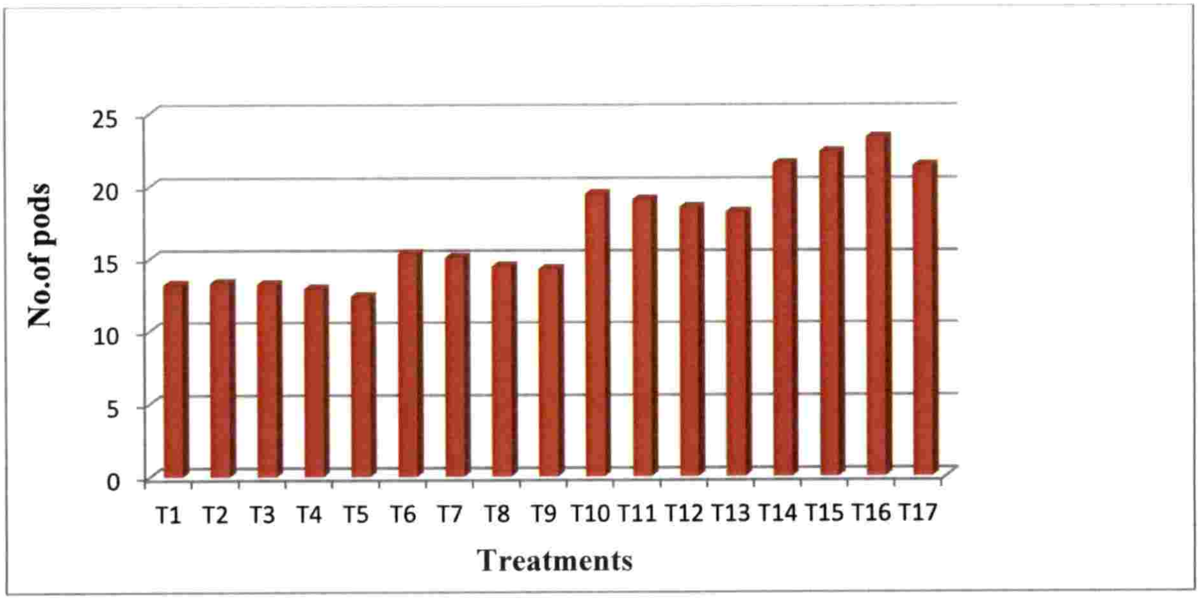

Fig 3: Effect of application of P and B on number of pods per plant

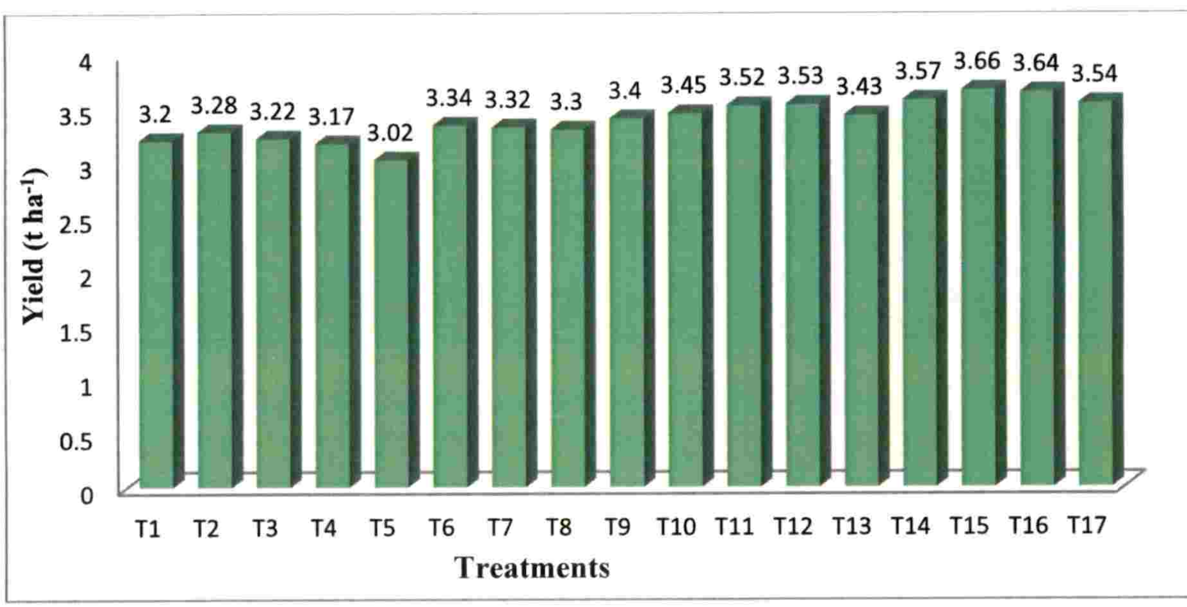

Fig 4: Effect of application of P and B on yield of groundnut

5.2.2 EC

There was a slight increase in EC due to application of soluble fertilizers.

5.2.3 Organic carbon

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

5.2.4 Available nitrogen

Application of P and B significantly affected available N status of 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. N has decreased with increased dose of B.

5.2.5 Available phosphorus

Application of P and B significantly affected 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 than initial P due to application of manures.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 B application also.

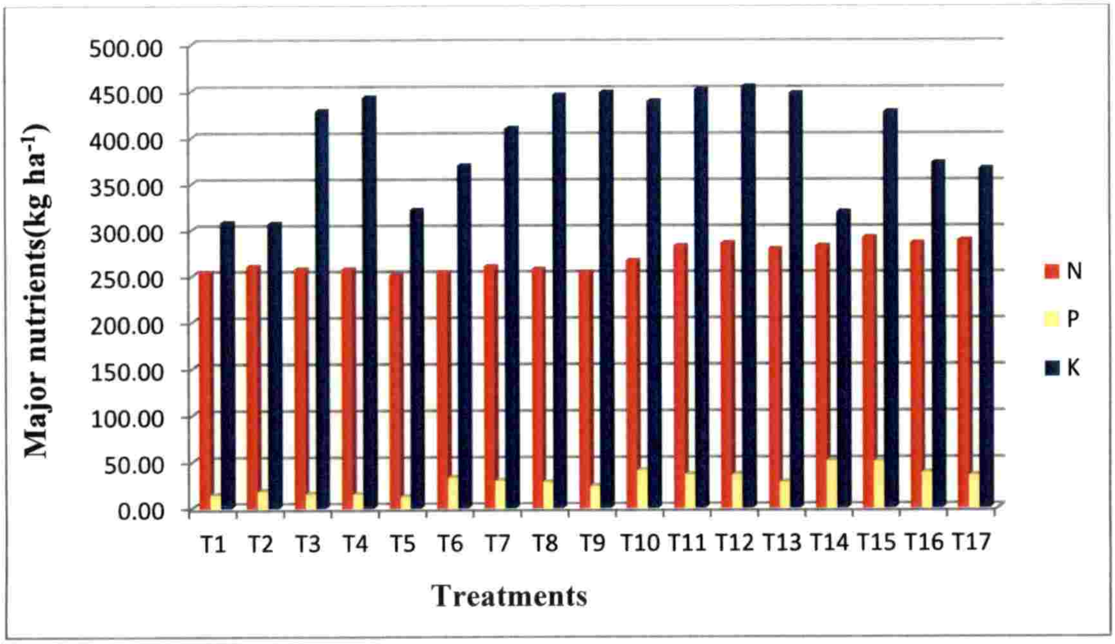

Fig 5: Effect of application of P and B on major nutrients in soil

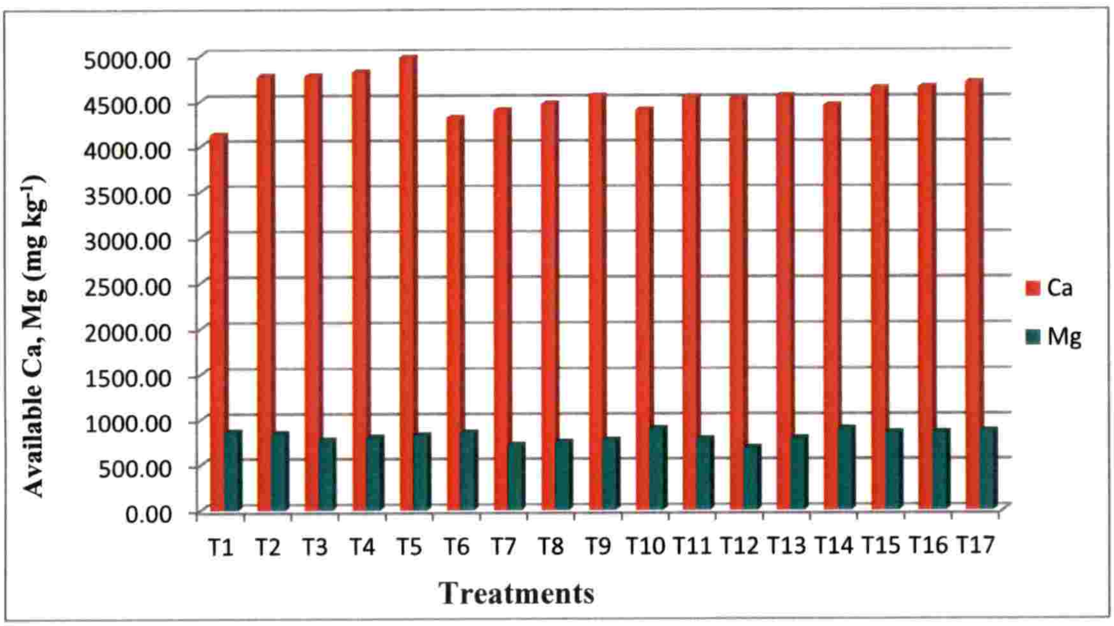

Fig 6: Effect of application of P and B on available Ca and Mg in soil

Available P decreased with increased dose of B application. An antagonism was observed between P and B. Comparable results were reported by Bingham *et al.* (1958) in citrus and May and Pritts (1993) in strawberry.

