IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-6, Issue-5, May 2018 E-ISSN: 2347-2693

Mathematical Model to Predict the Soil Macronutrients Status under the Influence of Phosphorus and Manure for Continuous Cropping System

M. Khajanchi[1*], R. Sharma[2], U. Pancholi[2]

[1]Department of Mathematics, Government College, Bundi, University of Kota, Kota (India)
[2] Department of Mathematics, Government College, Kota, University of Kota, Kota (India)

[*]Corresponding Author: mahikhajanchi2011@gmail.com, Tel.:9352238445

Available online at: www.ijcseonline.org

Accepted: 17/May/2018, Published: 31/May/2018

Abstract— In the present work we studied, how phosphorus fertilizer and manure affect the soil status of other macronutrients like nitrogen and potassium using mathematical model. By knowing the status of nutrients availability, a producer can manage things and get high crop yield. The model was applied to five fertilizer practices of a two year field experiment entitled "Integrated nutrient management in blackgram", conducted in Rajasthan College of Agriculture, Udaipur, Rajasthan, India.

Keywords- phosphorus, mathematical model, macronutrients, nitrogen soil status, potassium soil status

I. INTRODUCTION

A proper combination of nutrients is required by plants to grow, live and reproduce. Excess or lacking of any nutrient may cause problems. Soil is the major source to supply most of the essential nutrients, required by plants. Removing of nutrients by one crop and not replaced for next subsequent crop production will result in decreased yield accordingly. The requirements of fertilizers containing NPK (Nitrogen–Phosphorous–Potassium) have been increased in last few decades [1]. The importance of Fertilizers is to determine the nutritional content [2].

Producer or farmer can manage fertilizer application if he knows results of soil analysis i.e. the accurate amount of nutrient removed and replaced for crop production statistics. By using soil analysis producer can determine the level of nutrients available in soil and estimate the amount of nutrients needed to supplement in soil. These nutrients are of specific function and should be supplied to plants in right time and right quantity. Insufficient amounts of nutrients result into poor crop growth and low yield [3]. Excess supply of nutrients never helps in producing higher crop yield, even leads wastages as in addition of leaching, washing and many times raise serious causes for human health. The nitrate available in the plants may cause methemoglobinaemia disease in new born babies and creates problems in the intestine and stomach like abnormal acid secretion [4]. That's why, it is recommended to consume fruits or vegetables containing less nitrate [5].

To take high crop production, the supply of essential macronutrients is required. N is abundantly present in nature, but plants can't take it directly from the air. In addition to providing a place for crops to grow, soil is the only source for most of the essential nutrients required by the crop. When N is deficient in soil, cropping systems require N inputs [6]. Most of the available crop production technologies are based upon increasing the availability of N to crops. The augmentation of soil N is accomplished by various sources for supplying N to crops [7]. Inorganic fertilization is a option to alleviate its deficiency but it is expensive. Manure obtained from livestock could be a cheap source of nutrients, but it is required in bulk amount to satisfy plant nutrient requirements [8]. In West African countries the various type of organic manure like ruminant dung and poultry dropping are very popular for crop production and to improve agricultural practice. It helps to provide a good amount of nutrients needed in the soil and improve the physical condition of soil. Organic fertilizer plays an important role as a major contributor to supply plant macronutrients. It works as a storehouse for cation and improves their exchange capacity also reduces undesirable pH fluctuation [9].

In last few decades several studies have taken place to measure effect of various type of inorganic and organic fertilizer over soil and plant. Integrated Nutrient Management (INM) refers as the process to maintain the soil fertility and nutrient supply to plant for achieving an optimum level of productivity by optimizing the benefits from all possible sources of biological, inorganic and organic components in an integrated manner.

