Fertility status of soil and nutrients content of spring groundnut (*Arachis hypogaea* L.) as influenced by gypsum, nitrogen and Phosphorus application

ABSTRACT

The field investigation was carried out for two years at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during spring season of 2018 and 2019. The experiment was laid out in a split plot design replicated three times with four levels of gypsum (0, 125, 175 and 225 kg ha^{-1}) in combination with two gypsum application stages (full at sowing and 50 % at sowing + 50 % at flower initiation stage) in the main plot and three levels of nitrogen and phosphorus (15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}, 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}) in the sub-plot. The concentration of N, P, K, Ca and S nutrients in haulm and kernel were significantly improved with the higher application of gypsum, except for N concentration in the haulm. Available N, P, Ca and S in the post-harvest soil samples were maximum in the treatment receiving 225 kg ha^{-1} gypsum. The concentration of N, P, K, Ca and S in haulm and kernel was maximum with application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, except for K and Ca in kernel. Available N, P and K in the soil after crop harvest were highest in the treatment receiving 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}. The application of 225 kg ha^{-1}gypsum resulted in significantly maximum yield over lower levels. Gypsum applied in two split doses *i.e.* half at sowing time and remaining half at flower initiation stage resulted significantly higher pod yield as compared to full application at sowing times. Application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-}1 results significantly higher pod yield as compared to lower doses during both the years.

Keywords: Groundnut, Gypsum, Nitrogen, Phosphorus, Potassium, Calcium, Sulphur

Introduction

Groundnut (*Arachis hypogaea* L.) is the prominent and premier oilseed crop of India and belongs to the family *Leguminosae*. Groundnut covered an area of 4.73 million ha with production of 6.73 million tonnes and productivity of 14.22 quintal ha^{-1} in India during 2018-19 (Anonymous 2019). In Punjab, groundnut crop was grown over an area of 1.3 thousand ha with an average annual production of 2.6 thousand tonnes and the productivity of 19.8 quintal ha^{-1} during 2018-19 (Anonymous 2020).Groundnut kernels contain 48-50% edible oil, 25-34% protein, 10-20% carbohydrates and are a rich source of vitamins (E, K and B complex). Groundnut oil contains 40-50% oleic acid (MUFA) and 25-35% linoleic acid (PUFA) which makes the oil good from nutritive and culinary points of view. Since groundnut is a legume-oilseed crop, its requirement of phosphorus, calcium and sulphur is quite high. Therefore, the supply of nutrients in a judicious and balanced manner at appropriate time is very important to realize optimum production of the crop. Gypsum is commonly used as a source of calcium and sulphur for groundnut all over the world. The dissolution of gypsum is quite rapid and therefore readily adds Ca and S to the podding zone. Calcium present in the pod zone of 5 cm depth of soil is taken up by the pegs and developing pods, therefore gypsum should be applied close to the base of plant. Application of gypsum improves soil structure which favours effective pegging in groundnut (Agasimani*et al* 1992). Apart from providing Ca and S, gypsum also plays a significant role in the reclamation of alkaline soils. It causes micro-acidification therefore lowering down the soil pH and increasing the nutrient availability in soil (Alcordo and Recheigl 1993, Singh and Chaudhari 2007).Pod development is enhanced by application of gypsum at flowering stage since it increases the availability of Ca and S in the fruiting zone. Calcium maintains the membrane permeability and cell integrity, increases pollen germination, activates many enzymes involved in cell division and takes part in

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protein synthesis and carbohydrate transfer in groundnut. Calcium increases the growth and survival of the symbiotic bacteria in groundnut which therefore has a positive influence on biological nitrogen fixation. Zharare*et al* (2009) conducted a study using hydroponic nutrient solutions containing various concentrations of Ca and observed that the pod formation would not occur in the solutions without calcium. They also reported that increasing the amount of calcium was required for proper pod set, proper seed set and morphological development for maturing pods and seed. Deficiency of calcium leads to the production of immature pods, black embryo in seed, weak germination of seeds and increases production potential of aflatoxin and thus, decays peanut pod (Agasimani*et al* 1992, Evanylo 1989, Grichar 2002, Murata 2003). Sulphur is a component of protein and has an important role to play in oil synthesis. Sulphur finds an important role in the synthesis of sulphur containing amino acids like methionine and cysteine and synthesis of proteins, chlorophyll and oil.

