



# Effect of Udaipur Rock Phosphate, Single Super Phosphate and Their Combinations on Yield and Total Nutrient Uptake by a Groundnut-Maize Cropping System on the Acid Alfisols of Odisha State, India

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## Authors' contributions

*This work was carried out in collaboration among all authors. Author DS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DJ and GHS managed the analyses of the study. All authors read and approved the final manuscript.*

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## ABSTRACT

To find out the effect of low grade Udaipur rock phosphate on yield and nutrient dynamic in groundnut- maize cropping system, a field experiment was conducted in a randomized block design with three replications and eight treatments consisting of Udaipur rock phosphate (URP), single super phosphate (SSP) alone or in combinations with different ratios including phosphorus control from 2013-14 to 2015. The soil has a loam texture, a pH of 5.18, low available nitrogen and medium phosphorus and potassium. The highest maize equivalent yield of 6293 kg ha<sup>-1</sup> and relative agronomic efficiency (RAE) of 159% was recorded in SSP+ lime (0.2LR) treatment followed by URP+SSP (1:1). Combined application of SSP+ lime recorded higher P, Ca, Mg and S uptake by

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groundnut-maize cropping system. When the crops received URP+SSP mixture in 1:1 ratio, the RAE values were increased above the standard SSP treatment ( $T_3$ ) being 102% for groundnut, 105% for maize and 103% for groundnut-maize cropping system. The yield in URP+SSP mixture (1:1) was higher than for the SSP treatment, but the difference was not statistically significant ( $P > 0.05$ ). Thus, combined application of URP+SSP mixture (1:1) can safely be recommended in acid soils for short duration crops like maize and groundnut as against the more costly water soluble SSP fertilizer.

*Keywords: URP; yield; nutrient uptake; RAE; groundnut-maize cropping system.*

## 1. INTRODUCTION

Acid soils in India occupy about 90 million ha (Mha) [1], of which 49 Mha have pH less than 5.5. The supply of soil phosphorus (P) has been a major limiting factor in crop production due to high phosphorus fixation. When a water soluble P fertilizer is added to soil, a series of chemical reactions may take place. The dissolved P reacts with calcium phases in high pH soils and solid phase iron (Fe) and aluminium (Al) in low pH soils forming species that are less available to plants [2].

The phosphate rock (PR) deposit in India, including all grades and types is 260 million tonnes, of which 15.27 million tonnes are of high grade. The low-grade PR is unacceptable to the P-fertilizer industry due to its low  $P_2O_5$  and high  $CaCO_3$  content. This low-grade PR could be a cheaper P source for small and marginal farmers in acid soil regions. Several studies showed that application of SSP and PR mixture in a 1:1 ratio increased the dry matter yield of maize, groundnut, and linseed in acid soils [3,4,5,6].

The effectiveness of PR of low reactivity can also be increased by application of rock phosphate to a green manure crop preceding the main crop and inoculation of the field with either P solubilising micro-organisms or mycorrhiza [7], using rock phosphate and single super phosphate mixture (1:1) or partial acidulation of phosphate rock [7]. Phosphate rock having high  $Fe_2O_3 + Al_2O_3$  content may not be suitable for partial acidulation because of reversion of water soluble P to water insoluble P during the process [8]. Under these conditions, compaction of phosphate rock with single super phosphate in a ratio of 1:1 can be agronomically and economically sound for utilizing the indigenous phosphate rocks in developing countries [8]. Paliyal et al. [9], Panda [6], Marwaha and Kanwar [10] also reported the superiority of mixture of RP and SSP to individual ones in acid

red lateritic soil of Odisha and acid soil of Himachal Pradesh. The maize-groundnut cropping system is a popular cropping system in Odisha State, India. However, local research on the use of rock phosphates in combination with water soluble phosphate fertilizer is meagre and is consequently the subject of present study.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Site

The effects of Udaipur rock phosphate (URP) alone and in different combinations with single super phosphate (SSP) in groundnut-maize cropping system during two consecutive years (2013-2014 to 2015) was studied through a field experiment. The experiment was conducted in the Central Farm, Odisha University of Agriculture and Technology. The site is at Bhubaneswar  $85^{\circ}47' 18''$  E latitude  $20^{\circ}16' 51''$  N longitudes with an elevation of 25.9 m above mean sea level. 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.