In a study of combined effect of phosphorus and nitrogen on soyabean plant, it was found that growth, yield potential of soybean and an increase N_2 fixation can be achieved by using inoculation of *B. japonicum* and P with small dose of N fertilizer application. The highest improvement of 34.77% was obtained when 11.5 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 were combined with *B japonicum* [10]. At El-Khattara, in a field experiment on sandy soil it was found that combined application of different levels of N and P fertilizer with or without compost; influenced various attributes like growth and yield of okra plants significantly [11].
Combined or individual fertilization of N and P improve plant growth in saline soil. It was found that shoot dry weight of wheat crop in sandy soil was significantly affected by N and P individually and in combinations with and without salinity [12]. At south-western Ethiopia, in a field experiment there was a measure significant increase in the grain yield of food barley and observed significant improvement in most of the physico-chemical properties of soil under the application of FYM combined with different levels of inorganic N and P over the application of 100% mineral NP alone and the control [13]. A treatment of 5 t FYM ha^{-1} in combination with 75% recommended rates of inorganic N and P increased soil organic carbon content and available P.
In a long-term experiment it was found that combination of FYM and inorganic NP enhanced grain yield of maize, improve soil chemical properties and water use efficiency significantly as compared to the use of inorganic N and P fertilizers only [14]. In Udaipur of Rajasthan, results of a field experiment in clay loam soil has shown higher seed/grain and stover/straw yields of blackgram and wheat under the integrated use of 5 t FYM, 40 kg P_2O_5 and dual inoculation of PSB (*Bacillus megathereum* var.phosphaticum) and VAM (*Glomous faciculatum*) [15]. It shows that, INM involving both inorganic and organic fertilizer combinedly is the more effective and feasible approach to maintain a productive and healthy soil [16, 17].
In present work a mathematical model is developed and applied to available experimental data. Section 1 includes introduction, in section 2 we present mathematical model and steady state solution, section 3 contains validation of model, in next section 4 we present application of model and section 5 is devoted to result and discussion while in section 6 we present conclusion and future scope of work.

II. MODEL

In our previous work [7], we used a mathematical model to predict phosphorus status in soil on some available data to study the effect of P fertilizer and its residual effect on soil. In this paper we extend that study to find the status of other macronutrients in presence of P fertilizer for continuous cropping system under the assumption that no other macronutrients fertilizers were added to soil. So we modify the basic equation of previous model, as

$$M_{(i,1)} = M_{(i-1,2)} - U_{(i,1)} + E_1 \tag{1}$$

$$M_{(i,2)} = M_{(i,1)} - U_{(i,2)} + E_2 \tag{2}$$

if we take two crops in a year.
where $M_{(i,1)}$ and $M_{(i,2)}$ are the level of a macronutrient in soil after first and second crop in i^{th} year respectively. Here we assume that a fixed amount $U_{(i,1)}$ and $U_{(i,2)}$ are uptake of macronutrient by first and second crop respectively in i^{th} year. E_1 and E_2 are the built-up level of macronutrient due to the factor other than considered in basic equations for first and second crop respectively.
We assume that uptake of macronutrient $U_{(i,1)}$ by first crop depends on the macronutrient available in soil after the previous second crop $M_{(i-1,2)}$ i.e.

$$U_{(i,1)} = f(M_{(i-1,2)})$$

or $$U_{(i,1)} = \gamma_1 M_{(i-1,2)} + c_1 \tag{3}$$

where γ_1 shows the expected soil macronutrient efficiency $(0 \le \gamma_1 \le 1)$ for first crop and c_1 shows the uptake of macronutrient from unaccounted sources by first crop $(c_1 \ge 0)$.

Also uptake of macronutrient $U_{(i,2)}$ by second crop depends on the macronutrient available in soil after the previous first crop $M_{(i,1)}$ i.e.

$$U_{(i,2)} = g(M_{(i,1)})$$

or $$U_{(i,2)} = \gamma_2 M_{(i,1)} + c_2 \quad (4)$$

where γ_2 shows the expected soil macronutrient efficiency $(0 \le \gamma_2 \le 1)$ for second crop and c_2 shows the uptake of macronutrient from unaccounted sources by second crop $(c_2 \ge 0)$.

SOLUTION OF MODEL

Putting (3) in (1), we get

$$M_{(i,1)} = (1-\gamma_1)M_{(i-1,2)} + E_1 - c_1 \quad (5)$$

Using (4) in (2), we get

$$M_{(i,2)} = (1-\gamma_2)M_{(i,1)_2} + E_2 - c_2 \quad (6)$$

Using (6) in (5), we have

$$M_{(i,1)} = (1-\gamma_1)(1-\gamma_2)M_{(i-1,1)} + (1-\gamma_1)(E_2 - c_2) + (E_1 - c_1) \quad (7)$$

Using iteration in (7), we get

$$M_{(i,1)} = (1-\gamma_1)^2(1-\gamma_2)^2 M_{(i-2,1)} + [(1-\gamma_1)(1-\gamma_2)+1]\{(1-\gamma_1)(E_2 - c_2) + (E_1 - c_1)\}$$

