

Original Research Article

Thirteen Year Long Term Fertilization Effect on Soil P Balance and Sustainability of a Double Crop of Rice Grown in an Acidic *Inceptisol* under Sub-Tropical Climatic Situation

ABSTRACT

The goal of the study was to determine how long-term fertilizer management of a rice-rice production system affected the buildup or depletion of surface soil phosphorus (P) in a subtropical climate. The results showed that using FYM @ 5t ha⁻¹ season⁻¹ in conjunction with optimal NPK doses (80-40-60 kg ha⁻¹season⁻¹) resulted in significantly higher grain yield than using fertilizer alone at optimal, super optimal, or sub optimal doses or optimal level along with lime/Zn/Zn+B/Zn+S. The use of NPK and FYM together resulted in the highest yield sustainability. Phosphorus balance measured by indirect method (apparent P- balance) and direct method (true P-balance) was positive in all the fertilized treatments and negative in control and 100% N treatment that received no P. High yielding treatments (NPK + FYM or NPK + FYM + Lime) maintained a relatively lower P balance than optimal or super optimal doses because of more removal through higher biomass production. Addition of 50% more phosphorus in 150% NPK treatment caused 36.57% more P accumulation than 100% NPK treatment. Application of micro (Zn and B) and secondary(S) nutrients did not have any significant effect over and above 100% NPK treatment. Between the two methods, direct method registered more depletion in the two minus P treatments and less accumulation in all P treated soils than the indirect method. In soil with super optimal dose (150% NPK) there is highest positive balance (25.18 kg ha⁻¹ year⁻¹) as compared to 16.5 kg ha⁻¹year⁻¹in true method. Season wise grain yield and P uptake poorly correlated with apparent P balance ($r = 0.337$ to 0.438), true P balance($r = 0.457$ to 0.521) and total stock of P ($r = 0.457$ to 0.521). Whereas dry season, wet season and system sustainability strongly correlated with apparent P balance ($r = 0.694^{**}$, 0.583^{*} and 0.609^{*}), true P balance ($r = 0.724^{**}$, 0.628^{*} and 0.660^{*}) and total stock of P ($r = 0.724^{**}$, 0.628^{*} and 0.650^{*}). Thus true P balance and total stock of P in surface soil are better indicators of yield sustainability of each season and system as a whole; whereas, available P is closely related to the amount of residual fertilizer P in the soil. Consistent availability of the nutrient depends upon its total stock which in turn depends upon its balance. Knowledge on total stock and nutrient balance is very important for sustainability of a particular cropping system and evaluating various nutrient management practices for their suitability. Further study on composition of total stock of P with respect to various P fractions and their relative contribution to P uptake will be useful for identify the suitable management practice for P nutrition.

Key words *Apparent phosphorous balance; true phosphorous balance; P balance; FYM; sustainable yield index*

1. INTRODUCTION

Apart from nitrogen (N), phosphorus (P) is a limiting nutrient in many rice production areas, particularly in highly weathered soils in low latitude regions [1]. Although the total P content of soils may be large, only a small part of it is available for plant uptake [2, 3]. Most arable soils cannot supply sufficient amount of the element to the crops. Therefore P fertilizer is applied every season to overcome the deficiency. When fertilizer is applied to soil, only a small amount (10-30%) is taken up by the crop and a major part is not available to the present crop [4, 5]. In acid soils, P is mainly sorbed to iron (Fe) and aluminium (Al) oxides and hydroxides, and in calcareous soils to calcium (Ca) carbonates [6]. Considering very low use efficiency of these fertilizers, more amount of the element than the actual requirement is very often applied through fertilizers every season. This has led to P enrichment of the top soil of agricultural lands [7, 8]. The residual P can gradually be available to crop depending upon soil type and soil properties [6], weather condition [2] cropping system and management practices. The sorbed P can be gradually desorbed and used by plants, which may increase yields of subsequent crops [2]. The rates of P sorption and desorption are strongly dependent on the particular soil type, texture, pH, amounts of organic matter, and freely available sorption surfaces on Ca, Fe, and Al compounds [6]. The enrichment greatly depends upon the intensity of farming, type of crop and its removal, displacement of P through leaching, runoff and erosion. P is the nonrenewable source that is progressively depleted worldwide [9]. Compared to other nutrients P is least available to plants and is less mobile in soil due to its adsorption to iron and aluminum in paddy fields particularly in acidic soil.

Rice is one of the most important cereals consumed across the globe and grown in different environmental conditions. A rice–rice cropping system is usually practiced by farmers where either sufficient irrigation is available or in favorable lowland rainfed areas [10, 11]. Apart from irrigation availability, high consumer demand, a relatively stable market price, and assurance of a minimum support price by the government encourage the farmers to grow two rice crops continuously in consecutive seasons. Rice–rice cropping systems are most prevalent across a major portion of India as well as South Asia, especially among small and marginal farmers.

The amount of P needed for producing 1.0 t **annual** rice **was** in the range of **1.8–4.2 kg** as reported from the experiment conducted on a wide range of locations and soils (Entisols, Inceptisols, Vertisols, Mollisols and highly weathered soils) at 11 sites of five different countries (Philippines; Indonesia; Vietnam; China; India) [12]. Fertilizer P use efficiency is generally low in the year of first application but the fertilizer P continues to provide available P for several years. This is because, P is relatively immobile in soil and much of the residual fertilizer P from one application can remain available to subsequent crop [12]. It is therefore **exremely important** to characterize the P remaining in the soil after repeated fertilizer P application in **the same** agro ecosystem.

