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Article

Reducing phosphorus fertilizer input in high phosphorus soils for sustainable agriculture in the Mekong Delta, Vietnam

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Abstract: High rates of phosphorus (P) currently being applied to soils for the production of vegetables in the Mekong Delta, Vietnam has led to the concern of its negative effect on the economics and the environment. This research presents a comprehensive study on the determination of P supplying capacity in this region of Vietnam to examine the possibility of reducing P fertilizer input. One hundred twenty (120) soil samples were collected to evaluate total P and Bray 1 available P in the soils. Phosphorus maximum sorption, degree of P saturation, P release, and the effect of P fertilizer on corn (Zea mays L.) yield in greenhouse and fields were also determined. Total P concentrations of 56.7% soil samples evaluated yielded high P concentrations (>560 mg P/kg), while 74.2% of the samples had high Bray 1 available P concentrations (>20 mg P/kg soil). Maximum P sorption ranged from 149 to 555 mg P/kg soil, respectively and has negative correlation to available P (r = - 0.63*), degrees of P saturation ranged from 0.63 to 5.46% correlated to available P (r = 0.98**) and maximum P release ranged from 1.2 to 61.9 mg P/kg soil, respectively correlated to available P (r = 0.96**). Corn grown in soils with available P concentrations >15 mg P/kg did not respond to P fertilizer in greenhouse or field experiments. We conclude that many farmers in this region can reduce P fertilizer input, thus increasing their profits and reducing negative environmental impacts associated with excess soil P for sustainable agriculture.

Keywords: Total P, Bray 1 available P, P sorption, P saturation, P release, P fertilizer input, corn yield.

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1. Introduction

Much has been written about nitrogen (N), the primary nutrient driving world crop production [24], another element, phosphorus (P), is no less important for supporting crop yields [25] with greater implications for the environment in terms of eutrophication [10];[28]. Phosphorus fertilizer use in Vietnam increased by more than double since 2011 to 2015 [Error! Reference source not found.]. The highest rates of P fertilizer application are generally associated with high value crops like vegetables and applied by most of the farmers in the vegetable planting areas in the Mekong Delta of Vietnam (MD). This fragile area of Southeast Asia supplies a high percentage of food to Vietnam and is a source of food exports to surrounding countries. The water drained from the Mekong Delta also influences the environmental quality and the quality of life for millions of people, which has led to questions related to (1) whether additional P fertilizer inputs for the enhancement or maintenance of vegetable production are needed, and (2) if continuous high P application will increase P leaching into the environment causing negative environmental impacts.

[13] reported that in New York, USA, 47% of the soil samples tested had values equal to or higher than the critical agronomic soil test phosphorus value for field crops (4.5 mg/kg soils Morgan

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extractable P). According to [32], no yield increase of sorghum observed in soils with available P Bray 1 concentrations exceeded 15 mg P/kg. No response of corn (Zea mays L.) or cotton (Gossypium spp.) to P fertilizer in soils with available P concentrations of 60-120 mg P/dm3 or more was also reported by [3]. [7] reported on P enrichment in Podzols soil in South Eastern Vietnam. In the vegetable growing areas in Tien Giang province in the MD, where P fertilizer was applied at high rates, available P Bray 1 concentration in soils ranged from 129 to 234 mg P/kg [11]. These values are much higher than the 15 mg/kg available P level, where no further yield response to P fertilizer occurred as reported by [33].

The level of P leaching into the environment depends on P fertilizer and other P inputs and adsorption/release characteristic of soil that affects available P levels. In soils with high available P, the P release may also be high. Hence, P supplying capacity is high and can provide enough P for plants. However, if the amount of P release is in surplus of crop demands, it may cause P to move into the environment, resulting in negative environmental impacts [3]. The relationships between P fertilizer application regimes, total, and available P, and the level of soil P saturation are therefore needed to improve P management in soil [1]. This information is missing for the vegetable growing regions of the Mekong Delta, Vietnam, which should be studied to examine the possibility of reducing P fertilizer inputs in these regions..

