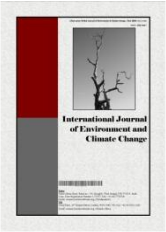

International Journal of Environment and Climate Change

12(7): 18-33, 2022; Article no.IJECC.85203
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

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

Sugyata Shivhare [a*], Kumbha Karna Rout [a], Mitali Mandal [a], Prasanna Kumar Samant [a], Pradipta Majhi [b], Amit Phonglosa [c] and Abhiram Dash [d]

[a] Department of Soil Science and Agricultural Chemistry, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, 751003, India.
[b] Krishi Vigyan Kendra, Odisha University of Agriculture and Technology, Jagatsinghpur, Odisha, 754160, India.
[c] Directorate of Extension Education, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, 751003, India.
[d] Department of Agricultural Statistics, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, 751003, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i730699

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/85203

Received 15 January 2022
Accepted 22 March 2022
Published 30 March 2022

Original Research Article

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^{-1}season^{-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

---

*Corresponding author: E-mail: sugyatashivhare@gmail.com;

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. The addition of 50% more phosphorus in 150% NPK treatment caused 9.77% more P accumulation than 100% NPK treatment. Between the two methods, the 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 a super optimal dose (150% NPK), there is the highest positive balance (25.18 kg ha^{-1} year^{-1}) as compared to 16.5 kg ha^{-1}year^{-1}in the true method. Seasonal wet and dry grain yield and P uptake poorly correlated with apparent P balance, true P balance and total stock of P. Whereas, sustainability of dry season, wet season and system yield strongly correlated with apparent P balance (r=0.587*, 0.690** and 0.604*), true P balance (r=0.681**, 0.781** and 0.693**) and total stock of P (r=0.680**, 0.780** and 0.692**). Thus true P balance and the 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 of total stock and nutrient balance is very important for the sustainability of a particular cropping system and evaluating various nutrient management practices for their suitability. Further study on the composition of the total stock of P with respect to various P fractions and their relative contribution to P uptake will be useful for identifying the suitable management practice for P nutrition.

Keywords: 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 a 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 aluminum (Al) oxides and hydroxides, and in calcareous soils to calcium (Ca) carbonates [6]. Considering the 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 topsoil of agricultural lands [7,8]. The residual P can gradually be available to crops depending upon soil type and soil properties [6], weather conditions [2] cropping system, and management practices. The sorbed P can be gradually desorbed and used by plants, which may increase the 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 (Philipines, Indonesia, Vietnam, China, and 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 crops [12]. It is therefore extremely important to characterize the P remaining in the soil after repeated fertilizer P application in the same agroecosystem.

Phosphorus balance or the addition and removal of nutrients from the soil play a dominant role in the maintenance of P stock in the 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. It can be directly measured from the changes in the total stock of P over years. Almost no or very little research has been carried out on the 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, the input of seeds through irrigation and atmospheric deposition, and outputs through surface drainage and leaching were considered to be usually low in one or more orders 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 the 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 the rice-rape system, and the apparent P balance (APB) were estimated to vary from –7.2 to 4.3 kg P $ha^{–1}$ $yr^{–1}$ [19]. A similar consistent increase in TP was also found in another long-term fertilization site (rice-wheat rotation) affiliated to the Chinese Academy of Sciences (CAS, from 1998), and the APB varied from –12.9 to 52.1 kg P $ha^{–1}$ $yr^{–1}$ [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 of total stock and nutrient balance is very important for the 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 the 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°17′ N, 85°49′ E and 30 m above mean sea level) which was started since 2005-06. The location of the experimental site is characterized as a sub-humid subtropical climate with a dry season from October to June and the 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,19.7$kgha^{-1}$.

2.2 Experimental Details

The experiment consisted of 12 manurial treatments viz., T_1= 100%PK, T_2= 100%NPK,

T_3= 150%NPK, T_4=100%NPK + Zn, T_5=100%NPK + FYM, T_6=100%NPK + FYM + Lime, T_7=100%NPK+B+Zn, T_8=100%NPK+S+Zn,T_9=100%N, T_{10}=100%NP, T_{11}= 100%NPK+lime, and T_{12}= Control, where 100% NPK correspond to 80-40-60 of N,P_2O_5 and K_2O kgha^{-1}. The experiment was laid out in randomized block design (RBD) with four replications. Rice cultivar Swarna (MTU 7029) was grown under the flooded condition in the wet season and Lalat in the dry season annually. Twenty-five-day old rice seedlings were transplanted at a spacing of 20 cm × 10 cm with 2-3 seedlings per hill to the puddled field in both the season's 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 the panicle initiation stage. The 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. The 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 seasons, biomass yield and phosphorus content in both grain and straw were determined. Both grain and straw yields were estimated after weighing air-dried samples and making adjustments for moisture content. Laboratory analysis for P content was done after drying the sample at 70^{o}C in the oven for 72 hours. The dried plant sample was digested in di acid (2:3) for the determination of phosphorus content [25]. Seven days after the harvest of the wet season 2018 crop, a surface soil sample was collected from each plot. It was processed and chemical analysis was done for Olsen's P and total P following the standard procedure of extraction and colorimetric estimation.