### 2.2 Experimental Design and Treatments

The experiment was conducted in a randomized block design with 8 treatments and 3 replications. Treatments were :  $T_1$ -Control P;  $T_2$ -100%P (URP);  $T_3$ -100% P(SSP);  $T_4$ - 75% P (URP) + 25% P (SSP);  $T_5$ -50% P (URP) + 50% P (SSP);  $T_6$ -25% P (URP) + 75% P (SSP);  $T_7$ - 200% P (URP) only on 1<sup>st</sup> crop;  $T_8$ - 100% P (SSP) + lime at 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 and rabi 2014-15 at a spacing of 30x10 cm. Except the control treatment ( $T_1$ ), the crop received recommended doses of N,  $P_2O_5$ ,  $K_2O$  at 20:40:40  $kg\ ha^{-1}$ . Control 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  $T_8$  with the sources as per treatments. The hybrid maize crop cv. P-3441 of 90 days duration was sown during kharif 2014 and kharif 2015 at a spacing of 60 x 30 cm. Except the control treatment ( $T_1$ ), the crop received recommended doses of N,  $P_2O_5$ ,  $K_2O$  at 100:50:50  $kg\ ha^{-1}$ . Control treatment ( $T_1$ ) received only N and  $K_2O$  100 and 50  $kg\ ha^{-1}$ . The crop received one third dose of nitrogen, full dose of P and half dose of K as basal at the time of sowing. Rest one third dose of nitrogen and half dose of potash were applied at 25 days after sowing (DAS). Remaining one third dose of nitrogen was applied at 50 DAS. Phosphorus was applied in all the treatments from  $T_2$  to  $T_8$  as per treatments at sowing. A composite soil sample (0 -15 cm depth) was collected from the experimental site before sowing of seeds and fertilizers application.

### 2.3 Crop Management

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

### 2.4 Soil Sampling, Processing and Analysis

Soil samples (0-15 cm) were collected from each treatment replication wise at flowering (30 DAS), pod formation (60 DAS) and harvesting (115 DAS) stage of groundnut crop and knee-high (30 DAS), tasseling (60 DAS) and harvesting stage (90 DAS) stage of maize crop. 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 [11]. 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 [11]. The pH was determined in 1:2.5 soil-water ratio by pH meter (ELICO LI 613 pH meter) as described 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) as described by Jackson (1973). Lime requirement value of soil was determined by Woodruff Buffer method [12]. The organic carbon content of soil was determined by Wet digestion procedure of Walkley and Black [13] as outlined in soil chemical analysis [14]. Exchange acidity, exchangeable acidity: Exchange acidity, exchangeable acidity were estimated by using the methods of Lin and Coleman [15] as described by Page et al. [14]. Exchangeable Calcium was determined using EDTA (Versenate) complexometric titration by using Calcon indicator as outline by Hesse [16]. 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  $KMnO_4$  method [17] 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 outlined by Page et al. [14]. 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 [18]. The available S content was determined turbidimetrically following the procedure of Chesnin and Yien [19] as described by Page et al. [14].

### 2.5 Plant Sampling, Processing and Analysis

For determination of nutrient uptake, plants were collected at flowering (30 DAS), pod formation (60 DAS) and harvesting (115 DAS) stage of groundnut crop and knee-high (30 DAS),

tasseling (60 DAS) and harvesting stage (90 DAS) stage of maize crop. Two plants from each plot were taken and labelled. The groundnut kernel, shell, haulm, maize grains and stovers were kept separately in envelopes, labelled properly and dried in hot air oven at 60°C for 48 hours. Each sample was ground separately with the help of a Willy mill to pass through 20 mesh sieve and was used for analysis 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. [20]. 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 [16]. The sulfur content was determined turbidimetrically following the modified procedure of Mossouemi and Cornfield [21].

## 2.6 Statistical Analysis of Data

Total pod and grain yield, haulm and stover yield were recorded after harvesting groundnut and maize crops respectively from each treatments. The data was analysed for individual years as well as pooled analysis for both the years. Fisher's method of analysis of variance was used for the analysis and interpretation of data as given by Panse and Sukhatme [22].

## 3. RESULTS AND DISCUSSION

### 3.1 Chemical and Physical Properties of Soil

The soil of the experimental site is loam in texture with 64.6% sand, 14.8% silt and 20.6% of clay (Table 1). The maximum water holding capacity is 31% with bulk density (BD) 1.59 Mg m<sup>-3</sup>. The soil is acidic in reaction (pH-5.18), non saline (EC- 0.09 dS m<sup>-1</sup>) with exchangeable Al<sup>3+</sup> and exchangeable H<sup>+</sup> of 0.05 and 0.06 c mol (p+) kg<sup>-1</sup> respectively. The soil is low in available N (239.0 kg ha<sup>-1</sup>), medium in P (14.64 kg ha<sup>-1</sup>) and K (150.0 kg ha<sup>-1</sup>) and S (27.4 kg ha<sup>-1</sup>) indicating low soil fertility. The CEC is 4.2 me/100 g soil and base saturation of 43%. The samples of URP used had 7.8% total P, 25.6% Ca, 0.26% Mg, 0.24% K and 1.2% S indicating a moderate reactivity of the material (Table 2).

