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Combined effect of rock phosphate with single super phosphate on yield and phosphorus use efficiency under maize-groundnut cropping sequence in Alfisols of Odisha

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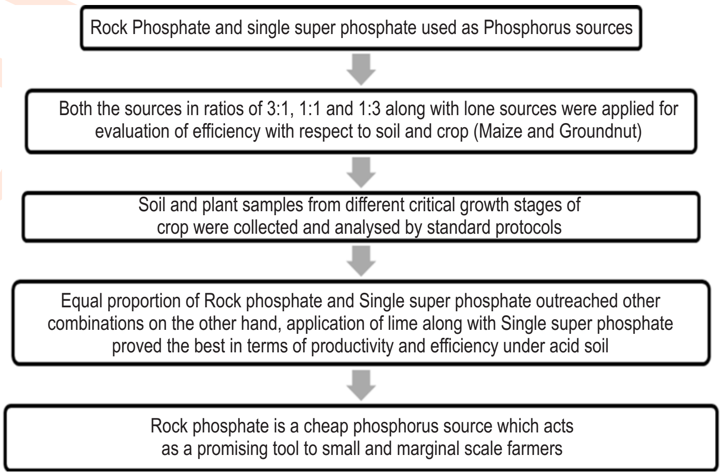
Abstract

Aim: The present study was conducted to investigate the effect of combined application of rock phosphate with water soluble phosphorus fertilizers on its efficiency in relation to soil and crop production.

Methodology: Rock phosphate and single super phosphate were used as supplemental source of phosphorus and applied in variable combinations at graded doses, with maize and groundnut as test crop. Lime was applied in combination with 100% SSP to analyse its effect. The composite surface (0-15 cm) soil samples were collected at critical growth stages of maize and groundnut and further analyzed for different physical and physico-chemical characteristics. The plant samples were collected from each treatment at harvest stage for nutrient analyses.



Results: Application of rock Phosphate increased the available phosphorus in soil. The combined treatment significantly influenced the yield attributes and nutrient uptake of both maize and groundnut crops. Among the combination, equal proportion of soluble single super phosphate and insoluble rock phosphate source of P outreached the other combination ratios. The highest agronomic phosphorus use efficiency and relative agronomic efficiency of the cropping sequence was obtained with the combined treatment of Single super phosphate along with lime.

Interpretation: Combination of rock phosphate which has been reported to be farmer's pocket friendly along with single super phosphate under acid soil conditions holds the potential to produce better results as compared to use of lone conventional water soluble phosphatic fertilizer like single super phosphate.

Key words: Agronomic phosphorus use efficiency, Relative agronomic efficiency, Rock phosphate, Single super phosphate

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Introduction

Adequate amount of phosphorus is essential for normal plant growth and development as it is a vital component of plant energy transport system. Moreover, it is also involved in many plant processes like photosynthesis, carbon metabolism, membrane formation, energy generation, nucleic acid synthesis, glycolysis, respiration, activation and inactivation of enzymes, and nitrogen fixation (Leidi *et al.,* 2000). Majority of soils (around 70-80%) in Odisha, being acidic in nature (Misra *et al.,* 2002) lose a greater portion of available phosphorus from applied water-soluble phosphorus fertilizers due to adsorption, precipitation or conversion to immobilized organic form. According to the findings of Holford (1997), more than 80% of the readily available phosphorus, of the applied phosphatic fertilizers gets converted into immobile and insoluble compounds and become unavailable to crops. Phosphorous being one of the major limiting nutrients with lower bioavailability indices needs more attention for an ever-increasing demand of agricultural production.