Again iterating, we get

$$M_{(i,1)} = (1-\gamma_1)^n(1-\gamma_2)^n M_{(i-n,1)} + \left[\sum_{j=0}^{n-1}(1-\gamma_1)^j(1-\gamma_2)^j\right]\{(1-\gamma_1)(E_2 - c_2) + (E_1 - c_1)\} \quad (8)$$

This equation shows the relationship of macronutrient in soil of $M_{(i,1)}$ and available soil macronutrient status at the end of (i-n)th crop

or $$M_{(i,1)} = (1-\gamma_1)^n(1-\gamma_2)^n M_{(i-n,1)} + \left[\frac{1-(1-\gamma_1)^n(1-\gamma_2)^n}{1-(1-\gamma_1)(1-\gamma_2)}\right]\{(1-\gamma_1)(E_2 - c_2) + (E_1 - c_1)\}$$

for n=i,

$$M_{(i,1)} = (1-\gamma_1)^i(1-\gamma_2)^i M_{(0,1)} + \left[\frac{1-(1-\gamma_1)^i(1-\gamma_2)^i}{1-(1-\gamma_1)(1-\gamma_2)}\right]\{(1-\gamma_1)(E_2 - c_2) + (E_1 - c_1)\} \quad (9)$$

In long run, the status of macronutrient in soil can be measured by taking limit i→∞, we get

$$M_1 = \left[\frac{(1-\gamma_1)(E_2 - c_2) + (E_1 - c_1)}{1-(1-\gamma_1)(1-\gamma_2)}\right] \quad (10)$$

where M_1 denotes the steady state of macronutrient in soil after first crop due to constant fertilization.

Similarly by using equation (5) in (6), we find

$$M_{(i,2)} = (1-\gamma_1)^i(1-\gamma_2)^i M_{(0,2)} + \left[\frac{1-(1-\gamma_1)^i(1-\gamma_2)^i}{1-(1-\gamma_1)(1-\gamma_2)}\right]\{(1-\gamma_2)(E_1 - c_1) + (E_2 - c_2)\} \quad (11)$$

In long run, the status of macro nutrient in soil can be measured by taking limit i→∞, we get

$$M_2 = \left[\frac{(1-\gamma_2)(E_1 - c_1) + (E_2 - c_2)}{1-(1-\gamma_1)(1-\gamma_2)}\right] \quad (12)$$

where M_2 represents the steady state of macronutrient in soil after second crop due to constant fertilization.

III. VALIDITATION OF DATA

Soil macronutrient status (observed and predicted from the model) can be tested by computing a reliability index as suggested by Leggett [19]. This index interprets that our model predictions agrees with observations within a factor of *k*. The index k_g is defined by using geometric approach and is justified with another index k_s developed by using statistical techniques. These indices k_g and k_s are given by,

$$k_g = \frac{1+\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1-y_i/x_i}{1+y_i/x_i}\right]^2}}{1-\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1-y_i/x_i}{1+y_i/x_i}\right]^2}}$$

and $$k_s = \exp\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\log\frac{y_i}{x_i}\right)^2}$$

where x_i is the predicted value using model while y_i is corresponding observed values respectively. If $k_g = k_s = 1$, then model is perfect.

IV. APPLICATION OF THE MODEL TO FIELD DATA

The above prescribed model was applied on investigation entitled "Integrated Nutrient Management in blackgram (Phaseolus mungo L.)" was conducted during 2003-04 and 2004-05 at RCA, Udaipur [15]. The region lies under typical sub-humid climatic conditions average annual rainfall 637 mm, soil of the experimental field was clay loam in texture. Initially, to ascertain various characteristics of the experimental field, soil samples were taken upto 15 cm depth contained 268.40 kg N ha^{-1}, 19.50 kg P ha^{-1} and 370.80 kg K_2O ha^{-1}. This experiment was consisted of thirty two treatment combinations, out of these we are using here only five which are

i. Control
ii. 50% P (20 kg P_2O_5 ha^{-1}) or (P-20)
iii. 75% P (30 kg P_2O_5 ha^{-1}) or (P-30)
iv. 100% P (40 kg P_2O_5 ha^{-1}) or (P-40)
v. FYM

The expected soil macronutrient efficiency parameter was calculated by $\gamma = \frac{\sum U_i^0 M_{i-1}^0}{\sum (M_{i-1}^0)^2}$

where U_i^0 and M_{i-1}^0 are uptake and soil available macronutrient values of control plots respectively.