**Table 1. Physico-chemical properties of the experimental soil**

Physical Parameters	Value
Sand (%)	64.6
Silt (%)	14.8
Clay (%)	20.6
Texture	Loam
Bulk density (Mg m <sup>-3</sup> )	1.59
Maximum Water Holding Capacity (%)	31
Chemical Parameters	
Exchange Acidity [cmol(p <sup>+</sup> )kg <sup>-1</sup> ]	0.11
Exchangeable Ca <sup>2+</sup> [cmol(p <sup>+</sup> )kg <sup>-1</sup> ]	1.31
Exchangeable Mg <sup>2+</sup> [cmol(p <sup>+</sup> )kg <sup>-1</sup> ]	0.13
pH <sub>w</sub> (1:2.5)	5.18
EC(dSm <sup>-1</sup> )	0.09
CEC (c mol (p <sup>+</sup> ) kg <sup>-1</sup> soil)	4.2
Base saturation (%)	43
Organic carbon (g kg <sup>-1</sup> soil)	3.4
Available N(kg ha <sup>-1</sup> )	239
Available P(Bray'-1) (kg ha <sup>-1</sup> )	14.64
Available K(kg ha <sup>-1</sup> )	150
Available S (kg ha <sup>-1</sup> )	27.4
Lime requirement [t CaCO <sub>3</sub> ha <sup>-1</sup> ]	1.75

**Table 2. Chemical composition of Udaipur rock phosphate (URP)**

Nutrients	Content (%)
Total P	7.8
Total K	0.24
Total Ca	25.6
Total Mg	0.26
Total S	1.2

### 3.2 Pod yield of the Groundnut

The pod yield of groundnut for two seasons without P fertiliser was 1554–1485 kg ha<sup>-1</sup> (Table 3). Application of P through different combinations significantly increased pod yield with the effects increasing in the order (T<sub>8</sub> > T<sub>5</sub> > T<sub>3</sub> > T<sub>6</sub> > T<sub>4</sub> > T<sub>2</sub> > T<sub>7</sub> > T<sub>1</sub>). The combined application of SSP with lime had the highest pod yield (2581 kg ha<sup>-1</sup>), perhaps due to better utilization of native and applied P with increase in soil pH. The exchangeable Al<sup>3+</sup> and exchangeable H<sup>+</sup> get neutralised with rise in pH resulted in reduction of P-fixation capacity of soil. Combined application of URP+SSP mixture in 1:1 ratio can be compared SSP, since both the treatments recorded 48-49% of higher yield over control. Since, the soil pH during crop growth period in SSP treatment (T<sub>3</sub>) was lower than URP+SSP (1:1) treatment (T<sub>3</sub>), a part of P from SSP get fixed resulting lower pod yield as compared to URP+SSP treatment. On the other

hand, in URP+SSP treatment, SSP met the P requirement of groundnut in the beginning of growing period and P derived from dissolution URP full filled the crop P requirement in latter stage of growth. Further, the data showed that the magnitude of yield in T<sub>4</sub> (2099 kg ha<sup>-1</sup>) and T<sub>6</sub> (2115 kg ha<sup>-1</sup>) were lower than T<sub>3</sub> and T<sub>5</sub>. These observations further showed that URP+SSP mixture in 1:1 ratio observed to be best combination for profitable yield in acid soils. Sole application of URP recorded significantly higher yield (23-26%) over control but, observed to be less effective as compared to URP+SSP mixture or SSP alone.

From two seasons' data, application of the recommended dose of P at 40kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> as SSP (standard treatment) recorded two seasons average yield of 2256 kg ha<sup>-1</sup>. Replacement of entire P dose through URP could not met P requirement reflecting yield decline by 15-17% with respect to standard SSP (T<sub>3</sub>) treatment.

However, application of URP+SSP mixture in 1:1 ratio gave a similar yield and seems to be an economically viable alternative to 100% water soluble SSP. On the otherhand, application of lime at 0.2LR with SSP raised the yield by 14% since liming raised soil pH and increased P availability. Several studies showed that application of SSP and PR mixture in 1:1 ratio increased in yield and P uptake by rice-groundnut system in acid soil [3], rice-linseed in coastal saline soil of Orissa [3], yield and P, Ca, and Mg uptake by maize in acid soil [4], finger millet-wheat yield in acid soil (pH- 4.7) of Himachal Pradesh [23]. Soils with high Ca content would slow down PR dissolution [24].