The conventional water soluble phosphatic fertilizer used by farmers in developing countries is limited due to high cost (Hammond *et al.,* 1986). In India, manufacture of conventional fertilizers require importing of large amount of premium grade phosphate rocks and sulphates from other countries and, therefore, involves a considerable foreign exchange. India exported about 351 and 135 million tonnes of phosphate rocks and sulphur in the year 2018-19 (IBM, 2019). Therefore, research priorities have been directed towards finding alternative phosphatic fertilizer for crop production. The aim of such investigations primarily revolved around the indigenous phosphatic rocks which are of poor quality and are not suitable as raw material for the production of conventional fertilizer (Begum *et al*., 2004). India is endowed with huge deposits of rock phosphate (Tarafdar, 2013). The estimated deposit of phosphate rocks in India is about 260 million tonnes (FAI, 2000) of which only 5.27 million tonnes can be rated as premium grade containing about 13.1% total phosphorus, while the remaining is of non-premium grade. The application of ground phosphate rocks directly to soil has given positive results in terms of phosphorus supply to crops, especially in acid soils. However, the efficiency of such materials is almost non-existent in neutral and alkaline soils.

The only solution would therefore be to suitably process indigenously available, less reactive phosphate rocks to make them more effective. Several methods such as thermal alternation (Rautaray *et al.,* 1994; Sammi Reddy *et al.,* 2000), partial acidulation (Cicek *et al.*, 2020; Ghosal and Chakraborty, 2012), microbial dissolution (Dubbey *et al.,* 1997; Roy *et al.,* 2015), amendment with organic matter (Sharif *et al.,* 2013; Meena and Biswas, 2015) and blending with water soluble fertilizers (Das and Sahu, 1988; Xiong *et al.,* 1996) have been successfully tried in the past to improve the efficiency of low grade phosphate rocks. The plant response to rock phosphate application is strongly dependent on its rate of dissolution and soil pH (Kumari and Phogat, 2008). Another alternative process is dry compaction of phosphate rocks with water soluble phosphatic fertilizers, which has been found to be cheaper and more cost effective than products produced by the wet granulation process (Menon and Chien, 1996). Compaction also eliminates the disadvantages associated with the application of mixtures of finely ground phosphate rocks and soluble phosphates (Pattanayak *et al.,* 2009; Owiti *et al.,* 2014). This method therefore holds a lot of promise in a country like India, which has huge deposits of phosphate rocks. With this research background, the present study was undertaken to evaluate the effect of rock phosphate application in combination with single super phosphate on yield, phosphorus uptake and its efficiency under maize-groundnut cropping sequence in *Alfisol* of Odisha.

Materials and Methods

Experimental site: The field experiment was conducted in dominant acid soil regions of dry land farm, OUAT, Bhubaneswar. It experiences tropical climate with mean maximum and minimum temperature of 32.6°C and 22.6°C during Kharif reason. During *Rabi* reason the mean daily temperature drops to 15°C with an average wind speed of 7 miles/hours. The soil of experimental site belonged to order *Alfisol*, with sandy clay loam texture, having sand, silt and clay percentage of 64.6, 14.8 and 20.6 respectively, pH_w (soil: water: 1:2) 5.20, electrical conductivity (EC) 0.09 dSm^{-1}, exchangeable Ca^{2+} and Mg^{2+} of 0.81and 0.13 C mol (P^+) kg^{-1} soil, organic carbon content 3.4 g kg^{-1} of soil and the available soil phosphorus and potassium were 15.7 kg ha^{-1} and 150 kg ha^{-1}, respectively.

Treatment details: There were eight treatments each replicated thrice in randomized block design *viz.,* T_1: Control; T_2: 100% RP; T_3: 100% SSP; T_4: 75% RP + 25% SSP; T_5: 50% RP+ 50% SSP; T_6: 25% RP + 75% SSP; T_7: 200% RP-only to first crop and T_8: 100% SSP + Lime @ 0.2 LR (1.75 t $CaCO_3$ ha^{-1}).