Phosphorus balance or the addition and removal of nutrient from the soil play a dominant role for maintenance of P stock in soil nutrient pool. Until now, very little research work has been reported on P balance in different crops and the works reported are only on the apparent P balance which is determined indirectly from the difference between addition and crop removal. But the actual P balance is different as there are other ways of nutrient displacement such as leaching, erosion and through weeds per organisms. It can be directly measured from the changes in total stock of P over years. Almost no or very little research has been carried out on P budget in specific cropping systems under different nutrient management practices.

Phosphorus balance could be determined by two major components: anthropogenic input as inorganic and organic fertilizers and amendments, and output of harvested crops including by-products like straw [13, 14, 15]. In contrast, input of seeds and that through irrigation and atmospheric deposition, and outputs through surface drainage and leaching were considered to be usually low in one or more order of magnitude [13, 14, 15]. Therefore, partial P balance (PPB), which is easily estimated by subtracting the P harvest from the input of P fertilizers and amendments, provides the information equivalent to entire P balance. The correlations between such PPB and increment in total P content [16, 17] (or plant available P test value in soil [12, 18] have been reported. These results indicate that PPB is a useful tool for predicting the change in soil P status and recommending the amount of P application practically. The significant positive increase of total P (TP) after 12-yr fertilization (mineral P plus pig manure) in rice-rape system, and the apparent P balance (APB) were estimated to vary from -7.2 to $4.3 \text{ kg P ha}^{-1} \text{ yr}^{-1}$ [19]. The similar consistent increase in TP was also found in the another long-term fertilization site (rice-wheat rotation) affiliated to Chinese Academy of Sciences (CAS, from 1998), and the APB varied from -12.9 to $52.1 \text{ kg P ha}^{-1} \text{ yr}^{-1}$ [20, 21].

Available P is closely related to the amount of residual fertilizer P in the soil [22]. Consistent availability of the nutrient depends upon its total stock which in turn depends upon its balance. Knowledge on total stock and nutrient balance is very important for sustainability of a particular cropping system and evaluating various nutrient management practices for their suitability. Though the rice-rice system seems to be feasible from a farmer's perspective, cereal-cereal cropping systems are often considered unsustainable and are discouraged [23] in terms of nutrient balance in the soil as well as agricultural sustainability [24]. This research has been carried out in a rice-rice based Long Term Fertilizer Experiment (LTFE) conducted under the aegis of Indian Council of Agricultural Research (ICAR) since 2005 on a dominant acidic *Inceptisol* of coastal Odisha on phosphorus in order to study its balance in soil as influenced by various fertilization schemes logically selected and experimented and the relationship of total P stock and balance with yield sustainability.

2. MATERIALS AND METHODS

2.1 Experimental site

The study was conducted in the experimental field of All India Coordinated Research Project (AICRP) on LTFE of ICAR at OUAT, Bhubaneswar, India ($20^{\circ}17' \text{ N}$, $85^{\circ}49' \text{ E}$ and 30 m above mean sea level)

which was started since 2005-06. The location of the experimental site is characterized as sub-humid subtropical climate with dry season from October to June and wet season from July to September. The average annual rainfall is 1628 mm, and the mean maximum and minimum temperatures are 31.40 and 21.10 degrees Celsius, respectively. The experimental soil is a pale yellow (10Y RR6/8), lateritic *Inceptisol* (*Udic Ustochrept*) sandy loam. The initial soil properties of 0-15cm layer were pH 5.3, Bulk density 1.55 gcc⁻¹, cation exchange capacity 3.75 cmol(+)kg⁻¹, soil organic carbon (SOC) 4.4gkg⁻¹, total P, 632 kg ha⁻¹, and available (Olsen) P, 19.7kg ha⁻¹.

2.2 Experimental details

The experiment consisted of 12 manurial treatments viz., T₁= 100%PK, T₂= 100%NPK, T₃= 150%NPK, T₄=100%NPK + Zn, T₅=100%NPK + FYM, T₆=100%NPK + FYM + Lime, T₇=100%NPK+B+Zn, T₈=100%NPK+S+Zn, T₉=100%N, T₁₀=100%NP, T₁₁= 100%NPK+lime, and T₁₂= Control, where 100% NPK correspond to 80-40-60 of N, P₂O₅ and K₂O kg ha⁻¹. The experiment was laid out in randomized block design (RBD) with four replications. Rice cultivar Swarna (MTU 7029) was grown under flooded condition in wet season and Lalat in dry season annually. Twenty five day old rice seedlings were transplanted at a spacing of 20 cm x 10 cm with 2-3 seedlings per hill to puddled field in both the seasons nitrogen (N) was applied in three splits i.e. 25% at puddling as basal, 50% topdressing at 18 days after transplanting and 25% topdressing at panicle initiation stage. Entire dose of phosphorus (P) was applied during puddling as basal and potassium (K) was applied in two splits, 50% at puddling as basal and 50% topdressing at panicle initiation (PI) stage. Entire FYM (5 t ha⁻¹ season⁻¹) was applied at the time of puddling. Necessary uniform intercultural, water management and plant protection measures were undertaken in general until the crop was matured for harvesting.

2.2.1 Biomass yield and P content in biomass

After harvesting in both the seasons, biomass yield and phosphorus content in both grain and straw was determined. Both grain and straw yields were estimated after weighing of air dried sample and making adjustment for moisture content. Laboratory analysis for P content was done after drying the sample at 70°C in oven for 72 hours. The dried plant sample was digested in di acid (2:3) for determination of phosphorus content [25]. Seven days after harvest of wet season 2018 crop, surface soil sample was collected from each plot. It was processed and chemical analysis was done for Olsen's P and total P following standard procedure of extraction and colorimetric estimation.