2.2.2 Sustainable yield index (SYI)

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

$$\mathbf{SYI = (Y - \sigma) / Ymax}$$

Where Y is the average grain yield of treatment of all the years, σ was the standard deviation of the treatments, and Ymax 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 took 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.

$$\textbf{True P balance (kgha}^{-1}\textbf{) = Total P}_i\textbf{– Total P}_f$$

$$\textbf{Annual True P balance (kgha}^{-1}\textbf{year}^{-1}\textbf{) = (Total Pi– Total P}_f\textbf{)/ t}$$

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 the 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 the 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 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.

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

Where '$P_{\text{fertilizer+manure}}$ (kgha^{-1})' is the phosphorous added through fertilizer and manure (kgha^{-1}), '$P_{\text{removed by crop biomass}}$ (kgha^{-1})' is phosphorous removed by the crop part which is displaced from the field in kgha^{-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 the 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 the 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 the highest yield of 44.53 q ha^{-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 a significant effect. P or K also significantly increased the grain yield. Application of 50% more NPK also was effective in producing a 13.25% significantly higher yield than 100% NPK. The application of zinc did not produce any significant effect over 100% NPK. There was no significant response to the application of B and S. Grain yield was significantly lower in the control plot (13.25 q ha^{-1}) than all other treatments except 100% N which also produced a vary 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 of 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. The application of zinc did not produce any significant effect over 100%NPK. Further, in the present investigation, the 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 in grain yield. From the results, it is also clear that FYM has a significant effect on grain yield in both seasons. The combination of FYM + Lime to 100% NPK resulted in a significant increase in grain yield in both seasons every year. However, the response to FYM was more in the wet season than in the dry season. A higher response to FYM in the wet season than the dry season has also been reported by [29,30]. A significant yield increase of 22.10% was also caused by 150% NPK over 100% NPK. 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 the individual season. Results pertaining to total P uptake of dry season 2017-18 wet season 2018 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. The uptake of nutrients was lower in the control plot due to the absence of an external source of nutrients 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 were 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 manurial treatments, 100% NPK + FYM (5t ha^{-1}) treatment is most sustainable in both dry and wet seasons (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 the highest SYI for rice with the conjoint application of NPK and FYM under an intensive double rice cropping system in LTFEs. The treatments without sufficient nutrient supply by fertilizers lead to low sustainability as compared to the treatments that supplied an adequate amount of nutrients through fertilizers reported [36]. The 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 seasons, similar results were reported by [37,38]. SYI in the dry season varied from 0.20 to 0.61 and in the wet season, it varied from 0.18 to 0.51. Sustainability with a 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 a synergistic effect on improving the 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 an optimum quantity of NPK fertilizers and organic manures.

Under the present condition of soil and climate, Phosphorous is considered an important nutrient required for crop growth. Sustainability was significantly improved with the 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 seasons. The SYI for 100% N and 100% NP was 0.35 and 0.47 in the dry season and 0.31, 0.35 in the wet season respectively.

3.4 Apparent P-balance

For sustainable crop production, knowledge of nutrient management of a crop or cropping system in the soil is very important. We always use the content of available nutrients in the soil for assessing soil that forms the basis of fertilizer recommendation. But the use of such information on short-term availability often leads to wrong management. Measurement of seasonal annual nutrient change based on the difference between nutrients added through different sources and nutrients 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 (Table 2). The different sources of P added to soil are fertilizers, manures, irrigation water and different ways of P removal from the soil is 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 the difference between nutrients added through fertilizer and FYM (6.56 kg P 5 t^{-1} FYM) and nutrients removed by crop uptake gives the apparent P balance which in reality is not the true balance as it is measured indirectly.

The 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 kg P ha^{-1} year^{-1}, as compared to 11.14 kg P ha^{-1} year^{-1} in NPK + FYM amended treatments. Similarly, on an average, there was the depletion of 10.10 kg P ha^{-1}year^{-1} in minus P treatments (control, N). With the 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 the addition of 120 kg P_2O_5 ha^{-1}year^{-1} in 150% NPK treatment, 44 years with 80 kg P_2O_5 ha^{-1}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 the control plot and 52 years 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 estimating 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 (Table 3). Data with respect to this change reveal that within 13 years of continuous cropping there is an accumulation of 96-210 kg P ha^{-1} or 7.36 - 16.15 kg P ha^{-1}year^{-1} in all phosphorus applied treatments. Highest accumulation of 16.15 kg P ha^{-1}yr^{-1} has occurred in 150% NPK treatment followed by 100% NPK + Zn treatment with 13.32kg P ha^{-1}year^{-1}. There is less accumulation (10.24 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 a 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 the control plot, there is a depletion of 108 kg P ha^{-1} in 13 years as compared to 165 kg P ha^{-1} in 100% N treatment. Respective per annum depletion in control and 100% N treatment is 8.30 kg P ha^{-1} and 12.7 kg P ha^{-1}.

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

When we compare both methods of estimation of P balance, the 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 a super optimal dose (150% NPK) there is the highest positive balance (25.18 kg ha^{-1} year^{-1}) as compared to 16.5 kg ha^{-1}year^{-1} in the true method. Less accumulation in the true method might be due to displacement of P from the sampling zone through mechanisms like the downward movement of P associated with finer particles to lower layers which are relatively fine-textured with an 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.