Field experiment: The field experiment was carried out with Maize-groundnut cropping sequence. The maize variety PAC-752 and groundnut variety TAG-24 were used as test crop in Kharif-2016 and Rabi 2016-17, respectively. The fertilizer dose was 150:50:50 and 20:40:40 ($N:P_2O_5:K_2O$) kg ha^{-1} for maize and groundnut crop, respectively. For maize, the entire P_2O_5 and lime was applied as basal with the sources as per treatment, while 50 per cent N and K was applied as basal and remaining 50% was applied at tasseling stage. All N, P_2O_5, K and lime were applied as basal dose for groundnut. The control plot received only N and K as nutrient sources. The sources of nutrient were urea, single super phosphate, rock phosphate and muriate of potash.

Collection, processing and analysis of soil samples: The composite surface (0-15 cm) soil samples were collected from each treatment during cropping period at critical growth stages of maize (knee high, tasseling, harvest) and groundnut (flowering, pod formation, harvest). The soil samples were shade dried, grinded, sieved through 2 mm sieve and used for analysis. The soil samples were analyzed for different physical and physico-chemical properties by adopting standard analytical procedures. The textural analysis was determined using Bouyoucos hydrometer method (Piper, 1950). The pH and EC were analysed in soil suspension (soil: water ratio of 1:2.5) using pH and EC meter (Jackson, 1973). The organic carbon content of soil was estimated using wet digestion method (Walkley and Black, 1934). The soil available N, P, K and S were analyzed using alkaline $KMnO_4$ method (Subbiah and Asija, 1956), Bray's 1 method (Bray and Krutz, 1945), neutral normal ammonium acetate method (Jackson, 1973) and turbidimetric method with 0.15 per cent $CaCl_2$ as extracting reagent (Chesin and Yien, 1951), respectively. The exchangeable Ca and Mg were determined by Versenate method (Hesse, 1971). The lime requirement was estimated by Woodruff buffer method (Woodruff, 1948).

Collection and analysis of plant samples: The plant samples were collected from each treatment after harvest of maize (100 DAS) and groundnut (90 DAS), oven dried, grinded to powder and stored for analysis. The samples were analyzed for phosphorus content using diacid extraction method followed by spectrophotometric estimation (Koening and Johnson, 1942) and expressed as percentage of phosphorus on dry weight basis. The total uptake of phosphorus at harvest stage of maize and groundnut was estimated.

Computation of phosphorus use efficiency indices: The efficiency of phosphorus fertilizer applied was computed in term of several indices *viz.,* apparent phosphorus recovery and agronomic phosphorous use efficiency using standard formulas.

Statistical analyses: The data on analysis of soil and plant samples, dry matter production, yield, phosphorus uptake and content in maize as well as groundnut were subjected to analysis of variance (ANOVA) and correlation statistics as suggested by Gomez and Gomez (1984) to find out the magnitude of treatment effect on various parameters and also to establish possible relationship among soil and plant characteristics in relation to crop performance. For statistical analysis of data, Microsoft Excel (Microsoft Corporation, USA) was used.

Results and Discussion

The available phosphorus status of soil was analyzed at different critical growth stages of maize followed by groundnut (Table 1). The overall available phosphorus content ranged from 8.0 to 30.4 kg ha^{-1} in maize and 7.94 to 31.7 kg ha^{-1} in groundnut irrespective of the growth stages and treatments imposed. Among the treatments, the highest available phosphorus of 30.4 kg ha^{-1} was recorded in the treatment that received equal proportion of rock phosphate and single super phosphate (50:50), which can be attributed to the dissolution of phosphorus from insoluble rock phosphate as mono calcium phosphate in single super phosphate (Owiti *et al.,* 2014). Compared to treatment receiving 100% rock phosphate, the sole application of single super phosphate recorded 15.5 per cent and 14.4 per cent higher available phosphorus during maize and groundnut cropping season probably due to the greater solubility of single super phosphate than rock phosphate (Akinrinde *et al.,* 1999; Akande *et al.,* 2010).