5.2.6 Available potassium

Compared to initial status, available K in all treatments was increased due to application of MOP. 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. Available K status of soil was affected by Mg content rather than P. Treatment which has highest Mg showed lowest 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 by 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 and B reduced available K content in soil mainly because of enhanced plant uptake.

5.2.7 Available calcium

Experimental field had high Ca content since it is a calcareous soil with high soil pH. Available Ca status in all treatments increased due to application of SSP. There was an increase in available Ca with increased dose of P application. This might be due to the presence of Ca in SSP. There was an increase in Ca with increased dose of B application due to positive interaction between Ca and B.

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 soil. 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) also.

5.2.9 Available sulphur

There was a noticeable increase in available S from T_1 to T_{17} due to increased dose of SSP application. Synergistic interaction between S and P was noted.

5.2.10 Available iron

Application of P and B significantly influenced Fe status of soil. Treatment having high B showed highest available Fe. Application of B enhanced available Fe content in soil whereas 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 raises P: Fe ratio and leads 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 induces 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 B significantly affected Zn content. Highest Zn was noticed in treatment, T_2 (P_0B_0 – P, 0 kg ha^{-1} and B, 0 kg ha^{-1}) and lowest was in treatment, T_{15} (P_3B_1- P, 90 kg ha^{-1} and B, 5 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

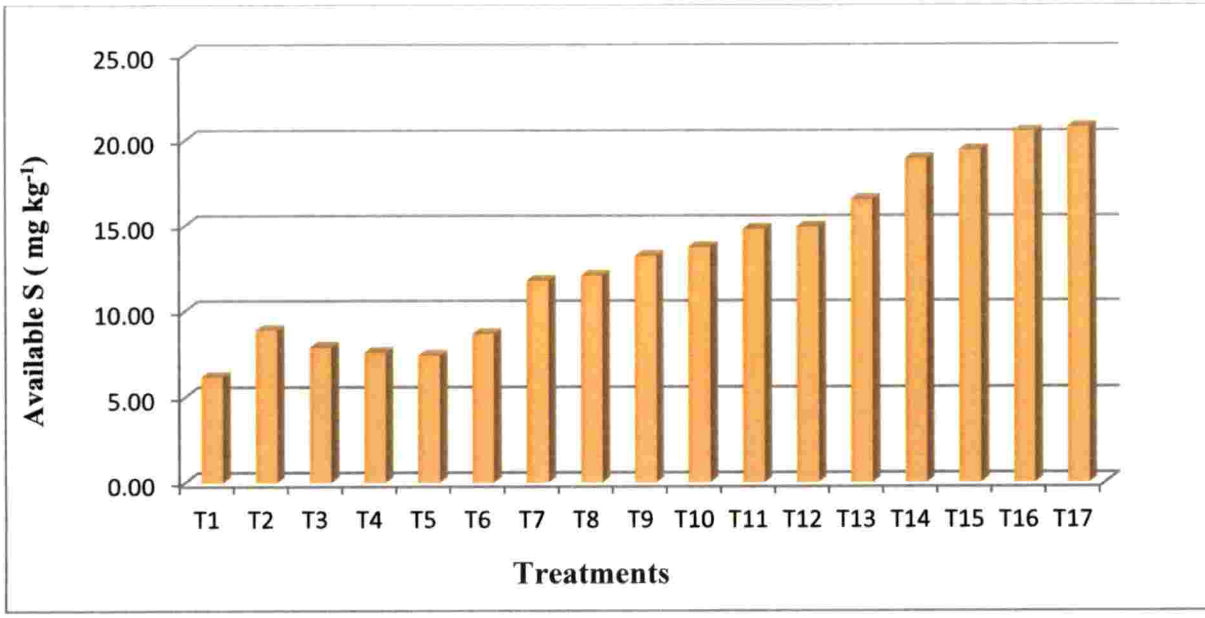

Fig 7: Effect of application of P and B on available S in soil

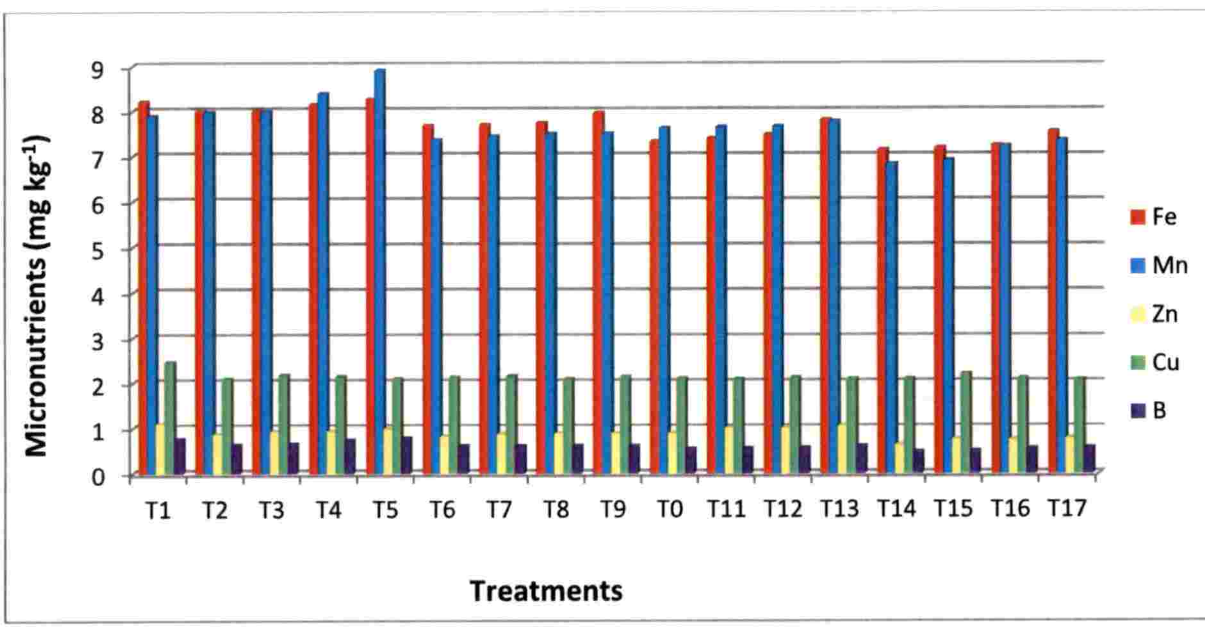

Fig 8: Effect of application of P and B on micronutrients in soil

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.

5.2.13 Available copper

Effect of available Cu was non-significant for main effect and interaction effect.

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_0B_3: P, 0 kg ha^{-1} and B, 15 kg ha^{-1}**)** and lowest was in treatment, T_{14} (P_3B_0: P, 90 kg ha^{-1} and B, 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 P AND B ON PLANT NUTRIENT CONTENT

Nutrient content in groundnut was significantly different for all nutrients. Since the fertilizer used for the supply of P is SSP, besides P, S and Ca were also added which improved the nutrient status of soil as well as nutrient content in plants. Significantly highest N was noted in T_{14} (P_3 B_0). Significantly highest P was noted in T_{15} (P_3 B_1). Highest K was noted in T_{13} (P_2 B_3). T_{17} (P_3 B_3) showed highest S content. T_5 (P_0 B_3) showed highest Ca, Fe, Zn and B content. Significantly highest Mn was noticed in T_9 (P_1 B_3). Significantly highest N, P, and S content were observed in treatments with high dose of P (90 kg ha^{-1}). Highest K content was noted in treatment having medium P (75 kg ha^{-1}).