Higher efficiency of a URP and SSP (1:1) 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 [25]. The lower efficiency of SSP in acid soil may be due to rapid fixation of water soluble P with free sesquioxides in soil [26].

### 3.3 Haulm Yield of Groundnut

Based on the two seasons' data, the mean haulm yield in control was 2776 kg ha<sup>-1</sup> and varied between 3458 to 4187 kg ha<sup>-1</sup> in other treatments (Table 4). Significantly higher yield (4187 kg ha<sup>-1</sup>) was recorded in SSP + lime

treatment over other treatments. Haulm yield in URP + SSP (1:1) treatment (3916 kg ha<sup>-1</sup>) was statistically at par with SSP (3874 kg ha<sup>-1</sup>) treatment. Sole application of URP seems to be inferior to URP + SSP combinations which recorded 3363 to 3458 kg ha<sup>-1</sup> haulm yield but significantly higher over control.

In acid soils, liming raised soil pH, improved efficiency of applied soluble SSP fertilizer, reduces P-fixation resulting higher pod and haulm yield. However, instead of applying entire P through SSP in acid soil, a mixture of URP + SSP (1:1) would be a best P management option for achieving optimum yield. The other URP+SSP combinations viz. 3:1 or 1:3 ratio were inferior to URP+SSP (1:1) but better than URP sole treatment.

### 3.4 Grain Yield of Hybrid Maize

The data presented in Table 5 showed that grain yield of hybrid maize significantly increased over control during both seasons. With the application of P fertilizer, the grain yield varied between 3772 to 5042 kg ha<sup>-1</sup> during kharif 2014 and 3852 to 5284 kg ha<sup>-1</sup> during kharif 2015. In control it was 3427 kg ha<sup>-1</sup> during 2014 and 3215 kg ha<sup>-1</sup> during 2015. The yield during 2015 was lower than 2014. In P treatments, significantly higher mean grain yield of 5163 kg ha<sup>-1</sup> was recorded in SSP + lime which is 55.46% higher over control might be due to increase in available P with rise in soil pH caused due to liming. Addition of calcium (through liming) and availability of other nutrients due to favourable soil pH enhanced plant growth and grain yield. Combined application of URP + SSP in 1:1 can be compared with SSP alone since both the treatments are statistically at par and recorded 28-30% higher yield over control. Other URP+SSP combinations (3:1 or 1:3) were inferior to 1:1 mixture might be due to decline in P availability.

Sole application of P (T<sub>2</sub> and T<sub>7</sub>) was better than control (13.04 to 14.78% higher yield over control), but inferior to URP+SSP mixture either in 3:1 or 1:3 ratio. The better efficiency of sole URP treatment was observed on maize (2<sup>nd</sup> and 4<sup>th</sup> season) might be due to prolonged dissolution of URP resulted in higher P availability.

### 3.5 Stover Yield of Hybrid Maize

The mean stover yield of hybrid maize over two seasons presented in Table 6 revealed that, the

yield in control was 2764 kg ha<sup>-1</sup> and varied between 3209 to 4274 kg ha<sup>-1</sup> in P treatments. Significantly highest stover yield of 4274 kg ha<sup>-1</sup> was recorded in SSP + lime treatment which was 54.6% higher over control because of increase in available P associated with rise in soil pH. In addition to P, the availability of other plant nutrients increased under favourable soil pH range. The yield in sole SSP treatment can be

compared with URP+SSP (1:1) treatment since both the treatments are at par and recorded about 29% higher yield over control. When 25% or 75% of P was replaced by URP, the yield was decreased to 3360-3367 kg ha<sup>-1</sup> which is about 15% higher over control. Sole application of URP to first crop or to each crop, although recorded 15-16% higher yield over control, but observed inferior to URP + SSP mixture.

**Table 3. Effect of treatments on pod yield of groundnut (kg ha<sup>-1</sup>)**

Treatments	Pod yield (kg ha <sup>-1</sup> )			
	Rabi 2013-14	Rabi 2014-15	Pooled Mean	% increase over control
T <sub>1</sub> :Control	1554	1485	1520	-
T <sub>2</sub> :100%URP	1877	1964	1921	26.38
T <sub>3</sub> :100%SSP	2225	2286	2256	48.42
T <sub>4</sub> :75%URP+25%SSP	2016	2182	2099	38.09
T <sub>5</sub> :50%URP+50%SSP	2193	2347	2270	49.34
T <sub>6</sub> :25%URP+75%SSP	2060	2169	2115	39.14
T <sub>7</sub> :200%URP on 1 <sup>st</sup> crop	1886	1861	1874	23.29
T <sub>8</sub> :100%SSP+0.2LR	2529	2632	2581	69.80
CD(0.05)	301	304	122	-

