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Sustainable yield index (SYI) of a groundnut-maize cropping system as influenced by sources and management of phosphorus on the acid Alfisols

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Abstract
To find out the stability index of a groundnut-maize cropping system through different sources and management of phosphorous in acid Alfisols of Odisha state, a field experiment was conducted in a randomized block design with three replications and seven treatments consist of Udaipur phosphate rock (UPR), single super phosphate (SSP) alone or their mixtures with different ratios including phosphorus control from 2013-14 to 2016. The soil has a loam texture, a pH of 5.2, low available nitrogen and medium phosphorus and potassium. The highest sustainable yield index (SYI) of 0.76 was recorded in SSP+ lime@0.2LR (T_7) treatment followed by 0.66 in URP+SSP @1:1 mixture (T_5). Application of UPR (T_2) alone was inferior to SSP and URP+SSP mixtures. Also stability index of URP+SSP mixture either in 3:1 (T_4) or 1:3 (T_6) were less than the T_3, T_5 and T_7 treatments. However, in UPR+SSP (1:1) mixture, SYI values of 0.75, 0.71 and 0.66 were recorded for groundnut, maize and groundnut-maize cropping system, respectively indicating relatively a higher value of yield stability index than the other UPR+SSP mixtures and sole SSP treatments.

Keywords: Acid soils, groundnut-maize cropping system, SSP, SYI, UPR

Introduction
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) [23]. 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) [24]. 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) [23] and 49% in hybrid maize (Pattanayak *et. al.*, 2009) [25]. 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) [12]. 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) [19, 3].
Thus, a proper P management strategy is required for improving and sustaining crop yields in the acid soils of Odisha. The maize-groundnut cropping system is one of the most popular cropping system in Odisha. A lot of work has been done regarding the use of rock phosphate in this situation. However research on use of rock phosphates compacted with water soluble

sources is very meagre. Therefore the present investigation aims at the efficiency of Udaipur Phosphate Rock alone and its different combination with single super phosphate in groundnut-maize cropping system.

Materials and Methods

The effects of Udaipur phosphate rock (UPR) alone and in different combinations with single super phosphate (SSP) in groundnut-maize cropping system during three consecutive years (2013-2014 to 2016) 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.

The experiment was conducted in a randomized block design with 7 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- 100% P (SSP) + lime@0.2LR. Each plot was 10 m x10 m. The groundnut crop cv. TAG 24 of 115 days duration was sown during rabi 2013-14, rabi 2014-15 and rabi 2015-16 at a spacing of 30x10 cm. Except the control treatment (T_1), the crop received recommended doses of N, P_2O_5, K_2O @ 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 $T_7$with the sources as per treatments. The hybrid maize crop cv. P-3441 of 90 days duration was sown during kharif 2014, kharif 2015 and kharif 2016 at a spacing of 60x 30 cm. Except the control treatment (T_1), the crop received recommended doses of N, P_2O_5, K_2O @ 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 DAS. Remaining one third dose of nitrogen was applied at 50 DAS. Phosphorus was applied in all the treatments from T_2 to T_7 as per treatments at sowing.

All the recommended agronomic practices i.e., irrigation, intercultural operations, 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, 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.

A composite soil sample (0-15 cm depth) was collected from the experimental site before sowing of seeds and fertilizers application. The sample was air dried under shade, crushed with wooden hammer and passed through 2 mm sieve and preserved in polythene bags for analysis of 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 sulfur. The texture of soil samples were determined with the help of Bouyoucous Hydrometer as given by Piper (1950) [26]. The bulk density of soil (undisturbed) was determined by Core method (Black, 1965) [1]. The water holding capacity of soil samples were determined by Keen Raczkowski Box method (Piper, 1950) [26]. The pH was determined in 1:2.5 soil-water ratio by pH meter (ELICO LI 613 pH meter) as described by Jackson (1973) [11]. As suggested by Jackson (1973) [11], 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) [32]. 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 were estimated by using the methods of Lin and Coleman (1960) as described by Page *et al.*, (1982) [20]. Exchangeable Calcium was determined using EDTA (Versenate) complexometric titration by using Calcon indicator as outline by Hesse (1971) [10]. 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) [30] 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) [2] as out lined by Page *et al*., (1982) [20]. 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) [9]. The available S content was determined turbidimetrically following the procedure of Chesnin and Yien (1952) [4] as described by Page *et al*., (1982) [20]. Vanadomolybdo phosphoric yellow color method was used total P determination (Jackson, 1973) [11] of Udaipur phosphate rock.

The groundnut crop was harvested (115-120 days) when more than 80% of pods showed dark streaks on the inner side of the shell. The border rows were removed first and there after the plants in the net plots were harvested separately treatment-wise. The pods were hand stripped and were sun dried to attain a constant weight before recording pod yield. After full maturity, maize cob from each net plot were harvested and threshed separately. Grain was sun dried and weighed. Then the yield values were recorded.

