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Yield, Nutrient Uptake and Economics of Rabi Groundnut (*Arachis hypogaea* L) Crop As Influenced By Different Phosphorus Sources

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ABSTRACT

Acid soils in general are deficient in phosphate due to high P-fixation capacity. Phosphate rock, a source of P is less expensive and eco-friendly which can be used profitably to meet the P requirement of crops for sustainable production. Therefore, it is essential to find ways and means to increase the efficiency of phosphate rock either by using it alone or as a mixture of phosphate rock and water soluble P fertilizer. A field experiment was conducted during rabi seasons of 2013-14, 2014-15 and 2015-16 study the effect of various sources of phosphorus on yield, nutrient uptake and economics of groundnut (*Arachis hypogaea* L) under acid Alfisols of Odisha. The experiment was laid out in randomized block design with seven treatments and three replications. The soil of the experiment site has a loam texture, a pH of 5.2, low available nitrogen and medium phosphorus and potassium. Results revealed that combined application of SSP with lime recorded significantly higher pod yield (2575 kg ha^{-1}) and P, K, Ca, Mg and S uptake by groundnut over other treatments. The effect of sole application of phosphate rock on pod yield and nutrient uptake by groundnut was inferior to other treatments except Control 'P'. Combined application of phosphate rock and SSP mixture in 1:1 ratio can be compared with water soluble SSP, since both the treatments recorded 57-62% of higher yield over Control 'P'. The yield in +SSP mixture (1:1) was statistically at par with SSP treatment with respect to yield and nutrient uptake. Highest benefit-cost ratio of 2.89 was recorded in +SSP (1:1) treatment. In +SSP (1:1) mixture, the RAE value was increased above the standard treatment (T_3) being 109%. The agronomic efficiency of the treatment further increased when the crop was limed along with SSP (140%).

Introduction

In India, about 49 million hectors of cultivated area are considered acidic, out of which 26 million hectare have pH below 5.6 and 2.3 million hectors between 5.5 and 6.5 (Bhumbla and Mandal, 1972). According to Sharma and Sarkar (2005)acid soils in India (pH < 6.5) occupies about 90 million ha (Mha) out of which 49 Mha have pH less than 5.5. A large part of Odisha is also covered with acidic red and laterite soil (Mitra *et al.*, 1993). Phosphorus is one of the most limiting nutrient in the soils of Odisha owing to P fixation and immobile nature of P (Pattanayak *et al.*, 2008).

Acid soils fix two-to-three times more P per unit surface area than neutral or calcareous soil and the fixed P in acid soil is held with five times more bonding energy than calcareous soils. The extent of P fixation from the added P varies from 97% under air-dry condition to 76% under submerged condition, which is dependent on the type and quantity of clay minerals, sesquioxide and organic matter content (Pattanayak and Misra, 1989). Even though the soils of Odisha are low (27%) to high (73%) in soil available P, crops grown in Odisha exhibited a significant yield loss due to omission of P, which is 37% in hybrid rice (Pattanayak *et al.,* 2008) and 49% in hybrid maize (Pattanayak *et al.,* 2009). Use of water soluble sources of phosphorus is highly limited because of high fixation and use availability of phosphorus to crop in the acid soils. The quantity of P required to develop a satisfactory phosphorus potential in these soils are so great that the use of processed phosphatic fertilizer is not economically feasible.

India's phosphate rock reserve is now, estimated at about 260 million tons. Out of this, 15 million tons can be categorized as high grade (>30 per cent P2O5), 19 million tons as medium grade (25-30 percent P_2O_5) 55 million tons low grade (11-25 per cent P_2O_5) and rest comes under unclassified grade (Jaggi, 1989). The largest deposits are found at Udaipur, in the state of Rajasthan followed by Lalitpur, Mussorie, Dehradun and Tehri Garwal of U.P, Sagar, kasipatnam of A.P. and Jhabua of M.P and Purulia of W.B.

In the present agricultural scenario, the high cost of conventional water soluble phosphatic fertilizers like SSP and DAP restricts their use by resource-poor farmers in developing countries like India. Thus, phosphatic fertilizers can be completely or partly substituted by phosphate rocks depending on the reactivity of the rock and soil pH. Crop response to phosphate rock application is strongly dependent upon the rate of dissolution of phosphate rock (Olsen, 1975; Chaverrie and Black, 1976).

Thus, a proper P management strategy is required for improving and sustaining crop yields in the acid soils of Odisha. Therefore, the present investigation aims at to study the efficiency of Udaipur phosphate rock, single super phosphate and their mixtures in different proportions in rabi Groundnut.