2.2.2 Sustainable yield index (SYI)

Sustainable yield index is a quantitative measure to assess sustainability of any system [26, 27] calculated by Pooled analysis of grain yields obtained in past years in both dry and wet seasons using the formula,

$$SYI = (Y - \sigma) / Y_{max}$$

Where, Y is the average of grain yield of a treatment of all the years, σ was the standard deviation of the treatments, and Y_{max} was the maximum yield observed over the years. Here data on season

Yields of past years documented in the project have been used for the calculation of SYI of each season and the system taken together.

2.2.3 Phosphorous balance

Phosphorus balance has been determined in two ways both direct (True Balance) and indirect (Apparent Balance).

2.2.4 True P- balance (TPB)

It is calculated directly from the actual field data. True balance is the difference between initial content of total soil P and P measured after some years, here 13 years of continuous cropping on post-harvest surface soil of wet season, 2018.

$$\text{True P balance (kg ha}^{-1}\text{)} = \text{Total P}_i - \text{Total P}_f$$

$$\text{Annual True P balance (kg ha}^{-1}\text{year}^{-1}\text{)} = (\text{Total P}_i - \text{Total P}_f) / t$$

Where, Total P_i and Total P_f are the surface soil total P content of initial soil and final soil respectively and 't' stands for number of years of cultivation, here 13 years.

2.2.5 Apparent P- balance (APB)

The apparent P balance has been determined by calculating the difference between P added and P removed each season (dry season 2017-18, wet season 2018) and then annual P balance was determined by summing up the balance of 2 seasons. For each treatment total P added was calculated for both the seasons by summing up of the phosphorus added through different sources via, fertilizer and FYM. Total P removal is the P displaced through both the straw and grain that is displaced from the field.

$$\text{Apparent P balance (kg/ha/year)} = \text{P}_{\text{fertilizer+ Manure (kg/ha/year)}} - \text{P}_{\text{removed by crop biomass(kg/ha/year)}}$$

Where, 'P_{fertilizer+manure} (kg ha⁻¹)' is the phosphorous added through fertilizer and manure (kg ha⁻¹), 'P_{removed by crop biomass} (kg ha⁻¹)' is phosphorous removed by the crop part which is displaced from the field in kg ha⁻¹ (assuming negligible P loss through leaching and surface runoff under the condition of study in experimental field as P in the puddled soil almost does not move down or go out of field). The treatment and season wise P balance determined by both the direct and indirect method have been compared and discussed under the prevailing experimental situation.

2.3 STATISTICAL ANALYSIS

The effect of the treatments on various soil properties, available P (Olsen's), total P, plant biomass yield and uptake was analyzed. Pearson's correlation (p<0.01) and p <0.05) was calculated to determine the relationship of P balance with crop yield, P uptake and SYI. Duncan's multiple range test (DMRT) was performed to find the effect of various treatments on different variables. All the statistical analysis was carried out using R statistical package.

3. RESULTS AND DISCUSSION

3.1 Grain yield

3.1.1 Dry season, 2017-18

Result on grain yield of dry season 2017-18 showed (**Table 1**) that highest yield of 44.53 qha⁻¹ was produced in 100% NPK + Lime + FYM treatment which was at par with 100% NPK + FYM demonstrating no effect of lime in presence of FYM applied @ 5 t ha⁻¹. But in absence of FYM, liming has significant effect. P or K also significantly increased the grain yield. Application of 50% more NPK also was effective in producing 10.04% significantly higher yield than 100% NPK. Application of zinc did not produce any significant effect over 100% NPK. There was no significant response to application of B and S. Grain yield was significantly lower in control plot (13.25 q ha⁻¹) than all other treatments except 100% N that also produced very low yield of 17.51 q ha⁻¹.

3.1.2 Wet season, 2018

The data revealed that the yield of wet season 2018 (**Table 1**) rice (cv. swarna) varied from a minimum of 17.77 q ha⁻¹ recorded in control to a maximum 48.91 q ha⁻¹ in 100% NPK + FYM + Lime treatments. Application of FYM @ 5 t ha⁻¹ was very effective in significantly increasing the grain yield over 100% NPK, whereas lime @ 1.0 t ha⁻¹ has no effect when applied along with FYM. Application of 50% more NPK also was effective in producing 10.04% significantly higher yield than 100%NPK. Application of zinc did not produce any significant effect over 100%NPK. Further, in the present investigation, application of B and S did not produce any significant effect over 100% NPK + Zn. Working on similar soil, [28] also found that continuous addition or exclusion of some secondary (S) and micro-nutrients (Zn and B) did not make any significant difference on grain yield. From the results it is also clear that FYM has significant effect on grain yield in both the seasons. Combination of FYM + Lime to 100% NPK resulted in significant increase in grain yield in both the seasons in every year. However, the response to FYM was more in wet season than in dry season. Higher response to FYM in the wet season than dry season has also been reported by [29, 30]. Significant yield increase by 22.10% was also caused by 150% NPK over 100% NPK. In a study conducted on *typic Ustochrept* on a clayey soil of Andhra Pradesh, [31] also reported more yield with 150% NPK than 100% NPK + FYM.

3.2 Phosphorous (P)-uptake

The crop yield and uptake of nutrients are interdependent. The total uptake of nutrients for rice was calculated by adding the nutrient uptake (**Table 1**) by both grain and straw yield of individual season. Results pertaining to total P uptake of dry season 2017-18 wet season 2018 and are presented in Table no.1. Total P uptake in dry season (2017-18) varied from 4.00 kg ha⁻¹ in control to 16.89 kg ha⁻¹ and in wet season 2018 varied from 3.87 kg ha⁻¹ in control to 20.55 kg ha⁻¹ in 100% NPK + Lime + FYM. 100% NPK + FYM was at par with 100% NPK + Lime + FYM. FYM amended plots resulted in more P uptake by releasing the organic acids during its decomposition [32] P uptake was more in all P treated plots than P minus treatments. Significantly higher uptake was recorded with super optimal dose (150% NPK) than 100% NPK. No significant effect was observed for secondary(S) and micronutrients (Zn and B) applied with optimal dose. Uptake of nutrients was lower in the control plot due to absence of external source of nutrient to the plants [33].