3.7 Total phosphorous (T P)

Data on changes in total P of surface soil layer (0-15cm) (Table 3) show that there is an accumulation of total P in all P treated soils and depletion in P minus treatments. Within 13 years of continuous cropping in non-fertilized control plot there is a decrease of total P by 17.08%. Among the P applied treatments, the highest accumulation (841.92 kg ha^{-1}) was found with the super optimal dose (150% NPK) which was 9.77% 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 2 and 31 kg ha^{-1} less than that of 100% NPK treatment. The addition of a recommended dose of K and Zn increased the total P by 5.36% and 5.08% respectively. On the other hand, the total P content decreased with the supplemental application of sulphur and boron.

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 40years in 150% NPK treatment, 66 years in 100% NPK treatment, and 57years in 100% NPK + FYM treatment. In contrast, the control plot will take 76 years to be completely exhausted with P while the 100% N-treated plot will take 50 years. Accumulation or depletion mostly depends 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 the relationship of P balance and the total stock of phosphorus in surface soil with grain yield, P uptake, and yield sustainability as measured through Pearson's correlation coefficient (Table 4) reveal that, grain yields of wet and dry season are poorly correlated with apparent P balance (r= 0.377 and 0.437), true P balance (r= 0.484 and 0.560) and total stock of P (r= 0.483 and 0.559) and similarly, P uptake also show non-significantly correlation with apparent P balance (r= 0.435 and 0.561), true P balance (r= 0.551 and 0.562) and the total stock of P (r= 0.550 and 0.563). Whereas, sustainability of dry season, wet season and system yield as measured in terms of SYI strongly correlated with apparent P balance (r= 0.587*, 0.690** and 0.604*), true P balance (r= 0.681**, 0.781** and 0.693**) and total stock of P(r= 0.680**, 0.780** and 0.692**).

From the results, it is clearly evidenced that although sustainability has a significant relationship with both apparent balances, true balance, and total stock, the relationship is stronger with true balance and total stock. Similarly, between the seasons, dry season sustainability has a greater correlation with P balance and stock than the wet season. Thus true P balance and the total stock of surface phosphorus are better indices of sustainability of yield of the rice-rice system. Regression analysis [Fig. 1. (a-i)] also substantiates the above findings. True P balance and the 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.