V. RESULT AND DISCUSSION

Estimation of γ, E and c for macronutrient nitrogen under different treatments and different crop are presented in table 1. soil N efficiency about P-40 and FYM are significantly high in comparison to control for blackgram. For wheat soil N efficiency is 17% higher than control about P-40, for P-30 and FYM it is almost same. The amount of nitrogen mobilized from unaccounted sources (c) is almost same for all treatment and for blackgram it varies from 1.94 to 1.57 and for wheat it varies from 10.86 to 11.09 kg/ha.

The value of *E* in table shows the there is build up about all treatments. For blackgram nitrogen build up for P-40 and FYM are almost 90% in comparison to control and for wheat almost same for all treatments. The predicted steady state soil N status for different treatments and crops are presented in table 2. For blackgram it is 16% higher about P-40 and FYM in comparison to control and for wheat it is same for all treatments.

Table 1. Estimation of γ , E and c for macronutrient N for different crops in sequence

Treatment	BLACKGRAM			WHEAT		
	γ_1	E_1 (Kg N ha^{-1})	C_1 (Kg N ha^{-1})	γ_2	E_2 (Kg N ha^{-1})	C_2 (Kg N ha^{-1})
Control	0.20	49.64	1.94	0.36	103.05	10.86
P-20	0.22	76.79	1.23	0.38	97.75	13.06
P-30	0.24	85.92	1.92	0.40	104.58	12.87
P-40	0.27	93.64	1.73	0.42	112.03	11.15
FYM 5	0.26	95.36	1.57	0.40	102.28	11.09

Table 2. Predicted steady state of soil N status for different crops in sequence

Treatment	BLACKGRAM (Kg N ha^{-1})	WHEAT (Kg N ha^{-1})
Control	249.05	250.57
P-20	276.20	256.99
P-30	280.42	259.49
P-40	287.80	266.58
FYM 5	290.87	266.50

Comparison of predicted soil N status for different crops and different treatments are presented in table 3 and table4. The reliability indices showing the agreement between observed and predicted soil nitrogen status in table 5. It shows, under all treatment and for both crops the predicted values closely agreed with observed values.

Table 3. Observed and predicted value of soil N status (Kg ha^{-1}) after harvesting of Blackgram year wise

Treatment	2003-04		2004-05	
	Observed	Predicted	Observed	Predicted
Control	258.61	258.94	278.95	254.10
P-20	293.61	272.40	289.92	274.35
P-30	295.95	274.97	293.41	277.95
P-40	296.93	279.59	296.38	284.32
FYM 5	301.18	280.85	298.99	286.40

Table 4. Observed and predicted value of soil N status (Kg ha^{-1}) after harvesting of Wheat year wise

Treatment	2003-04		2004-05	
	Observed	Predicted	Observed	Predicted
Control	276.96	254.68	271.85	252.67
P-20	282.21	274.82	277.14	265.68
P-30	283.05	276.00	278.63	266.97
P-40	284.03	279.42	281.60	272.01
FYM 5	285.15	281.96	281.06	273.39

Table5. Reliability indices for the proposed model for N

INDICES	CROP	Treatment				
		CONTROL	P-20	P-30	P-40	FYM
Kg	BLACKGRAM	1.06817904	1.06804499	1.06667663	1.05305363	1.05973600
	WHEAT	1.08187079	1.03589920	1.03571564	1.02746614	1.02133980
Ks	BLACKGRAM	1.06820459	1.06804723	1.06667874	1.05305515	1.05973950
	WHEAT	1.08187160	1.03589991	1.03571651	1.02746683	1.02134021

Estimation of γ , E and c for macronutrient potassium under different treatments and different crop are presented in table 6. soil K efficiency about P-40 and FYM are approximately 20% high in comparison to control for blackgram. For wheat soil K efficiency is 25% higher than control about P-40, for P-30 and FYM it is almost same. The amount of potassium mobilized from unaccounted pool (c) is almost same for all treatment and for blackgram and for wheat it varies from 0.58 to 0.79 kg/ha.

The value of *E* in table shows the there is build up about all treatments. For blackgram potassium build up for P-40 and FYM are almost 150% in comparison to control and for wheat almost same for all treatments. The predicted steady state soil K status for different treatments and crops are presented in table 2. For blackgram it is 18% higher about P-40 and FYM in comparison to control and for wheat it is almost 15% higher about P-40 and FYM in comparison to control.