3.3 Sustainable yield index (SYI)

For any cropping system, both productivity and sustainability of yield are two important goal functions. In the present investigation (**Table 1**) sustainability in yield as influenced by Long Term manorial practices was studied by determining the sustainable yield index (SYI) from the dry and wet season yields of 13 years from 2005 wet season till 2018 wet season. Results on SYI reveal that among the 12 manorial treatments, 100% NPK + FYM (5t ha^{-1}) treatment is most sustainable in both dry and wet seasons ($\text{SYI}_{\text{dry, wet}} = 0.61, 0.51$) followed by 100% NPK + FYM + lime (0.59, 0.50). Lowest sustainability was recorded in unmanured control (0.20, 0.18) and 100% N treatment (0.35, 0.31). [30, 34, 35] also reported highest SYI for rice with conjoint application of NPK and FYM under intensive double rice cropping system in LTFEs. The treatments without sufficient nutrient supply by fertilizers leads to low sustainability as compared to the treatments that supplied adequate amount of nutrients through fertilizers reported [36]. Addition of 50% more NPK or Zn, or Zn + B or Zn + S or lime over 100% NPK did not make any significant impact on SYI. In both the seasons similar results were reported by [37, 38]. SYI in dry season varied from 0.20 to 0.61 and in wet season it varied from 0.18 to 0.51. Sustainability with recommended dose of fertilizer and conjunctive use of secondary (S) and micronutrients (Zn and B) without organic manure failed to increase grain yield and sustainability. On the other hand combination of FYM in optimum quantity had synergistic effect on improving efficiency of optimum doses of NPK and correcting deficiency of Zn, B and S and was superior to super optimal dose (150% NPK).

Application of 100% NPK + FYM improved soil fertility by stimulating microbial activity, improving soil physical health, improving pH of the acid soil, CEC, total and available pools of nutrients including micronutrients to sustain the yield under intensive sub-tropical rice-rice cropping system. Application of deficient secondary (S) and micronutrients (Zn and B) through fertilizer without organic manure can thus be avoided and issues of deteriorating crop productivity and soil health under rice-rice system can be efficiently addressed by combined application of optimum quantity of NPK fertilizers and organic manures.

Under the present condition of soil and climate, Phosphorous is considered as an important nutrient required for crop growth. Sustainability was significantly improved with addition of phosphorus to nitrogen. The treatment supplied with only N was less sustainable than the treatment supplied with both N and P in both the seasons. The SYI for 100% N and 100% NP was 0.35 and 0.47 in dry season and 0.31, 0.35 in wet season respectively.

3.4 Apparent P-balance

For sustainable crop production, knowledge on nutrient management of a crop or cropping system in a soil is very important. We always use the content of available nutrient in a soil for assessing soil that forms the basis of fertilizer recommendation. But use of such information on short term availability often leads to wrong management. Measurement of seasonal **annual nutrient** change based on the difference between nutrient added through different sources and nutrient removed through different ways from the surface soil provides an estimate of nutrient balance which is called apparent nutrient balance per unit time per unit area (represented in **Table 2**). The different sources of P added to soil are fertilizers, manures, irrigation water and different ways of P removal from soil are

displacement by harvested above ground biomass, leaching and runoff. Under the present situation of controlled experimentation, there is no runoff /erosion loss of P and leaching loss is minimum under a double crop of flooded and puddled rice [39]. Through irrigation water, P added is also negligible. Thus difference between nutrient added through fertilizer and FYM ($6.56 \text{ kg P } 5 \text{ t}^{-1} \text{ FYM}$) and nutrient removed by crop uptake gives the apparent P balance which in reality is not the true balance as it is measured indirectly.

Result reveal that apparent P balance is positive in all the fertilized treatments and negative in control and 100% N treatment that received no P. Positive nutrient balance varied from lowest of 9.75 kg ha^{-1} in NPK + Lime to a highest of 25.18 kg ha^{-1} in 150% NPK treatment. Positive balance leads to accumulation and negative balance, depletion of P. P balance in FYM amended treatment such as NPK +FYM and NPK +FYM +Lime is less than that in NPK treatment because of greater removal in these two treatments due to greater biomass and yield than NPK alone [40].

On an average 100% NPK added treatment (-FYM) accumulated $14.35 \text{ kg P ha}^{-1} \text{ year}^{-1}$, as compared to $11.14 \text{ kg P ha}^{-1} \text{ year}^{-1}$ in NPK + FYM amended treatments. Similarly on an average, there was depletion of $10.10 \text{ kg P ha}^{-1} \text{ year}^{-1}$ in minus P treatments (control, N). With addition of 50% more phosphorus in 150% NPK treatment there is 36.57 % more accumulation than that of 100% NPK treatment. Application of micro (Zn and B) and secondary(S) nutrients did not have any significant effect over and above 100% NPK treatment.

With this rate of accumulation the stock will be doubled in 25 years with addition of $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1} \text{ year}^{-1}$ in 150% NPK treatment, 44 years with $80 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1} \text{ year}^{-1}$ in 100% NPK and 57 years in 100% NPK + FYM treatments. In contrast, 80 years will be required for complete exhaustion of the P from the soil surface of control plot and 52 year in 100% N treatments. With more balanced nutrition accumulation is relatively low.