The yield data was recorded, compiled in appropriate tables, and analyzed statistically as per the procedure appropriate to the design (Panse and Sukhatme, 1989) [22] and Gomez and Gomez (1976) [7]. Whenever the treatmental differences were significant, critical difference were calculated at five per cent probability level and used for interpretations.

Empirical formulae

Sustainable Yield Index (SYI) : $\frac{y-\sigma}{ymax}$

where, y – average yield of a treatment over the years, σ - standard deviation (SD) and ymax – observed maximum yield of a plot over the years.

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-5.18), non saline (EC- 0.09 dS m^{-1}) with exchangeable acidity of 0.11, exchangeable Ca^{2+},

exchangeable Mg^{2+} c mol (p+) kg^{-1}soil. The soil is is low in organic carbon (3.4 g kg^{-1} soil), low in available N (239 kg ha^{-1}), medium in P (Bray'-1) (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%. Lime requirement of the experimental soil is 1.75 t $CaCO_3$ ha^{-1}.
The total P_2O_5content of Udaipur rock phosphate (URP) used in this experiment was 17.9%.

Pod yield of groundnut
The pod yield of groundnut for three 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 ($T_7 > T_5 > T_3 > T_6 > T_4 > T_2 > T_1$). The combined application of SSP with lime had the highest pod yield (2575 kg ha^{-1}), perhaps due to better utilization of native and applied P with increase in soil pH and decreased exchangeable decreased P-fixation by the soil. Combined application of URP+SSP mixture in 1:1 ratio can be compared SSP, since both the treatments recorded 56.7-61.7% of higher yield over control. Since, the soil pH during crop growth period in SSP treatment (T_3) was lower than URP+SSP (1:1) treatment (T_3), 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_4 (2170 kg ha^{-1}) and T_6 (2137 kg ha^{-1}) were lower than T_3 and T_5. 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 (38.7%) over control but, observed to be less effective as compared to URP+SSP mixture or SSP alone.
From three seasons' data, application of the recommended dose of P @ 40kg P_20_5 ha^{-1} as SSP (standard treatment) recorded three seasons average yield of 2249 kg ha^{-1}. Replacement of entire P dose through URP could not met P requirement reflecting yield decline by 13% with respect to standard dose.
However, application of URP+SSP mixture in 1:1 ratio gave statistically at par yield and seems to be economically viable alternative to 100% water soluble SSP. On the otherhand, application of lime @0.2LR with SSP raised the yield by 14.5% since liming raised soil pH and increased P availability. Several workers advocated the advantage of URP+SSP mixture over SSP since, the P release from URP would be faster in acidic P deficient soil. Soils with high Ca content would slow down PR dissolution. (Hammond *et al.*, 1986) [8].
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) [16]. 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) [17].

Grain yield of hybrid maize
The data presented in Table 2 showed that grain yield of hybrid maize significantly increased over control during three seasons. With application of P fertilizer, the grain yield varied between 3877 kg ha^{-1} to 5118 kg ha^{-1}. In control it was 3135 kg ha^{-}1. In P treatments, significantly higher mean grain yield of 5118 kg ha^{-1} was recorded in SSP + lime which is 63.2% higher over control was 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 36.6-40.7% 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_2) was better than control (23.7% 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 was due to prolonged dissolution of URP resulted in higher P availability.

Sustainable Yield Index
Sustainability refers to the maintenance and/or enhancement of productivity on a long term basis through integrated land management (Randhawa, 1994) [28]. Singh *et al.* (1990) [29] proposed the SYI as a quantitative measure to assess sustainability of an agricultural practice.
In the concept of SYI, low value of σ (SD) suggests sustainability of the system. On the otherhand, if SD is large, SYI will be low indicating unsustainable management practice. The index takes the values between zero and unity. In India, SYI is being used to measure the potentiality of different crops or cropping systems or a management practice by many workers.
In this study, the SYI was computed based on the yield obtained under different P-treatments over three years. The SYI of groundnut, maize and groundnut-maize cropping system are presented in Table 1, 2 and 3. The SYI values in control treatment for groundnut, maize and groundnut-maize cropping system were 0.41, 0.47 and 0.41 respectively. With application of different sources of P, these values were increased which varied between 0.62 to 0.85, 0.61 to 0.84 and 0.56 to 0.76 for groundnut, maize and groundnut-maize cropping system, respectively. Sole application of URP (T_2) alone recorded SYI values 0.62, 0.61 and 0.56 for groundnut, maize and groundnut- maize cropping system, respectively. Application of URP+SSP mixture in 3:1 (T_4) and 1:3 (T_6) recorded SYI values 0.69 and 0.68, 0.66 and 0.65, 0.62 and 0.61 for groundnut, maize and groundnut-maize cropping system, respectively. Application of P through SSP (T_3) recorded SYI values for groundnut, maize and groundnut-maize cropping system was 0.72, 0.69 and 0.64, respectively. Highest SYI values for groundnut- 0.85, maize- 0.84 and groundnut-maize – 0.76 were resulted through application SSP + lime@0.2LR (T_7). Irrespective of the crop, the lower SYI values in control treatment implies that the decrease in available P due to extensive cropping without P addition might have led to the imbalance fertilization. Reduction in yield reflected in decline SYI values for groundnut, maize and groundnut - maize cropping system in control. Application of URP (T_2) alone recorded or URP+SSP mixture either in 3:1 or 1:3 ratio could not be sustainable since the SYI is lower than the treatments T_3, T_5 and T_7. Highest SYI values for in SSP + lime@0.2 LR treatment suggested that, inclusion of lime with SSP, increased soil pH, reduces P-fixation capacity of soil, better development of roots and plant growth with adequate availability of P and Ca in soil resulted in higher yield and higher SYI. This results further showed that the yield of