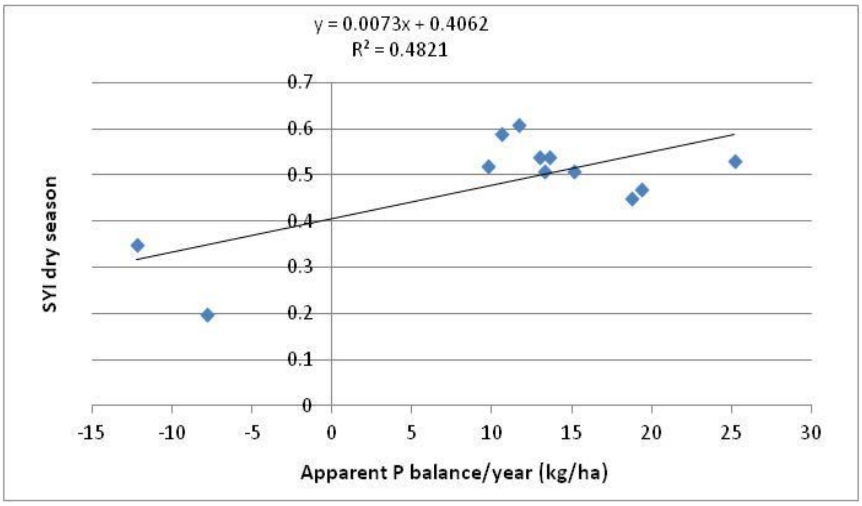

Fig. 1 (a) Effect of apparent P-balance on yield sustainability of dry season

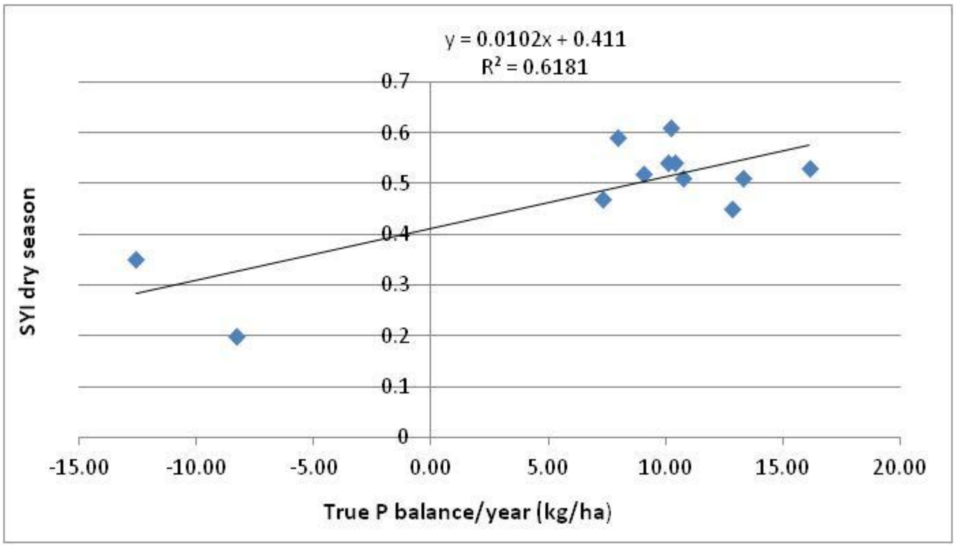

Fig. 1 (b) Effect of True P-balance on yield sustainability of dry season

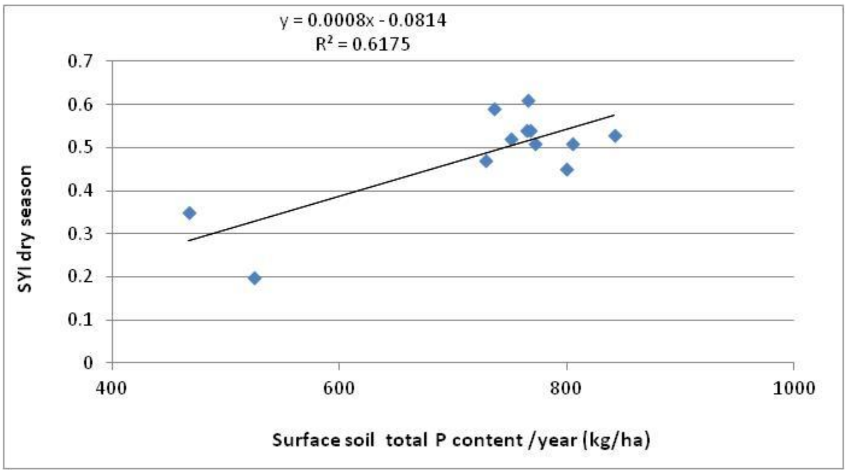

Fig. 1 (c) Effect of total P of surface soil on yield sustainability of dry season