Low P status of soil decreased N, P, K 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

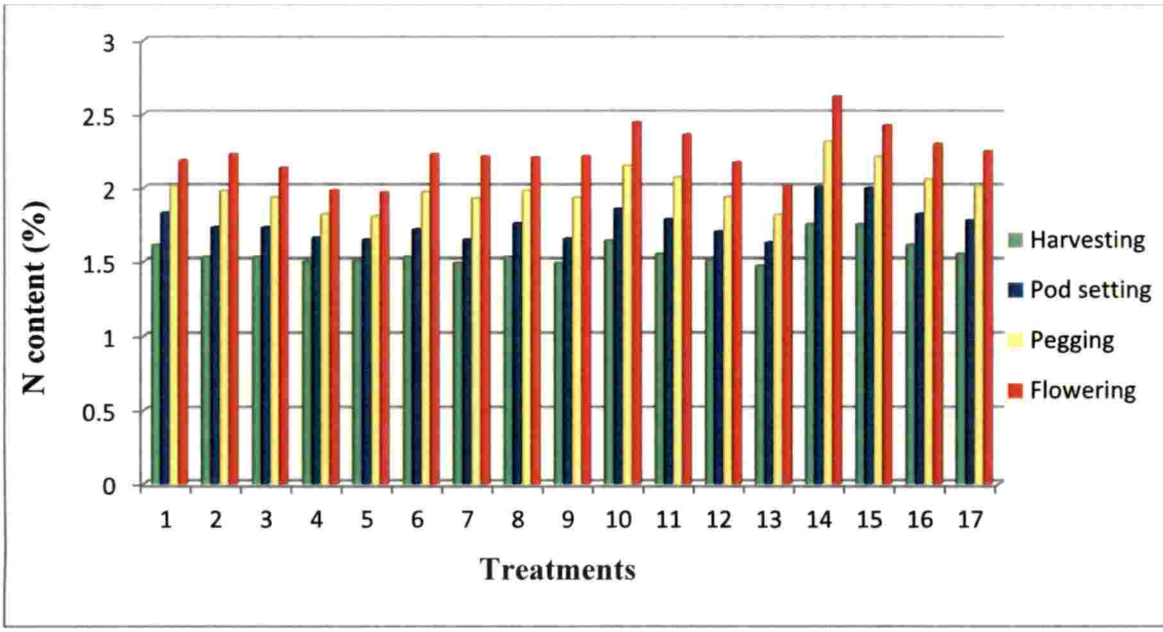

Fig 9: Effect of application of P and B on nitrogen content in plant at different stages

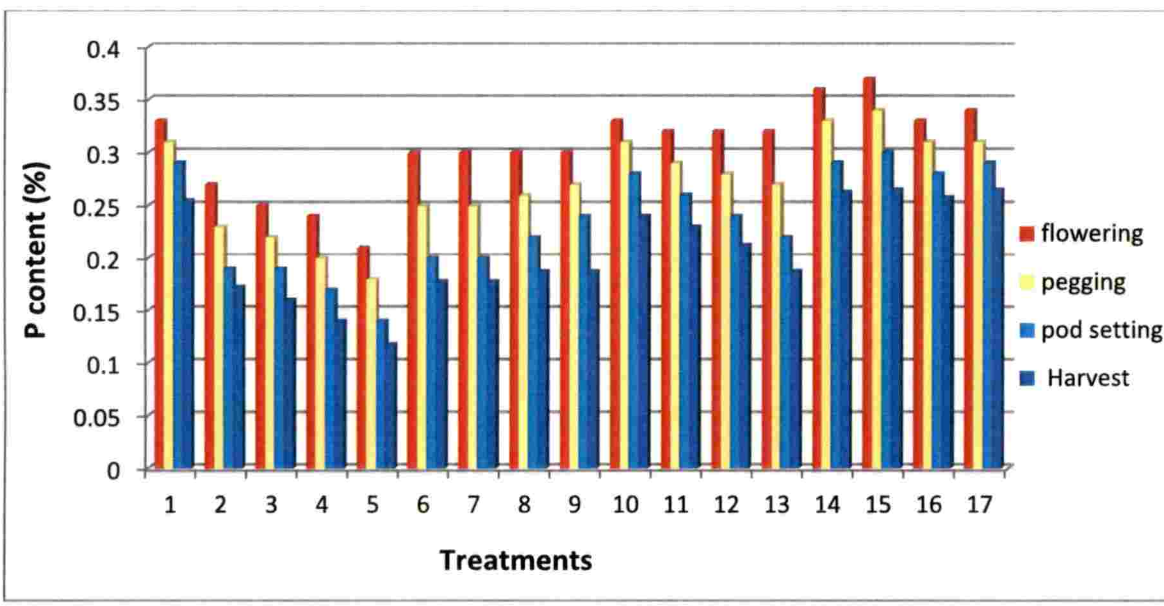

Fig 10: Effect of application of P and B on phosphorus content in plant at different stages

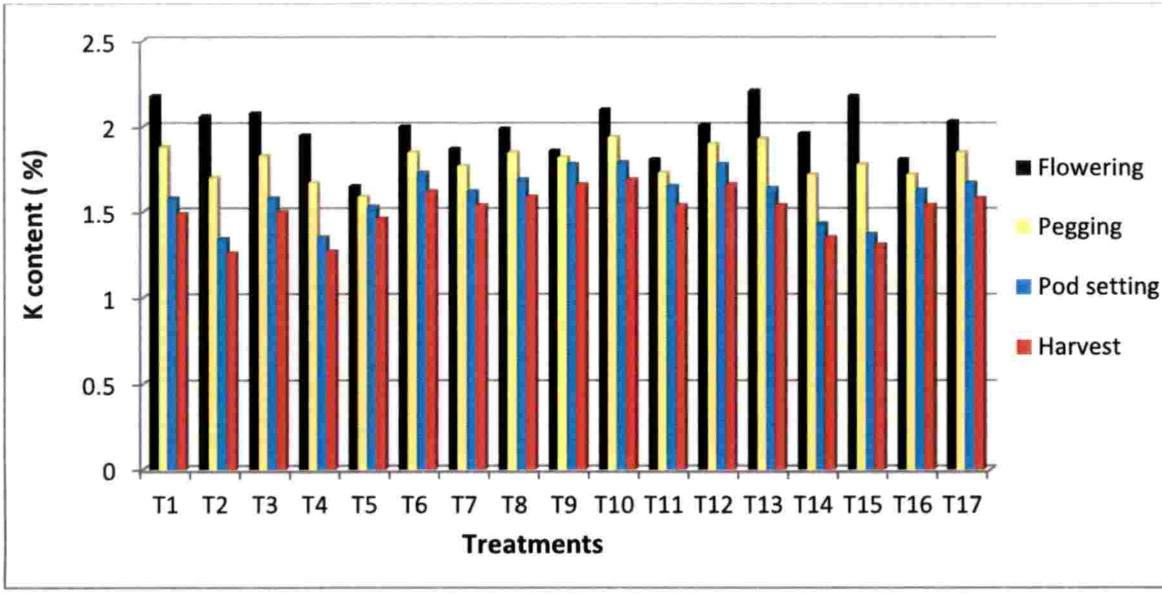

Fig 11: Effect of application of P and B on potassium content in plant at different stages

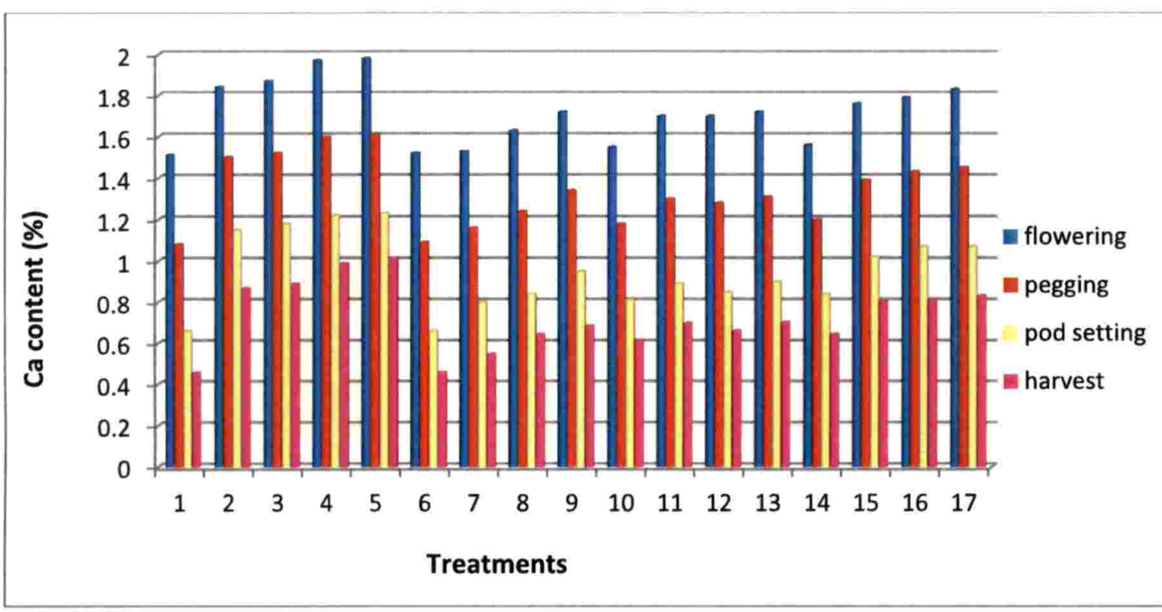

Fig 12: Effect of application of P and B on calcium content in plant at different stages