groundnut-maize cropping system is more stable and sustainable when the crop received lime along with SSP.
On the other hand, in absence of lime, full dose of P through SSP (T_3) could not maintain the yield stability. The reduction in yield in SSP treatment as compared to SSP + lime was due to acidic pH associated with decrease in availability of P as well as several other nutrients. Replacement of 50% P through URP in T_5 (URP+SSP in 1:1 ratio) recorded SYI values 0.75, 0.71 and 0.66 for groundnut, maize and groundnut- maize cropping system, respectively indicating that higher value of yield stability index in T_5 than all other treatments except T_7. In URP+SSP treatment, SSP met the P requirement of groundnut in the beginning of growing period and P derived from dissolution of URP full filled the crop P requirement in latter stage of growth. Such a mixture further reduced P fixation by depressing the activity of free Fe and Al in soil solution and enhance the dissolution of RP by action of initial soil acidity created in the rhizosphere of the plant roots. The lower efficiency of SSP in acid soil was due to rapid fixation of water soluble P with free sesquioxides in soil.
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) (Jena, 2013) [13]. However, addition of chemical fertilizer without lime could not be as effective as lime + NPK (Hammond *et al.*, 1986) [8].
In a field study in Brazil Prochnow *et al*. (2004) [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. 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 (Mitra and Misra, 1991) [18], yield and P, Ca and Mg uptake by maize in acid soil (Das *et al.*, 1990) [5] of Odisha, Finger millet- wheat yield in Himanchal Pradesh (Dwivedi and Dwivedi, 1992) [6].
Higher efficiency of mixture may be due to the starter effect provided by water soluble SSP during initial growth stages. The lower efficiency of SSP in acid soil is due to rapid fixation of P with free oxides (Misra and Panda, 1969) [17]. Panda (1987) [21], 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.

Table 1: Effects of treatments on sustainable yield index (SYI) of groundnut

Treatments	Mean pod yield (kg ha^{-1})	SD	Y max	SYI
T_1:Control	1435	341	2632	0.41
T_2:100%UPR	1990			0.62
T_3:100%SSP	2249			0.72
T_4:75%UPR+25%SSP	2170			0.69
T_5:50%UPR+50%SSP	2320			0.75
T_6:25%UPR+75%SSP	2137			0.68
T_7:100%SSP+0.2LR	2575			0.85
C.D. (0.05)	127			-

Table 2: Effects of treatments on sustainable yield index (SYI) of maize

Treatments	Mean grain yield (kg ha^{-1})	SD	Y max	SYI
T_1:Control	3135	646	5284	0.47
T_2:100%UPR	3877			0.61
T_3:100%SSP	4284			0.69
T_4:75%UPR+25%SSP	4126			0.66
T_5:50%UPR+50%SSP	4410			0.71
T_6:25%UPR+75%SSP	4067			0.65
T_7:100%SSP+0.2LR	5118			0.84
C.D. (0.05)	194			-

Table 3: Effects of treatments on sustainable yield index (SYI) of maize equivalent yield

Treatments	Mean maize equivalent yield (kg ha^{-1})	SD	Y max	SYI
T_1:Control	3632	518	7571	0.41
T_2:100%UPR	4800			0.56
T_3:100%SSP	5377			0.64
T_4:75% UPR +25%SSP	5184			0.62
T_5:50% UPR +50%SSP	5542			0.66
T_6:25% UPR +75%SSP	5113			0.61
T_7:100%SSP+0.2LR	6263			0.76
C.D.(0.05)	211			-

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

Conclusion
The yield of groundnut-maize cropping system was more stable and sustainable when the crop received lime along with SSP. Replacement of 50% P through URP in T_5 (URP+SSP in 1:1 ratio) recorded higher SYI values than other five treatments indicating that the yield stability of groundnut-maize cropping system could be maintained in long run due to gradual dissolution of P from phosphate rock.

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