3.5 True balance

Measurement of the difference between total yearly P input and P output is an indirect way of estimation of P balance. But assessment through measurement of change in total P in soil over a particular period of time is the direct way of estimation of change in P status which we can name as true P balance (represented in **Table 3**). Data with respect to this change presented in table no. 2.reveal that within 13 years of continuous cropping there is accumulation of $96\text{--}210 \text{ kg P ha}^{-1}$ or $7.36\text{--}16.15 \text{ kg P ha}^{-1} \text{ year}^{-1}$ in all phosphorus applied treatments. Highest accumulation of $16.15 \text{ kg P ha}^{-1} \text{ yr}^{-1}$. has occurred in 150% NPK treatment followed by 100% NPK + Zn treatment with $13.32 \text{ kg P ha}^{-1} \text{ year}^{-1}$. There is less accumulation ($10.24 \text{ kg P ha}^{-1}$) in NPK + FYM treatments. Application of lime also caused less accumulation which is due to more crop yield and more P uptake. This balance gives a real picture of P input-output balance taking all factors into account without any presumption. In P non treated soil (Control and 100%N treatments) there is negative balance or depletion of phosphorus which largely depended not only on the P added by fertilizer and manure and displaced through straw and grain but on the entire P transformation process and its displacement.

In control plot there is depletion of 108 kg P ha^{-1} in 13 years as compared to 167 kg P ha^{-1} in 100% N treatment. Respective per annum depletion in control and 100% N treatment is $8.30 \text{ kg P ha}^{-1}$ and $12.8 \text{ kg P ha}^{-1}$. More depletion in direct measurement might be due to negative balance with respect to P added through irrigation water.

3.6 Apparent P balance (APB) *vis a vis* True P-balance (TPB)

When we compare both the methods of estimation of P balance, direct method registered more depletion in the two minus P treatments and less accumulation in all P treated soils (**Table 2 and 3**). In soil with super optimal dose (150% NPK) there is highest positive balance ($25.18 \text{ kg ha}^{-1} \text{ year}^{-1}$) as compared to $16.5 \text{ kg ha}^{-1} \text{ year}^{-1}$ in true method. Less accumulation in true method might be due to displacement of P from the sampling zone through mechanisms like down ward movement of P associated with finer particles to lower layers which are relatively fine textured with accumulation of more silt and clay content. The low yielding treatments like control and 100% N that did not receive any phosphorus recorded negative balance or depletion of P in both the types of estimation. The actual depletion was less than that shown as apparent balance.

3.7 Total phosphorous (T P)

Data on changes in total P of surface soil layer (0-15cm) (**Table 3**) show that there is accumulation of total P in all P treated soils and depletion in P minus treatments. Within 13 years of continuous cropping without phosphorus resulted in a decrease of 5 kg P ha^{-1} or 0.81% from the initial 632 kg ha^{-1} . Among the P applied treatments, highest accumulation ($841.92 \text{ kg ha}^{-1}$) was found with the super optimal dose (150% NPK) which was 36.57% more than that with optimal dose (100% NPK). Total P content in high yielding treatments such as 100% NPK + FYM and 100% NPK + FYM + lime was less than that of 100% NPK treatment. Addition of recommended dose of K to 100% NP increased the total P by 5.46%. On the other hand, the total P content decreased with application of micro and secondary nutrients (Zn, S and B) in conjunction with 100% NPK.

Less accumulation in high yielding treatments is due to more removal by the above ground crop biomass which is displaced from the field. A simple calculation based on the changes measured in this study suggests that the total stock of P will be doubled in 40 years in 150% NPK treatment, 66 years in 100% NPK treatment and 57 years in 100% NPK + FYM treatment. In contrast, the control plot will take 76 years to be completely exhausted with P while 100% N treated plot will take 52 years. Accumulation or depletion mostly depend upon yearly P balance as P is less mobile in soil.

3.8 Correlation of Phosphorus balance and total stock with grain yield, P uptake and Yield Sustainability

The results on relationship of P balance and total stock of phosphorus in surface soil with grain yield, P uptake and yield sustainability as measured through Pearson's correlation coefficient (Table 4 and Fig. 1(a to i)) reveal that seasonal grain yield and P uptake poorly correlated with apparent P balance ($r = 0.337$ to 0.438), true P balance ($r = 0.457$ to 0.521) and total stock of P ($r = 0.457$ to 0.521). Whereas dry season, wet season and system sustainability as measured in terms of SYI strongly correlated with apparent P balance ($r = 0.694^{**}$, 0.583^{*} and 0.609^{*}), true P balance ($r = 0.724^{**}$, 0.628^{*} and 0.660^{*}) and total stock of P ($r = 0.724^{**}$, 0.628^{*} and 0.650^{*}).

From the results it is clearly evidenced that although sustainability has significant relationship with both apparent balance, true balance and total stock, the relationship is stronger with true balance and total stock. Similarly between the seasons, dry season sustainability has greater correlation with P balance and stock than wet season. Thus true P balance and total stock of surface phosphorus are

better indices of sustainability of yield of rice-rice system. Regression analysis [Fig. 1. (a-i)] also substantiates the above findings. True P balance and total stock of P are more strongly correlated than apparent P balance and sustainability of dry season crop more depended on P balance and total stock in surface soil.

4. CONCLUSION

The results demonstrated that conjunctive use of FYM @ 5 t ha⁻¹season⁻¹ with optimal doses of NPK (80-40-60 kg⁻¹ ha⁻¹season⁻¹) produced significantly higher grain yield with more sustainability than optimal or super optimal or sub optimal doses of fertilizer alone. Yield with application of lime (1.0 t ha⁻¹season⁻¹) or Zn (0.4% seedling root dipping) or Zn +B (foliar spray with 0.5% Borax) or Zn + S (250 kg gypsum) over optimal doses of NPK was significantly lower. Highest yield sustainability was also found with conjoint application of NPK and FYM.