2. Materials and Methods

A total of one hundred and twenty (120) soil samples were collected from four (4) provinces in the major vegetable planting areas in the MD, Vietnam. These samples were from Thot Not (30 soil samples) in Can Tho province, Cho Moi (30 soil samples) in An Giang province, Binh Tan (30 soil samples) in Vinh Long province, and Chau Thanh (30 soil samples) in Tra Vinh province. These studied soils belong to different soil types namely Fluvisols, Gleysols, and Arenosols. Total P was determined by digesting the soil with concentrated sulphuric acid (H2SO4) and perchloric acid (HClO4), and available P measured by the Bray 1 method (0.05 M HCl+0.03 M NH4F) [16]. Figure 1a and 1b showed the corn field and research location of the study.

Figure 1a: The study corn field in the Mekong Delta, Vietnam (Thuy, 2015).

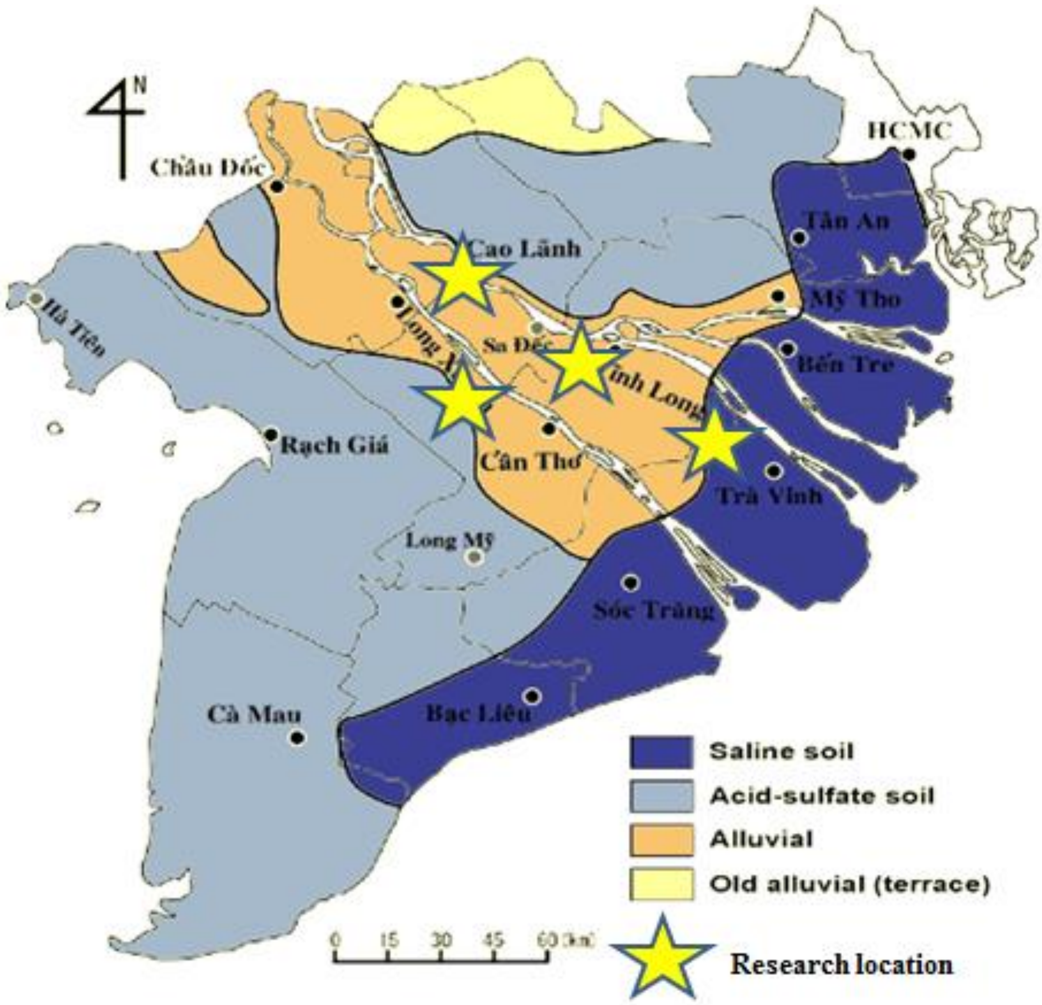

Figure 1b: Research location in the Mekong Delta, Vietnam (Thuy, 2015).

