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Full Length Article

Establishing P Fertilization Recommendation Index of Different Vegetables by STP with the "3414" Field Experiments in South China

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Abstract

The aim of this study was to establish phosphorus fertilization recommendation index of different vegetables (leafy, gourd and leguminous vegetables) by soil test P (Olsen-P and Bray1-P) with the “3414” experiments of 121 sites during 2007-2010 in 30 counties of Guangdong Province, China. The results showed that relationship between vegetable relative yield and soil test P was linear with plateau and logarithmic equation model. The optimal amount of P fertilizer was established with soil test P by logarithmic equation mathematical models. The soil P content was calculated by the relative yield of 50, 75, 90 and 95%, to obtain the soil P abundance and deficiency indicators. Taking plentiful-lack of soil-test P as an index, soil Olsen-P and Bray1-P were classified into five classes corresponding to relative yield of 50, 75, 90 and 95%. This study shows P fertilizer recommended rates were rendered by the models of soil test P with Olsen-P and Bray1-P for “3414” field experiments for three vegetables. © 2014 Friends Science Publishers

Keywords: Phosphorus; Recommended fertilizer; STP (soil-test P); Different vegetables

Introduction

Phosphorus is an essential nutrient element for production of limiting agricultural enhancement in most regions of the world and a vital non-renewable natural resource, and management decisions concerning P fertilization affect crop yield and grower profitability (Dawson and Hilton, 2011; Veneklaas *et al*., 2012). The P fertilizers produced in China before 1990s used to be low-graded. The situation has been changing rapidly in recent years. The forecasts suggest that demand for fertilizer will increase further in 2030 (Zhang *et al*., 2008; Van Vuuren *et al*., 2010). In China, in a continued effort to increase profitability, many farmers have over-applied P resulting in very high STP (soil-test P) levels in many fields (Vitousek *et al*., 2009; Zhang *et al*., 2011).

In South China, many farmers have been applying excessive P fertilizer for the requirements of vegetable during the last 30 years, which was not considered with different varieties of vegetables originally testing STP (soil-test P). Agricultural non-point source pollution contributed more than point source pollution when the surface runoff occurred a few days after P application coupled with heavy rainfall. Research has demonstrated that plants yield response to P for various STP levels and has calibrated various soil P tests (Dodd *et al*., 2005; Mallarino and Atia, 2005). Several STP methods, such as BP (Bray1-P) and OP (Olsen-P), are routinely used to predict P sufficiency for crops (Irving and McLaughlin, 1990; Mallarino and Atia, 2005). These tests were designed to extract a fraction of P that correlates with plant uptake, but not necessarily to correlate well with every vegetable (Chen *et al*., 2004; Mkhabelaa and Warman, 2005). Thus, the methods for determining critical concentrations of soil test phosphorus for different vegetables provides insights into P nutrition, and can serve as a guide to improved agricultural practice in South china, as indicators of P deficiencies in production; however, neither indicator provided information about excess P fertilization.

Materials and Methods

Experiment Design

The experiments were conducted during 2007-2011 in 30 counties of Guangdong Province, china. Vegetables for the test were represented by the samples of 37 selected in leafy vegetable (*Brassica campestris* L.), 43 selected in gourd vegetable (*Momordica charantia*) and 34 selected in leguminous vegetable (*Vigna unguiculata* (Linn.).

A total of 121 sites were selected. Each site received a completely “3414” design with three factors (N, P, K), four levels (0, no fertilizer; 2 level, approaching optimum amount of local site; 1 level = 2 level×0.5; 3 level = 2 level×1.5 (excessive fertilization), and 14 treatments ($N_0P_0K_0$, $N_0P_2K_2$, $N_1P_2K_2$, $N_2P_0K_2$, $N_2P_1K_2$, $N_2P_2K_2$, $N_2P_3K_2$, $N_2P_2K_0$, $N_2P_2K_1$, $N_2P_2K_3$, $N_3P_2K_2$, $N_1P_1K_2$, $N_1P_2K_1$, $N_2P_1K_1$).