Nitrogen is the main structural component of plant cell. It plays a significant role in plant metabolism and is involved in the synthesis of proteins, amino acids and nucleic acids. Groundnut is a self-fertilizing crop, since its most of the nitrogen requirement is met by the nitrogen-fixing bacteria that are present in the root nodules. Williams (1979) suggested that at very high yield levels, the nitrogen requirement of groundnut cannot be met from symbiotic nitrogen fixation alone. To meet the nitrogen requirement during early growth stages, nitrogen could be applied as starter dose (Farag and Zahran 2014). Phosphorus plays an important role in formation of root nodules and fixation of atmospheric nitrogen (Brady and Well 2002). Phosphorus is an important structural component of membrane system of the cell, chloroplast and mitochondria. It is an essential constituent of nucleic acid, amino acids, phytin, proteins, nucleoproteins and energy rich phosphate bonds (ADP and ATP). It is involved in the transfer of energy in major metabolic processes like photosynthesis, transformation of sugars and starch and nutrient movement in plants. Imbalanced and

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inadequate use of nutrients is the main reason for lower yield of groundnut. However, very less information on the balanced nutrition of spring groundnut is available. Therefore, there is a need to develop a nutrient management strategy to achieve the potential production of spring groundnut. Keeping all these points in view the present study was undertaken to find out the optimum mineral nutrition of spring groundnut.

Materials and Methods

The field experiments of the present study were conducted at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during spring season of 2018 and 2019. Ludhiana is located at an elevation of 247 m above mean sea level and lie at 30°56′ latitude and 75°52′ longitude, which represents the central agro-climatic zone of Punjab.The average weekly maximum and minimum temperatures during the *spring* season of 2018 were 36.2˚C and 22.1˚C respectively, whereas during *spring* season of 2019, the corresponding values were 36.1˚C and 21.5˚C respectively. The weekly mean relative humidity ranged from 21-73% and 29-68% during the cropping seasons of 2018 and 2019, respectively. Total rainfall of 223.6 mm was recorded during the crop season of 2018, whereas the corresponding value for the *spring* season of 2019 was 105.9 mm. The soil of experimental field was loamy sand in texture having pH 8.17, electrical conductivity 0.58 dS m^{-1} and organic carbon 0.33%. The available nitrogen (N), available phosphorus (P), available potassium (K), available calcium (Ca) and available sulphur (S) of the soil were 156.1 kg ha^{-1}, 16.29 kg ha^{-1}, 323.5 kg ha^{-1}, 114 ppm and 24.8 kg ha^{-1}, respectively. The experiment was laid out in a split plot design replicated three times with four gypsum levels (0, 125, 175 and 225 kg ha^{-1}) in combination with two stages of gypsum application (Full at sowing and 50% at sowing + 50% at flower initiation stage) in the main plot and three levels of nitrogen and phosphorus (15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}, 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}) in the sub-plot. Second split of gypsum was applied at

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flower initiation stage *i.e.* at 30 days after sowing while all the doses of nitrogen and phosphorus were applied at the time of sowing. Groundnut variety 'TAG 37A' was sown at the spacing of 30 cm × 15 cm in the second week of March during both the years. All the cultural practices were followed as per general recommendations. Nitrogen and phosphorus were applied through DAP while the remaining nitrogen requirement was met by using urea.

The samples of groundnut plant (haulm and kernel) were collected at harvest, dried in sun and then oven-dried at 60º C for 24 hours. The samples were grounded and then the samples were analysed for total nitrogen, phosphorous, potassium, calcium and sulphur. The N content in haulm and kernel samples was estimated by using Kjeldahl's distillation method (Jackson 1967). The P content in haulm and kernel samples was estimated by Vanadomolybdo- phosphoric yellow colour method in HNO_3 as suggested by Jackson (1967). K concentration in plant acid extract was determined by using Flame Photometer after digesting the samples with diacid mixture as suggested by Jackson (1967). Calcium concentration in haulm and kernel samples was estimated by versenate titration with 0.01 N EDTA solution using purpurate indicator after digesting the samples with diacid mixture (Cheng and Bray 1951). S concentration in haulm and kernel samples was estimated by turbidemetric method and the intensity of turbidity was determined using colorimeter 34 at 420 nm, as given by Chesnin and Yien (1951).