**Table 4. Effect of treatments on haulm yield of groundnut (kg ha<sup>-1</sup>)**

Treatments	Haulm yield (kg ha <sup>-1</sup> )			
	Rabi 2013-14	Rabi 2014-15	Pooled Mean	% increase over control
T <sub>1</sub> :Control	2931	2621	2776	-
T <sub>2</sub> :100%URP	3533	3384	3458	24.57
T <sub>3</sub> :100%SSP	4045	3703	3874	39.55
T <sub>4</sub> :75%URP+25%SSP	3741	3705	3723	34.11
T <sub>5</sub> :50%URP+50%SSP	3918	3914	3916	41.07
T <sub>6</sub> :25%URP+75%SSP	3748	3587	3667	32.10
T <sub>7</sub> :200%URP on 1 <sup>st</sup> crop	3529	3197	3363	21.14
T <sub>8</sub> :100%SSP+0.2LR	4319	4055	4187	50.83
CD(0.05)	572	496	230	-

**Table 5. Effect of treatments on grain yield of hybrid maize (kg ha<sup>-1</sup>)**

Treatments	Grain yield (kg ha <sup>-1</sup> )			
	Kharif 2014	Kharif 2015	Pooled Mean	% increase over control
T <sub>1</sub> :Control	3427	3215	3321	-
T <sub>2</sub> :100%URP	3772	3852	3812	14.78
T <sub>3</sub> :100%SSP	4251	4315	4275	28.73
T <sub>4</sub> :75%URP+25%SSP	3937	4087	4012	20.81
T <sub>5</sub> :50%URP+50%SSP	4174	4461	4321	30.11
T <sub>6</sub> :25%URP+75%SSP	4032	4036	4034	21.47
T <sub>7</sub> :200%URP on 1 <sup>st</sup> crop	3826	3683	3755	13.07
T <sub>8</sub> :100%SSP+0.2LR	5042	5284	5163	55.46
CD(0.05)	331	322	184	-

**Table 6. Effect of treatments on stover yield of hybrid maize (kg ha<sup>-1</sup>)**

Treatments	Stover yield (kg ha <sup>-1</sup> )			
	Kharif 2014	Kharif 2015	Pooled Mean	% increase over control
T <sub>1</sub> :Control	2851	2678	2764	-
T <sub>2</sub> :100%URP	3179	3239	3209	16.10
T <sub>3</sub> :100%SSP	3547	3594	3570	29.16
T <sub>4</sub> :75%URP+25%SSP	3309	3411	3360	21.56
T <sub>5</sub> :50%URP+50%SSP	3454	3694	3574	29.38
T <sub>6</sub> :25%URP+75%SSP	3356	3378	3367	21.82
T <sub>7</sub> :200%URP on 1 <sup>st</sup> crop	3195	3182	3188	15.34
T <sub>8</sub> :100%SSP+0.2LR	4172	4376	4274	54.63
CD(0.05)	289	262	160	-

Considering T<sub>3</sub> (100% P though SSP) as standard treatment, application of recommended dose P@ 50 kg ha<sup>-1</sup> to maize in acid soil (pH-5.18) with low available P (Bray's 1-14.64 kg ha<sup>-1</sup>) recorded mean stover yield of 3570 kg ha<sup>-1</sup>. Application of lime @ 0.2 LR with SSP, increased yield by 20% over the standard treatment T<sub>3</sub>. Combined application of SSP+URP in 1:1 ratio maintained the same productivity. However, supplement of P through URP by 75% or 25% decreased the productivity by 6%. When entire P was substituted though URP, the productivity was further declined by 10% as compared to SSP.

### 3.6 Yield of Groundnut–Maize Cropping System

Table 7 present the maize equivalent yield for groundnut–maize cropping system over two years. Groundnut and maize received P at 40 and 50 kg P<sub>2</sub>O<sub>5</sub> per hectare respectively. The cropping system received 180 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> over two years. The maize equivalent yield was calculated based on the selling price of groundnut and maize @ Rs.48.90/- and Rs.17.00/- per kg respectively. The data showed that the mean maize equivalent yield of 3846 kg ha<sup>-1</sup> was recorded in control without any P source. The equivalent yield in P treatments varied from 4572 to 6293 kg ha<sup>-1</sup>. Application of SSP+ lime recorded maximum yield of 6293 kg ha<sup>-1</sup> which is significantly higher over other treatments.