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N_2 level received 150, 187.5, 90 kg N ha^{-1}, as Urea [$CO(NH_2)_2$] (N, 46%), P_2 level received 30, 120, 135 kg P_2O_5 ha^{-1}, as Calcium superphosphate (P_2O_5, 12%), and K_2 level received 99, 180, 172 kg K_2O ha^{-1}, as KCl (K_2O, 60%). Fertilizers application was made before vegetables planting. Plot size was 20 m^2 for 78 sites with three or four replications. Each site was located within a farmer's field and was managed by the farmer with vegetables system. The space of leafy vegetable was 0.20 m × 0.20 m and for gourd and leguminous vegetables was 0.8 m × 0.6 m by one line per plot. Production was measured by plot at harvest.

Sampling and Laboratory Procedures

Soil samples from all experimental sites were collected from three replications before planting at the beginning of experiment. Each sampling included five cores per plot taken to a depth of 20 cm. Collected before each field test mixed topsoil (0~20 cm) soil samples based, air-dried over 1 mm sieve before the nutrient analysis.

Soil phosphorus was extracted with sodium bicarbonate (Olsen method, 0.5 M $NaHCO_3$) (Olsen *et al.*, 1954) and hydrochloric acid-ammonium fluoride (Bray 1 method) (Bray and Kurtz, 1945), respectively. Soil phosphorus content was measured by anti-determination of molybdenum.

At maturity, vegetable production data was calculated by non-phosphorus (P_0) and phosphorus level 2 (P_2) under N 2 level, 2 levels of potassium.

Data Analysis

The methods of indicators about soil available phosphorus levels: For each experimental site, vegetable relative yield (RY) was calculated as: $RY\%=RY_{(P0)}/RY_{(P2)}\times100\%$, where $RY_{(P0)}$ stands for vegetable yield in each (P_0) treatment, $RY_{(P2)}$ for the maximum vegetable yield at that site. The relationship between the effective relative yield and soil phosphorus was obtained by logarithmic equation. The soil phosphorus content was calculated by the relative yield of 50, 75, 90 and 95%, to obtain the soil phosphorus abundance and deficiency indicators. Phosphorus determination is very low, low, medium, high and very high at the relative yield of 50%, 50-75%, 75-90%, 90-95% and >95%, respectively.

The calculating method of the amount of recommended fertilizer: The function of phosphate effect was set up according to the regression analysis between the output and fertilizer applied by 50 to 70 trials. Based on economic output and fertilizer applied, the best amount of P fertilizer was calculated with the marginal analysis of each test point by a logarithmic equation model. The optimal amount of phosphorus applied was obtained according to the average adopted when the three functions are suit. The corresponding correlation analysis between the optimal amount of phosphorus applied and soil phosphorus content were established. The technical indicators of P fertilizer recommended at all levels of soil phosphate were set up by the formula of every vegetable. Logarithmic equation, and linear with plateau model were adopted (Cerrato and Blackmer, 1990).

Results

Linear with Plateau Models between Soil-Test P Concentration and Vegetable Relative Yield

In this study, soil-test of Olsen-P and Bray1-P content were measured, samples of 37 selected in leafy vegetable, 43 points gourd vegetable and 34 of leguminous vegetable production data extraction agent for two kinds of soil phosphorus measured relative yield of vegetables and field trials were configured by logarithmic equation (Fig. 2).