[4] reported on the rating category for total P being (170-260 mg P/kg soil) for low; (270-350 mg P/kg soil) medium; (350-560 mg P/kg soil) medium-high and (>560 mg P/kg) high. Rating category for Bray 1 available P content was according to the report of [16] classified as (3-7 mg P/kg soil) for low; (7-20 mg P/kg soil) medium and (>20 mg P/kg soil) high. Phosphorus sorption was determined according to the method described by [12] using nine (9) soil samples selected from the four (4) provinces, which had available P contents ranging from low to high value (6.8 - 120.3 mg P/kg). The amount of P added to soils ranged from 120 to 2,400 mg P/kg. The ratio of soil to solution in these tests was 1:20. The amount of phosphorus sorbed by the soil was determined by the Olsen method using 0.5 N $NaHCO3$ (pH 8.5) as the extracting solution. Maximum P sorption in soil was determined based on the Langmuir equation for the relationship between phosphorus sorption and phosphorus concentration at equilibrium in soil solution given as:

$$\frac{C}{q} = \frac{1}{b}C + \frac{1}{k \times b}$$

Where C represents the concentration of the solution after equilibrium (mg P/L), q, the amount of P sorbed (mg P/kg soil), b, the maximum phosphorus sorbed, and k, a constant. The slope of the line when plotting C/q (y-axis) versus C (x-axis) is equal to 1/b and the y-intercept value is equal to 1/ (k + b).

Degree of P saturation was examined as an index for evaluating the possibility of P release causing negative impact to the environment. Degree of P saturation was calculated according to the method described by [23]:

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$$DPS = (Pox/PSC) *100$$

Where DPS is the degree of P saturation (%), Pox is the extracted by ammonium oxalate (mg P/kg) and PSC (Maximum phosphorus sorption capacity of the soil, mg P/kg), the maximum P sorption determined based on Langmuir equation.

Phosphorus release was determined following the method described by [26] for nine (9) soil samples used for P sorption study. The amount of P release extracted at ratios of 1:10; 1:60; 1:120; 1:240 soil: water was at different shaking extraction times (that is, after 1, 12, 24 or 48 h), respectively. Maximum P release (mg P/kg soil) was calculated as the difference between the highest P release value and the P release value at 1 h of the1:240 ratio.

A greenhouse study was carried out at Can Tho University from 1st to 9th 2011. Two consecutive crops of baby corn (Zea mays L.) with trade name "Amaizing" were grown in forty (40) soil samples selected from the four (4) provinces and conducted in a Randomized Complete Block Design (RCBD). The two factors considered were (1) 10 different soils in each province (40 soil samples in 4 provinces), which had available P Bray 1 content ranging from low to high values and (2) 2 rates of P fertilizer application (0 and 90 kg P2O5/ha). Treatments were replicated thrice to give a total experimental unit of 240 pots. The 40 different soil samples ranged from 5.8 to 76.9 mg/kg soil for Can Tho province, 6.8 to 87.2 mg/kg soil for An Giang province, 13.1 to 120 mg/kg soil for Vinh Long province, and 12.7 to 224 mg/kg soil for Tra Vinh province. N and K fertilizers were applied at a rate equivalent to 160 kg N/ha and 90 kg K2O/ha. Baby corn was planted as the test crop for the two cropping seasons and yield determined by measuring the total weight of the corn ear.

Field experiments were also carried out in An village, Cho Moi district, An Giang province from 1st to 9th 2011 with two consecutive crops grown at two sites (Sites 1 and 2) having high and medium available P contents of 20.5 and 15.1 mg P/kg, respectively. At the onset of planting the second crop, one more site (Site 3) with low available P content of 6.8 mg P/kg was selected for examining corn response to P fertilizer in low available P soil. Hybrid sweet corn of variety F1 M × 10 was used in these experiments. The experiments carried out using a Randomized Complete Block Design (RCBD) with three P fertilizer rates (0, 45, and 90 kgP2O5/ha) and four replications produced 12 experimental plots in each of the sites. The size of the experimental plots was 33-47 m2. Nitrogen and potassium fertilizer were fixed at doses of 160 kg N/ha and 90 kg K2O/ha. Measured characteristics were the same as for greenhouse experiments.

3. Statistical Analysis

Data were statistically analyzed for ANOVA using the general linear model function and treatment means differentiated using the Turkey test. Simple linear regression and correlation were also calculated. The Minitab software v16 was used for all statistical analysis.