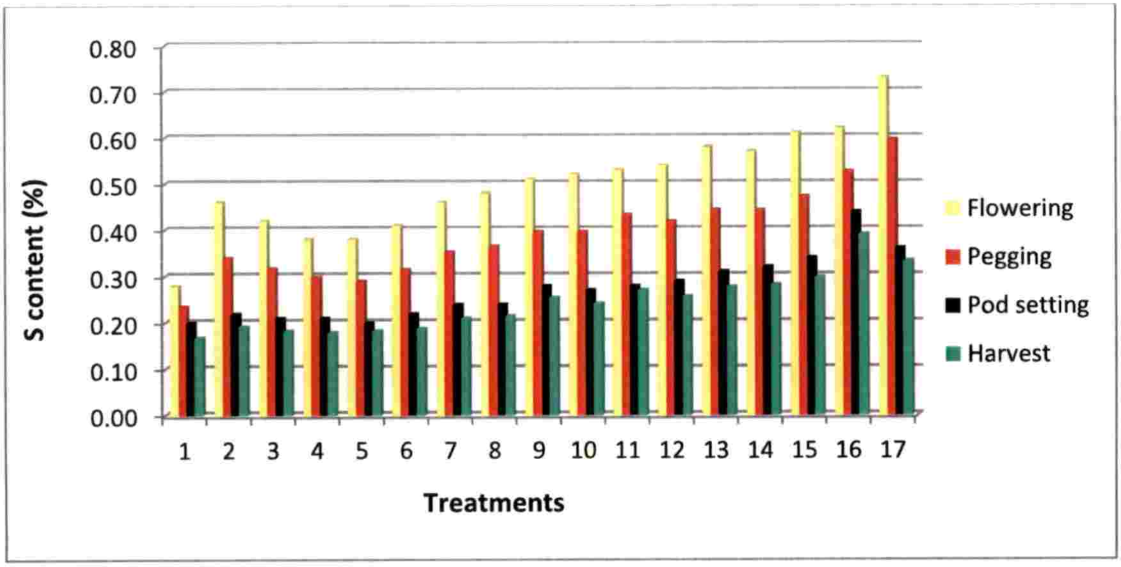

Fig 13: Effect of application of P and B on sulphur content in plant at different stages

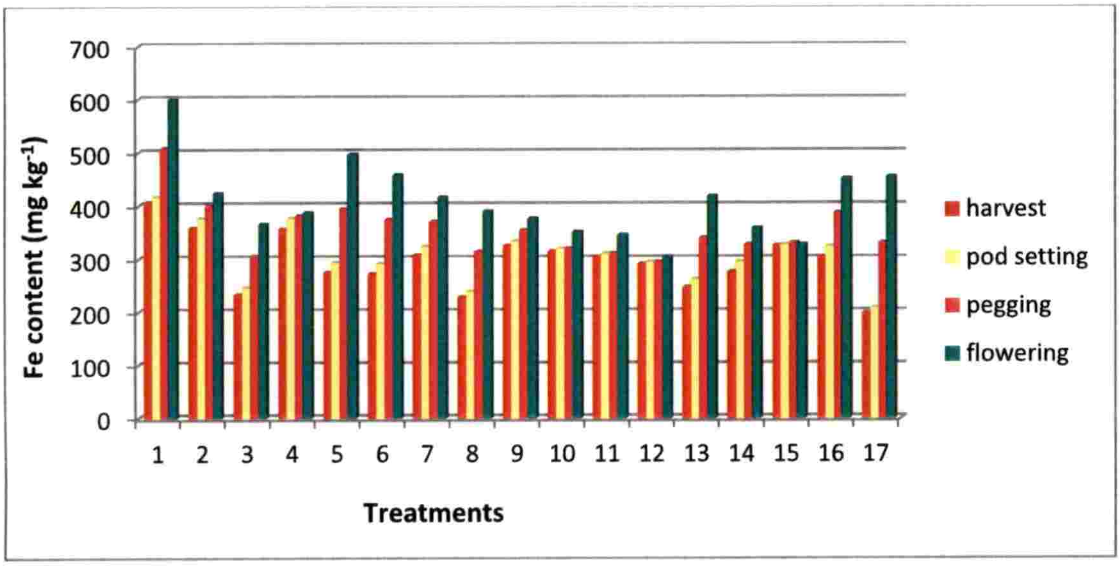

Fig 14: Effect of application of P and B on iron content in plant at different stage

matter production and yield. The findings of Nakagawa *et al.* (1981) and Patel *et al.* (1981) and also supported the result.

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

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 B. 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). Uptake of N was more in pod compared to plant.

Uptake of P by groundnut was highest in P_3B_0 (P 90 kg ha^{-1} B 0 kg ha^{-1}) at all stages. Highest uptake was noted in treatment having highest P content. 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 of the crop. Uptake of P by pod was higher than uptake by plant.

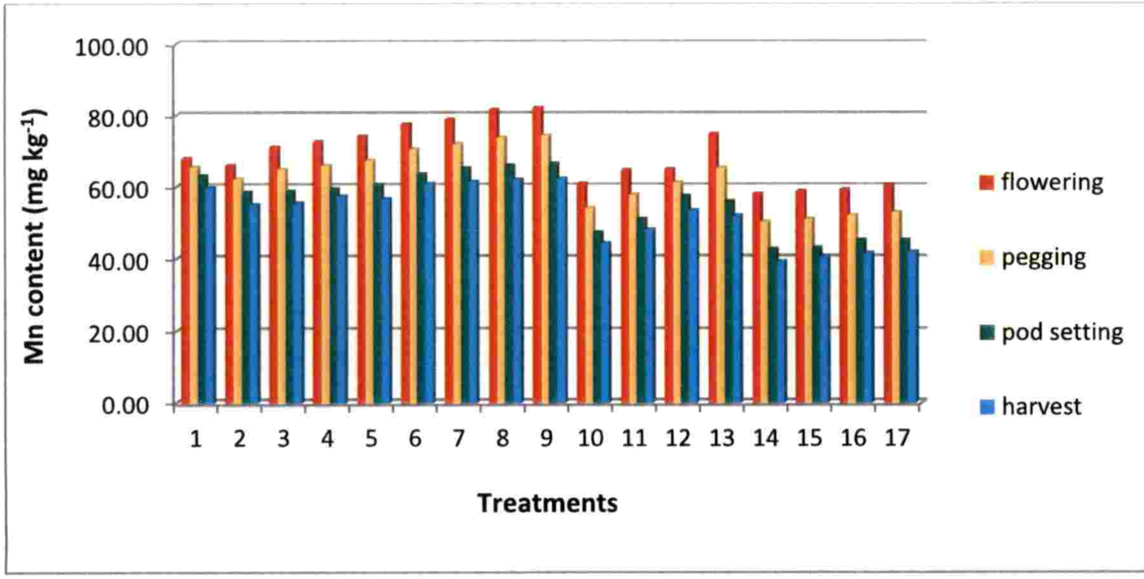

Fig 15: Effect of application of P and B on Manganese content in plant at different stages

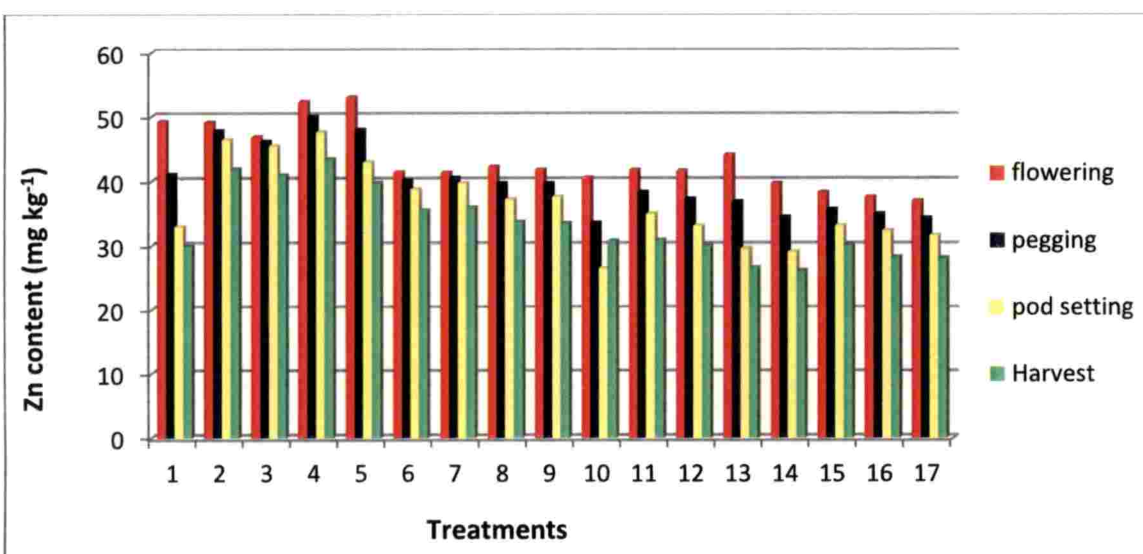

Fig 16: Effect of application of P and B on zinc content in plant at different stages

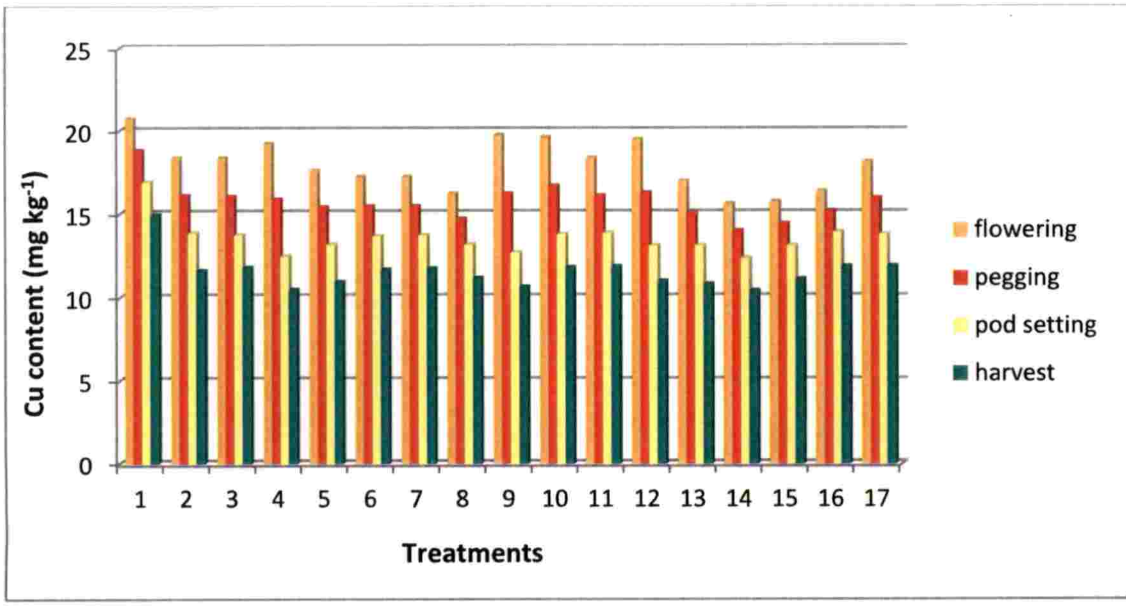

Fig 17: Effect of application of P and B on copper content in plant at different stages