The results indicated that response of vegetables relative yield on soil-test P measured with two routine methods for trials was linear with plateau models across all vegetable species. Based on these models, calculated leafy vegetable maximum yield and minimum soil-test P concentration by Olsen-P or soil Bray-P were 69.9 kg P kg^{-1} soil, 297.2 kg P kg^{-1} soil, respectively ($P < 0.01$, Fig. 1a, b). This indicates that two soil P test methods had significant difference in leafy vegetables yield; calculated gourd vegetable maximum yield and minimum soil-test P concentration by Olsen-P or soil Bray-P were 89.3 kg P kg^{-1} soil, 356.9 kg P kg^{-1} soil, respectively ($P < 0.01$, Fig. 1c, d). This indicates that two soil P test methods had significant difference in gourd vegetables yield. Calculated leguminous vegetable maximum yield and minimum soil-test P concentration by Olsen-P or soil Bray-P were 36.5 kg P kg^{-1} soil, 44.7 kg P kg^{-1} soil, respectively ($P<0.01$, Fig. 1c, d). This indicates that two soil P test methods had no difference in leguminous vegetables yield.

When soil-test P content was 0 kg P kg^{-1} measured by soil Olsen-P or soil Bray-P, leafy vegetables relative yield was 69.9% and 57.4%. This indicates that minimum relative yield of leafy vegetables had significant difference between two soil P test methods. Gourd relative yield of 60.7 and 64.0% indicates that minimum relative yield had no difference between two soil P test methods. Likely leguminous relative yield of 52.5 and 50.0% indicates that minimum relative yield of gourd vegetables had no difference between two soil P test methods.

Logarithmic Equation Models between Soil-Test P Concentration and Vegetable Relative Yield

The relative yield had high correlation (leafy vegetable, $r=0.7657^{**}$, $n=37$, Fig. 2a; gourd vegetable, $r=0.6549^{**}$, $n=43$, Fig. 2c; leguminous vegetable, $r=0.745^{**}$, $n=34$, Fig. 2e) with soil-test of the Olsen-P, which indicated that relative yield of three vegetables significantly correlated with Olsen-P.

Table 1: Abundance and deficiency indexes of available phosphorus of different extraction methods

Vegetable species	Classification	Relative yield (%)	Olsen-P (mg kg^{-1})	Bray1-P (mg kg^{-1})	Total amount of P_2O_5 recommended (kg hm^{-2})
Leafy vegetable	Very Low	<50	<5	<4	95
	Low	50~75	5~20	4~40	65~95
	Medium	75~90	20~70	40~170	45~65
	High	90~95	70~100	170~280	35~45
	Very High	>95	>100	>280	<35
Gourd vegetable	Very Low	<50	<5	<1	200
	Low	50~75	5~20	1.0~20	150~200
	Medium	75~90	20~70	20~130	110~150
	High	90~95	70~120	130~250	95~110
	Very High	>95	>120	>250	<95
Leguminous vegetable	Very Low	<50	<2	<9.0	160
	Low	50~75	2~18	9.0~50	110~160
	Medium	75~90	18~60	50~160	90~110
	High	90~95	60~95	160~230	80~90
	Very High	>95	>95	>230	<80