The available phosphorus was more in different combinations of rock phosphate and soluble sources rather than lone water-soluble sources which seems to be due to increased dissolution of rock phosphate into mono-calcium phosphate (Mona, 2015). Thereafter, the availability of phosphorus in soil decreased by 1.7 to 21.6% (from knee-height to harvesting of maize) and 3.2 to 27% (from flowering to harvesting of groundnut) suggesting the fixation of excess phosphorus with aluminum and iron in *Alfisol* (Rajan *et al.,* 1996). Various studies (Rajan *et al.,* 1991; Robinson *et al.*, 1994) indicated that the amount of dissolved phosphorus in rock phosphate increased either exponentially or linearly with the increase in soil pH in acid soils, this in turn strongly suggest the application of lime with phosphorus fertilizer as the best phosphorus management

Table 1: Available phosphorus status (kg ha^{-1}) of soil at different growth stages of maize-groundnut cropping sequence

Treatments	Maize			Groundnut		
	Knee height (30 DAS)	Tasseling (60 DAS)	Harvest (100 DAS)	Flowering (30 DAS)	Pod formation (60 DAS)	Harvest (90 DAS)
T_1: Control (-P)	8.14	8.03	8.0	8.21	8.05	7.94
T_2: 100% P (RP)	21.3	18.43	16.7	22.9	18.43	16.7
T_3: 100% P (SSP)	24.6	20.2	22.2	26.2	20.2	22.2
T_4: 75% (RP) + 25% (SSP)	29.6	25.8	24.1	28.8	25.8	24.1
T_5: 50% P (RP) + 50% (SSP)	30.4	26.7	24.8	31.7	26.7	24.8
T_6: 25% P (RP) + 75% (SSP)	20.7	19.2	18.1	22.5	19.2	18.1
T_7: 200% P through RP (Only on 1^{st} crop)	18.4	17.0	16.3	20.4	17.0	16.3
T_8: 100% P (SSP) + 0.2LR	29.6	23.6	26.4	30.3	23.6	26.4
LSD(p=0.05)	4.70	4.87	3.96	4.70	4.87	3.96
CV(%)	7.42	8.86	7.32	7.42	8.86	7.32

Table 2: Effect of different phosphorus sources on crop productivity and dry matter production under maize-groundnut cropping sequence (t ha^{-1})

Treatments	Maize			Groundnut		
	Grain	**Stover**	**Total biomass**	**Pod yield**	**Haulm yield**	**Total biomass**
T_1: Control (-P)	2.43	3.04	5.47	1.80	2.54	4.34
T_2: 100% P (RP)	4.18	5.01	9.19	2.51	3.62	6.13
T_3: 100% P (SSP)	4.51	5.43	9.94	2.45	3.91	6.36
T_4: 75% (RP)+25% (SSP)	4.37	5.68	10.05	2.62	4.08	6.70
T_5: 50% P (RP) + 50% (SSP)	4.94	5.80	10.74	2.71	4.95	7.66
T_6: 25% P (RP)+ 75% (SSP)	4.62	4.97	9.59	2.43	3.73	6.16
T_7: 200% P through RP (Only on 1st crop)	4.12	4.82	8.94	2.32	3.14	5.46
T_8: 100% P (SSP)+ 0.2LR	5.14	5.97	11.11	2.94	5.08	8.02
LSD(p=0.05)	0.76	0.71	-	0.42	1.37	-
CV(%)	7.00	5.00	-	6.13	6.73	-

Table 3: Effect of different phosphorus sources on phosphorus concentration and uptake in maize

Treatments	Concentration (%)		Phosphorus uptake (kg ha^{-1})		
	Grain	**Stover**	**Grain**	**Stover**	**Total**
T_1 Control (-P)	0.15	0.05	3.65	1.52	5.17
T_2 100% P (RP)	0.14	0.08	5.85	4.08	9.93
T_3 100% P (SSP)	0.18	0.09	8.11	4.88	12.99
T_4 75% (RP)+25% (SSP)	0.17	0.10	7.42	5.68	13.1
T_5 50% P (RP) + 50%(SSP)	0.18	0.09	8.89	5.22	14.12
T_6 25% P (RP)+ 75%(SSP)	0.17	0.10	7.85	4.97	12.82
T_7 200% P through RP (Only on 1st crop)	0.12	0.08	4.94	3.86	8.80
T_8 100% P (SSP)+ 0.2LR	0.20	0.10	10.28	5.97	16.25
LSD(p=0.05)	0.06	0.03	2.59	1.56	-
CV(%)	14.06	14.37	13.43	13.84	-