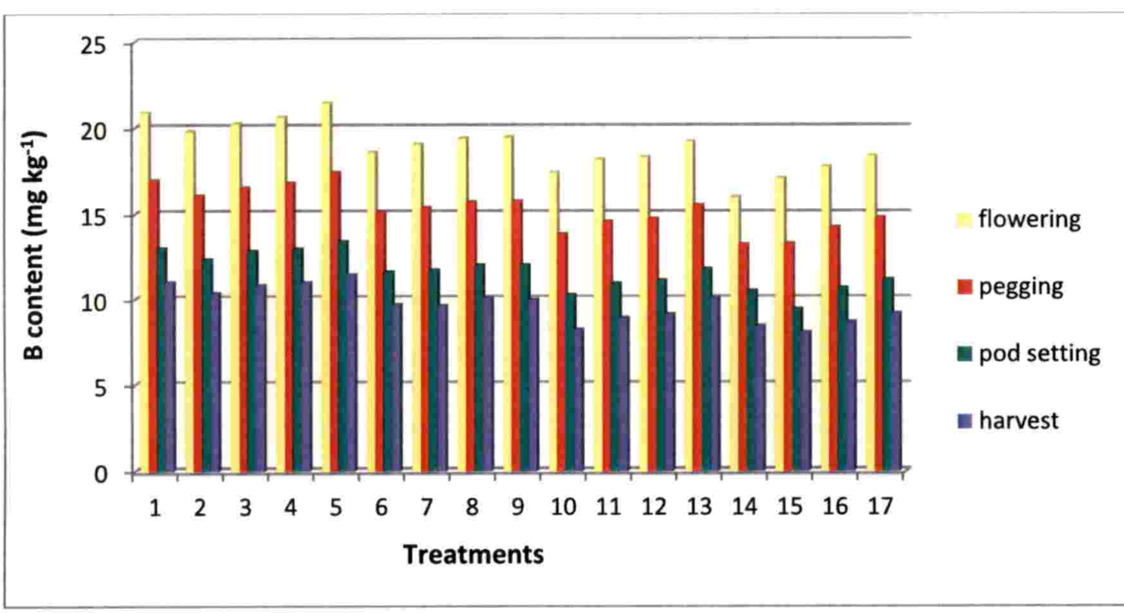

Fig 18: Effect of application of P and B on boron content in plant at different stages