Both groundnut and maize crops responded positively to combined application of lime and P (T<sub>8</sub>) under acidic and low P environment and recorded 64% higher yield over control. The beneficial effect of lime was observed with a rise in pH, reduction in P-fixation capacity resulted in higher availability of P, Ca, Mg and S. Replacement of 50% of P though URP seems to

be beneficial to the crops, since the yield in SSP and URP+SSP in 1:1 ratio were at par and recorded 40-41% higher yield over control. This showed that in acid soil, combined application of URP+SSP in 1:1 ratio could sustained crop yield and maintained soil P Status.

**Table 7. Maize equivalent yield\* (kg ha<sup>-1</sup>) of the groundnut-maize cropping system as influenced by different treatments**

Treatments	Pooled mean	% increase over control
T <sub>1</sub> :Control	3846	-
T <sub>2</sub> :100% URP	4669	21.40
T <sub>3</sub> :100%SSP	5382	39.94
T <sub>4</sub> :75%URP+25%SSP	5025	30.65
T <sub>5</sub> :50%URP+50%SSP	5425	41.05
T <sub>6</sub> :25%URP+75%SSP	5058	31.51
T <sub>7</sub> :200%URP on 1 <sup>st</sup> crop	4572	18.88
T <sub>8</sub> :100%SSP+0.2LR	6293	63.62
CD(0.05)	197	-

\*Maize equivalent yield was calculated on the selling price of groundnut-Rs 48.90/- and maize-Rs 17.00/- per kg

Several studies explained the superiority of SSP and phosphate rock mixture in 1:1 ratio over water soluble SSP. In a field study in Brazil, Prochnow et al. [27] reported that the dry matter yield of wheat and rye grains with PR: SSP compaction at 1:1 ratio was equal with SSP because the water soluble SSP able to provide available P to plants initially (starter effect), resulting in better plant root development, which in turn allowed the plant to utilize PR more effectively in later stage.

The results of the study further indicated that URP and SSP mixture either in 3:1 or 1:3 ratio with a yield level of about 5000 kg ha<sup>-1</sup> were

better than URP alone. The system yield in sole URP treatments either applied to first crop or each crops recorded 19-21% higher over control.

Considering the yield in SSP ( $T_3$ ) as standard (5382 kg ha<sup>-1</sup>), the productivity of groundnut-maize cropping system increased by 17% through liming. The productivity in URP+SSP mixture in 1:1 ratio maintained the same yield level as standard, but decreased by 7% when mixed with 3:1 or 1:3 ratio. The productivity level was further decreased by 13-17% when URP was applied alone.

Phosphorus is a limiting factor in crop production in acid soils due to high P-fixation. Liming of acid soils is a common practice to raise soil pH and increase the availability of several plant nutrients. Direct use of rock phosphate may be an alternative source of P in acid soils. The effect of URP alone or in combination with SSP in different ratio on yield up groundnut- maize cropping system over two years were evaluated in our field experiment.

The mean yield of groundnut and maize in control (without P) was 1520 and 3321 kg ha<sup>-1</sup> respectively. Application of lime with SSP increased the groundnut pod yield by 69.80% and maize grain yield by 55.46% over control. Similarly, the maize equivalent yield of groundnut-maize cropping system increased by 63.62% over control. Liming raised the soil pH and created a neutral pH environment in the root zone that induced the availability of several nutrients and crop yield [28,29]. Sharma and Sarkar [1] reported that application of lime @ 200- 400 kg ha<sup>-1</sup> in furrows along with chemical fertilizer at sowing increased the crop yield by 14 to 52% over farmer's practice.

A series of farmer's trials were conducted by OUAT, Bhubaneswar in acid soils of Odisha, with varying pH levels. Addition of lime @ 0.2 LR with NPK increased the yield over farmer's practice by 17-36% in groundnut (pH 4.0-6.3), 5-21% in green gram (pH 3.8-6.5), 90-93% in pigeon pea (pH 5.2-6.0) and 37-49% in sunflower (pH 5.5-6.3) [30]. However, addition of lime alone without chemical fertilizer could not be as effective as lime + NPK. Further, rise in soil pH and exchangeable Ca resulting from liming are detrimental to PR dissolution (Hammond et al. 1986 b). The beneficial effect of lime with SSP was significantly observed in groundnut- maize cropping system since SSP could meet the P requirement of crops at initial stage that helps in root proliferation and root activities.