Results on P balance showed that both Apparent P balance (APB) and True P balance (TPB) were positive in all the fertilized treatments and negative in control and 100% N treatment that received no P. Highest yielding treatments (NPK + FYM or NPK + FYM + Lime) maintained a relatively lower P balance than optimal or super optimal doses because of more removal through higher biomass production. On an average 100% NPK added treatment (-FYM) accumulated 14.35 kg P ha⁻¹year⁻¹, as compared to 11.14 kg P ha⁻¹year⁻¹ in NPK + FYM amended treatments. Similarly on an average, there was depletion of 10.10 kg P ha⁻¹year⁻¹ in minus P treatments (control, N). With addition of 50% more phosphorus in 150% NPK treatment there is 36.57% more accumulation than that of 100% NPK treatment. Application of micro (Zn and B) and secondary (S) nutrients did not have any significant effect over and above 100% NPK treatment.

When we compare both the methods of estimation of P balance, direct method registered more depletion in the two minus P treatments and less accumulation in all P treated soils. In soil with super optimal dose (150% NPK) there is highest positive balance (25.18 kg⁻¹ ha⁻¹season⁻¹) as compared to 16.5 kg ha⁻¹year⁻¹ in true method.

Season wise grain yield and P uptake poorly correlated with apparent P balance ($r=0.337$ to 0.438), true P balance ($r= 0.457$ to 0.521) and total stock of P ($r= 0.457$ to 0.521). Whereas dry season, wet season and system sustainability as measured in terms of SYI strongly correlated with apparent P balance ($r= 0.694^{**}$, 0.583^{*} and 0.609^{*}), true P balance ($r= 0.724^{**}$, 0.628^{*} and 0.660^{*}) and total stock of P ($r= 0.724^{**}$, 0.628^{*} and 0.650^{*}). Regression analysis also substantiated the above findings. Thus true P balance and total stock of P in surface soil are better indicators of yield sustainability of each season and system as a whole. Thus, total P-status of soil and its true balance exhibited its influence on sustainability of double crop of rice grown under subtropical acidic Inceptisol. Among the treatments combination of FYM to 100%NPK is most sustainable with moderate status of total P on surface soil. Future study is required to know the composition of total P with respect to various fractions and their relative contribution to P uptake. This will be useful to identify the suitable nutrient management practice for P nutrition in rice-rice cropping system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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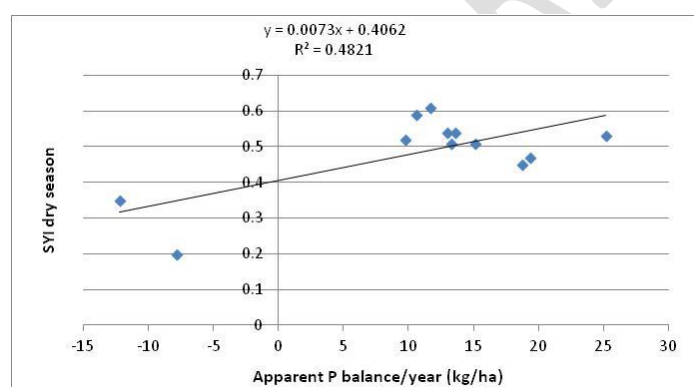


Fig. 1 (a) Effect of apparent P-balance on yield sustainability of dry season

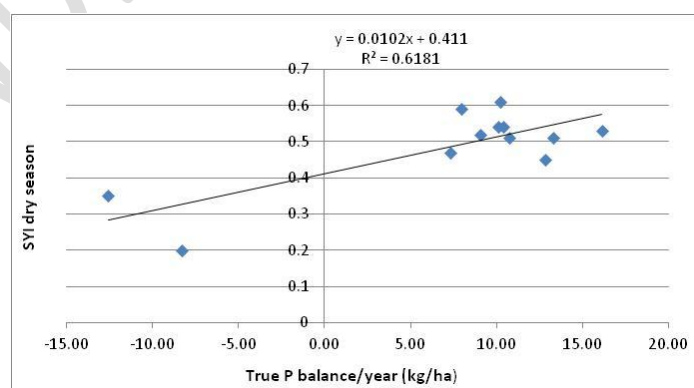


Fig. 1 (b) Effect of True P-balance on yield sustainability of dry season

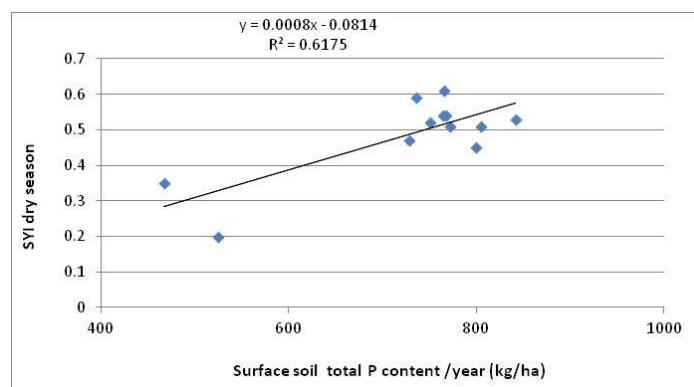


Fig. 1 (c) Effect of total P of surface soil on yield sustainability of dry season