The soil pH was determined in 1:2 soil-water suspension using an Elico-glass electrode pH meter (Jackson 1967). Electrical conductivity of soil was determined in 1:2 soil-water suspension equilibrated for 24 hour using a conductivity bridge (Jackson 1967). Organic carbon was determined by rapid titration method as detailed by Walkley and Black (1934). Available N of soil was estimated by alkaline potassium permanganate method given by Subbiah and Asija (1956). Available P of soil was estimated by 0.5 N $NaHCO_3$ method suggested by Olsen *et al* (1954). Available K of soil was determined by using neutral 1 N

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ammonium acetate solution as extracting agent as in the method given by Piper (1966). Available Ca in soil was estimated by versenate titration with 0.01 N EDTA solution as given by Cheng and Bray (1951). Available S of soil was determined by turbidemetric method given by Chesnin and Yien (1951).

Results and Discussion

Nutrient concentration in plant

Application of different gypsum levels exerted a significant influence on the kernel N, P, K, Ca and S concentration as well as haulm P, K, Ca and S concentration of groundnut plants (Table 1). N content in haulm was influenced non-significantly by different gypsum levels. However, an increasing trend in the N content of haulm was seen with the increasing levels of the applied gypsum. Application of 225 kg ha^{-1} gypsum resulted in maximum kernel N, P, K and S concentration and haulm P and S concentration, which was statistically at par with 175 kg ha^{-1} and 125 kg ha^{-1} gypsum, while significantly higher than control. Application of each of 225 kg ha^{-1}, 175 kg ha^{-1} and 125 kg ha^{-1} gypsum gave similar haulm K content, which was significantly higher over control. Both 225 kg ha^{-1} gypsum and 175 kg ha^{-1} gypsum, each of them gave highest kernel and haulm Ca content, which was at par with 125 kg ha^{-1} gypsum, while significantly higher than the control. Rao and Shaktawat (2005) supported the findings of the present study and reported that the application of 250 $kgha^{-1}$ gypsum significantly increased the N, P, K, Ca and S concentration in kernel and haulm of groundnut over control. Likewise, Pathak *et al* (2013) reported that seed Ca and S concentration increased with increase in the rates of gypsum application. The increase in nutrient content due to gypsum application might be due to improved nutritional environment in the rhizosphere as well as in the plant system which leads to translocation of N, P and S to reproductive parts which ultimately increased the N, P and S concentration in the kernel of

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groundnut (Alcordo and Recheigl 1993). Also, the application of gypsum might have improved the rhizosphere conditions and thus increased the absorption of nutrients.

The effect of gypsum application stage on the haulm N, P, K, Ca and S concentration and kernel N, P, K and Ca concentration was found to be non-significant (Table 1). However, split application of gypsum recorded higher concentration of all the nutrients in haulm and kernel as compared to the application of full dose of gypsum at sowing. But the S concentration in kernel was influenced significantly by the time of gypsum application. Split application of gypsum (50% at sowing + 50% at flower initiation stage) gave significantly higher S content in kernel (0.364%) over the application of full dose of gypsum at sowing (0.359%).

Nitrogen and phosphorus levels exerted a significant influence on the haulm N, P, K, Ca and S concentration and kernel N, P and S concentration of groundnut plants (Table 1). However, the K and Ca concentration in kernel was non-significantly influenced by nitrogen and phosphorus levels. The maximum N content in kernels was obtained with the application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, which was significantly higher as compared to the other two doses of nitrogen and phosphorus. The maximum N and P content in haulm was observed with the application of each of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}, which was significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. Maximum kernel P and S concentration and haulm K, Ca and S concentration was observed with the treatment receiving 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}, which was at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}, while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}. El-Habbasha*et al* (2013) reported similar observations and reported that the increase in N levels significantly increased N and K content in seeds and haulm of groundnut. Likewise, Gobarah*et al* (2006) reported that increasing the dose of phosphorus fertilizer significantly increased N and P content in plants of groundnut. These results were supported by Rao and