Materials and Methods

Experimental site

The effects of Udaipur phosphate rock (UPR) alone and in different combinations with single super phosphate (SSP) on groundnut crop during three consecutive years (2013-2014 to 2015-16) was studied through a field experiment. The experiment was conducted in the Central Farm, Odisha University of Agriculture and Technology, Bhubaneswar. It is situated at about 64 km away from the Bay of Bengal within the East and South- Eastern Coastal Plain agro-climatic zone of Odisha and falls under the East Coastal Plains and Hills zone of the humid tropics of India. The climate is characterized as hot, moist and sub-humid with hot summers and mild winters. Broadly, 76% of the annual rainfall is received during June - September. The rainfall is monsoonal and unimodal. The south-west monsoon usually sets in around mid-June and recedes by mid-October.

Experimental design and treatments

The experiment was conducted in a randomized Control 'P' block design with 7 treatments and 3 replications. Treatments were : T_1-; T_2-100%P (UPR); T_3-100% P(SSP); T_4- 75% P (UPR) + 25% P (SSP); T_5-50% P (UPR) + 50% P (SSP); T_6-25% P

(UPR) + 75% P (SSP); T_7- 100% P (SSP) + lime@0.2 LR. Each plot was 10 m x10 m. The groundnut crop cv. TAG 24 of 115 days duration was sown during rabi 2013-14 to rabi 2015-16 at a spacing of 30x10 cm. Except the Control 'P' treatment (T_1), the crop received recommended doses of N, P_2O_5, K_2O @ 20:40:40 kg ha^{-1}. Control 'P' treatment (T_1) received only N and K_2O at 20 and 40 kg ha^{-1}respectively. All N, P, K were applied as basal dose. Phosphorus was applied in all the treatments from T_2 to T_7 with the sources as per treatments. A composite soil sample (0-15 cm depth) was collected from the experimental site before sowing of seeds and fertilizers application.

Crop management

All the recommended agronomic practices i.e., irrigation, intercultural operations, pest control 'P' were uniformly kept in all the treatments as and when needed. The mean temperatures during groundnut crop growing seasons were 26.5°C, 28.0°C and 27.8°C respectively while the relative humidity 67.6%, 67.0% and 67.3% respectively. The mean temperatures during hybrid maize crop growing seasons were 27.9°C, 28.8°C and 28.9°C respectively while the relative humidity 83.7%, 82.3%and 82.1% respectively.

Soil sampling, processing and analysis

Soil samples (0-15 cm) were collected from each treatment replication wise at initial and harvesting stage of groundnut. The samples were air dried under shade, crushed with wooden hammer and passed through 2 mm sieve and preserved in polythene bags for analysis. Analyses were for: soil texture, bulk density, water holding capacity, pH, electrical conductivity, lime requirement value, organic carbon, exchange acidity, exchangeable acidity, exchangeable calcium, effective cation exchange capacity, available nitrogen, available phosphorus, available potassium, available sulphur. The texture of soil samples were determined with the help of Bouyoucous Hydrometer as given by Piper (1950). The bulk density of soil (undisturbed) was determined by Core method (Black, 1965). The water holding capacity of soil samples were determined by Keen Raczkowski Box method (Piper, 1950). The pH was determined in 1:2.5 soil-water ratio by pH meter (ELICO LI 613 pH meter) as described by Jackson (1973). As suggested by Jackson (1973), the electrical conductivity of soil samples was determined in 1:2.5 soil-water suspension by conductivity meter (ELICO CM 180 Conductivity meter). Lime requirement value of soil was determined by Woodruff Buffer method (Woodruff, 1948). The organic carbon content of soil was determined by Wet digestion procedure of Walkley and Black (1934) as outlined in soil chemical analysis (Page *et al.*, 1982). Exchange acidity, exchangeable acidity: Exchange acidity, exchangeable acidity were estimated by using the methods of Lin and Coleman (1960) as described by Page *et al.*, (1982). Exchangeable Calcium was determined using EDTA (Versenate) complexometric titration by using Calcon indicator as outline by Hesse (1971). Effective Cation Exchange Capacity refers to the sum of the milli equivalents of Ca, Mg, K, Na plus H and Al. Exchangeable Ca, Mg, K and Na were extracted using neutral normal ammonium acetate and determined separately. Available nitrogen in soil was determined by alkaline KMnO4 method (Subbiah and Asija, 1956) using Kelplus nitrogen auto analyzer (Kelplus: Model classic DX). Available phosphorous in the soil was determined by Bray's 1 method (Bray and Kurtz, 1945) as out lined by Page *et al*., (1982). Available potassium was determined by extracting the soil with neutral normal ammonium acetate solution and estimated by flame photometer as described by Hanway and Heidal (1952). The available S content was determined turbidimetrically following the procedure of Chesnin and Yien (1952) as described by Page *et al*., (1982).

