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Research Article

Extrapolation of post-harvest soil test values in barnyard millet-based cropping sequence through multivariate analysis

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Abstract
The soil test value is based on the soil test-based fertilizer prescription/ recommendation equation. Each crop harvesting after the next crop is necessary to analyze the soil. Therefore, it is necessary to develop an alternative technique to predict postharvest soil tests after the harvest of every crop. For that a study was conducted in mixed black calcareous soils at Tamil Nadu agricultural University, Coimbatore to develop the post-harvest prediction equations for available nitrogen, phosphorus and potassium in barnyard millet cropping sequence based on a multiple regression model by considering post-harvest soil test value as the dependent variable and initial available nutrients, fertilizer doses and crop yield or crop nutrient uptake as an independent variables. The developed model was validated by computing R^2 value, RMSE (root means square error), RE (relative error), and the ratio of performance to deviation (RPD) and the developed model was found to be valid. Using the validated model, post-harvest soil test values were predicted. A fertilizer recommendation was made for blackgram based on predicted post-harvest soil test values in the barnyard millet-blackgram cropping sequence. The predicted soil test values were compared with actual soil test values and it revealed that the developed model is fairly accurate and best-fitted with more precision. The predicted post-harvest soil test values of barnyard millet could be used in order to prescribe fertilizer for desired yield targets for subsequent crops.

Keywords: Barnyard millet, Multivariate analysis, Post-harvest soil, Test value

INTRODUCTION

Soil test-based fertilizer prescriptions were built on the soil test values and post-harvest soil samples have to be analyzed for making fertilizer recommendation for each crop. The continuous cropping system without adequate and balanced fertilization has created the widespread problem of multiple nutrient deficiencies. For solving all these problems, one of the sustainable nutrient management techniques as "Soil Test Crop Response based Integrated Plant Nutrition System (STCR-IPNS)" can be applied for sustained soil health and higher crop productivity (Subba Rao and Lenka, 2020). A soil test is a baseline for the soil test crop response-based fertilizer prescription. As India has a large number of small farm holdings, analyzing such a large number of soil samples to make soil test-based fertilizer recommendations before and after each crop is time-consuming, expensive and it is neither cost-effective nor ecologically friendly.

On the other hand, Farmer's intensive cropping practices results relatively short periods between two successive crops. It is impossible to analyze soil samples in such a short period of time to provide fertilizer recommendations for the following crop. Therefore, it is vital to forecast soil test values after the crop has been harvested (Gangola *et al.,* 2017). Hence, an alternative approach is needed to predict the post-harvest soil test values after the harvest of every crop without soil testing.

Ramamoorthy and Velayutham (1971) developed a method to recommend the application of fertilizer for the next crop in a cropping sequence using estimates of available nutrients in the soil after harvesting the first crop. Multivariate analysis approaches, such as multiple linear regressions (MLR) analysis, offer a versatile option for predicting post-harvest soil test nutrient levels. With the information of baseline soil test results, yield and amount of applied nutrients through fertilizer, prediction of soil nutrients left over after a crop suggests the new options for making a fertilizer prescription for individual crops and cropping sequence. Singh *et al*. (2018) constructed numerous linear equations that were fairly accurate in predicting post-harvest soil test values of N, P, and K in lentil crop with significant ($p > .01$) coefficients (R^2) of 0.91, 0.82, and 0.74, respectively. They advocated the use of such equations while prescribing fertilizers for the following crop in a crop rotation. In this context, the present study developed post-harvest prediction equations using parameters of a field experiment on barnyard millet-based cropping sequences and validated for making fertilizer recommendation.

MATERIALS AND METHODS

Study area

The experiment was conducted at the eastern block farm of Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, with barnyard millet as the test crop. The experimental field's soil belonged to the Periyanaickenpalayam soil series (mixed black calcareous). It is taxonomically known as Vertic Ustropept, and sandy clay loam in texture. The soil was moderately alkaline (pH 8.30) and non-saline (EC 0.49 dSm^{-1}) by following Jackson 1973. The soil had 172 kg ha^{-1} N (Subbiah and Asija, 1956), 21.0 kg ha^{-1} P (Olsen *et al*., 1954) and 505 kg ha^{-1} K (Stanford *et al*., 1949).