Shaktawat (2005) who reported that the application of 60 kg P_2O_5 ha^{-1} significantly increased the N, P, K, Ca and S concentration in kernel and haulm of groundnut over 20 kg P_2O_5 ha^{-1}. Nitrogen fertilization may increase the cation exchange capacity of plant roots and thus makes them more efficient in absorbing nutrient ions. The application of higher doses of nitrogen was responsible for better root and shoot development and resulted in greater absorption of nutrients in haulm and kernel (Patel *et al* 2014). Also, the increase in S uptake because of N application could be due to the synergistic effect of N and S in plants. The increased availability of nutrients in root zone coupled with increased metabolic activity at cellular level might have increased nutrient uptake and their accumulation in vegetative plant parts (Sharma *et al* 2013). Application of phosphorus might have led to the development of extensive root system, thus resulting in the improved absorption of nutrients from the soil.

Effect of different treatments on properties of soil

The different treatments of gypsum levels, gypsum application stage as well as nitrogen and phosphorus levels had a marked effect on the properties of soil after the crop harvest.

Soil pH: Different gypsum levels were observed to have a non-significant effect on the soil pH after crop harvest(Table 3). However, the range of pH observed was 8.22 to 8.29 varying non-significantly between various gypsum levels. These results were supported by Chen and Warren (2011) who observed that gypsum application improves the pod filling of groundnut without changing the soil pH.Chakrabarti (1990) also reported that the soil pH did not show significant variation in gypsum applied soil. The effect of gypsum application stage on pH of soil after crop harvest was non-significant. Nitrogen and phosphorus levels also had a non-significant effect on soil reaction after crop harvest. pH value of 8.27, 8.26 and 8.25 was observed with 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}, 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} and 35 kg

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N ha^{-1} + 40 kg P_2O_5 ha^{-1} respectively. Kharade (2009) also reported that the application of different levels of nitrogen did not affect soil pH.

Electrical conductivity: A non-significant effect of gypsum levels was noticed on the EC of soil after the harvest of crop(Table 3). EC value of soil varied non-significantly between various gypsum levels ranging between 0.62 to 0.63 dS m^{-1}. Similarly, Chakrabarti (1990) reported that the electrical conductivity of soil did not show significant variation in gypsum applied soil. EC of the soil after crop harvest was non-significantly influenced by the stage of application of gypsum.Nitrogen and phosphorus levels also had a non-significant effect on the electrical conductivity of soil after crop harvest. EC value of soil varied non-significantly between various nitrogen and phosphorus levels ranging between 0.62 to 0.63 dS m^{-1}.

Organic carbon: Gypsum levels had a non-significant effect on the organic carbon in soil at harvest(Table 3). An increase, though non-significant in OC of soil was observed with increase in the dose of gypsum. The values of organic carbon ranged between 0.34 to 0.35%. Chakrabarti (1990) advocated that the soil organic carbon did not show significant variation in gypsum applied soil. Gypsum application stage also had a non-significant effect on the organic carbon of soil at crop harvest. Nitrogen and phosphorus levels exerted a non-significant influence on the organic carbon of soil at harvest. However, a non-significant increase in the organic carbon of soil was observed with increase in the levels of applied nitrogen and phosphorus.

*Available nitrogen:*The available N in soil after the crop harvest was influenced significantly by different gypsum levels (Table 4). Successive increase in gypsum dose witnessed an increase in the available N of the soil. 225 kg ha^{-1} dose of gypsum resulted in highest available N (226.1 kg ha^{-1}), which was statistically at par with 175 kg ha^{-1} gypsum

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(221.8 kg ha^{-1}) while significantly higher than the other levels of gypsum. These findings are in corroboration with the results ofAulakh*et al* (1980) who reported that N availability increased with the application of sulphur through gypsum. The increase in available nitrogen may be due to increased supply of sulphur as sulphur may enhance the nodulation by increasing the supply of sulphur containing proteins, which are essential for multiplication and growth of rhizobia, which fix atmospheric nitrogen. Available N of soil after crop harvest differed non-significantly with different gypsum application stages. However, split application of gypsum resulted in higher available N (219.2 kg ha^{-1}) as compared to application of full dose of gypsum at sowing.Nitrogen and phosphorus levels exerted a significant influence on the available N of soil after crop harvest. Use of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in highest available N (229 kg ha^{-1}), which was significantly higher as compared to the other two levels of nitrogen and phosphorus. Mohapatra and Dixit (2010) reported that the increase in available N in soil could be due to higher amount of N fixation by *Rhizobium* under more favourable conditions of soil and lysis of nodules and secretion of N from these nodules. Also, application of phosphorus may enhance N_2-fixation in groundnut which in turn, improved the N status of the soil (Agboola and Fayemi 1972).