Plant sampling, processing and analysis

For determination of nutrient uptake, plants were collected at harvesting (115 DAS) stage of groundnut crop. Two plants from each plot were taken and labelled. The groundnut kernel, shell, haulm were kept separately in envelops, labelled properly and dried in hot air oven at 60ºC for 48 hour. Each sample was ground separately with the help of a Willy mill to pass through 20 mesh sieve and was used for analysis for different elements. The kernel, shell and haulm samples were analyzed for determination of N, P, K, Ca, Mg and S concentration. Nitrogen in the processed sample was determined by Kjeldahl digestion method as described in A.O.A.C. (1960). Total phosphorus (P) was analysed by spectrophotometer (Elico UV-VIS spectrophotometer Model SI 164) at 470 nm as described by Jackson (1973). Potassium (K) was estimated as described by Jackson (1973) with the help of flame photometer (Model: Chemiline-411). The calcium and magnesium content of plant samples were determined by EDTA titration method as described by Hesse (1971). The sulphur content was determined turbidimetrically following the modified procedure of Mossouemi and Cornfield (1963). The oil content of the kernel samples was estimated by cold percolation method suggested by Kartha and Sethi (1957) by using petroleum ether.

Statistical analysis of data

Total pod, haulm, kernel and shell yield were recorded after harvesting groundnut from each treatments. The data was analysed for individual years as well as pooled analysis for three years. Fisher's method of analysis of variance was used for the analysis and interpretation of data as given by (Panse and Sukhatme, 1989).

Results and Discussion

The soil of the experimental site is loam in texture with water holding capacity is 31%, bulk density (BD) 1.59 Mg m^{-3}. The soil is acidic in reaction (pH-5.2), non saline (EC-0.09 dS m^{-1}) with exchangeable acidity of 0.11, Exchangeable Ca^{2+} 1.31, Exchangeable Mg^{2+} 0.13 c mol (p^{+}) kg^{-1} soil respectively. The soil is low in organic carbon (3.4 g kg^{-1} soil), low in available N (239 kg ha^{-1}), medium in P (14.64 kg ha^{-1}) and K (150 kg ha^{-1}) and S (27.4 kg ha^{-1}) indicating low soil fertility. The CEC is 4.2 c mol (p+) kg^{-1} soil and base saturation of 43%.

The total P_2O_5 content of Udaipur phosphate rock (UPR) used in this experiment was 17.9%.

Pod yield of groundnut

The mean pod yield of groundnut for two seasons without P fertiliser was 1435 kg ha^{-1} (Table 1). Application of P through different combinations significantly increased pod yield with the effects increasing in the order ($T_8 > T_5 > T_3 > T_6 > T_4 > T_2 > T_7 > T_1$). The combined application of SSP with lime had the highest pod yield (2575 kg ha^{-1}), was due to better utilization of native and applied P with increase in soil pH. The exchangeable Al^{3+} and exchangeable H^{+} get neutralised with rise in pH resulted in reduction of P-fixation capacity of soil. Combined application of UPR+SSP mixture in 1:1 ratio can be compared with SSP treatment, since both the treatments recorded 57-62% of higher yield over control 'P'. Since, a part of P from SSP get fixed resulting lower pod yield as compared to UPR+SSP treatment. On the other hand, in UPR+SSP treatment, SSP met the P requirement of groundnut in the beginning of growing period and P derived from dissolution UPR full filled the crop P requirement in latter stage of growth. Further, the data showed that the magnitude of yield in T_4 (2170 kg ha^{-1}) and T_6 (2137 kg ha^{-1}) were lower than T_3 and T_5. Sole application of UPR recorded significantly higher yield (38.7%) over control 'P' but, observed to be less effective as compared to UPR+SSP mixture or SSP alone. Application of the recommended dose of P @ 40kg P_20_5 ha^{-1} as SSP (standard treatment) recorded an yield of 2249 kg ha^{-1}. Replacement of entire P dose through UPR could not met P requirement reflecting yield decline by 11.5% with respect to standard dose. However, application of UPR+SSP mixture in 1:1 ratio gave an yield of 2320 kg ha^{-1} which was statistically at par with SSP treatment (T_3) and seems to be economically viable alternative to 100% water soluble SSP. On the other hand, application of lime @0.2LR with SSP raised the yield by 14.5% since liming raised soil pH and increased P availability. Liming created a neutral pH environment in the root zone that induced the availability of several nutrients and crop yield (Panda, 2007; Jena, 2008). Sharma and Sarkar (2005) reported that application of lime @ 2-4 q ha^{-1} in furrows along with chemical fertilizer at sowing increased the crop yield by 14 to 52% over farmer's practice. Addition of lime @ 0.2 LR with NPK increased the yield over farmer's practice by 17-36% in groundnut (pH 40.-6.3) (Jena, 2013). The beneficial effect of lime with SSP was significantly observed in groundnut since SSP could meet the P requirement of crops at initial stage that helps in root proliferation and root activities. Several workers advocated the advantage of UPR+SSP mixture over SSP since, the P release from UPR would be faster in acidic P deficient soil. Soils with high Ca content would slow down PR dissolution (Hammond *et al.*, 1986). Higher efficiency of a mixture may be due to the starter effect provided by water soluble phosphate in initial growth stages. Such a mixture may depress the activity of toxic Al species in the soil solution and enhance the dissolution of RP by action of initial soil acidity created in the rhizosphere of the plant roots (Mc Lean and wheeler, 1964). The lower efficiency of SSP in acid soil may be due to rapid fixation of water soluble P with free sesquioxides in soil (Misra and Panda, 1969).