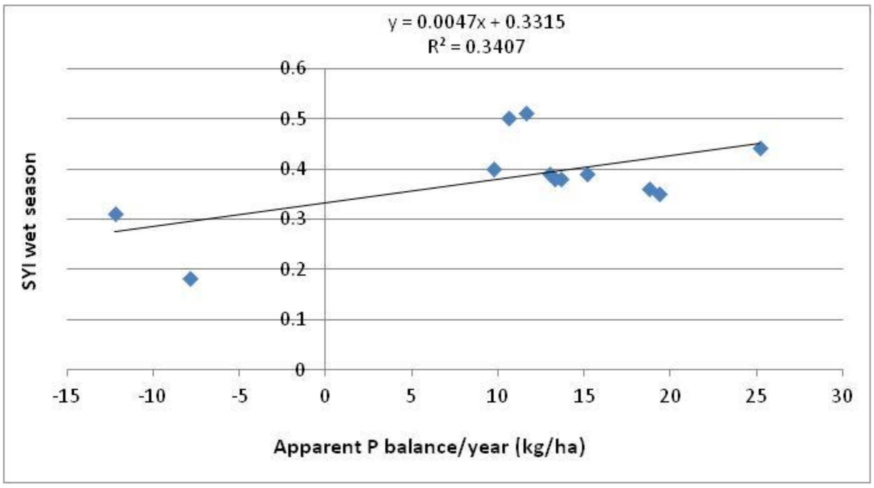

Fig. 1 (d) Effect of apparent P-balance on yield sustainability of wet season

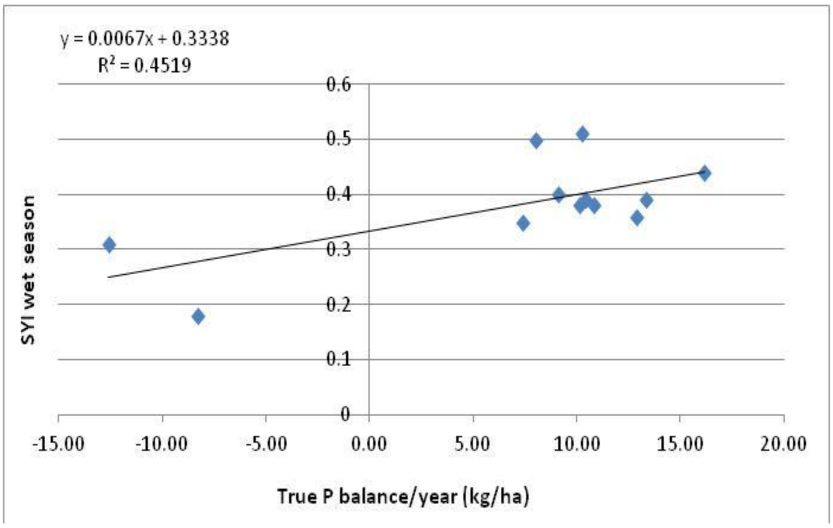

Fig. 1 (e) Effect of True P-balance on yield sustainability of wet season

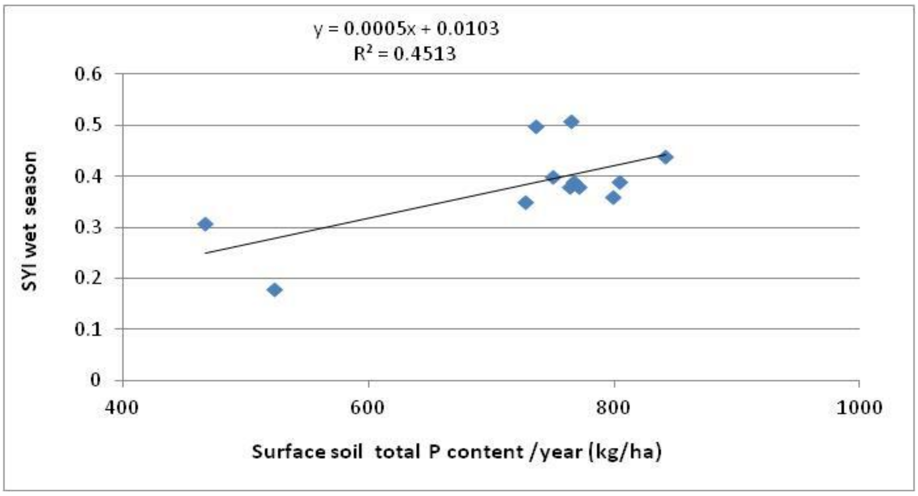

Fig. 1 (f) Effect of total P of surface soil on yield sustainability of wet season