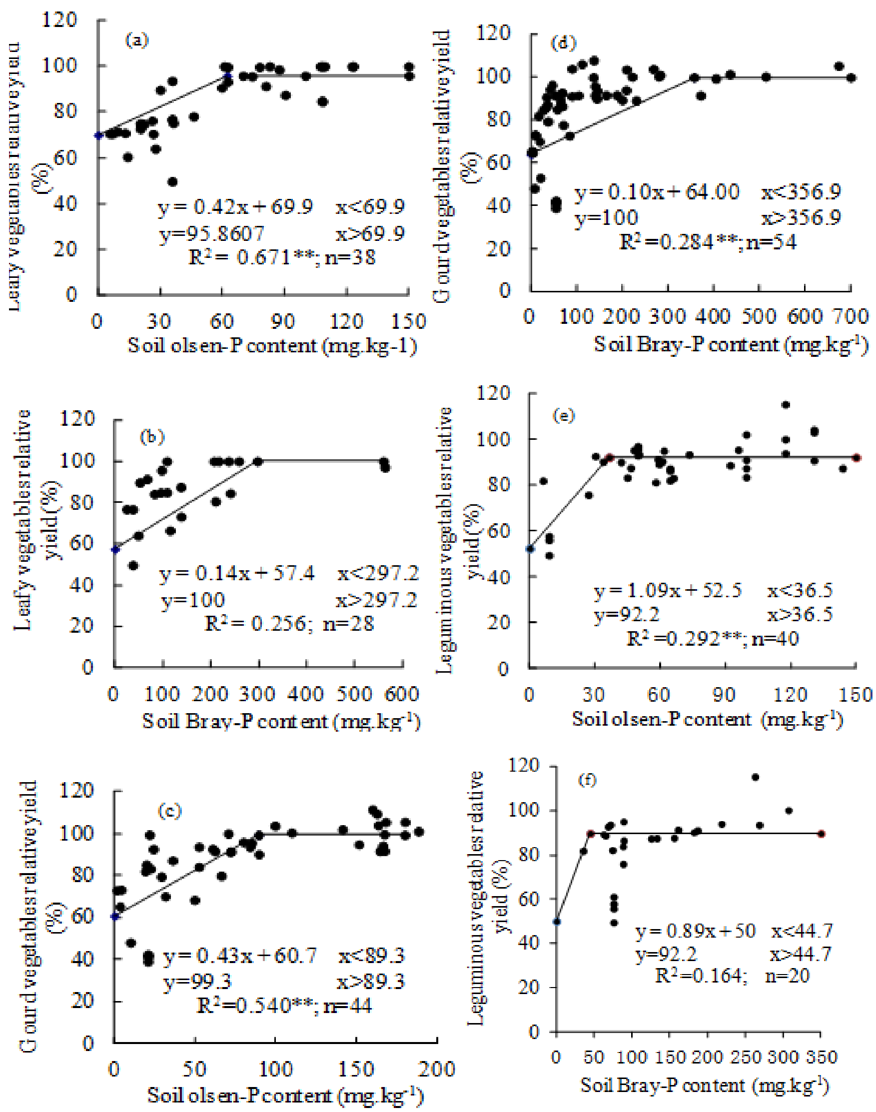

Fig. 1: Relationship between soil-test P (Olsen-P: a, c, e; Bray-P: b, d, f) and relative yield of different vegetables with linear with plateau model across 2007-2011 South China locations. Leafy vegetable (a, b); Gourd vegetable (c, d); Leguminous vegetable (e, f)