Haulm, kernel, shell yield and shelling percentage

Based on the three seasons data, the mean haulm yield in control 'P' was 2631 kg ha^{-1} and varied between 3573 to 4168 kg ha^{-1} in other treatments (Table 1). Significantly higher yield (4168 kg ha^{-1}) was recorded in SSP + lime treatment over other treatments. Haulm yield in UPP + SSP (1:1) treatment (3923 kg ha^{-1}) was statistically at par with SSP (3862 kg ha^{-1}) treatment. Sole application of UPR seems to be interior to UPR + SSP combinations which recorded 3573 kg ha^{-1} haulm yield but significantly higher over control 'P'. The other UPR+SSP combinations viz. 3:1 or 1:3 ratio increased haulm yield by 44.66 and 41.54% respectively.

Similar trend in kernel and shell yield were recorded in present study. Significantly, higher kernel yield of 1828 kg ha^{-1} was recorded in SSP+ lime followed by 1626 kg ha^{-1} in UPR+SSP (1:1) and 1572 kg ha^{-1} in SSP treatment (Table 1). In absence of P, the kernel yield in control 'P' was 915 kg ha^{-1}.

The shell yield in control 'P' was 520 kg ha^{-1} and increased by 24.2 to 43.6% in other treatments (Table 1). Highest increase over control 'P' was recorded in SSP + lime

(43.6%) followed by UPR +SSP (1:1) (33.3%) and SSP (30.2%) treatment. The shelling percentage in control 'P' was 63.8% and increased significantly in other treatments. Application of calcium through lime helps in bold seed formation resulting higher shelling percentage (71%) as compared to other treatments (Table 1). The shelling percentage in UPR was 67.5% as against 69.9% in SSP treatment. When UPR combined with SSP in different proportions, it varied from 68.3 to 70.1%.

Marwaha and Kanwar (1981) also reported the superiority of RP and SSP mixture to individual one in acidic laterite soils of Odisha and acid soils of Himanchal Pradesh.

Protein content

From the Table 1 it is clear that the protein content of kernel varied significantly among the treatments imposed. Application of P increased the protein content of kernel significantly. The highest protein content (23.97%) was recorded in the treatment receiving SSP + lime (T_7) followed by (22.75%) with the treatment receiving UPR+ SSP in (1:1)

Oil content

From the Table 1 it is observed that there was significant difference among the treatments. The treatment with SSP+ lime recorded the maximum oil content (49.69%), followed by the treatment with UPR + SSP (1:1) (49.33%). But these were at par with the treatment SSP (T_3) (48.92%).

Relative agronomic efficiency (RAE)

The relative agronomic efficiency of treatments was calculated taking SSP as standard treatment. The data presented in Table 2 showed that the RAE values for groundnut varied from 60-140. Based on the RAE values, the efficiency of different P treatments were evaluated and found that sole application of UPR or UPR+SSP mixture either in 3:1 or 1:3 ratio could not be compared with standard SSP (T_3) treatment since the RAE values were lower than SSP treatment and varied between 60 to 90%. However, when the crops received UPR+SSP mixture in 1:1 ratio, the RAE values were increased above the standard treatment (T_3) being 109%. The agronomic efficiency of the treatment further increased when the crop was limed along with SSP. The beneficial effect of lime was reflected on crop yield and recorded RAE value of 140% in groundnut.

Economics

The data showed that the benefit-cost ratio was highest in UPR+SSP (1:1) treatment (2.89) followed by 2.81 in SSP+ lime and 2.78 in SSP treatment. In Control 'P' it was 1.83. The benefit-cost ratio was 2.50 in sole UPR treatment (T_2). In UPR+SSP mixture (3:1 and 1:3) treatments the ratio of 2.78 and 2.65 were recorded respectively. The highest net return of Rs 81059/- was obtained in SSP+ lime treatment followed by Rs 74161/- in UPR+SSP (1:1) treatment.