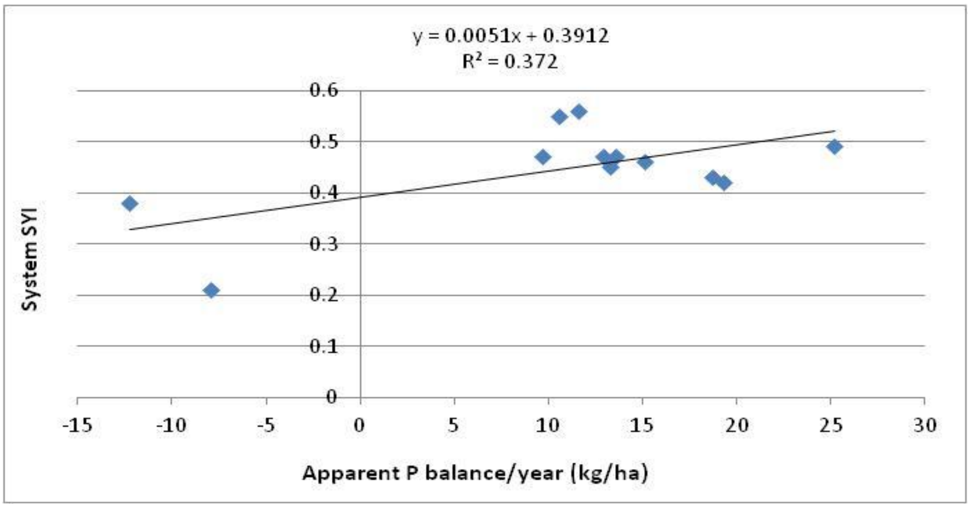

Fig. 1 (g) Effect of apparent P-balance on system yield sustainability

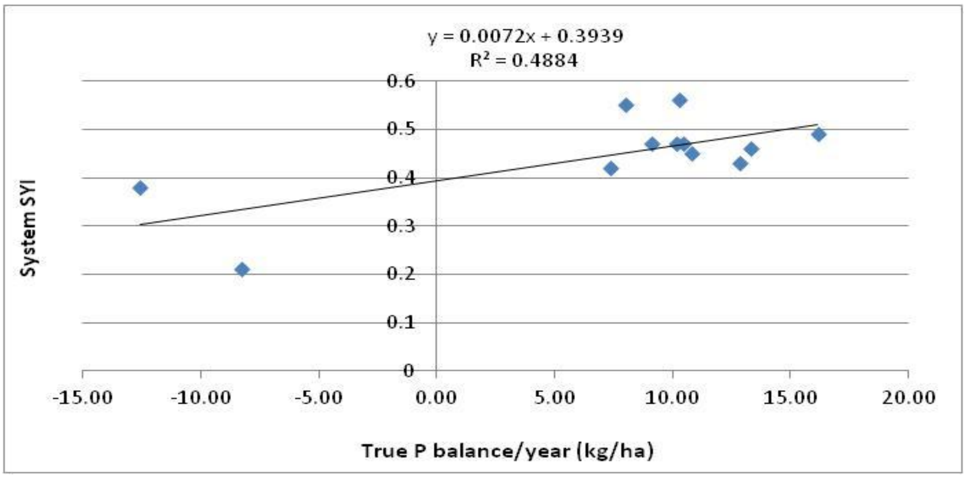

Fig. 1 (h) Effect of True P-balance on system yield sustainability

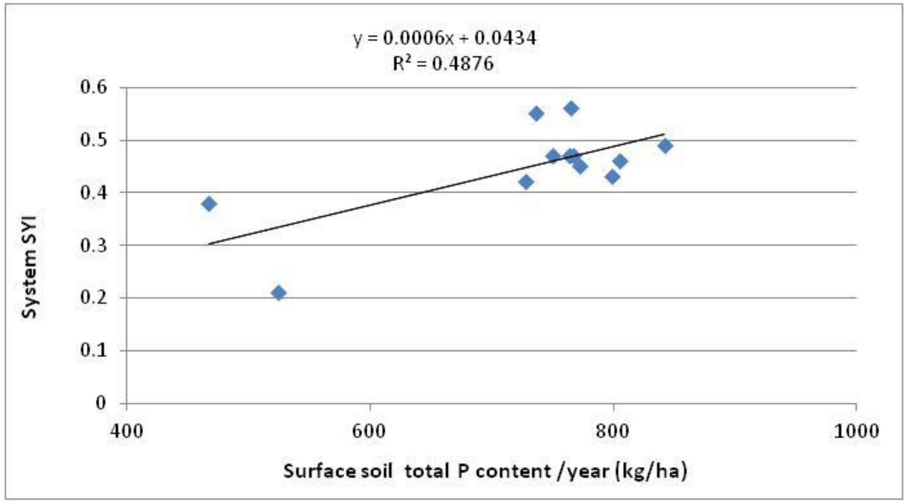

Fig. 1 (i) Effect of total P of surface soil on system yield sustainability

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

Treatments	Grain yield (q ha^{-1})		Sustainability Yield Index (SYI)			P uptake (kg ha$^{-1)}$	
	Dry season 17-18	Wet season 18	Dry season	Wet season	Total System	Dry season 17-18	Wet season 18
100% PK	22.91^{de}	28.73^{e}	0.45	0.36	0.43	7.66^{ef}	8.52^{e}
100% NPK	30.63^{bc}	34.56^{bc}	0.54	0.39	0.47	10.01^{cd}	11.97^{cd}
150% NPK	34.69^{b}	38.03^{b}	0.53	0.44	0.49	12.44^{b}	14.78^{b}
100%NPK + Zn	26.25^{cde}	33.53^{bcd}	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^{fg}	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^{fg}	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}

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

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^{ef}	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	10.20^{cd}	7.27^{de}	17.47	11.43^{d}	6.04^{cd}	34.94	21.63^{c}	13.31^{cd}
100% N	0	5.08^{gh}	-5.08^{f}	0	7.15^{e}	-7.15^{h}	0	12.23^{e}	-12.23^{h}
100 %NP	17.47	6.75^{fg}	10.72^{b}	17.47	8.83^{e}	8.64^{b}	34.94	15.58^{d}	19.3^{6b}
100% NPK+lime	17.47	11.61^{bc}	5.86^{e}	17.47	13.58^{bc}	3.89^{ef}	34.94	25.19^{b}	9.75^{f}
Control	0	4.00^{h}	-4f	0	3.87^{f}	-3.87^{g}	0	7.87^{f}	-7.87^{g}

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 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}) (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 (±)	-	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 in term of linear correlation coefficient (r)

P balance	Grain Yield		P-Uptake		Sustainable Yield Index		
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	System
Annual Apparent Balance	0.437	0.417	0.561	0.435	0.587*	0.690**	0.604*
Annual True Balance	0.560	0.484	0.562	0.551	0.681**	0.781**	0.693**
Total stock P	0.559	0.483	0.563	0.550	0.680**	0.780**	0.692**

4. CONCLUSION

The results demonstrated that conjunctive use of FYM @ 5 t ha^{-1}season^{-1} with optimal doses of NPK (80-40-60 kg^{-1} ha^{-1}season^{-1}) produced significantly higher grain yield with more sustainability than optimal or super optimal or sub-optimal doses of fertilizer alone. Yield with the application of lime (1.0 t ha^{-1}season^{-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. The highest yield sustainability was also found with the 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. The apparent and true P balance were 11.65kgha^{-1}year^{-1} and 10.24kgha^{-1}year^{-1} in 100%NPK+FYM treatment as compared to 12.96 and 10.41 in optimal and 25.18 and 16.15 in super optimal doses respectively. With the addition of 50% more phosphorus in 150% NPK treatment, there is 9.77% more accumulation than that of 100% NPK treatment. Within 13 years, application of Zn along with NPK caused 4.95% more P accumulation in surface soil. But supplemental application of Zn+B and Zn+S did not have any impact on total P content of surface soil.

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

Seasonal grain yields of wet and dry season are poorly correlated with apparent P balance (r= 0.377 and 0.437), true P balance (r= 0.484 and 0.560) and total stock of P (r= 0.483 and 0.559) and similarly, P uptake also show non-significant correlation with apparent P balance (r= 0.435 and 0.561), true P balance (r= 0.551 and 0.562) and the total stock of P (r= 0.550 and 0.563). Where as, sustainability of dry season, wet season and system yield as measured in terms of SYI strongly correlated with apparent P balance (r= 0.587*, 0.690** and 0.604*), true P balance (r= 0.681**, 0.781** and 0.693**) and total stock of P(r= 0.680**, 0.780** and 0.692**). Regression analysis also substantiated the above findings. Thus true P balance and the total stock of P in surface soil are better indicators of yield sustainability of each season and system as a whole. Thus, the total P-status of soil and its true balance exhibited its influence on the sustainability of double-crop rice grown under subtropical acidic *Inceptisol*. Among the treatments combination of FYM to 100%NPK is most sustainable with the moderate status of total P on the 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 the rice-rice cropping system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nishigaki T, Tsujimoto Y, Rinasoa S, Rakotoson T, Andriamananjara A, Razambelo T. Phosphorus uptake of rice plants is affected by phosphorus forms

and physic chemical properties of tropical weathered soils. 2019;435: 27–38.