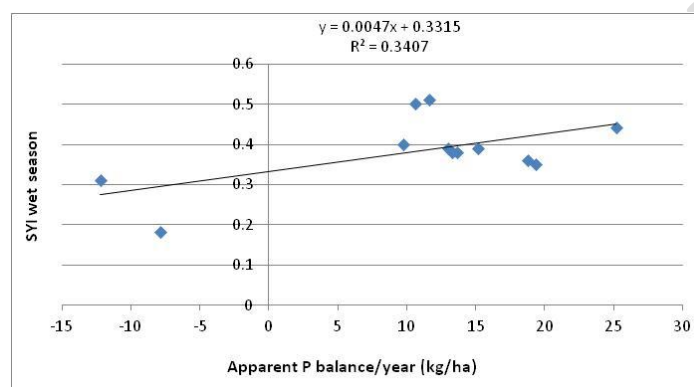


Fig. 1 (d) Effect of apparent P-balance on yield sustainability of wet season

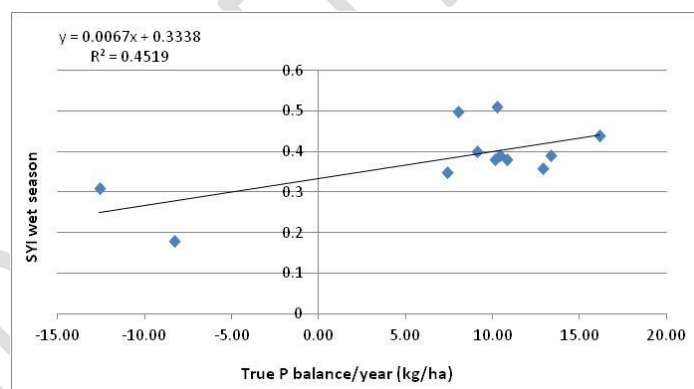


Fig. 1 (e) Effect of True P-balance on yield sustainability of wet season

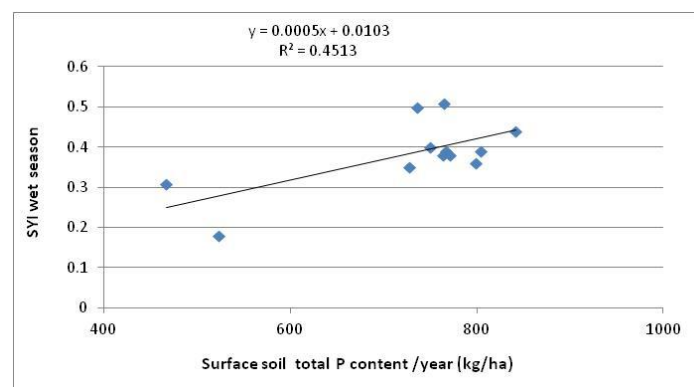


Fig. 1 (f) Effect of total P of surface soil on yieldsustainability of wet season

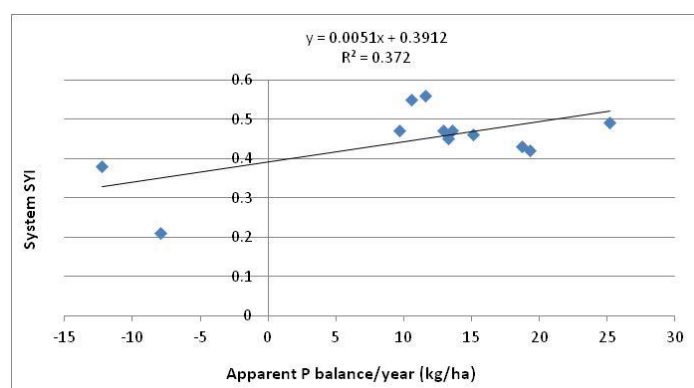


Fig. 1 (g) Effect of apparent P-balance on system yield sustainability

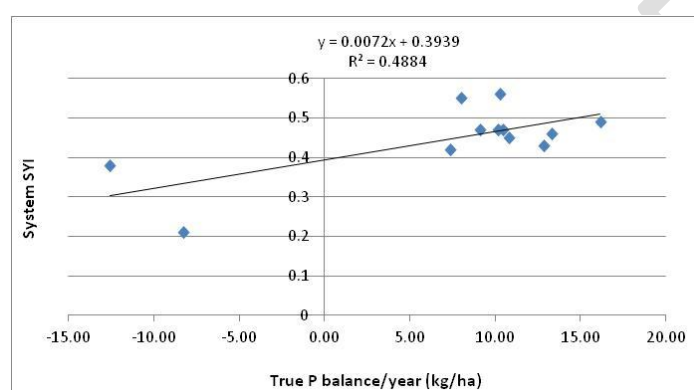


Fig. 1 (h) Effect of True P-balance on system yield sustainability

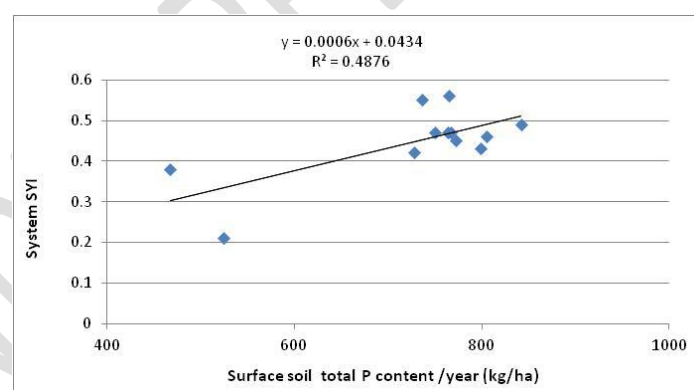


Fig. 1 (i) Effect of total P of surface soil on system yield sustainability

Table 1. Long term effect of 13 years of cropping and manurial treatments on grain yield, sustainability and P uptake.