Phosphorus content and uptake by groundnut

Phosphorus content and its uptake by groundnut crop presented in Table 3 and 5 showed that, P content in groundnut plant is in the order of kernel > haulm > shell. It varied between 0.25 to 0.31% in kernel, 0.13 to 0.14% in haulm and 0.09 to 0.12 % in shell. In control 'P' without P application, P accumulation in kernel was lowest and increased significantly in P treatments. Significantly highest accumulation was recorded in SSP+ lime treatment followed by SSP and SSP+UPR mixture, but all were statistically at par. Sole application of UPR to groundnut recorded higher P accumulation than control 'P' but both were at par.

Similar trend was observed with respect to P uptake (Table 5). The P uptake by groundnut plants was in the order of haulm > kernel > shell. The magnitude of phosphorous uptake by kernel, haulm and shell in P treatments, varied between 2.29 to 5.67, 3.42 to 5.84 and 0.47 to 0.90 kg ha^{-1}, respectively. Significantly highest P uptake in kernel was recorded in SSP+ lime treatment followed by SSP, SSP+UPR mixture in 1:1 ratio. Similar trend was observed in shell and haulm.

Total P uptake by groundnut crop was calculated based on the uptake by kernel + shell + haulm (Table 5). Total P uptake in control 'P' was 6.18 kg ha^{-1} and significantly increased by 54-101% in P treatments. Combined application of SSP+ lime raised soil pH, increased P availability and P accumulation in plant and finally enhanced the P uptake by 101% over control 'P'. Application of entire P though SSP or UPR+SSP mixture in 1:1 ratio behaved similarly and recorded about 81% higher uptake over control 'P'. On the other hand, sole application of UPR or UPR+SSP mixtures in 3:1 or 1:3 ratio were inferior to other treatments but recorded 54% to 69% higher P uptake over control 'P'.

Potassium content and uptake by groundnut

Potassium content in different plant parts of groundnut crop is in the order of shell > haulm > kernel. It varied between 0.48 to 0.49% in kernel, 0.86 to 0.92% in shell and 0.83 to 0.92% in haulm (Table 3). Among the treatments lowest potassium accumulation was recorded in control 'P', but increased significantly in P treatments indicating that potassium accumulation was greatly influenced with P application. Further the data showed that there was much impact of liming on K accumulation.

Similar trend was observed with respect to potassium uptake by groundnut crop. A critical observation of the data presented in Table 5 made it evident that mean potassium uptake in kernel, shell and haulm of groundnut varied between 4.48 to 8.77, 4.47 to 6.55 and 21.84 to 38.35 kg ha^{-1}, respectively. The total potassium uptake by groundnut varied between 30.79 to 53.77 kg ha^{-1}. In control 'P' treatment it was 30.79 kg ha^{-1} and increased significantly with P application either though water soluble or water insoluble source. Application of lime with SSP increased the potassium uptake significantly by 74.6% over control 'P'. This was due to increase in available P because of liming resulted in better root development and nutrient acquisition capacity leading to higher biomass production. Potassium acquisition and uptake is greatly influenced by P application.

Application of full dose of P either though SSP or mixture of UPR+SSP in 1:1 ratio recorded similar uptake value which was about 59.3% higher over control 'P' but, inferior to SSP+ lime treatment .Sole application of P though UPR recorded about 37.7% higher potassium uptake over control 'P' as against 45.5 to 47.6% in UPR+SSP mixture either in 1:3 or 3:1 ratio respectively.

Calcium content and uptake by groundnut

A critical observation of the data presented in Table 4 made it evident that calcium content in groundnut plant parts was in the order of haulm > shell > kernel. Average calcium content over two seasons in haulm, shell and kernel varied from 0.54 to 0.94, 0.29 to 0.49 and 0.11 to 0.16%, respectively. In control 'P' treatment, the accumulation of calcium in haulm, shell and kernel was 0.54, 0.29 and 0.11%, respectively. Application of SSP+ lime or SSP alone resulted significantly higher calcium accumulation over other treatments. It was due to increase in pH and calcium addition though lime and SSP which enhanced calcium availability in soil and uptake by crop. The calcium accumulation in groundnut due to application of UPR alone or in combination with SSP either in 3:1 or 1:3 ratio was at par and better than control 'P' treatment.

A critical observation of the data presented in Table 6 made it evident that calcium uptake by kernel, shell and haulm varied between 1.01 to 2.92, 1.51 to 3.51 and 14.21 to 36.68 kg ha^{-1}, respectively. In control 'P' treatment, mean calcium uptake by kernel, shell and haulm was 1.01, 1.51 and 14.21 kg ha^{-1}, respectively and significantly increased in P treatments. Application of lime + SSP recorded maximum calcium uptake followed by SSP treatment was due to better P-availability, highest biomass production and calcium accumulation in groundnut. Uptake of calcium in UPR+SSP with 1:1 ratio was at par with SSP alone. On the other hand, the treatments receiving full P through UPR alone or UPR+SSP mixture in 3:1 or 1:3 ratio recorded significantly lower calcium uptake as compared to SSP+ lime or SSP treatment, but better than control 'P'.