2. Syers JK, Johnston AE, and Curtin D. Efficiency of soil and fertilizer phosphorus use. Reconciling changing concepts of soil phosphorus behaviour with agronomic information. FAO Fertilizer and Plant Nutrition Bulletin. Food and Agricultural Organization of the United Nations, Rome, Italy; 2008.
3. Krupenikov IA, Boincean BP, and Dent DL. The black earth: ecological principles for sustainable agriculture on chernozem soils. Springer, Dordrecht, the Netherlands;2011.
4. Manske CGB, Ortiz-Monasterio JJ, Van Ginkel M, Gonzalez RM, Rajaram S, Molina E, and Vlek PLG. Traits associated with improved P-uptake efficiency in CIMMYT's semidwarf spring bread wheat grown on an acid Andisol in Mexico. Plant Soil. 2000;221; 189–204.
5. Sarkar S, Bhaduri D, and Chakraborty K. Plant adaptation mechanisms in phosphorus-deprived soil: mitigation of stress and way to balanced nutrition. Adv. Plant Physiol. 2014;15; 254–282.
6. Brady NC, and Weil RR. The nature and properties of soils, in Chapter 14: soil phosphorus and potassium. 11th ed. Prentice-Hall International Inc., Upper Saddle River, NJ, USA.1999;445–486.
7. Kashem MA, Akinremi OO, Racz GJ. Phosphorus fractions in soil amended with organic and inorganic phosphorus sources. Can. J. Soil Sci. 2004;84: 83–90.
8. Qian P, Schoenau JJ, Wu T, and Mooleki P. Phosphorus amounts and distribution in a Saskatchewan soil after five years of swine and cattle manure application. Can. J. Soil Sci. 2004; 84(3);275–281.
9. Van Kauwenbergh S. World Phosphate Rock Reserves and Resources, IFDC Technical Bulletin, 75. International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, USA; 2010.
10. Deep M, Kumar RM, Saha S, Singh A. Rice-based cropping systems. Indian Farming. 2018;68: 27–30.
11. Lal B, Gautam P, Panda BB, Raja R, Singh T, Tripathi R, Shahid M, Nayak AK. Crop and varietal diversification of rainfed rice based cropping systems for higher productivity and profitability in Eastern India. PLoS ONE. 2017;12:175-709.
12. Dobermann A, Cassman KG, Cruz PCS, Adviento MAA, Pampolino MF. Fertilizer inputs, nutrient balance and soil nutrient supplying power in intensive, irrigated rice system. III. Phosphorus. Nutrient Cycling in Agroecosystems. 1996;46;111–125.
13. Nanzyo M. Progress and prospect of the research on paddy soil management under various rice growing system. 1. Progress in nutrient behavior and management research on paddy soil (2) Phosphorus. Jpn. J. Soil Sci. Plant Nutr. 1996;67;317-321.
14. Cho JY, Han KW, and Choi JK.Balance of nitrogen and phosphorus in a paddy field of central Korea. Soil Sci. Plant Nutr. 2000;46;343-354.
15. Pheav S, Bell RW, Kirk GJD, and White PF. Phosphorus cycling in rainfed lowland rice ecosystems on sandy soils. Plant Soil.2005;269;89-98.
16. Blake L, Johnston A, Poulton P. et al. Changes in soil phosphorus fractions following positive and negative phosphorus balances for long periods. Plant and Soil. 2003;254;245–261. Available:https://doi.org/10.1023/A:1025544817872
17. Lee Chang Hoon, Chang Young Park, Ki Do Park, Weon Tae Jeon, PilJoo Kim. Long-term effects of fertilization on the forms and availability of soil phosphorus in rice paddy. Chemosphere. 2004;56:299–304.
18. Nishio M. Analysis of the actual status of phosphate application in arable farming in Japan. Jpn. J. Soil Sci. Plant Nutr. 2003;74;435-443.
19. Zhang HC, Cao ZH, Shen QR, and Wong MH. Effect of phosphate fertilizer application on phosphorus (P) losses from paddy soils in Taihu Lake Region I. Effect of phosphate fertilizer rate on P losses from paddy soil. Chemosphere. 2003;50;695-701.
20. Lin DX, Hu Feng, Fan X H, Yang LZ. Effect of longterm fertilization on phosphorus transformation in paddy soil in the Taihu Lake region. Chinese Journal of Applied & Environmental Biology. 2006;12:453–456.
21. Yan X, Wang D J, Zhang H L, Zhang G, Wei Z Q. 2013b. Organic amendments affect phosphorus sorption characteristics

in a paddy soil. Agriculture, Ecosystems & Environment. 2013b;175: 47–53.