Treatments	Dry season 2017-18 (kg ha ⁻¹)			Wet season 2018 (kg ha ⁻¹)			Annual P (kg ha ⁻¹)		
	P added	P uptake	P balance	P added	P uptake	P balance	P added	P uptake	P balance
100% PK	17.47	7.66 ^{et}	9.81 ^{bc}	17.47	8.53 ^e	8.95 ^b	34.94	16.18 ^d	18.76 ^b
100% NPK	17.47	10.01 ^{cd}	7.46 ^{de}	17.47	11.97 ^{cd}	5.5 ^{cde}	34.94	21.98 ^c	12.96 ^{cde}
150% NPK	26.2	12.44 ^b	13.76 ^a	26.2	14.78 ^b	11.42 ^a	52.4	27.22 ^b	25.18 ^a

100%NPK + Zn	17.47	8.66 ^{de}	8.81 ^{cd}	17.47	11.14 ^b	6.33 ^c	34.94	19.8 ^c	15.14 ^c
100%NPK + FYM	24.03	16.62 ^a	7.41 ^{de}	24.03	19.79 ^a	4.24 ^{def}	48.06	36.41 ^a	11.65 ^{def}
100%NPK+Lime+FYM	24.03	16.89 ^a	7.14 ^{de}	24.03	20.55 ^a	3.48 ^f	48.06	37.44 ^a	10.62 ^{ef}
100% NPK+B+Zn	17.47	8.90 ^e	8.57 ^{cd}	17.47	12.42 ^{cd}	5.05 ^{cdef}	34.94	21.32 ^c	13.62 ^{cd}
100%NPK+S+Zn	17.47	11.41 ^d	11.41 ^d	17.47	11.41 ^d	6.04 ^{cd}	10.19 ^e	11.63 ^{bc}	13.31 ^{cd}
100% N	Treatments 0	5.08 ^{gh}	-5.08 ^h	0	7.15 ^e	-7.15 ^h	Dry 0	Wet 2.23 ^e	-12.23 ^h
100 %NP	17.47	21.86 ^{eg}	31.32 ^{cde}	17.47	8.83 ^e	0.42 ^f	season 17	season 18	19.3 ^{bb}
100% NPK+lime	17.47	11.61 ^{bc}	5.86 ^f	17.47	13.58 ^{bc}	3.89 ^{ef}	17.47	21.19 ^b	9.75 ^f
Control	100% PK	0	22.91 ^h	28.73 ^e	8.45	3.87 ^f	0.43 ^g	7.66 ⁰	8.52 ⁷
SEm (±)	100% NPK	-	30.63 ^{bc}	34.56 ^{bc}	0.54	0.39	0.47 ⁵⁸	10.01 ^{cd}	11.87 ^{cd}
CD (p=0.05)	150% NPK	-	34.56 ^b	38.03 ^b	0.53	0.44	0.49 ⁵⁹	12.44 ^b	14.29 ^b
	100%NPK + Zn	26.25 ^{cde}	33.53 ^{bed}	0.51	0.39	0.46	8.66 ^{de}	11.14 ^b	
	100%NPK + FYM	43.47 ^a	47.50 ^a	0.61	0.51	0.56	16.62 ^a	19.79 ^a	
	100% NPK+ Lime + FYM	44.53 ^a	48.91 ^a	0.59	0.50	0.55	16.89 ^a	20.55 ^a	
	100% NPK+B+Zn	25.60 ^{de}	35.12 ^{bc}	0.54	0.38	0.47	8.90 ^e	12.42 ^{cd}	
	100%NPK+S+Zn	27.63 ^{cde}	35.82 ^{bc}	0.51	0.38	0.45	10.20 ^{cd}	11.43 ^d	
	100% N	17.51 ^{tg}	29.70 ^{de}	0.35	0.31	0.38	5.08 ^{gh}	7.15 ^e	
	100 %NP	21.86 ^{eg}	31.32 ^{cde}	0.47	0.35	0.42	6.75 ^{tg}	8.83 ^e	
	100% NPK+lime	35.25 ^b	38.07 ^b	0.52	0.40	0.47	11.61 ^{bc}	13.58 ^{bc}	
	Control	13.25 ^g	17.77 ^f	0.20	0.18	0.21	4.00 ^h	3.87 ^f	
	SEm (±)	1.58	21.09	-	-	-	0.61	0.58	
	CD (p=0.05)	4.54	60.72	-	-	-	1.76	1.68	

LSD (p<0.05%): in each coloum the values (mean of four replicates observations) followed by common letters are not significantly different (p<0.05%) between treatments by DMRT

Table 2. Effect of long term manurial treatments on P removal and Apparent P balance in 2017-18

Table 3. Long term effect of manurial treatments on True P balance in the top layer (0-15cm) of soil P after 13 years of continuous cropping.

Treatments (0-15 cm)	Initial (2005) total P of soil (A) (kg ha ⁻¹)	Total P after 13 yrs (2018) of top soil (kg ha ⁻¹) Kharif 2018 (B)	Balance P after 13 years (kg ha ⁻¹) (B-A)	P balance/ year (kg ha ⁻¹) (B-A)/13
100% PK	632	799	167	12.85
100% NPK	632	767	135	10.41
150% NPK	632	842	210	16.15
100%NPK + Zn	632	805	173	13.32
100% NPK + FYM	632	765	133	10.24
100% NPK+ Lime+ FYM	632	736	104	7.98
100% NPK+B+Zn	632	764	132	10.13
100%NPK+S+Zn	632	772	140	10.79
100% N	632	467	-164	-12.6
100 %NP	632	728	96	7.36

100% NPK+lime	632	750	118	9.09
Control	632	524	-108	-8.3
SEm (\pm)	-	48.5	48.5	3.73
CD ($p=0.05$)	-	139.64	139.64	10.74

Table 4. Relationship of grain yield, P uptake and sustainable yield index, with P balance and total stock of P under long term manorial practice

P balance	Grain Yield		P-Uptake		Sustainable Yield Index		
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Total
Annual Apparent Balance	0.437	0.377	0.562	0.435	0.587*	0.690**	0.604*
Annual True Balance	0.559	0.483	0.562	0.550	0.681**	0.781**	0.693**
Total stock P	0.559	0.483	0.562	0.550	0.680**	0.780**	0.692**