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Determination of Phosphorus Fertilizer Dose for Rice Using Mitscherlich-Bray Equation

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Authors' contributions

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

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ABSTRACT

Soil fertility maps in India showed that more than 90% of Indian soils are deficient in available phosphorus (P) although built-up is also reported in some areas. In this study, the modified Mitscherlich–Bray (MB) response equation was used to generate P fertilizer rates for aerobic rice by supplying with graded dose of P fertilizers. Three strip of different P gradient was created. Response of aerobic rice to added P suggested that crop showed a diminishing return with increasing dose of P. The data fitted to Mitscherlich-Bray (MB) equation showed that the theoretical maximum yield was estimated to be 60.847 (±0.394) q ha^{-1}, the value of c related to the efficiency of the soil and fertilizer P is 0.084 (±0.008) and the R^2 calculated using the uncorrected sums of squares is 0.988 that the MB equation is quite reliable. The estimated P rates for rice based on soil test values, price of fertilizers/price of crop ratio, and marginal rate of return would range from 57 – 68 kg ha^{-1} and this is much higher than the general recommended dose of 22 kg ha^{-1}.

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1. INTRODUCTION

Phosphorus (P) is an essential element for all life forms on earth. In plants, P makes up about 0.2% of the plant dry matter and crop requires P in large quantities. The GIS-based soil fertility maps of India showed that more than 90% of the soils are deficient in available P [1]. This demonstrate that most agricultural soil requires huge quantity of external supply of P to obtain optimum yield and maintain soil health. In contrast, buildup of available P is also observed in many fields particularly maize-wheat cropping system in northwest India as result of long-term P fertilization [2]. Therefore, fertilizer recommendation should be based on soil test and crop response through proper calibration [3].

The Mitscherlich–Bray (MB) response equation modified by [4] offers a way of estimating fertilizer P rates from soil test P values, crop yield and applied fertilizer P. It assumes existence of some mathematical relationship between crop yield and available P. The MB equation was successful in determining the P fertilizer requirement for some crops [3,5,6]. According to MB equation, increase in plant growth with each successive addition of a fertilizer nutrient is progressively smaller and follows the law of diminishing return. The MB equation as modified by [4] presented in their paper was:

$$y = A\,(1 - \exp[-c\,(x + f(T)] \qquad (1)$$

where, y is the predicted yield obtained by application of x units of P fertilizer to a soil with a soil P test value T. The parameter A is defined as maximum theoretical yield and c is related to the efficiency of the soil and fertilizer P. The function f(T) relates T to an amount of plant available P in the soil. Mombiela et al. [4] defined total effective phosphorus (TEP) as f(T) + x. The function f(T) was taken to be a linear function of T. The MB equation then became:

$$y = A\,(1 - \exp[-c(TEP)]) \qquad (2)$$

where, TEP = bT + x, and b is a constant. Thus, the final form of the MB equation used to correlate crop yield with soil and fertilizer P in this study is:

$$y = A\,[I - \exp(-c(a + bT)] \qquad (3)$$

As yield response were of a diminishing return form, optimal P fertilizer recommendation (PR) were calculated by the following equation [7]:

$$PR = (1/c)\ln[cA\,(1 + R)/b] - bT \qquad (4)$$

where, p = price of fertilizer/price of crop, R = marginal rate of return, and other terms is defined previously. Thus, this paper aims to estimate the economically optimum P fertilizer recommendation from soil P test values from aerobic rice receiving graded P dose.

2. MATERIALS AND METHODS

2.1 Study Site

The experiment was carried out in 2019-21 at the Zonal Agriculture Station, Mandya, Karnataka. The soil is sandy clay loam in texture, pH 7.80, had medium level of organic carbon (0.55%), and belong to Typic Rhodostalfs. The initial status of available N, P and K was 156.8, 17.1 and 103.2 kg ha^{-1}, respectively.

2.2 Gradient Experiment

In the first year, prior to the main crop experiment, artificial P fertility gradient was created by dividing the experimental field into three rectangular strips which were applied with low (11 kg P ha^{-1}), medium (22 kg P ha^{-1}) and high dose of P (33 kg P ha^{-1}) in strip I, II and III, respectively. Then exhaustive fodder maize (African tall) was grown until maximum vegetative stage to stabilize and allow the nutrient to undergo transformation in the soil by plant and microbes.

2.3 Test Crop Experiment

In the second year, after the exhaust crop was harvested, each fertility gradient experiment was further divided into sub-plots. P fertilizer was added to all the plots at 0, 11, 22 and 33 kg P ha^{-1} in a randomized block design as basal and aerobic rice (MAS 946-1) was grown to study the crop response to P fertilizers. All recommended agronomic practices for aerobic rice were followed. All the plots were given adequate doses of N and K, applied as urea and muriate of potash, respectively. Grain yields of the crops were determined at full crop maturity. The data on yield, soil test and quantity of P fertilizers added from the field experiment was used to plot the MB response equation.

2.4 Soil P Analysis

Available P in soil is analyzed using Olsen et al. method [8].

2.5 Data Analysis

The equation was fitted using the nonlinear regression procedure of SPSS [9] to estimate the constants A, b, and c, as well as the predicted yield.

3. RESULTS AND DISCUSSION

3.1 Creation of P Fertility Gradients

Soil P test values from each strip suggested that soil P fertility gradient was successfully created. The soil P test value in strip I, II and III was 10.9, 21.1 and 39.0 kg P ha^{-1}, respectively. In general quantity of fertilizers added to create fertility gradient have direct effect of soil P test values. Singh et al. [10] also reported that the available P increase with increasing fertility level, and the highest available P was reported in strip III.