4. Result and Discussion

4.1. Total and available phosphorus concentrations

Table 1 shows the total phosphorus contents in the soils evaluated. Soils in the high category (total P was > 560 mg P/kg) accounted for 56.7% of the total studied samples. [9] reported that there was an increase of total P in 48% of the area in 1990 and 73% in 2001 due to P run-off from the agricultural soils in Everglades in America, and total P > 500 mg P/kg considered as rich. Table 1 shows that available P Bray 1 concentrations ranged from 3.6 to 224 mg/kg, with 74.0% of the soil samples classified as high (that is, concentrations were 20.4 mg P/kg or higher). The reason may be high rates of P applied to soils for the production of vegetables in the Mekong Delta of Vietnam. Along with this study, the survey results of 120 farmers in 4 provinces of Can Tho, An Giang, Vinh Long, and Tra Vinh showed that farmers applied from 109 to 194 kg P2O5/ha on leaf vegetables, baby corn hybrid sticky corn and tomato. The high P content in these soils attributed to high phosphorus fertilizer application is similar to the report of [11].

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Table 1: Total P and Bray 1 available P concentrations, and ratings of 120 soils from 4 provinces in major vegetable planting area in Vietnam.

Range of soil P	Rating[a] category	Samples in rating category (%)
Total P (mg/kg soil)		
568-1048	High	56.7
393-524	Medium-High	36.1
306-349	Medium	6.2
131	Low	1.0
Bray 1 available P (mg/kg soil)		
20.4-224	High	75.0
7.3-19.5	Medium	20.0
3.6-6.8	Low	5.0

4.2. Maximum Phosphorus Sorption

Table 1 shows that the correlation between P sorption content and equilibrium P in soil solution, which followed a simple Langmuir equation had a high determination coefficient, R2, of 0.72 to 0.99. Therefore, this equation could be used to calculate the qm value. Maximum P adsorption concentrations (qm) were high (384-588 mgP/kg) in soils with low and medium P available content and lower (149-454 mg/kg) in soils with high available P. It seems that the soil samples with initial high P available contents had most P fixation sites almost saturated, with less P sorbed. These results are in line with the report of [5], indicating P fixation occurred rapidly at low concentrations and depended on soil characteristics. The predominant reactions are precipitation at high P concentration in solution and adsorption at low P concentration [6];[20].

[31] reported on a higher sorption on calcareous soils with qm = 691 - 1664 mg P/kg, while [30] found similar results with our study on Spodozols (qm=224 - 560 mg P/kg). Our results also showed a negative correlation between maximum P sorption and available P with correlation coefficient r = -0.63* (P<0.05), therefore the higher available P in soils, and the lesser P from fertilization was sorbed, resulting in high P leached to the environment. Hence, it is important to note that when more P fertilizer is added to soils already containing high amounts of available P, P sorption in soil decreases and the risk in P run-off to environment becomes high in these soils. Therefore, P fertilizer rates in these major vegetable growing areas should be adjusted to prevent the risk in P run-off to the environment, especially in high available P soils.

Table 2: Langmuir equation and its determination coefficient (R^2), maximum P sorption, degree of P saturation (DPS), maximum P release, and correlation coefficient (r) between these parameters in the studied soils from 4 provinces in Vietnam.

Available P category	Available P content (mg/kg)	Langmuir Equation $C/q = C/q_m + (1/k)\, q_m$	R^2	Maximum P sorption (mg/kg)	DPS (%)	Maximum P release (mg/kg)
Low	6.8	C/q = 0.0018C +0.0038	0.98	555	0.63	1.2
Medium	12.7	C/q = 0.0026C + 0.0071	0.96	384	1.10	4.3
	13.1	C/q = 0.0017C + 0.0083	0.73	588	0.97	6.0

High	20.5	C/q = 0.0022C + 0.0045	0.72	454	1.97	6.2
	38.1	C/q = 0.0050C + 0.0263	0.98	200	2.42	6.7
	47.3	C/q = 0.0029C + 0.0145	0.99	344	3.12	30.0
	87.2	C/q = 0.0023C + 0.0133	0.97	424	5.28	33.0
	92.4	C/q = 0.0067C + 0.0112	0.97	149	4.69	36.5
	120.3	C/q = 0.0037C + 0.0039	0.99	270	5.46	62.0
r of maximum P sorption, DPS, and maximum P release with available P, respectively.				-0.63*	0.98**	0.96**
r of DPS and maximum P release with maximum P sorption					-0.61*	-0.52^{ns}
r of maximum P release with DPS						0.91*