Table 6. Estimation of γ , *E* and *c* for macronutrient K for different crops in sequence

Treatment	BLACKGRAM			WHEAT		
	γ_1	E_1 (Kg K ha^{-1})	c_1 (Kg K ha^{-1})	γ_2	E_2 (Kg K ha^{-1})	c_2 (Kg K ha^{-1})
Control	0.06	10.21	0.10	0.25	68.29	0.79
P-20	0.07	18.69	0.09	0.28	74.52	0.60
P-30	0.08	22.28	0.09	0.30	83.62	0.57
P-40	0.08	26.42	0.08	0.32	91.01	0.54
FYM	0.08	27.35	0.09	0.29	80.01	0.58

Table 7. Predicted steady state of soil K status for different crops in sequence

Treatment	BLACKGRAM (Kg K ha^{-1})	WHEAT (Kg K ha^{-1})
ontrol	247.65	253.03
P-20	265.76	265.58
P-30	278.35	277.12
P-40	293.07	289.85
FYM	287.49	282.87

Comparison of predicted soil K status for different crops and different treatments are presented in table 8 and table9. The reliability indices showing the agreement between observed and predicted soil potassium status in table 10. It shows, under all treatment and for both crops the predicted values closely agreed with observed values.

Table 8. Observed and predicted soil K status (Kg ha^{-1}) after harvesting of Blackgram year wise

Treatment	2003-04		2004-05	
	Observed	Predicted	Observed	Predicted
Control	359.06	334.27	327.28	308.57
P-20	364.49	336.26	335.96	313.08
P-30	366.75	337.94	338.52	316.76
P-40	370.48	341.73	343.43	323.54
FYM	370.84	341.72	343.34	322.80

Table 9. Observed and predicted soil K status (Kg ha^{-1}) after harvesting of Wheat yearwise

Treatment	2003-04		2004-05	
	Observed	Predicted	Observed	Predicted
Control	338.76	327.61	310.43	305.48
P-20	341.89	331.97	311.11	310.14
P-30	344.15	334.89	313.67	314.35
P-40	347.73	340.33	318.88	321.45
FYM	346.26	340.14	317.99	320.15

Table10. Reliability indices for the proposed model for Potassium

INDICES	CROP	Treatment				
		CONTROL	P-20	P-30	P-40	FYM
Kg	BLACKGRAM	1.06771240	1.07868969	1.07737906	1.07358807	1.07511922
	WHEAT	1.02660787	1.02116469	1.01954005	1.01637368	1.01358304
Ks	BLACKGRAM	1.06771332	1.07869037	1.07738062	1.07359084	1.07512178
	WHEAT	1.02660848	1.02116544	1.01954065	1.01637389	1.01358315

VI. CONCLUSION AND FUTURE SCOPE

The theoretical approach given by the above suggested mathematical model is valid as it helps in the prediction of soil macronutrient within the permitted limit of difference. The model is also helpful for calculation of steady state of soil macronutrient status for a particular fertilizer treatment in a continuous cropping system. This method can also be helpful in the estimation of soil status of other essential nutrient like sulphar and micronutrients like zink, copper etc.

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Authors Profile

Mr. M. Khajanchi completed his Bachelor of science in 2003 and Master of science in 2006 from Maharshi Dayanand Saraswati University, Ajmer and qualified NET (JRF) exam. He has worked as Lecturer in SMPBJ Govt. College, Sheoganj from 2008 to 2011and as Assistant Professor in MLV Textile College, Bhilwara. He is currently pursuing Ph.D. from University of Kota. He is a member of Rajasthan Ganitha Parishad.

Dr. R. Sharma completed his Master of science and received his degree of Ph.D from University of Rajasthan, Jaipur. He has published many research papers in reputed international research journal. He is also author of many books. He is a life member of Rajasthan Ganitha Parishad. Presently he is Associate professor in the department of mathematics, Government College, Kota. He has experience of more than 34 years of teaching UG, PG and M.Phil classes. Two PhDs have been awarded under his supervision. He is also member of Staff Selection Board of many institutions.

Dr. U. Pancholi completed her Master of Science in 1980 from University of Rajasthan, Jaipur and Ph.D in 2014 from University of Kota. She has published 5 research paper in journal of repute. she has written chapter for various publishers like Astran, New Delhi and Sarup, New Delhi. She had been chairperson of Board of studies in Mathematics at University of Kota, Kota. Presently she is heading the department of mathematics, Govt. College, kota for almost 8 years. She has experience of 35 years of teaching UG, PG and M.Phil classes. She is also member of Staff Selection Board of many organizations.