22. Tang X, Li J M, Ma Y B, Hao X Y, Li X Y. Phosphorus efficiency in long-term (15 years) wheat-maize cropping systems with various soil and climate conditions. Field Crops Research. 2008;108:231–237.
23. Bhatt MK, Labanya R, Joshi HC, Chandra R, and Raverkar KP. Long-term effects of inorganic fertilizers and FYM on soil chemical properties and yield of wheat under rice-wheat cropping system. ENVIS Bulletin Himalyan Ecology. 2017;25: 28-35.
24. Jat ML, Majumdar K, McDonald A, Sikka AK, Paroda RS. Book of extended summaries. National Dialogue on Efficient Nutrient Management for Improving Soil Health. In Proceedings of the TAAS, ICAR, CIMMYT, IPNI, CSISA, FAI, New Delhi, India. 2015;56:28-29.
25. Jackson ML. Soil chemical analysis. Prentic Hall of India Pvt. Ltd., New Delhi;1973.
26. Wanjari RH, Singh MV, & Ghosh PK. Sustainable Yield Index: An Approach to Evaluate the Sustainability of Long-Term Intensive Cropping Systems in India, Journal of Sustainable Agriculture. 2004;24(4):39-56,
    DOI: 10.1300/ J064v24n04-05.
27. Ghosh PK, Venkatesh MS, Hazra KK, Kumar N. Long term effect of pulses and nutrient management on soil organic carbon dynamics and sustainability on an Inseptisol of indogangatic plains of India. Experimental Agriculture. 2012;48:473-487.
    DOI:10.1017/S0014479712000130
28. Majhi P, Rout KK, Sahoo D, Behera M, and Behera BB. Nitrogen fertility of an Inceptisol planted to rice-rice as influenced by three years of continuous manuring with various organic and inorganic sources. Journal of Research, OUAT. 2003;21(1):55-61.
29. Majhi P, Rout KK. Effect of continuous application of different inorganic macro and micro nutrients and FYM on crop yield and changes in soil pH and SOC of an acidic typic Ustochrepts under sub tropical rice-rice eco-system. The Bioscan. 2016;11(3):1811-1815.
30. Shahid M, Nayak AK, Shukla AK, Tripathi R, Kumar A, Mohanty S, Bhattacharyya P, Raja R, and Panda BB. Long-term effects of fertilizer and manure applications on soil quality and yields in a sub-humid tropical rice-rice system. Soil Use Management. 2013;29;322–332.
31. Srilatha M, Sharma SHK, Devi MU, Rakha KB. Grain yield and soil nutrient status of rice-rice cropping systemas influenced by nutrient management under long term fertilizerexperimentation. Jornal of Progressive Agriculture. 2014;5(1):85-89.
32. Arulmozhiselvan K, Elayarajan M, and Sathya S. Effect of long term fertilization and manuring on soil fertility, yield and uptake by finger millet on Inseptisol. Madras Agricultural Journal; 2013;100;490-494.
33. Ghosh D, Mandal M, Pattnayak S. Long term effect of integrated nutrient management on dynamics of phosphorous in an acid Inceptisols of Traopical India. Communications in Soil Science and Plant Analysis;2021.
    DOI:10.1080/00103624.2021.1924186
34. Shahid M, AK Nayak C. Puree R, Tripathi B, Lal P, Gautam P, Bhattacharya S, Mohanty A, Kumar BB, Panda et al. Carbon and nitrogen fractions and stocks under 41 years of chemical and organic fertilization in a sub-humid tropical rice soil. Soil and Tillage Research. 2017;170:136–46.
    DOI:10.1016/j.still.2017.03.008
35. Majhi P., Rout KK. Nanda G., Singh M. Soil quality for rice productivity and yield sustainability under long -term fertilizer and manure application. Communications in Soil Science and Plant Analysis.2019;50(11):1330–43.
    DOI:10.1080/00103624.2019.1614607
36. Bhattacharyya R, Kundu S, Prakash V, Gupta HS. Sustainability under combined application of mineral and organic fertilizers in a rainfed soybean-wheat system of the Indian Himalayas. European Journal of Agronomy. 2008;28(1): 33–46.
    DOI:10.1016/j.eja.2007.04.006
37. Kang GS, Beri V, Sidhu BS, Rupela OP. A new index to assess soil quality and sustainability of wheat-based cropping systems. Biology and Fertility of Soils. 2005;41(6):389–98.
    DOI:10.1007/s00374-005-0857-4
38. Kumari G, Thakur SK, Kumar N, Mishra B. Long-term effect of fertilizer, manure, and lime on yield sustainability and soil organic carbon status under maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

in Alfisols. Indian Journal of Agronomy. 2013;58(2):152–58.

39. Bhatt R, Kukal SS, Busari MA, Arora S,Yadav M. Sustainability issues on rice—Wheat cropping system. Int. Soil Water Conserv. Res. 2016;4:64–74.
40. Ahmed W, Jing H, Kaillou L, Qaswar M, Khan MN, Jin C. Changes in phosphorus fractions associated with soil chemical properties under long-term organic and inorganic fertilization in paddy soils of southern China. PLoS ONE. 2019;14(5); e0216881. Available:https://doi.org/10.1371/journal.pone.0216881

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/85203