4.3. Degree of P Saturation

In soils with low and medium available P, the degree of P saturation (DPS) ranged from 0.63-1.23%. Table 1 shows the DPS values were higher in soils with high available P, ranging from 1.74-5.46%. The DPS in these soils from Vietnam were lower than the critical level of DPS (25%) for evaluating P contamination in ground water [29]. They reported that a DPS >25% indicates a surplus of P in soils and P fertilization is not advised. However, in a recent study, [23] evaluated P leaching risk by comparing the actual DPS of the soils and the critical DPS of the soil type. They observed that the critical phosphorus saturation degree varies from 5 to 78%, and about 43% of the agricultural land in the Netherlands exceeded the critical DPS value for the soil type. They concluded that a large area of agricultural land in the Netherlands contributes, or is expected to contribute to the P pollution of surface water in the nearby future.

[34] reported that when P sorbed increases due to high P application, P release also increases, hence the risk of P contamination in water increases. [34] observed the DPS of 0.02-0.27% on submerged soils, 4-20% on vegetable soils, and 4-10% on fruit garden soils. The DPS values of our studied soils were at the low value in the range reported by [34], and was at the low value in the range of the DPS critical value as reported by [22]. In our study, the available P concentrations in these same soils was observed to increase by 7.2 and 56.0 mg P/kg (data not shown) after five applications of 90 kg P2O5/ha in the greenhouse study. Therefore, the risk of P run-off to the environment is expected to increase if P fertilizer is continuously applied at this high rate. [24] also reported that excess P can cause P run-off or leaching to water resources, raising concerns about the agricultural contribution to eutrophication of inland waters and marine environments.

4.4. Phosphorus Release and Correlation

Phosphorus released from soil reached a maximum content at an extraction ratio of 1:240, soil: water. However, there were some soil types with high available P content that also released high amounts of P at the extraction ratio of 1:60 and 1:120, although the differences were not statistically significant (P <0.05) compared to the 1:240 extraction ratio (Figure 2).

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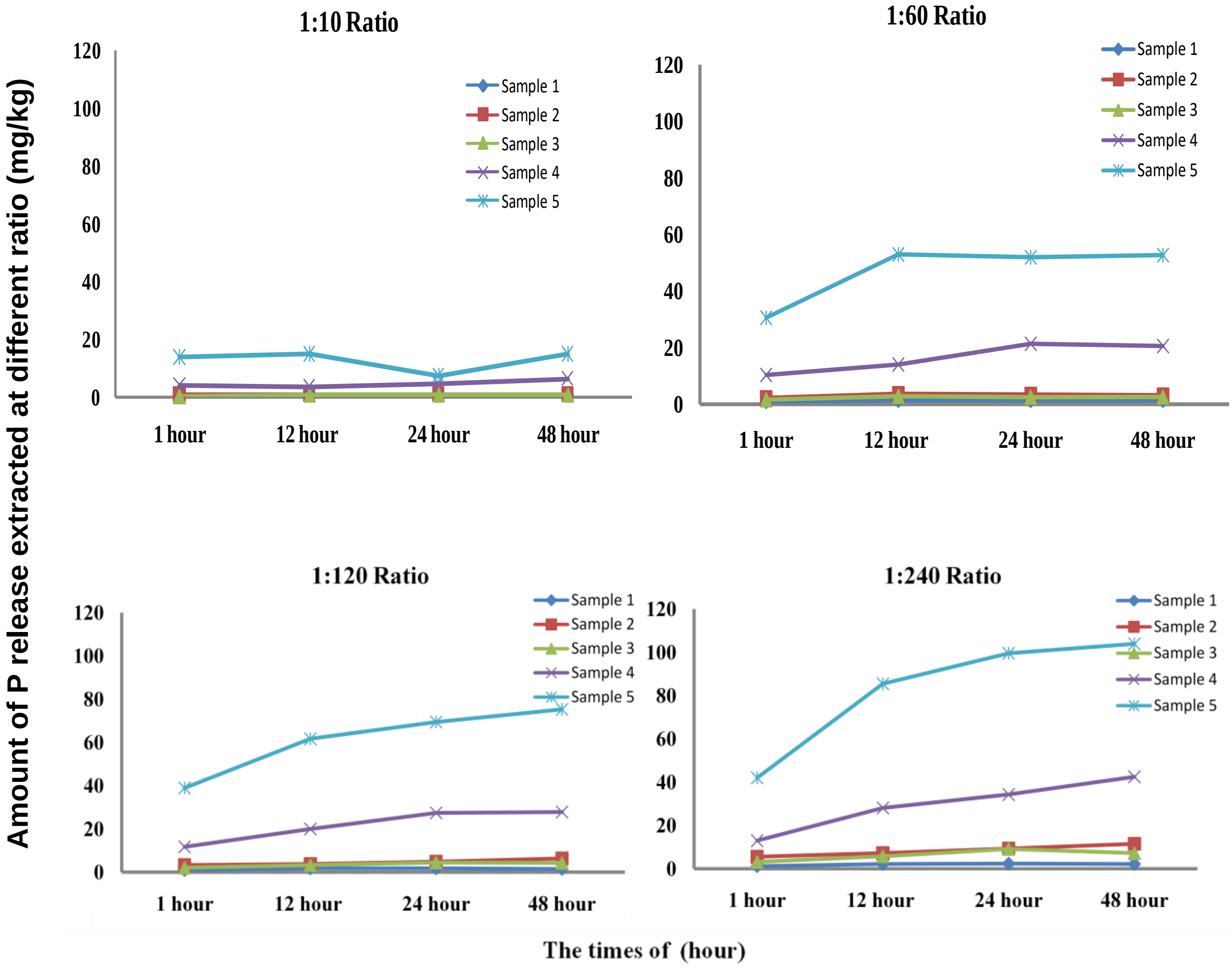