practice in *Alfisols*. The data pertaining to yield and dry matter production of maize and groundnut is presented in Table 2. The data indicates that the treatment receiving conjoint application of 100% P through single super phosphate and lime recorded the highest grain yield of 5.14 t ha^{-1} (111.5% increase over control) and stover yield of 5.97 t ha^{-1} (96.3% increase over control)in maize with similar trend being followed in groundnut having highest pod yield of 2.94 t ha^{-1} (63.3% increase over control) and haulm yield of 5.08 t ha^{-1} (100% increase over control).

This is due to the fact that addition of lime created better chemical and biological environment in soil which enhanced the amount of phosphorus release from the soluble source and resulted in enhanced nutrient availability thereby improving the production (Ranong, 1998; Opala, 2017). The above treatment was followed by the treatment receiving equal proportion of phosphorus through rock phosphate and single super phosphate, but both treatments were at par with respect to crop productivity. There was a progressive increase in crop yield and dry matter production with the increase in dose of soluble phosphorus in the form of single super phosphate along with rock phosphate up to 50%. The highest dry matter of 11.11 t ha^{-1} and 8.02 t ha^{-1} was recorded in maize and groundnut, respectively. Studies have shown that application of fertilizer phosphorus (rock phosphate or single super phosphate) increased productivity and biomass production of corn and groundnut over no fertilizer application (Kamara *et al.,* 2011; Cong, 2017). The solubilization of rock phosphate is associated with release of organic acids that decreases the pH, chelates the cations bounded to phosphate, thereby leading to an increased solubility of mineral phosphates (De Amaral Leite *et al.*, 2020; Nacoon *et al.*, 2020).

There was significant reduction in dry matter production of both maize (9.94 t ha^{-1}) and groundnut (6.36 t ha^{-1}) with application of single super phosphate. This reduction in lone single super phosphate treatment as compared to single super phosphate with lime application may be attributed to rapid fixation of water-soluble phosphorus with free sesquioxides present in

Table 4: Effect of different phosphorus sources on phosphorus concentration and uptake in groundnut

Treatments	Concentration (%)			Phosphorus uptake (kg ha^{-1})			
	Vine	Husk	Kernel	Vine	Husk	Kernel	Total
T_1 Control (-P)	0.14	0.06	0.33	0.77	0.38	3.82	4.98
T_2 100% P (RP)	0.32	0.10	0.48	1.97	0.84	8.35	11.16
T_3 100% P (SSP)	0.28	0.12	0.47	1.76	0.90	7.90	10.56
T_4 75% (RP)+25% (SSP)	0.29	0.11	0.45	1.97	0.96	8.32	11.25
T_5 50% P (RP) + 50%(SSP)	0.32	0.14	0.51	2.40	1.30	9.60	13.30
T_6 25% P (RP)+ 75%(SSP)	0.25	0.10	0.47	1.68	0.76	7.35	9.79
T_7 200% P through RP (Only on 1st crop)	0.23	0.08	0.43	1.50	0.58	6.10	8.20
T_8 100% P (SSP)+ 0.2LR	0.32	0.15	0.48	2.70	1.21	9.80	13.7
LSD(p=0.05)	0.14	0.06	0.14	0.68	0.33	3.94	-
CV(%)	13.90	20.17	11.08	14.37	14.06	14.52	-

Table 5: Effect of different phosphorus sources on efficiency indices under maize-groundnut cropping sequence (kg grain kg^{-1} P applied)