Application of SSP alone (100% P) or URP+SSP mixture (1:1 ratio) recorded higher yield of 48.42-49.34% over control in groundnut, 28.73 to 31.11% in maize and 39.94 to 41.05% in maize equivalent yield of cropping system. But, the yield in URP+SSP (1:1 ratio) treatment was higher than SSP. Since, the soil pH during crop growth period in SSP treatment was lower than URP+SSP (1:1 ratio) treatment, a part of P from water soluble SSP get fixed in acid soil lowering grain yield as compared to URP+SSP treatment. Further, in URP +SSP treatment, SSP met the plant P requirement in the beginning and P released through URP dissolution satisfy the crop requirement in latter stage of growth. Several workers advocated the advantage of RP +SSP mixture over SSP, since the P release from RP would be faster in acidic P deficient soil.

### 3.7 Relative Agronomic Efficiency (RAE)

The relative agronomic efficiency of treatments was calculated taking SSP as standard treatment. The data presented in Table 8 showed that the RAE values for groundnut, maize and ground-maize cropping system varied between 48-144, 45-193 and 47-159%, respectively. Based on the RAE values, the efficiency of different P treatments were evaluated and found that sole application of URP or URP+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 48 to 80% for groundnut 45 to 75% for maize and 47 to 79% for groundnut-maize cropping system. However, when the crops received URP+SSP mixture in 1:1 ratio, the RAE values were increased above the standard treatment ( $T_3$ ) being 102% for groundnut, 105% for maize and 103% for groundnut-maize cropping system. 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 values of 144% in groundnut, 193% for maize and 159% for groundnut-maize cropping system.

The agronomic efficiency of rock phosphate depends on its crystal chemical structure, especially molar ratio- $CO_3/PO_4$  of apatite [31]. The Indian phosphate rocks having very low  $CO_3/PO_4$  ratio are not very reactive. Chien and Frisen [32] showed that a high reactive ground North Carolina PR with 4.2% citrate soluble P was equally effective for maize in acid soil as 100% citrate soluble TSP. Similar results were



reported by Smithson et al. [33], Msolla et al. [34], Szilas et al. [35] in Sub-Saharan Africa. In general the agronomic effectiveness of different PRs sources correlated well with citrate solubility of PR [36,37]. Sharma et al. [38] reported that RAE of MRP+PSB with respect to DAP was 69-106% in rice-rape seed-mung bean cropping system in India. Among crop species, rape is highly efficient in utilizing PR. The exudation of mallic acid and citric acid by rape roots is thought to be responsible for PR dissolution.

### 3.8 Total Nutrient Uptake by Groundnut-Maize Cropping System

Total nutrient uptake by groundnut-maize cropping system presented in Table 9 showed that, in control treatment, phosphorus uptake

was 19.38 kg ha<sup>-1</sup> and increased by 73-76% with the application of SSP or URP+SSP mixture (1:1). Maximum phosphorus uptake of 38.71 kg ha<sup>-1</sup> was recorded in SSP + lime treatment which is about 100% higher over control. Sole application of URP to first crop or each crop recorded 33 to 39% higher uptake over control.

Application of P alone or with lime has little effect on potassium uptake. In control treatment, potassium uptake by groundnut-maize cropping system was 107.73 kg ha<sup>-1</sup> and increased by 15 to 37% with URP, SSP or URP + SSP treatments. Maximum potassium uptake of 171.7 kg ha<sup>-1</sup> was recorded in SSP+ lime might be due to application of lime increased the biomass production resulted in higher potassium uptake.

**Table 8. Relative agronomic efficiency (RAE) of different treatments in groundnut, maize and groundnut-maize cropping system**

Treatments	RAE based on groundnut pod yield (%)	RAE based on maize grain yield (%)	RAE based on maize equivalent yield (%)
T <sub>1</sub> :Control	-	-	-
T <sub>2</sub> :100%URP	54.48	51.46	53.58
T <sub>3</sub> :100%SSP	100.00	100.00	100.00
T <sub>4</sub> :75%URP+25%SSP	78.80	72.43	76.75
T <sub>5</sub> :50%URP+50%SSP	102.04	104.82	102.80
T <sub>6</sub> :25%URP+75%SSP	80.84	74.73	78.91
T <sub>7</sub> :200%URP on 1 <sup>st</sup> crop	48.10	45.38	47.27
T <sub>8</sub> :100%SSP+0.2LR	144.16	193.08	159.30