Table 1. Rice grain yield (q ha^{-1}), added P (kg ha^{-1}) and Olsen soil test P (kg ha^{-1}) used in calibration study

Added P	Gradient		
	I	II	III
0	37.17	53.63	58.55
11	51.71	57.98	59.85
22	57.25	59.63	60.35
33	59.36	60.27	60.54
Olsen P	10.9	21.1	39.0

3.2 Response of Aerobic Rice to Added Phosphorus

Grain yield of aerobic rice at different levels of added P at each fertility gradient is presented in Table 1. A significant increase in grain yield was observed with the application of P in low fertility strip. This showed that rice crop is responsive to P fertilizer application. In medium and high fertility strips, the increase in crop yield is not as prominent as in the low fertility strip. It also showed that increase in grain yield with each successive addition of P fertilizer is progressively smaller which is in agreement with the condition of MB equation.

3.3 Relationship between Grain Yield and TEP

The grain yield under varying dose of P in different fertility strip is subjected to MB equation [eqn. (1)]. A good relationship was obtained between grain yield of crops and TEP. The model parameters such A, b and c are given in Table 2 and plotted in Fig. 1. The theoretical maximum yield was estimated to be 60.8 q ha^{-1}. The R^2 calculated using the uncorrected sums of squares associated with the model is highly significant. The value of TEP was also estimated through linear regression, which is then plotted against the predicted and actual yields to provide a clear picture of yield response to TEP (Fig. 1). The curve pattern shows that the crop response curve obeys the Mitscherlich curve [11] and the response can be used to obtain optimum P dose. With increase in TEP, the predicted yield increase. The TEP is a linear combination of soil and fertilizer P. The nutrient efficiency coefficient, c indicates how quickly the predicted yield approaches asymptotic maximum as the TEP increases [7]. This showed that soil test should not be the only basis for fertilizer recommendation [12].

Table 2. Response function and their 95% confidence intervals (CI) obtained by nonlinear regression procedure of SPSS using MB equation

A	b	c	R^2
60.847 (±0.394)*	1.087 (±0.102)	0.084 (±0.008)	0.988

**Values in parenthesis is the standard error*

3.4 Soil Test-based P Fertilizer Recommendations for Aerobic Rice

The parameters from the modified MB equation were considered reliable enough to use for the estimation of P fertilizer recommendation [Fig. 1]. This equation reflects the assumption of the modified MB equation that soil and fertilizer P can be substituted in some proportion [3]. Thus, the b parameter explains how much soil P can be substituted by fertilizer P. The scenario that most likely prevailed in India for rice during the period under experimentation is presented in Table 3. A survey in the P fertility status of farmers' field in Mandya area suggested that Olsen P status falls under medium category [1]. Based on this scenario (R = 0.2, p = 0.008), the fertilizer P rates for aerobic rice calculated estimated to be 68.2, 62.8 and 57.3 kg ha^{-1} if the soil test value was 10, 15 and 20 kg ha^{-1}, respectively. This suggested that there is a dire need of site-specific nutrient management system rather than the generally adopted general recommendations that is made for large areas [13].

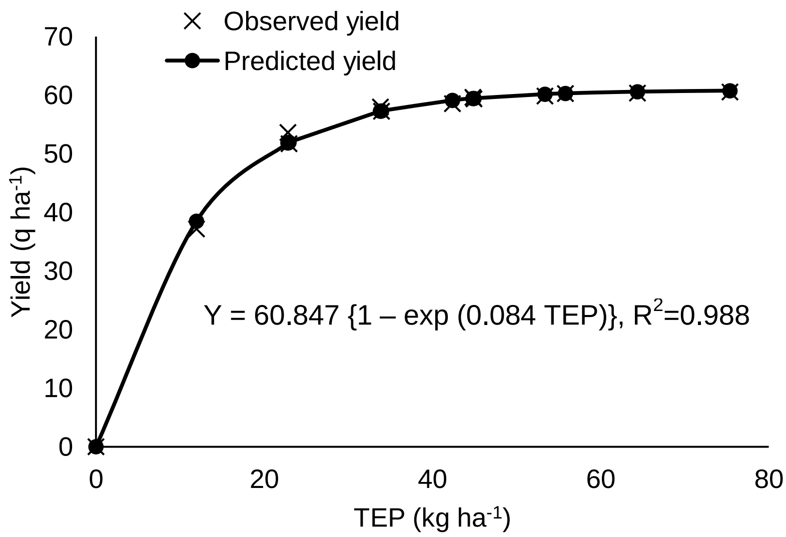

Fig. 1. Relationship of yield and total effective P under field conditions

Table 3. Equations for P fertilizer rates (P_R) on kg ha^{-1} based on a given soil test values in kg ha^{-1}, price of fertilizers/price of crop ratio (p) and marginal rate of return (R) based on [Eqn. (4)]

R = 0.1, p = 0.006	R = 0.2, p = 0.006	R = 0.1, p = 0.008	R = 0.2, p = 0.008
81.46 – 1.087 T	82.49 – 1.087 T	78.03 – 1.087 T	79.07 – 1.087 T

4. CONCLUSION

Rice responded well to P fertilizer application, especially in soil having low and medium available P. The aerobic rice has a theoretical yield of 60.847 q ha^{-1}, and fit well the MB equation. The estimated P rates for rice would range from 57 – 68 kg ha^{-1} and this is much higher than the general recommended dose of 22 kg ha^{-1}. Further study should focus on verification and comparison of agronomic characteristics at field level.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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