The mean total calcium uptake by groundnut over three seasons varied from 16.73 to 43.11 kg ha^{-1} (Table 6). In control 'P' treatment, it was 16.73 kg ha^{-1} and significantly increased by 89.96 to 157.68% in P treatments. Significantly highest uptake of 43.11 kg ha^{-1} was recorded in SSP+ lime treatment which was 157.68 % higher than control 'P'. Addition of calcium through lime and SSP significantly increased the total biomass yield and calcium accumulation in plant resulted in higher calcium uptake.

Application of UPR+SSP mixture in 1:1 ratio was inferior to SSP or SSP+ lime treatment but, better than all other treatments, since it recorded 120.26% higher calcium uptake over control 'P'. Sole application UPR or UPR+SSP mixture in 3:1 or 1:3 ratio recorded significantly higher calcium uptake by 89.96 to 102.39% over control 'P', although these combinations were inferior to UPR+SSP mixture in 1:1 ratio.

Magnesium content and uptake by groundnut

It is observed from the Table 4 that magnesium accumulation in kernel, shell and haulm of groundnut varied 0.03 to 0.04, 0.07 to 0.11 and 0.13 to 0.22%, respectively. The magnitude of magnesium accumulation in groundnut was lower than calcium. In control 'P' treatment magnesium accumulation in kernel, shell and haulm was 0.03, 0.07 and 0.13%, respectively and increased significantly with P application.

Maximum magnesium accumulation in groundnut plant was recorded in T_3 when the crop received full P through SSP. Inclusion of lime with SSP decreased magnesium accumulation as compared to SSP alone. It was due to increase in Ca and K concentration in soil depressed plant magnesium uptake due to competitive inhibition. Application of UPR alone or with SSP either in 1:1, 3:1 or 1:3 mixture recorded significantly higher magnesium accumulation in haulm over control 'P', but were at par with SSP or SSP+ lime treatments. On the other hand, there was no significant difference in magnesium accumulation in kernel or shell. Magnesium uptake by haulm was higher than kernel. The data presented in Table 6 showed that in control 'P' treatment, magnesium uptake by kernel, shell and haulm was 0.27, 0.36 and 3.42 kg ha^{-1}, respectively and significantly increased in treatments.

Total magnesium uptake by groundnut in control 'P' was 4.05 kg ha^{-1} and increased by 75.80 to 144.19% in different P treatments. Significantly maximum total magnesium uptake of 9.89 kg ha^{-1} was recorded in SSP+ lime treatment which is 144.19% higher over control 'P'. Combined application of UPR+SSP mixture in 1:1 ratio can be compared with standard SSP treatment, since the uptake varied from 8.72 to 9.87 kg ha^{-1}.

Other combinations of UPR and SSP mixture could not match with these treatments since the magnesium uptake values decreased although it was higher by 75.80 to 95.31 % over control 'P'.

Sulphur content and uptake of sulphur by groundnut

Table 4 depicts the accumulation of sulphur in kernel, haulm and shell of groundnut over two seasons. Irrespective of the treatments, the magnitude of sulphur accumulation was in order of shell > haulm > kernel. In control 'P', the mean content of sulphur was 0.08% in kernel, 0.25% in shell and 0.16% in haulm. Application of full dose of P through UPR either to first crop or all crops increased the sulphur accumulation in groundnut but was at par with control 'P'. On the other hand, addition of SSP or SSP+ lime had positive effect on sulphur content and the values were significantly higher than all others treatments. Combined application of UPR+SSP mixtures either in 1:1 or 3:1 or 1:3 ratio were at par with UPR (T_2) treatment.

A critical observation of the data presented in Table 6 made it evident that mean sulphur uptake over two seasons by groundnut kernel, shell and haulm varied from 0.73-2.01, 1.30-2.69 and 4.21-10.00 kg ha^{-1} respectively. Irrespective of the treatments, sulphur uptake by haulm was higher than kernel was due to higher concentration of sulphur in haulm. Addition of SSP or SSP+ lime significantly increased the sulphur uptake by kernel, shell and haulm over all other treatments. On the other hand, application of UPR alone or with SSP in 1:1, 3:1 or 1:3 significantly recorded higher sulphur uptake over control 'P', but all these combinations were at par.