**Table 9. Effects of treatments on total nutrient uptake by groundnut-maize cropping system**

Sl. no.	Treatments	Nutrient uptake by groundnut- maize cropping system (kg ha <sup>-1</sup> )				
		P	K	Ca	Mg	S
T1	Control	19.38 (-)	107.73 (-)	28.77 (-)	9.16 (-)	14.68 (-)
T2	100% P(URP)	27.08 (39.73)	126.75 (17.65)	47.70 (65.80)	12.37 (35.04)	21.33 (45.30)
T3	100% P(SSP)	33.56 (73.17)	147.10 (36.54)	69.50 (141.57)	16.44 (79.47)	31.78 (116.48)
T4	75% P(URP)+25% P(SSP)	29.95 (54.54)	133.98 (24.37)	56.49 (96.35)	13.48 (47.16)	25.99 (77.04)
T5	50% P(URP)+50% P(SSP)	34.16 (76.26)	147.38 (36.80)	65.24 (126.76)	15.26 (66.59)	29.93 (103.88)
T6	25%P(URP)+75%P (SSP)	29.66 (53.04)	135.03 (25.34)	55.56 (93.11)	13.25 (44.65)	27.22 (85.42)
T7	200% P(URP) only on 1 <sup>st</sup> crop	25.86 (33.44)	124.35 (15.43)	46.86 (62.88)	11.89 (29.80)	20.38 (38.82)
T8	100%P(SSP)+Lime@0.2 LR	38.71 (99.74)	171.87 (59.54)	76.88 (167.22)	17.18 (87.55)	35.74 (143.46)

\* Figures in parentheses indicate the percent increase over control

Calcium uptake by groundnut–maize cropping system increased from 28.77 kg ha<sup>-1</sup> in control to 76.88 kg ha<sup>-1</sup> (167% higher) in SSP+ lime treatment. Application of SSP or URP +SSP mixture 1:1 ratio recorded 126 to 141% higher Ca uptake over control. Sole application of URP or URP+ SSP mixture in 3:1 or 1:3 ratio recorded 62- to 96% higher uptake indicating that use of P fertilizer whether soluble or insoluble significantly influenced calcium accumulation and uptake by groundnut–maize cropping system. Increase in pH reduces P-fixing capacity in acid soil. Besides, the continuous availability of phosphorus helps in proliferation of root development and hence better nutrient accumulation and biomass production.

Magnesium uptake in control was 9.16 kg ha<sup>-1</sup> and increased by 29 to 88% in different treatments. Sole application of URP to first crop or all crops increased magnesium uptake by 29-35% over control. The values were increased by 44 to 47% when the crop received URP + SSP mixture either in 1:3 or 3:1 ratio. Sole application of SSP proved to be better (79% higher uptake) than URP +SSP mixture in 1:1 ratio (66%). Maximum magnesium uptake of 17.18 kg ha<sup>-1</sup> was recorded in SSP + lime treatment which is 88% higher over control.

Sulphur uptake by groundnut-maize cropping system in control was 14.68 kg ha<sup>-1</sup> and increased by 38.82 to 143.46% in other treatments. Application of lime with SSP (T<sub>8</sub>) recorded maximum sulphur uptake (35.74 kg ha<sup>-1</sup>) which is 143.46% higher over control. Sole application of URP or URP+SSP mixture in 3:1 or 1:3 mixture recorded 38.82 to 85.42% higher sulphur uptake over control. Sole application of SSP was found better than URP + SSP mixture in 1:1 ratio since the former treatment recorded 31.78 kg ha<sup>-1</sup> S uptake as compared to 29.93 kg ha<sup>-1</sup> in later treatment.

Nutrient uptake by crops depend 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- maize cropping system as compared to SSP or URP+SSP mixture might be due to higher biomass production . Sole application of URP was found inferior to SSP+ lime, SSP or URP+ SSP (1:1) mixture treatments with respect to nutrient uptake.

Several studies showed that the application of RP+SSP in 1:1 ratio increased the yield and P

uptake by rice–groundnut in acid soil [3], yield and P, Ca and Mg uptake by maize in acid soil [4] of Odisha, Finger millet- wheat yield in Himanchal Pradesh [23].

#### 4. CONCLUSION

Application of lime with SSP significantly increased the pod yield, grain yield, relative agronomic efficiency and P, Ca, Mg and S uptake by maize-groundnut cropping followed by URP+ SSP mixture in 1:1 ratio. Sole application of URP either to first crop or to all crops recorded significantly higher yield over control but, observed to be less effective as compared to URP+SSP mixture or SSP alone. Among the URP+SSP combinations 1:1 mixture proved superior with respect to yield, relative agronomic efficiency and nutrient uptake. Application of URP+SSP mixture in 1:1 ratio gave at par yield results to 100% water soluble SSP. But in URP+SSP mixture in 1:1 ratio, the RAE values were increased above the standard treatment (SSP). Thus,combined application of URP+SSP mixture in 1:1 ratio can safely be recommended for short duration crops like maize and groundnut as against costly water soluble SSP fertilizer in acid soils.

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#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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