Treatments	Maize		Groundnut		Maize-groundnut	
	APUE	RAE (%)	APUE	RAE (%)	APUE	RAE (%)
T_1: Control (-P)	-	-	-	-	-	-
T_2: 100% P (RP)	80.2	83	41.2	89	52.3	85
T_3: 100% P (SSP)	95.3	100	37.2	100	62.2	100
T_4: 75% (RP)+25% (SSP)	88.8	102	46.9	117	58.0	107
T_5: 50% P (RP) + 50% (SSP)	115.0	118	52	164	75.0	132
T_6: 25% P (RP)+ 75% (SSP)	100.3	92	36.1	90	65.5	92
T_7: 200% P through RP (Only on 1st crop)	77.4	78	29.8	55	45.4	71
T_8: 100% P (SSP)+ 0.2LR	124	126	65.3	182	80.2	144

soil (Misra and Panda, 1969). The highest phosphorus content of 0.20% in grain and 0.10% in stover along with highest phosphorus uptake of 10.28 kg ha^{-1} and 5.97 kg ha^{-1} was recorded in the treatment that received single super phosphate and lime (Table 3). The phosphorus content and uptake in maize straw and grain increased with an increase in magnitude of single super phosphateand with rock phosphate combination. Similar trend was observed in groundnut with respect to phosphorus content and uptake (Table 4), which recorded the highest phosphorus content (0.32% in vine, 0.15% in husk and 0.48% in kernel) and uptake (13.7 kg ha^{-1}) in the treatment that received 100% phosphorus as single super phosphate and lime. The beneficial effect of lime with single super phosphate was significantly observed in groundnut-maize cropping system since single super phosphate could meet the phosphorus requirement of crops at initial stage that helped in root proliferation and root activities.

The phosphorus uptake was higher in rock phosphate and single super phosphate combined treatments compared to control and lone source of rock phosphate. Higher efficiency of combination was probably due to the starter effect provided by water soluble phosphate during initial growth stages which depressed the activity of toxic aluminium species in the soil solution and enhance the dissolution of rock phosphate by action of initial soil acidity created in the rhizosphere of the plant roots (Mc Lean and Wheeler, 1964; Prochnow *et al.,* 2004). Several studies have reported that application of equal proportion of rock phosphate along with single super phosphate increased the phosphorus uptake by rice-groundnut (Mitra *et al.,* 1991; Panda 1987), groundnut-maize (Sarangi *et al.,* 2020) and maize (Das *et al.,* 1990) in acid soils of Odisha. The agronomic phosphorus use efficiency (APUE) in the cropping sequence ranged between 52.3 to 80.2 kg pod per kg of P applied (Table 5). The combination of soluble source of phosphorus as single super phosphate with rock phosphate had higher APUE than lone sources. The addition of SSP as a starter dose enhanced the root growth and activity that enhanced the dissolution rate of rock phosphate in various combined treatments as compared to sole rock phosphate treatment (Sarangi *et al.*, 2020b). Considering the yield of both crops in the cropping sequence, the relative agronomic efficiency (RAE) of phosphorus sources varied from 71 to 144% (Table 5). Similar results of obtaining higher efficiency of rock phosphate, when applied with different combinations of it with single super phosphate has been reported by Ghosal *et al.* (2003) and Sarkar *et al.* (2018).

The result emanated from the study concluded that application of lone single super phosphate with lime was the best treatment followed by treatment which receivedmixture of rock phosphate and single super phosphate in equal proportion. The conjoint application of rock phosphate with water soluble single super phosphate has the potential to improve phosphorus use efficiency compared to lone source of rock phosphate in acid soil. Hence, the water soluble P_2O_5 fertilizers in combination with rock phosphate may be recommended in acidic *Alfisols* under maize-groundnut cropping system.

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Add-on Information

Authors' contribution: S. Mohanty: Contributed to the laboratory work and writing of the manuscript, **G.H. Santra:** Guided for the proceedings of the laboratory work and research paper communication, **P.P. Rout:** Prepared manuscript as per guidelines of the journal, **and S. Mishra:** Performed the statistical procedures for the manuscript.

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