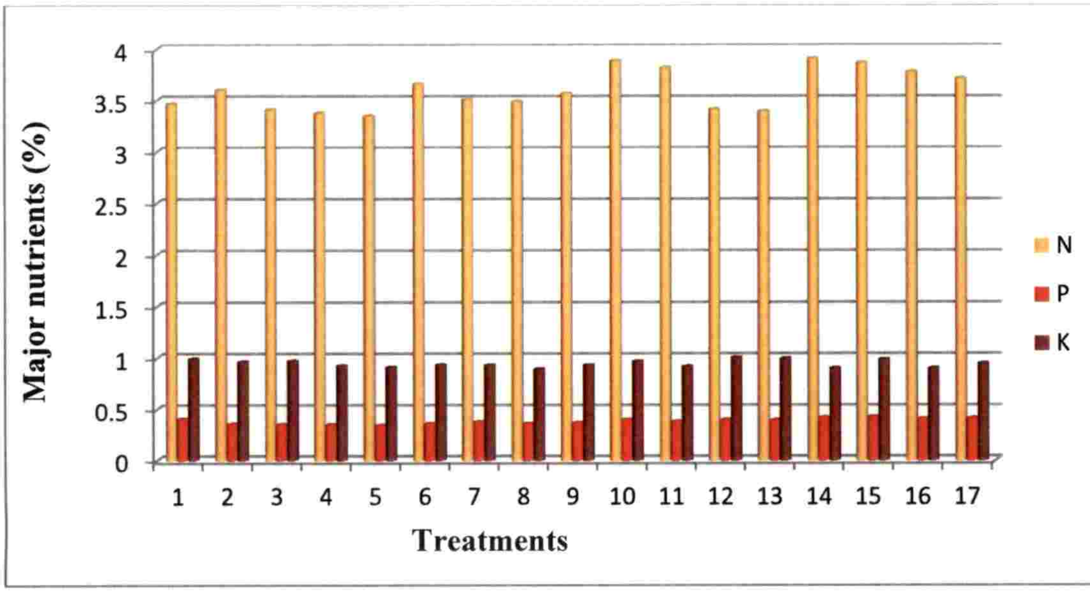

Fig 19: Effect of application of P and B on major nutrients content in pod

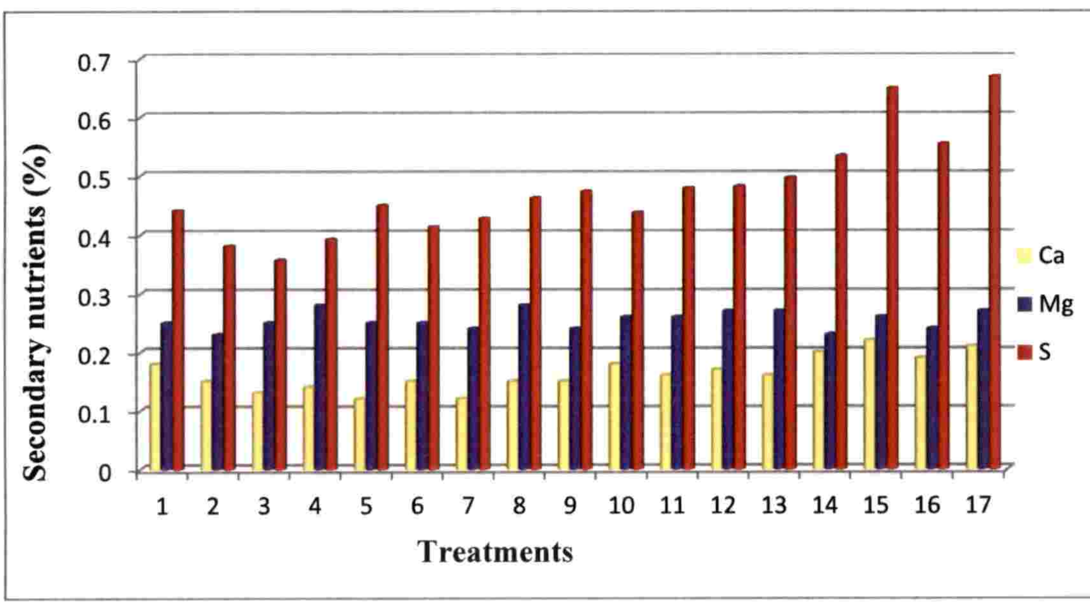

Fig 20: Effect of application of P and B on secondary nutrients content in pod

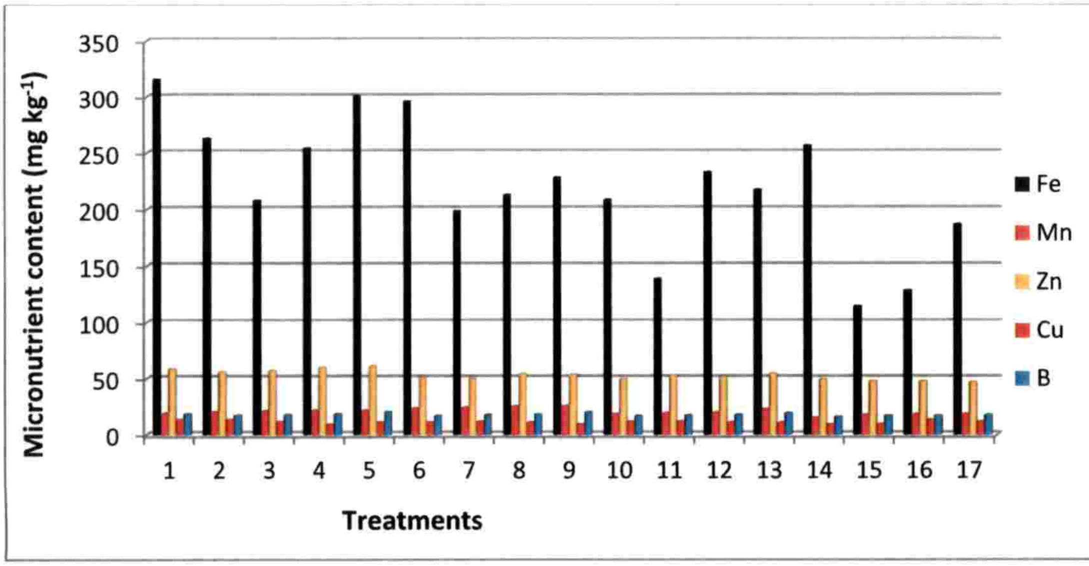

Fig 21: Effect of application of P and B on micro nutrients content in pod

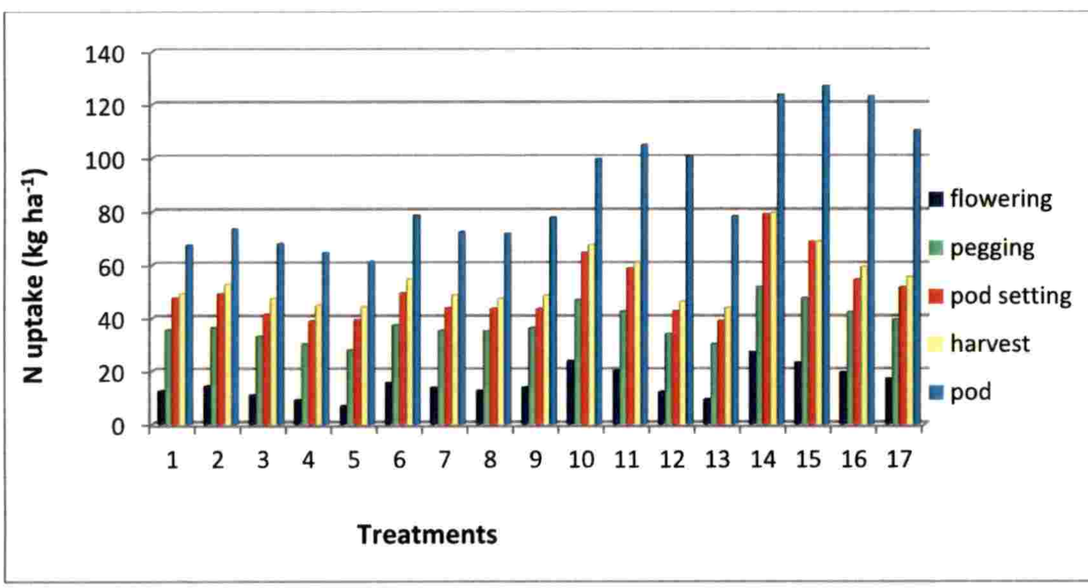

Fig 22: Effect of application of P and B on N uptake by plant at different stages and by pod

Highest K was noted in treatment T_{13} (P_2 B_3) which was supplied with medium doses of P (75 kg ha^{-1}). 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 up to harvest due to the increased dry matter production. Groundnut crop was a heavy feeder of Ca. 90 per cent of Ca uptake was during flowering and pod formation stages (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).

Mg shows positive interaction with N and P (Ranade and Malvi, 2011). Mg uptake was less compared to Ca except pod uptake. Generally, the binding strengths of potassium and Ca are much stronger than magnesium and they easily out-compete magnesium for exchange sites, so the uptake of magnesium was low compared to Ca uptake, but pod uptake of magnesium at harvest was more compared to Ca, because of Ca immobility towards the reproductive parts in plant (Meena *et al.*, 2007). 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).

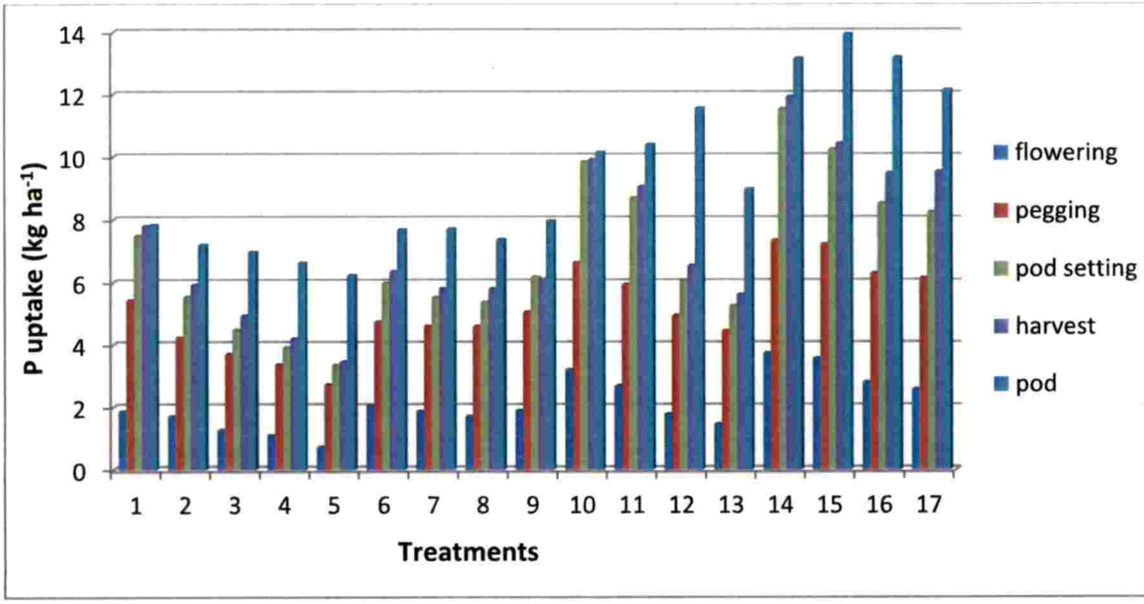

Fig 23 Effect of application of P and B on P uptake by plant at different stages and by pod

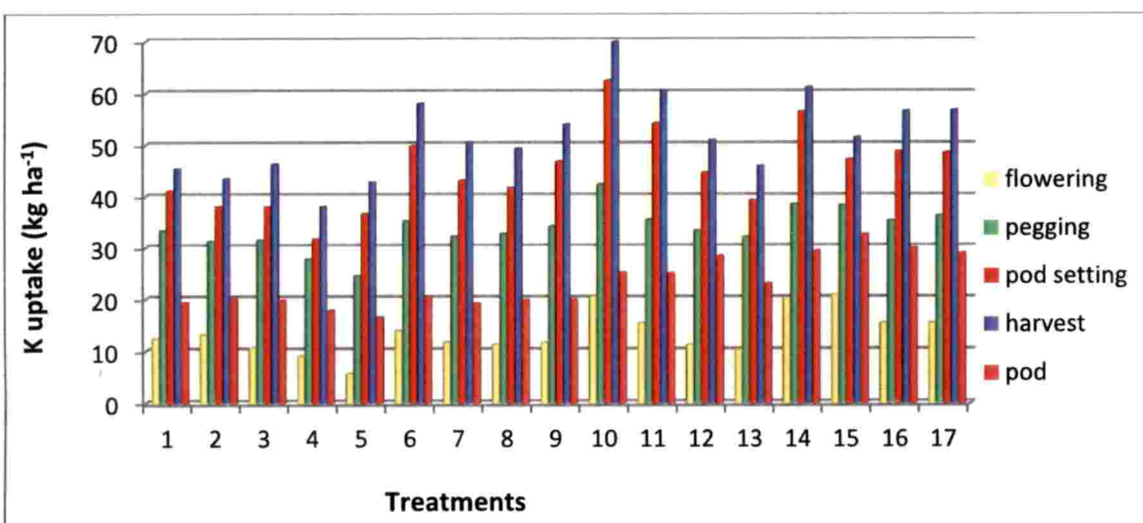

Fig 24 Effect of application of P and B on K uptake by plant at different stages and by pod

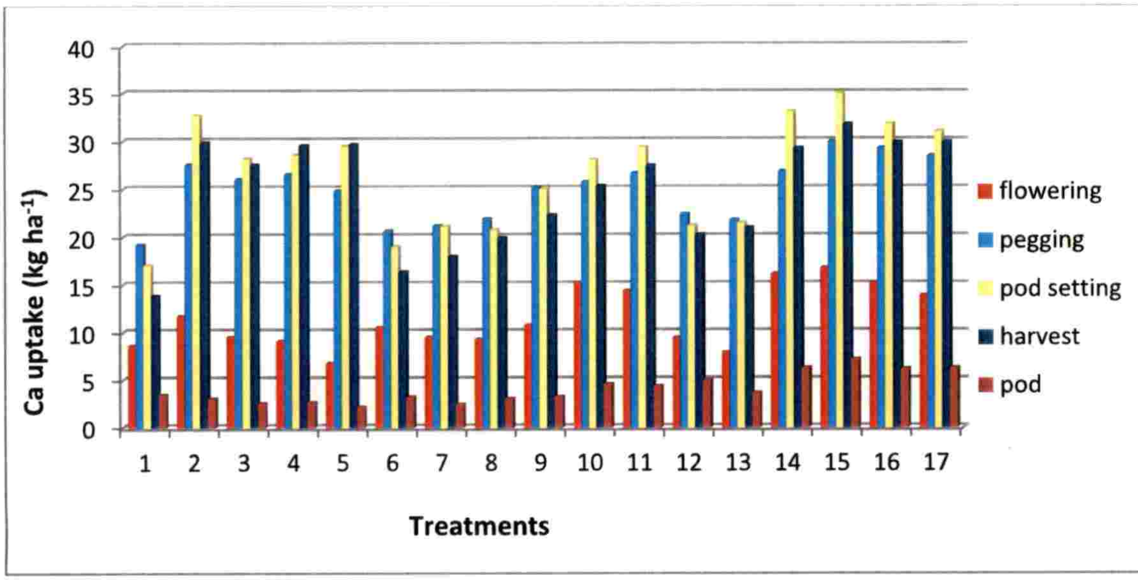

Fig 25 Effect of application of P and B on Ca uptake by plant at different stages and by pod