Available phosphorus: Gypsum levels exerted a significant influence on the available P of soil after the harvest of crop (Table 4). Application of 225 kg ha^{-1} gypsum gave maximum available P (22.84 kg ha^{-1}), which was statistically at par with 175 kg ha^{-1} (22.39 kg ha^{-1}), while significantly higher than 125 kg ha^{-1} and control. The effect of gypsum application stage on available P was non-significant. Split application of gypsum resulted in higher available P of soil (21.82 kg ha^{-1}) as compared to basal application of gypsum, although the difference was non-significant.Available P of soil after crop harvest was significantly influenced by the different levels of nitrogen and phosphorus. Use of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} recorded highest available P (23.57 kg ha^{-1}), which was significantly

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higher over other doses of nitrogen and phosphorus. The increase in phosphorus availability might be due to synergistic effect of nitrogen with phosphorus which increased the availability of P in the soil.

Available potassium: Gypsum levels had non-significant effect on the available K of soil after crop harvest (Table 4). The available K of soil displayed an increase with increased levels of gypsum, although the increase was non-significant.Gypsum application stage also exerted a non-significant influence on the available K of soil. Split application of gypsum resulted in higher available K of soil (260.7 kg ha^{-1}) as compared to the basal application of gypsum, although the difference was non-significant.Nitrogen and phosphorus levels exercised a significant effect on the available K of soil after the harvest of crop. Maximum available K in soil was recorded with the treatment 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} (267.8 kg ha^{-1}), which was statistically at par with 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (262.9 kg ha^{-1}), while significantly higher than treatment 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (248.5 kg ha^{-1}). Parallel findings were observed by Hasan (2018) who noticed that the application of 27 kg N ha^{-1}+82 kg P_2O_5 ha^{-1} resulted in higher potassium content of soil as compared to lower doses of nitrogen and phosphorus. The increase in potassium availability might be due to synergistic effect of nitrogen with potassium which increased the availability of K in the soil (Bhikane 2002).

Available calcium: The available Ca of soil after crop harvest was influenced significantly by various gypsum levels (Table 4). Use of 225 kg ha^{-1} gypsum recorded highest available Ca in soil (109.4 ppm), which was statistically at par with that of 175 kg ha^{-1} gypsum (108.1 ppm) while significantly higher than 125 kg ha^{-1} gypsum and control. Similarly, Sharma *et al* (1971) and Puntamkar*et al* (1972) observed an increase in the available Ca of soil with application of gypsum. Gypsum application stage had a significant influence on the available Ca of soil after crop harvest. Split application of gypsum recorded significantly higher available Ca of soil (107.2 ppm) in comparison to application of full dose of gypsum at sowing (105.5 ppm). Hallock and Allison (1980b) also achieved similar results and reported that the application of gypsum at early flowering stage resulted in higher Ca content in soil as compared to control.Available Ca of soil after crop harvest was affected non-significantly by various doses of nitrogen and phosphorus. However, with increase in the levels of nitrogen and phosphorus, an increasing trend of soil available Ca was observed, though the difference was non-significant.

Available sulphur: Application of different gypsum doses had a significant influence on the available S of soil after crop harvest (Table 4). Use of 225 kg ha^{-1} gypsum recorded highest available S in soil (30.36 kg ha^{-1}), which was statistically at par with that of 175 kg ha^{-1} gypsum (29.42 kg ha^{-1}) while significantly higher than 125 kg ha^{-1} gypsum and control. The results were confirmed by Jat and Ahlawat (2010) who reported that with an increase in the dose of gypsum application, the available S content in soil was significantly improved.Gypsum application stage had a non-significant influence on the available S of soil after the harvest of crop. Split application of gypsum resulted in higher available S in soil (28.52 kg ha^{-1}) as compared to application of full dose of gypsum at sowing, though the difference was non-significant.Nitrogen and phosphorus levels exerted a non-significant effect on the available S of soil after crop harvest. However, with increase in the levels of nitrogen and phosphorus, an increasing trend of available S in soil was observed.