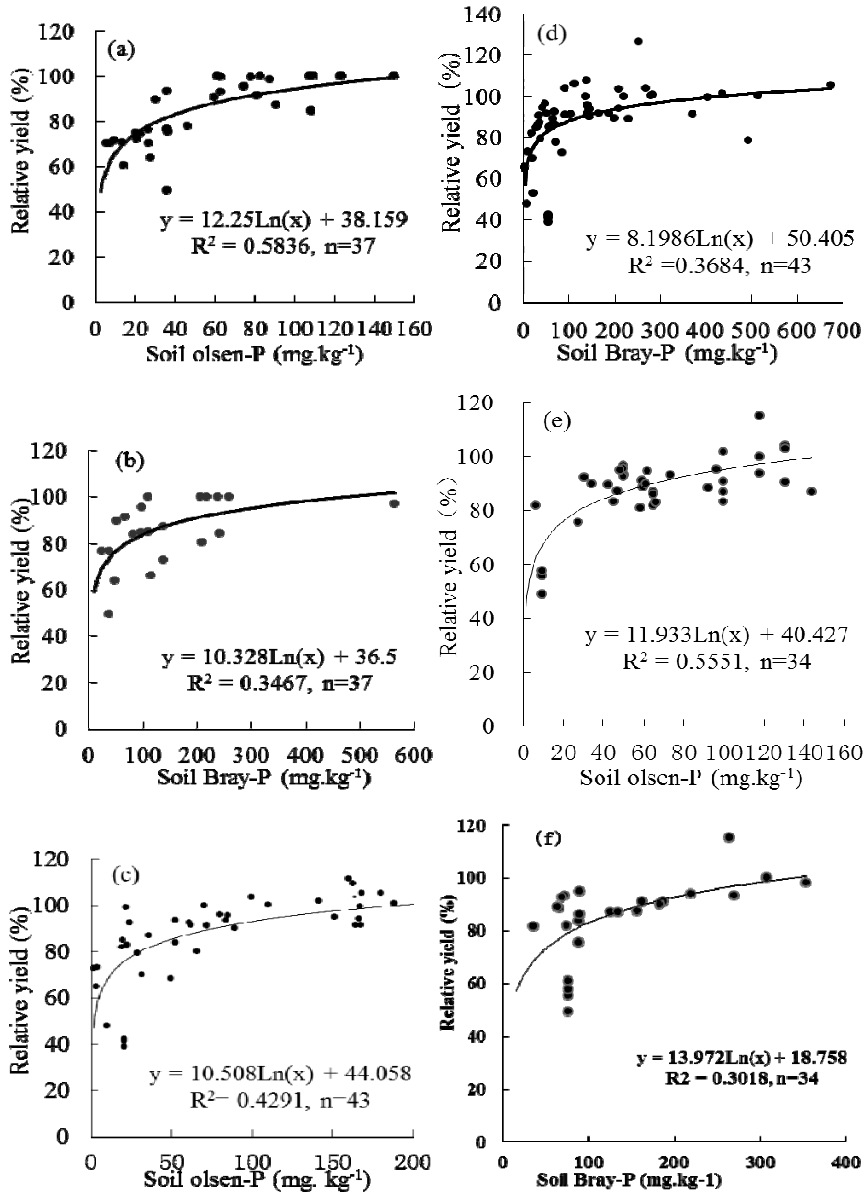

Fig. 2: Relationship between soil-test P (Olsen-P: a, c, e; Bray-P: b, d, f) and relative yield of different vegetables with linear with logarithmic equation model across 2007-2011 years. Leafy vegetable (a, b); Gourd vegetable (c, d); Leguminous vegetable (e, f)

Similarly, the relative yield had high correlation (leafy vegetable, r=0.5888**, n=37, Fig. 2b; gourd vegetable, r =0.6077**, n=43, Fig. 2d; leguminous vegetable, r=0.5493**, n=34, Fig. 2f) with soil-test of Bray1-P, which indicates that relative yield of three vegetables were significantly correlated with Bray1-P.

The Mathematical Models of Relationship between Phosphorus Applied and Soil Olsen-P Test in Three Vegetable Species

The field model parameters are based on results from three vegetable species. The mathematical models of relationship between optimum phosphorus applied and soil Olsen-P test in three vegetable species, leafy (Fig. 3a), gourd (Fig. 3b) and leguminous vegetables (Fig. 3c) suggest the data fitted the model very well and given the good fit observed with the field data, the parameters were considered reliable enough to use for the estimation of fertilizer recommendations.

P Fertilizer Recommended Abundance and Deficiency Indexes of Soil Soil-test P of Different Extraction Methods