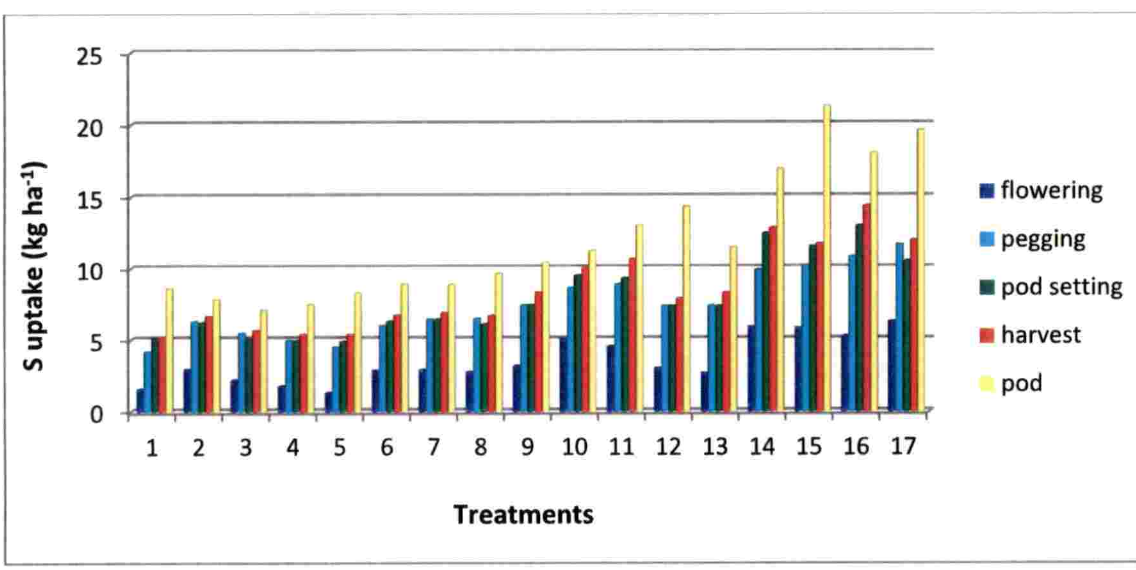

Fig 26 Effect of application of P and B on S uptake by plant at different stages and by pod

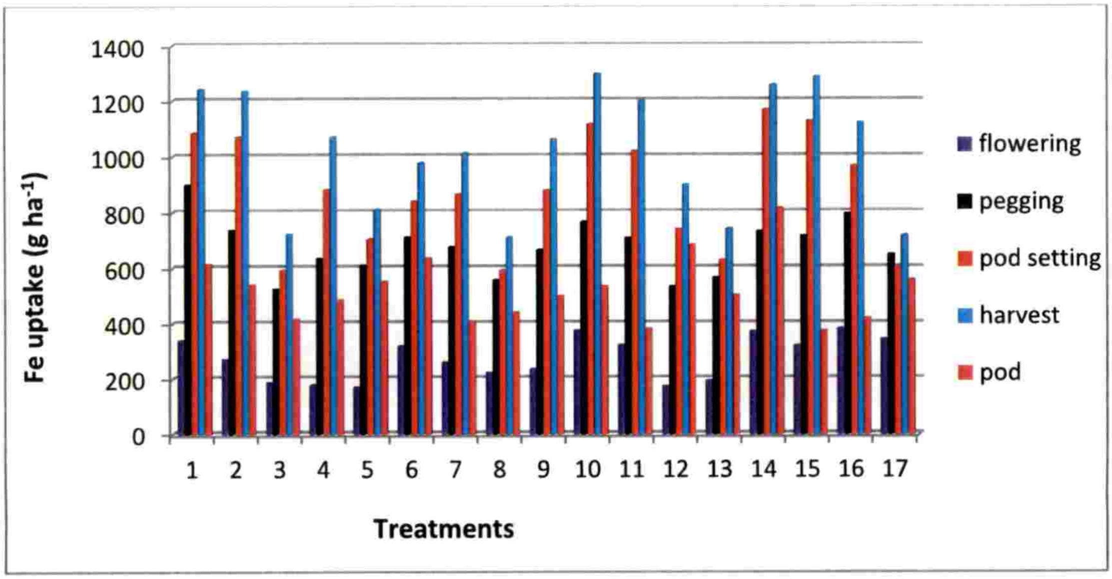

Fig 27 Effect of application of P and B on Fe uptake by plant at different stages and pod

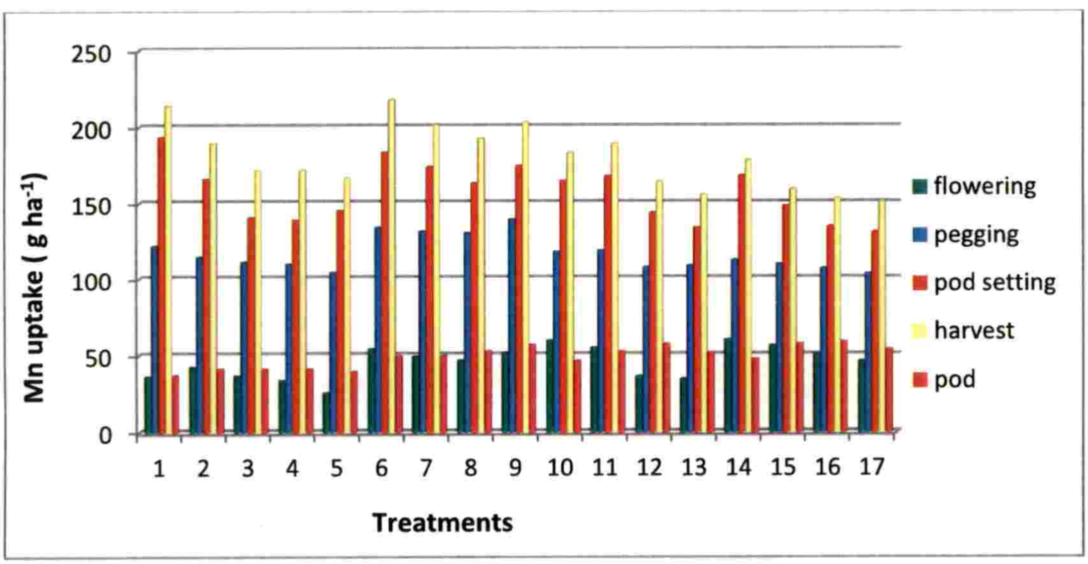

Fig 28: Effect of application of P and B on Mn uptake by plant at different stages and pod

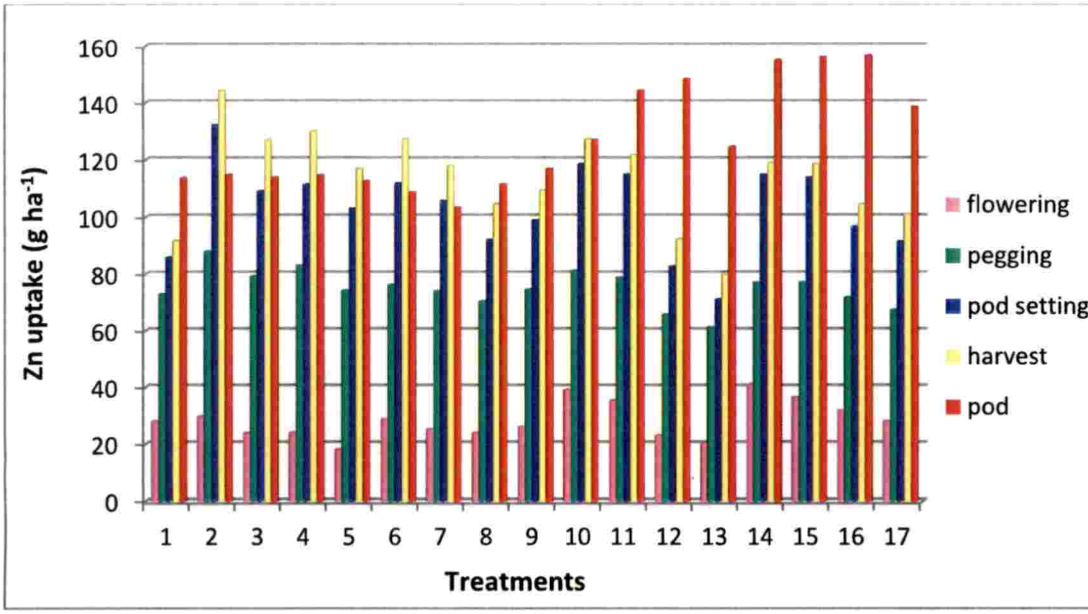

Fig 29 Effect of application of P and B on Zn uptake by plant at different stages and pod