Yield

Application of 225 kg ha^{-1} gypsum resulted in maximum pod yield of 43.04 q ha^{-1} in 2018 and 46.84 q ha^{-1} in 2019 and it was significantly higher as compared to the other doses (Control, 125 and 175 kg ha^{-1}) of gypsum. The influence of gypsum on growth and yield attributes was found significant which resulted in a significant increase in the pod yield of groundnut. Sulphur might have encouraged total biomass production and kernel development

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in groundnut, which was finally reflected in the improved pod yield. Calcium plays an important role in groundnut pod development and it was necessary for proper filling of pods in adequate quantities in the fruiting zone. Gypsum application stage also significantly influenced the pod yield of spring groundnut during both the years. Highest pod yield of 39.49 q ha^{-1} in 2018 and 42.99 q ha^{-1} in 2019 was observed with the split application of gypsum (50% at sowing + 50% at flower initiation stage) which was significantly higher over application of full dose of gypsum at the time of sowing. Application of 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} gave maximum pod yield of 39.66 q ha^{-1} in 2018 and 43.68 q ha^{-1} in 2019 which was statistically at par with the pod yield obtained by the application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} (38.68 q ha^{-1} in 2018 and 42.36 q ha^{-1} in 2019) while significantly higher than that of 15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} (36.60 q ha^{-1} in 2018 and 39.43 q ha^{-1} in 2019) during both the years. The application of increased levels of nitrogen and phosphorus resulted in more nutrient availability to plant and resulted in greater utilization of assimilates into pods and ultimately increased the number of pods, 100-seed weight and the yield of groundnut. The increase in yield due to phosphorus application might be attributed to the activation of metabolic processes, where its role in building phospholipids and nucleic acid is known.

Conclusions

The application of gypsum @ 225 kg ha^{-1} significantly increased the uptake of major nutrients and improved the soil fertility status in terms of higher availability of major nutrients in the soil under spring groundnut. Application of gypsum to spring groundnut in two split doses *i.e.* half at sowing time and remaining half at flower initiation stage resulted in higher uptake of major nutrients as well as higher availability of major nutrients in the soil in comparison with the basal application of gypsum. Application of nitrogen and phosphorus @ 35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} resulted in maximum nutrient uptake as well as improvement

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in the soil fertility status in comparison to the lower doses Application of gypsum @ 225 kgha^{-1} at two split and application of 25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} also increased the yield of groundnut.

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UNDER PEER REVIEW

Table 1: Nitrogen, phosphorus and potassium concentration in haulm and kernel as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels

Treatments	N (%)				P (%)				K (%)			
	Haulm		Kernel		Haulm		Kernel		Haulm		Kernel	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Gypsum levels												
Control	1.75	1.73	4.16	4.18	0.268	0.268	0.540	0.551	1.53	1.54	0.732	0.727
125 kg ha^{-1}	1.75	1.75	4.31	4.32	0.278	0.279	0.561	0.566	1.56	1.57	0.761	0.756
175 kg ha^{-1}	1.76	1.76	4.32	4.33	0.278	0.281	0.562	0.567	1.57	1.57	0.762	0.763
225 kg ha^{-1}	1.76	1.77	4.32	4.36	0.280	0.281	0.564	0.567	1.57	1.58	0.763	0.768
CD (p=0.05)	NS	NS	0.13	0.13	0.008	0.009	0.019	0.012	0.03	0.03	0.024	0.023
Gypsum application stage												
Full at sowing	1.74	1.75	4.24	4.28	0.276	0.276	0.556	0.560	1.55	1.56	0.753	0.747
50% at sowing + 50% at flower initiation stage	1.76	1.76	4.31	4.31	0.277	0.278	0.558	0.566	1.56	1.57	0.756	0.759
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels												
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	1.72	1.72	4.21	4.17	0.271	0.273	0.545	0.556	1.52	1.55	0.746	0.749
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	1.77	1.77	4.28	4.29	0.279	0.279	0.562	0.564	1.56	1.58	0.758	0.754
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	1.77	1.77	4.34	4.43	0.279	0.280	0.564	0.568	1.58	1.58	0.760	0.756
CD (p=0.05)	0.04	0.05	0.05	0.11	0.006	0.005	0.012	0.008	0.03	0.02	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

UNDER PEER REVIEW

Table 2: Calcium and sulphur concentration in haulm and kernel as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels .

Treatments	**Ca (%)**				**S (%)**			
	Haulm		**Kernel**		**Haulm**		**Kernel**	
Gypsum levels								
Control	1.11	1.11	0.360	0.364	0.245	0.248	0.347	0.352
125 kg ha^{-1}	1.16	1.16	0.376	0.376	0.254	0.255	0.362	0.364
175 kg ha^{-1}	1.19	1.18	0.376	0.378	0.255	0.257	0.364	0.366
225 kg ha^{-1}	1.19	1.19	0.377	0.378	0.257	0.258	0.365	0.367
CD (p=0.05)	0.04	0.05	0.010	0.010	0.008	0.007	0.012	0.010
Gypsum application stage								
Full at sowing	1.16	1.16	0.372	0.372	0.252	0.252	0.357	0.360
50% at sowing + 50% at flower initiation stage	1.17	1.17	0.372	0.376	0.253	0.257	0.362	0.365
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels								
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	1.14	1.14	0.370	0.371	0.248	0.251	0.352	0.356
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	1.18	1.16	0.372	0.374	0.254	0.255	0.362	0.365
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	1.18	1.18	0.375	0.377	0.256	0.258	0.364	0.366
CD (p=0.05)	0.03	0.02	NS	NS	0.005	0.004	0.008	0.006
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

UNDER PEER REVIEW

Table 3: pH, EC and OC of soil (after harvest of crop) as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels (mean of 2 years)

Treatments	pH		EC (dS m^{-1})		OC (%)	
	2018	2019	2018	2019	2018	2019
Gypsum levels						
Control	8.24	8.19	0.61	0.62	0.33	0.35
125 kg ha^{-1}	8.25	8.28	0.62	0.63	0.34	0.34
175 kg ha^{-1}	8.24	8.33	0.64	0.63	0.35	0.34
225 kg ha^{-1}	8.22	8.31	0.63	0.63	0.35	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Gypsum application stage						
Full at sowing	8.24	8.27	0.62	0.62	0.34	0.35
50% at sowing + 50% at flower initiation stage	8.24	8.28	0.62	0.63	0.35	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels						
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	8.25	8.28	0.62	0.62	0.34	0.34
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	8.23	8.27	0.63	0.63	0.34	0.35
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	8.23	8.28	0.62	0.63	0.35	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

UNDER PEER REVIEW

Table 4: Available N, P, K, Ca and S of soil (after harvest of crop) as influenced by gypsum levels, gypsum application stage and nitrogen and phosphorus levels (mean of 2 years)

Treatments	Available nutrients									
	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})		Ca (ppm)		S (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Gypsum levels										
Control	206.0	205.6	18.70	19.82	252.3	253.6	100.3	102.1	23.57	24.42
125 kg ha^{-1}	211.1	211.6	20.76	22.44	259.9	257.9	105.5	107.9	27.94	28.62
175 kg ha^{-1}	226.1	217.5	21.92	22.86	264.8	259.5	107.0	109.2	29.03	29.81
225 kg ha^{-1}	227.7	224.6	22.10	23.56	269.4	260.5	108.1	110.6	30.04	30.68
CD (p=0.05)	NS	NS	1.56	1.27	NS	NS	2.5	2.6	1.93	1.82
Gypsum application stage										
Full at sowing	216.4	210.2	20.52	21.91	261.3	256.2	104.4	106.6	27.06	27.97
50% at sowing + 50% at flower initiation stage	219.1	219.5	21.22	22.43	261.9	259.6	106.1	108.3	28.24	28.80
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen and phosphorus levels										
15 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1}	206.3	200.5	18.95	19.59	249.6	247.4	104.4	107.0	27.00	27.85
25 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1}	217.8	215.1	20.90	22.54	263.6	262.1	105.3	107.4	27.62	28.45
35 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}	229.1	228.9	22.75	24.37	271.6	264.1	106.0	108.0	28.32	28.85
CD (p=0.05)	10.6	13.2	1.75	1.66	12.7	12.9	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