Phosphorus nutrient abundance and deficiency and

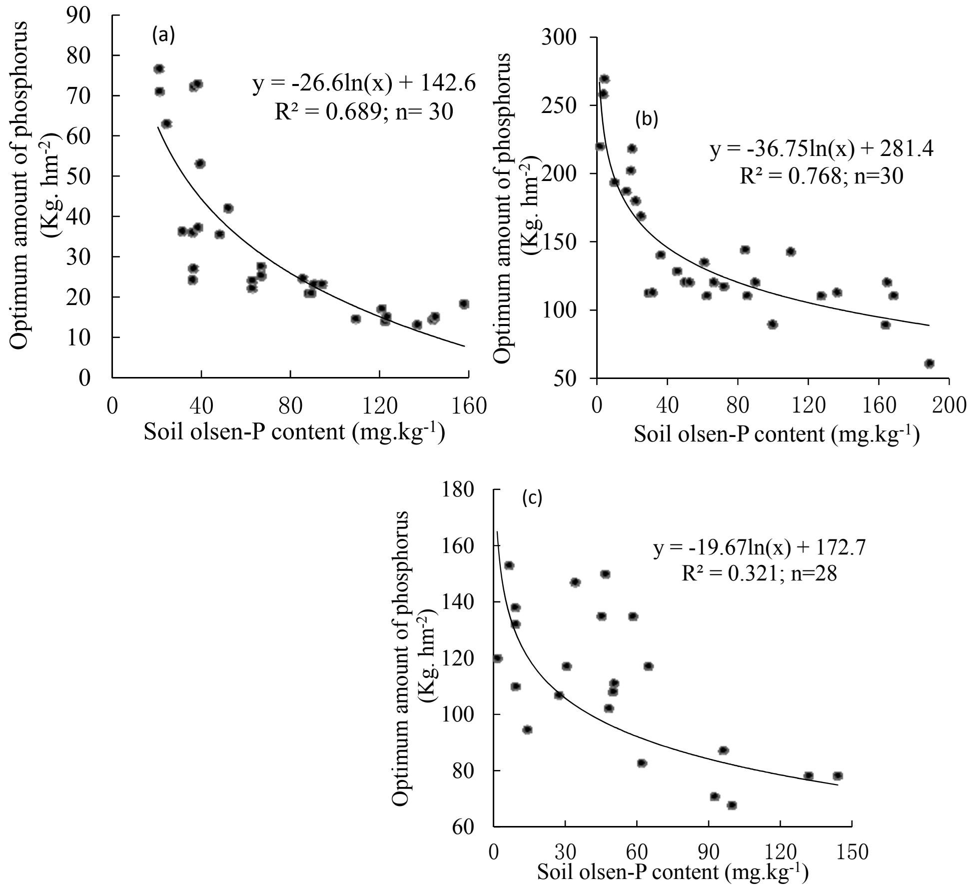

Fig. 3: The mathematical models of relationship between phosphorus applied and soil olsen-P test in three vegetable species. Leafy vegetable (a); Gourd vegetable (b); Leguminous vegetable (c)

fertilization recommendation index of three vegetable species were established based on "3414" field experiments of trail. Taking plentiful-lack of soil-test P as an index, soil Olsen-P and Bray1-P were classified into five classes corresponding to relative yield of 50%, 75%, 90% and 95%. Fertilizer recommended rates were simulated by the models for "3414" field experiments for three vegetables.

Phosphorus fertilizer recommended with leafy vegetable (P_2O_5, kg hm^{-2}) were $P_2O_5 \geq 95$, $65 \leq P_2O_5 < 95$, $45 \leq P_2O_5 < 65$, $35 \leq P_2O_5 < 45$, $P_2O_5 < 35$, when soil fertilizer was classified as very low, low, medium, high and the highest according to soil-test P [w(soil-test Olsen-P, kg hm^{-2}): $P_2O_5 < 5$, $5 \leq P_2O_5 < 20$, $20 \leq P_2O_5 < 70$, $70 \leq P_2O_5 < 100$, $P_2O_5 \geq 100$; w(soil-test Bray1-P, kg hm^{-2}): $P_2O_5 < 4$, $4 \leq P_2O_5 < 40$, $40 \leq P_2O_5 < 170$, $170 \leq P_2O_5 < 280$, $P_2O_5 \geq 280$].