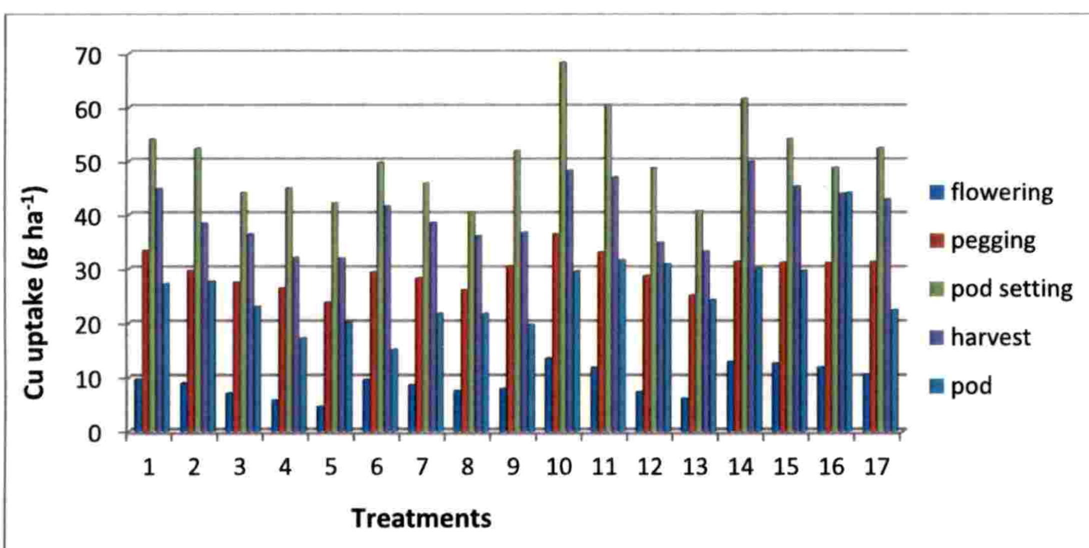

Fig 30 Effect of application of P and B on Cu uptake by plant at different stages and pod

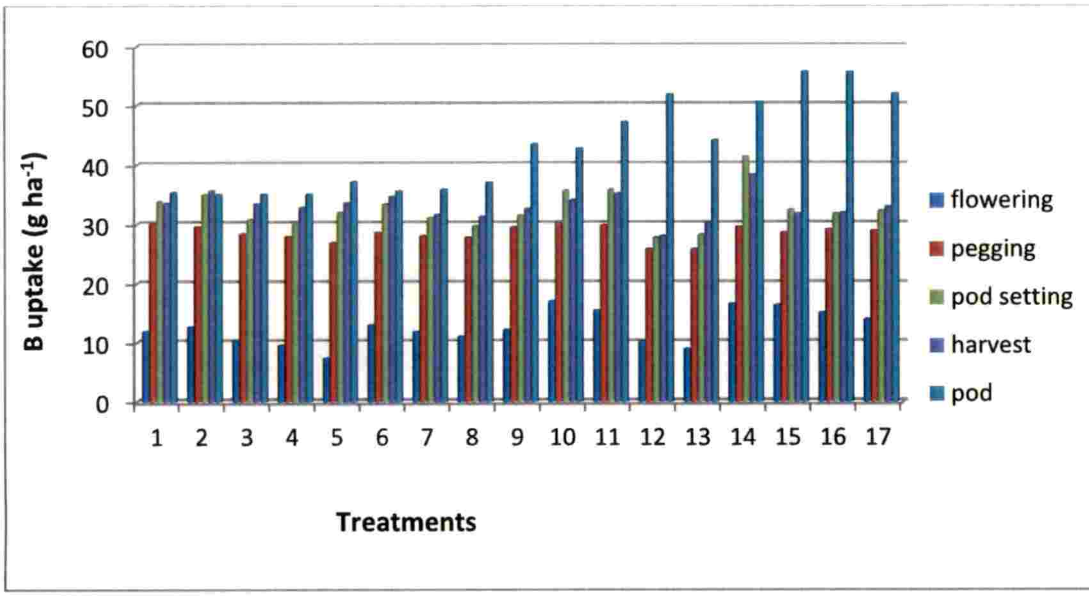

Fig 31 Effect of application of P and B on B uptake by plant at different stages and pod

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 S involvement in amino acids, proteins and oil synthesis in pod.

Rate of micro nutrient uptake was higher from 30 to 90 DAS and lower at harvest. At harvest, iron, zinc and copper uptake was more in pod than in haulm, whereas uptake was more in haulm than in pod in case of manganese and boron. Uptake of zinc by pod was higher than that of plant and this might be due to zinc involvement in amino acids and protein metabolism in pod. The data on uptake by haulm and pod at harvest stage revealed that uptake of B by plant was higher than that of pods. The B 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 is high (B was immobile in plant system), so the uptake by pods was lesser compared to haulm (Meena *et al.*, 2007). Since B is immobile in plant, B uptake was more by plant than pod.

Summary

6. SUMMARY

In Kerala, black soils are seen in Chittur taluk of Palakkad district occupying an area of 2000 ha. These are sufficient in all nutrients except phosphorus (P) and boron (B). So availability of P and B is one of the yield limiting factors in this soil. Finding the interaction between B 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 B. Soil that showed deficiencies of both P and B was selected for field experiment. 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. Experiment was laid out in factorial RBD with 17 treatments and 4 replications. Treatment combinations were made with four levels of P and four levels of B with soil test based recommendations as control. N and K levels are kept same (based on POP recommendations of KAU) for all treatments except for the first treatment where soil test based recommendations was given. Single super phosphate (SSP) was used as source of P and borax was used as source of B.

- Soil was sufficient in all nutrients except P and B.
- Application of P at 90 kg ha^{-1} increased plant height and number of leaves per plant.
- Application of P at 90 kg ha^{-1} and B at10 kg ha^{-1} resulted in highest number of pods
- Application of P at 90 kg ha^{-1} and B at 5 kg ha^{-1} resulted in highest yield (3.66 t ha^{-1}).

- Effect of application of different doses of P and B was non-significant for pH, EC and OC.
- N content in soil increased by increasing levels of P and decreased by increased dose of B.
- Application of P decreased B content in soil and vice versa. P and B have negative interaction due to anionic competition.
- K content decreased with increased dose of P and B application.
- Ca content in soil was increased with increased levels of P due to the addition of Ca through SSP. Ca increased with increased dose of B.
- Mg has synergistic interaction with P.
- S has a positive interaction with P and B. The available S was increased with increased dose of P and B application. Noticeable increase in S content was occurred through addition of SSP.
- 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.
- Cu content in soil was non-significant to the addition of different levels of P and B.
- Plant nutrient content showed a decreasing trend from flowering to harvest stage.
- Content of N, P, K, Ca and S was increased with increased levels of P due to enhanced availability from soil.
- Content of Fe, Mn, Zn and B decreased with increased dose of P due to reduced availability and competition.
- Uptake of nutrients followed increasing trend from flowering to harvest due to increased dry matter production.
- Uptake of N, P, S, Zn and B were higher in pod than plant.
- Application of P at 90 kg ha^{-1} and B at 0 kg ha^{-1} resulted in highest protein content.

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Future line of work

- Conduct OFT in different location before recommending for the farmers for adoption.
- Fractionation of phosphorus and boron in Vertisol.
- Influence of phosphorus and boron application on biological properties of black soils.
- Interaction study of phosphorus and boron using different sources of nutrients.

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PHOSPHORUS AND BORON INTERACTIONS IN BLACK COTTON SOILS OF KERALA WITH RESPECT TO GROUNDNUT (*Arachis hypogaea* L.)

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ABSTRACT OF THESIS

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ABSTRACT

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 nutrients. 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 sufficient in all nutrients except phosphorus (P) and boron (B). Finding the interaction between B and P in black soils will help to understand the factors determining the availability of these nutrients to crops.

The present study was carried out in College of Horticulture, Vellanikkara during 2016-18. The objectives of the study were to find out the interactions of boron and phosphorus in black cotton soils of Palakkad and to assess the treatment level of boron (B) and phosphorus (P) 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 B. Field experiment was carried out where deficiency of both P and B was noticed.

Experiment was laid out in factorial RBD with 17 treatments and 4 replications. Treatment combinations were made with four levels of P and four levels of B with soil test based recommendations as control. N and K levels are 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 B_0 - 0 kg ha^{-1},

B_1 - 5 kg ha^{-1}, B_2 - 10 kg ha^{-1} and B_3 - 15 kg ha^{-1} were the four levels of borax. Single super phosphate (SSP) was used as source of P and borax was used as source of B.

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 like plant height and number of leaves per plant were recorded at flowering, pegging, pod setting and harvest stages and yield parameters like number of pods per plant and yield were recorded at harvest stage. Plant nutrient content was analyzed and uptake was computed at different stages *viz.,* flowering, pegging, pod setting and harvest stages whereas pod nutrient content and uptake was computed only at harvest stage.

Soil nutrient status, plant nutrient content and uptake of nutrients were affected by main effect and interaction effect of P and B. Application of P at 90 kg ha^{-1} and B at 0 kg ha^{-1} resulted in highest plant height and number of leaves per plant. Application of P at 90 kg ha^{-1} and B at 5 kg ha^{-1} resulted in highest number of pods per plant and yield. Application of P at 90 kg ha^{-1} and B 0 kg ha^{-1} resulted in highest protein content in groundnut.

Application of increased dose of P reduced availability of B due to anionic competition. 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. K content in soil was reduced with increased dose of P application. Ca and S were increased due to its supply through fertilizer in soil.

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