Figure 2: Phosphorus release over time at different extraction rates on surveyed soils. Samples 1, 2, 3, 4, and 5 were selected as representative for the nine (9) studied samples, which have available P concentration (mg/kg soil) being 6.8, 13.1, 20.5, 47.3, and 120.3 mg/kg, respectively.

Maximum P released ranged from 1.2 to 6.0 mg P/kg in soils with low and medium available P content, and from 6.2- 62.0 mg P/kg in soils with high available P content. Table 2shows that the linear correlation analysis between P release and available P concentrations showed a high correlation coefficient of r = 0.96**. A positive correlation also existed between maximum P release and degree of P saturation (r = 0.91**), meaning when soil is saturated with P, most of the site for P sorption is occupied, and more P released. Hence, there was a tendency to increase maximum P release with an increase in P availability and the risk of P run-off to the environment in high available P soils. Although soil P testing alone will not answer all questions about P loss because the potential P loss depends on run-off potential and management practice at the site, these relationship, however, can provide scientific bases for establishing preliminary soil test P criteria to identify the P leaching loss potential and then combine with site hydrology and P management practices for a more comprehensive P loss risk assessment [31].

4.5. Corn Responses to P Fertilizer

4.5.1 Corn Responses to P Fertilizer in Greenhouse Experiment

Figure 3 shows corn response to P fertilizer from two (2) consecutive crops in the greenhouse experiment on soils from Thot Not – Can Tho, Cho Moi - An Giang, Binh Tan – Vinh Long, and Chau Thanh – Tra Vinh. Results showed that there were no statistically significant differences in corn yield

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of 90 kg P2O5/ha treatments and the zero P treatment (that is, the control) for all four studied sites. Although there were many more positive yield responses than no or negative yield responses, a general trend for less yield response in high available P soils was observed. Because application of P fertilizer in soils of medium and high P available content did not result in a statistically significant increase in corn yield, reduction of P fertilizer use in these soils should be considered, especially where farmers have continually applied high rates of P fertilizer