The mean total sulphur uptake by groundnut over two seasons varied from 6.24 to 14.70 kg ha^{-1}. In control 'P' treatment it was 6.24 kg ha^{-1} and increased by 50.32% with sole UPR application. The standard treatment which receives 100% P through SSP recorded 115.38% higher sulphur uptake over control 'P' and also better than UPR+SSP mixtures, since UPR+SSP mixture in 1:1, 3:1 or 1:3 ratio recorded 71.63 to 94.07% higher uptake over control 'P'. Integration of SSP with lime was found to be best treatment among all other combinations since it recorded 14.70 kg ha^{-1} which is 135.58% higher over control 'P'.

Generally plants take up about 10-15% of applied P from soil, but higher recoveries observed through phosphate demanding crops in phosphate poor soils. When a mixture of water soluble and water insoluble phosphates is used the crop will take up higher proportion of P from the soluble than insoluble form and the presence of soluble P depress the uptake of P from the insoluble source. Liming the soil raised the soil pH, increases the availability of iron and aluminium phosphate which are more readily available to the crops.

Nutrient uptake by crops depends on magnitude of nutrient content in plant parts and biomass yield. In this study, combined application of SSP + lime recorded higher P, K, Ca, Mg and S uptake by groundnut as compared to SSP or UPR+SSP mixture was due to higher biomass production. Sole application of UPR was found inferior to SSP+ lime, SSP or UPR+ SSP (1:1) mixture treatments with respect to nutrient uptake.

Table.1 Effect of treatments on yield of groundnut (kg ha^{-1}) (Pooled data of 3 years)

Treatments	Pod yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Kernel yield (kg ha^{-1})	Shell yield (kg ha^{-1})	Protein content in kernel (%)	Oil content (%)	Shelling percentage (%)
T_1:Control 'P'	1435	2631	915	520	19.62	45.31	63.76
T_2:100%UPR	1990	3573	1344	646	20.32	45.56	67.54
T_3:100%SSP	2249	3862	1572	677	22.39	48.92	69.90
T_4:75%UPR+25%SSP	2170	3846	1483	687	21.63	46.26	68.34
T_5:50%UPR+50%SSP	2320	3923	1627	693	22.75	49.33	70.13
T_6:25%UPR+75%SSP	2137	3724	1470	667	21.58	47.21	68.79
T_7:100%SSP+0.2LR	2575	4168	1828	747	23.97	49.69	70.99
CD(0.05)	127	302	141	68	3.74	1.05	1.63

Table.2 Relative Agronomic Efficiency (RAE) and benefit cost ratio of different treatments (Pooled data of 3 years)

Treatments	Pod yield (kg ha^{-1})	RAE (%)	Gross Return (Rs)	Gross cost of cultivation (Rs)	Net Return (Rs)	B:C
T_1:Control 'P'	1435	-	70171	38295	31876	1.83
T_2:100%UPR	1990	60	97311	38967	58344	2.50
T_3:100%SSP	2249	100	109976	39608	70368	2.78
T_4:75%UPR+25%SSP	2170	90	106113	39127	66986	2.71
T_5:50%UPR+50%SSP	2320	109	113448	39287	74161	2.89
T_6:25%UPR+75%SSP	2137	86	104499	39448	65051	2.65
T_7:100%SSP+0.2LR	2575	140	125917	44858	81059	2.81

*The selling price of groundnut @Rs 48.90/-per kilogram

Table.3 Effects of treatments on P and K content (%) of groundnut (Pooled data of 3 years)

Treatments	Content (%)					
	Kernel		Shell		Haulm	
	P	K	P	K	P	K
T_1:Control 'P'	0.25	0.49	0.09	0.86	0.13	0.83
T_2:100%UPR	0.28	0.48	0.12	0.92	0.14	0.84
T_3:100%SSP	0.31	0.49	0.12	0.92	0.14	0.91
T_4:75%UPR+25%SSP	0.29	0.49	0.11	0.91	0.14	0.83
T_5:50%UPR+50%SSP	0.30	0.49	0.12	0.89	0.14	0.89
T_6:25%UPR+75%SSP	0.29	0.49	0.11	0.89	0.14	0.85
T_7:100%SSP+0.2LR	0.31	0.48	0.12	0.89	0.14	0.92
CD(0.05)	0.02	0.02	0.01	0.07	0.01	0.04

Table.4 Effects of treatments on Ca, Mg and S Content (%) by groundnut (Pooled data of 3 years)