Phosphorus fertilizer recommended with gourd vegetable (P_2O_5, kg hm^{-2}) were $P_2O_5 \geq 200$, $110 \leq P_2O_5 < 200$, $110 \leq P_2O_5 < 150$, $95 \leq P_2O_5 < 110$, $P_2O_5 < 95$, when soil fertilizer was classified as very low, low, medium, high and the highest according to soil-test P [w(soil-test Olsen-P, kg hm^{-2}): $P_2O_5 < 5$, $5 \leq P_2O_5 < 20$, $20 \leq P_2O_5 < 70$, $70 \leq P_2O_5 < 120$, $P_2O_5 \geq 120$; w(soil-test Bray1-P, kg hm^{-2}): $P_2O_5 < 1$, $1 \leq P_2O_5 < 20$, $20 \leq P_2O_5 < 130$, $130 \leq P_2O_5 < 250$, $P_2O_5 \geq 250$].

Phosphorus fertilizer recommended with gourd vegetable (P_2O_5, kg hm^{-2}) were $P_2O_5 \geq 160$, $110 \leq P_2O_5 < 160$, $90 \leq P_2O_5 < 110$, $80 \leq P_2O_5 < 90$, $P_2O_5 < 80$, when soil fertilizer was classified as very low, low, medium, high and the highest according to soil-test P [w(soil-test Olsen-P, kg hm^{-2}): $P_2O_5 < 2$, $2 \leq P_2O_5 < 18$, $18 \leq P_2O_5 < 60$, $60 \leq P_2O_5 < 95$, $P_2O_5 \geq 95$; w(soil-test Bray1-P, kg hm^{-2}): $P_2O_5 < 9$, $9 \leq P_2O_5 < 50$, $50 \leq P_2O_5 < 160$, $160 \leq P_2O_5 < 230$, $P_2O_5 \geq 230$].

Discussion

Critical concentrations of STP are used to identify soils where response to P fertilization should be expected. There is however, little agreement concerning the methods that should be used to identify critical STP concentrations for P fertilizer applied in different vegetables. In the present study, these results have raised more concerns that the agronomic interpretation of the soil P test varies among different vegetable crops would usually be expected to respond to added P at this test level. Two soil P test methods exist relative to the exact P requirement of vegetable yield and P fertilization levels required to produce the required levels in the soil (Sims *et al*., 2000), which indicates that different vegetables probably require more or less supplemental P to optimize agronomic crop performance. Based upon these research findings, P additions should be set up to those known to provide agronomic benefits by two ways of soil P test (Olsen-P or Bray1-P), and excess P additions should be avoided to maximize economic return, although vegetables have higher agronomic P requirements (Sharpley *et al.*, 1996; 2000).

In general, P in agro-ecosystems must be managed to ensure P availability for optimum crop production and to minimize the losses of P (Beegle *et al*., 2005). Soil testing to assess the soil available P status and to provide guidance for potential P additions is a key step in the management process (Beegle *et al*., 2005). Equations for calculating three recommendations are shown in Fig. 3. Thus, the extent to fertilizer P for each vegetable is given by the optimum amount of phosphorus according to Olsen-P in soil, respectively (Fig. 3). With the knowledge of extractable P content for any site in the district, it should now be possible to prescribe an economically optimum P fertilizer recommendation (Ussiri *et al*., 1998). From phosphorus fertilization recommendation index, we found that three vegetable species should be supplied with phosphorus fertilization according to soil-test P with Olsen-P or Bray1-P, which were classified into five classes corresponding to relative yield of 50%, 75%, 90% and 95% by the models for "3414" field experiments for three vegetables.

In conclusion, the programs of phosphorus requirements and management for the intensive vegetable production were rendered on measurement of soil available phosphorus results with Olsen-P and Bray1-P by using the "3414" experiments in three vegetables, to improve the continued use of the phosphorus resources, and minimize non-point sources of pollution on surface and ground waters. Overall, the results of this study demonstrated that selection of five classes STP concentration with Olsen-P and Bray1-P could be a major factor affecting the profitability of P fertilization in three different vegetables taking plentiful-lack of soil-test P as an index.

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