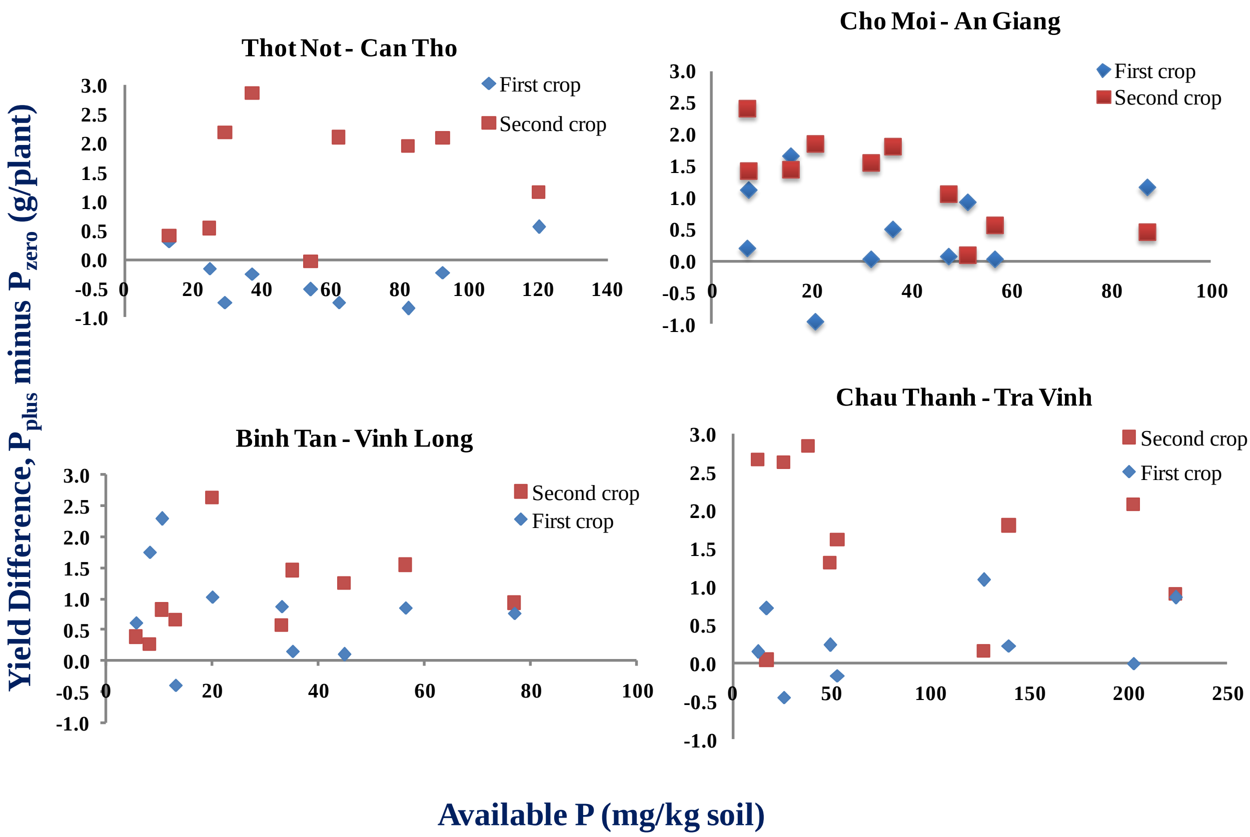

Figure 3: Baby corn yield differences (greenhouse experiment) grown in soils with different levels of available P and left unfertilized or fertilized at 90 kg P_2O_5/ha.

4.5.2 Corn Responses to P Fertilizer in the Field

Results in Figure 4 showed that there was no statistically significant difference in corn yield among zero P fertilizer treatments (7.6 t/ha), 45 kg P2O5/ha treatments (8.4 t/ha) and 90 kg P2O5/ha treatments (8.7 t/ha) at site 1 (available P in soil was 20.5 mg P/kg), and among zero P fertilizer treatment (5.9 t/ha), 45 kg P2O5/ha treatments (5.2 t/ha), and 90 kg P2O5/ha treatments (5.5 t/ha) at site 2 (available P in soil was 15.1 mg P/kg) for the first growing season. In the second crop, similar results were obtained when no yield response was found at Sites 1 and 2. [33] reported no increase in yield of sorghum in high phosphorus soil (> 15 mg P/kg-Bray 1), and a crop growth response to P fertilizer but no response on yield observed in soils with available P content from medium to low (<15 mg P/kg). For corn plant, [33] observed that there is a high probability (>80%) of grain yield increase with starter P fertilizer for no-till corn on soils of Bray 1 available P ≤ 15 mg /kg and yield increase was less in higher P soils.