Treatments	Content (%)								
	Kernel			Shell			Haulm		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
T_1:Control 'P'	0.11	0.03	0.08	0.29	0.07	0.25	0.54	0.13	0.16
T_2:100%UPR	0.13	0.03	0.08	0.39	0.10	0.29	0.77	0.17	0.18
T_3:100%SSP	0.15	0.04	0.11	0.49	0.11	0.36	0.94	0.22	0.24
T_4:75%UPR+25%SSP	0.12	0.03	0.10	0.36	0.08	0.28	0.77	0.18	0.19
T_5:50%UPR+50%SSP	0.15	0.04	0.11	0.38	0.09	0.30	0.81	0.19	0.21
T_6:25%UPR+75%SSP	0.15	0.04	0.10	0.34	0.08	0.29	0.78	0.18	0.21
T_7:100%SSP+0.2LR	0.16	0.04	0.11	0.47	0.11	0.36	0.88	0.20	0.24
CD(0.05)	0.02	0.01	0.01	0.04	0.01	0.02	0.06	0.02	0.02

Table.5 Effects of treatments on P and K uptake (kg ha^{-1}) by groundnut (Pooled data of 3 years)

Treatments	Uptake (kg ha^{-1})							
	Kernel		Shell		Haulm		Total	
	P	K	P	K	P	K	P	K
Control 'P'	2.29	4.48	0.47	4.47	3.42	21.84	6.18	30.79
100% P(UPR)	3.76	6.45	0.78	5.94	5.00	30.01	9.54	42.4
100% P(SSP)	4.87	7.70	0.81	6.23	5.41	35.14	11.09	49.07
75% P(UPR)+25% P(SSP)	4.30	7.27	0.76	6.25	5.38	31.92	10.44	45.44
50% P(UPR)+50% P(SSP)	4.88	7.97	0.83	6.17	5.49	34.91	11.2	49.05
25%P(UPR)+75%P (SSP)	4.26	7.20	0.73	5.94	5.21	31.65	10.2	44.79
100%P(SSP)+Lime@0.2 LR	5.67	8.77	0.90	6.65	5.84	38.35	12.41	53.77
CD(0.05)	0.34	0.70	0.09	0.63	0.54	3.02	1.03	4.05

Table.6 Effects of treatments on Ca, Mg and S uptake (kg ha^{-1}) by groundnut (Pooled data of 3 years)

Treatments	Uptake (kg ha^{-1})											
	Kernel			Shell			Haulm			Total		
	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S	Ca	Mg	S
T_1:Control 'P'	1.01	0.27	0.73	1.51	0.36	1.30	14.21	3.42	4.21	16.73	4.05	6.24
T_2:100%UPR	1.75	0.40	1.08	2.52	0.65	1.87	27.51	6.07	6.43	31.78	7.12	9.38
T_3:100%SSP	2.36	0.63	1.73	3.32	0.74	2.44	36.30	8.50	9.27	41.98	9.87	13.44
T_4:75%UPR+25%SSP	1.78	0.44	1.48	2.47	0.55	1.92	29.61	6.92	7.31	33.86	7.91	10.71
T_5:50%UPR+50%SSP	2.44	0.65	1.79	2.63	0.62	2.08	31.78	7.45	8.24	36.85	8.72	12.11
T_6:25%UPR+75%SSP	2.21	0.59	1.47	2.27	0.53	1.93	29.05	6.70	7.82	33.53	7.82	11.22
T_7:100%SSP+0.2LR	2.92	0.73	2.01	3.51	0.82	2.69	36.68	8.34	10.00	43.11	9.89	14.7
CD(0.05)	0.35	0.09	0.28	0.53	0.14	0.37	4.73	1.22	1.27	5.42	1.31	1.75

Chadrakar (2015) reported that liming significantly increased P and K uptake of maize by 45% and 24% respectively over control 'P'. Nurlaeny *et al.,* (1996) reported that liming increases colonization of roots with arbuscular mycorrhizal fungi that increase P uptake and other nutrients with low mobility.

Sarkar (2013) reported that application of lime +FYM with 100% or 50% RDF (NPK) resulted in higher N, P, K, Ca and S uptake by summer green gram in Assam, maize and wheat in Himachal Pradesh and maize in Meghalaya.

This study concluded based on the yield, RAE, nutrient content and uptake, liming with SSP was the best management practice in acid soils followed by UPR+ SSP mixture in 1:1 ratio. Sole application of UPR recorded significantly higher yield over control 'P' but, observed to be less effective as compared to UPR+SSP mixture or SSP alone. Among the UPR+SSP combinations, 1:1 mixture proved superior with respect to yield, relative agronomic efficiency, nutrient uptake and oil content. Application of UPR+SSP mixture in 1:1 ratio gave statistically at par yield, nutrient uptake, oil content results to 100% water soluble SSP. Further highest benefit-cost ratio of 2.89 was recorded in 1:1 mixture treatment (T_5). Also the RAE value was found higher (109%) than the standard SSP treatment (100%). Thus, combined application of UPR+ SSP mixture in 1:1 ratio is also an economically viable phosphorus management practice in acid soils against the costlier water soluble SSP fertilizer.

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