UNDER PEER REVIEW

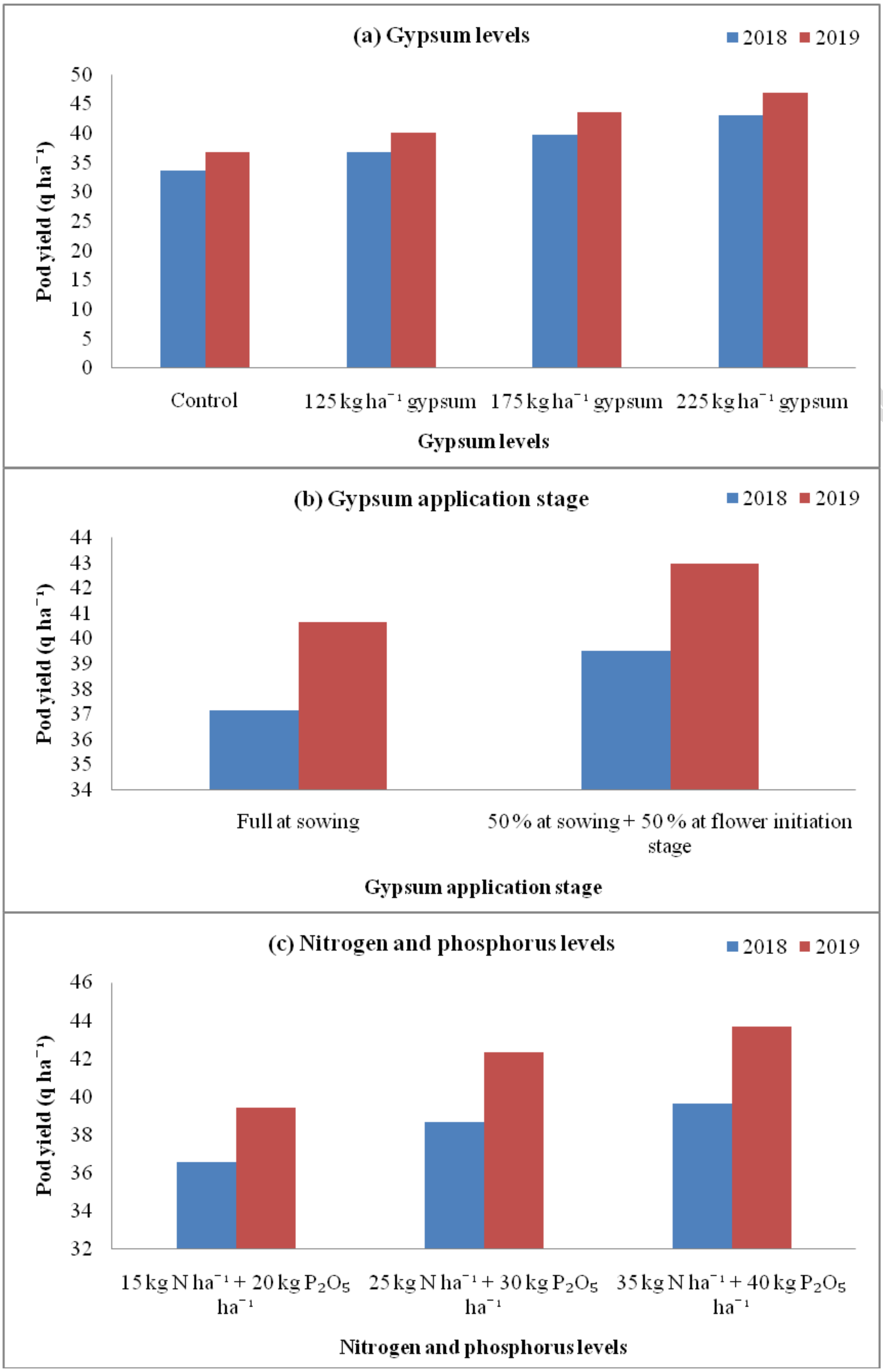

Fig. 1: Pod yield of groundnut as influenced by (a) gypsum levels, (b) gypsum application stage and (c) nitrogen and phosphorus levels