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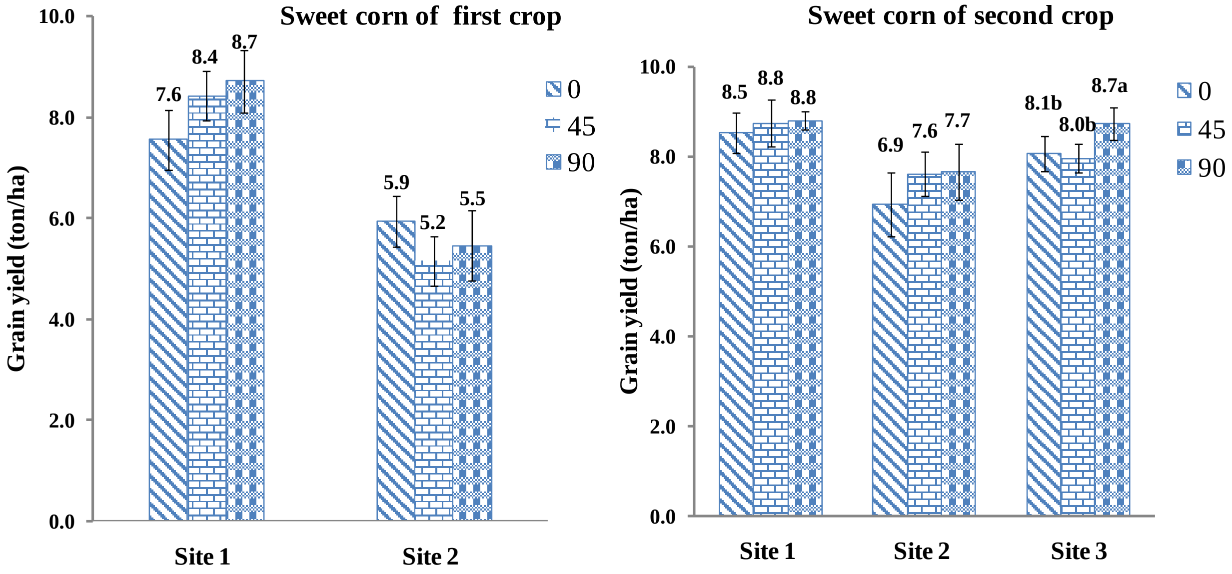

Figure 4: Corn yield at treatments of 0, 45 and 90 kg P_2O_5 in three (3) studied sites at Cho Moi- An Giang.

Sites 1, 2, and 3 had available P concentration (mg/kg soil) being 20.5, 15.1, and 6.8 mg P/kg. respectively.

In our study, when soils with poor available P content (6.8 mg P/kg) was treated with 90 kg P2O5/ha, corn yield increased (8.7 t/ha) in comparison to the zero P fertilizer treatment of 8.01 t/ha. Lower yields were obtained from soil treated with 45 kg P2O5/ha (8.0 t/ha) and this yield were not statistically different from the zero P fertilizer treatments. Thus, it seems if soils from this region of Vietnam are deficient in P, at least a 90 kg P2O5/ha treatment is needed to increase crop yield, but when available P Bray 1 was at medium to high content (from 15 to >20 mg P/kg), P fertilization was not advised. This result is in line with reports of [14]; [18];[19]; [17].

5. Conclusions

Fluvisols, Gleysols and Arenosols, in major vegetable growing areas of the Mekong Delta, Vietnam, where most of the farmers applied P fertilizer at high rate, total P of 56.7% of the studied samples >560 mg P/kg are considered rich in P. Available P of 74.0% of the soil samples >20 mg P/kg were classified rich in available P.

Maximum P sorption ranged from 149 to 555 mg P/kg soil and were negatively correlated to available P (-0.63*). Degrees of P saturation remained low ranging from 0.63 to 5.46% and correlated to available P (r =0.98**), while maximum P release ranged from 1.2 to 61.9 mg P/kg soil correlated to available P (r = 0.96**). In high available P soil, the degree of P saturation increased with P sorption becoming lesser, and an increase in P released, hence the risk of P leaching to the environment will increase if P fertilizer is applied continuously at a high rate, considerate for the sustainable development.

In addition, corn yield did not significantly increase ($P < 0.05$) in soils where available P Bray 1 concentrations were >15 mg P/kg. Therefore, it is advised not to apply P or P at reduced rates in these soils. In soils with low P Bray 1 (< 7 mg P/kg), P sorption was high with low P released and yield responses to P fertilizer application. Therefore, applying P fertilizer to these soils is recommended. The results of the study were provided to farmers to maximize P fertilizer use efficiency that will reduce fertilizer costs, increase income and reduce the adverse effects on the environment. .

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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