Gradient experiment

Gradient experiment is a preliminary experiment for the inductive methodology for developing the fertilizer prescription equations (Ramamoorthy *et al*.,1967). For the development of fertility gradient, the field was divided into three equal strips with a graded dose of fertilizers *viz*., strip I ($N_0P_0K_0$), strip II ($N_1P_1K_1$) and strip III ($N_2P_2K_2$). Whereas strip I was absolute control, in strip II recommended dose 90 kg of N, P_2O_5 and K_2O were applied based on the fixing capacity of the soil. Strip III received the double dose that of strip II. An exhaustive crop, fodder sorghum (*var* CO 30) was grown to harvest and soil samples were collected at each strip before and after the harvest of gradient crop and analyzed for available N (Subbiah and Asija, 1956), P (Olsen *et al*., 1954) and K (Stanford *et al*., 1949). Plant samples were analyzed for total N, P and K content and uptake values were computed (Tandon,2001). The variation in fertility status, nutrient uptake and yield among the strips confirmed the development of fertility gradient in the field.

Test crop experiment

The test crop experiment with barnyard millet (*var*. MDU 1) was undertaken after verifying gradient development at the experimental site. The experiment utilized a fractional factorial randomized block design. Each strip was split into 24 plots for the test crop experiment, totalling 72 plots in three strips. To accommodate three levels (0, 6.25 and 12.5 t ha^{-1}) of farmyard manure (FYM), 72 plots were separated into three blocks (each with 24 plots). The selected twenty-one treatments combination of four levels of nitrogen (0, 20, 40, and 60 kg ha^{-1}), phosphorous (0, 10, 20, and 30 kg ha^{-1}), and potassium (0, 20, 40, and 60 kg ha^{-1}) along with three controls were randomized in each strip and block, with all 24 treatments present in each strip in either direction. Plotwise soil samples (72 plots, 0 -15 cm depth) were collected before sowing and after the harvest of barnyard millet crop and analyzed for available nitrogen, phosphorus and potassium. After the harvest of barnyard millet, grain and straw yields were recorded. The grain and plant samples were collected and digested (diacid for nitrogen and tri acid for phosphorus and potassium) to determine the total nitrogen, phosphorus and potassium content for computing the total uptake (Tandon,2001).

Prediction equations for post-harvest soil test values

The study used a multiple regression model to predict post-harvest soil test values, which were derived by statistical analysis of the post-harvest soil test values as dependent variable. Soil test values are dependent on initial soil test values and other related factors such as yield/ uptake and fertilizer dosages.

The following is the functional relationship:

YPHS = f (F, ISTV, yield / nutrient uptake) …. Eq.1

Where YPHS is the post-harvest soil test value, F is the applied fertilizer nutrient and ISTV is the initial soil test value of N/P/K.

The equation will take the mathematical form,

YPHS = a+b_1F+b_2 IS+b_3 yield / uptake …. Eq.2

where a is the absolute constant and b_2 and b_3 are the regression coefficients for the two variables. The post-harvest soil test levels of N, P, and K after barnyard millet were predicted using the above regression equations.

Validation of regression equations

A multiple regression model with a high R^2 value indicates an insufficient accuracy for forecasting value precision. The prediction precision of the generated model was also calibrated and confirmed using the following methods:

Root means square error (RMSE) and relative error (RE)

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{A}_i - \mathrm{P}_i)^2}{n}} \quad \text{…. Eq.3}$$

$$\mathrm{RE} = \sqrt{\frac{\sum_{i=1}^{n}((\mathrm{A}_i - \mathrm{P}_i)/\mathrm{A}_i)^2}{n}} \times 100 \quad \text{…. Eq.4}$$

Where the A_i and P_i are actual and predicted post-harvest soil test values of nutrients at i^{th} data point and n is the number of data points.

The RMSE reveals how close the actual and predicted values are. The lower the RMSE, the more predictable the model is.

RE is a percentage representation of the relative difference between actual and projected values. If the RE is less than 10%, the prediction is considered as excellent, between 10% and 20% as good, between 20% and 30% as fair and bad if the RE is more than 30% (Jamison *et al*., 1991: Zhu *et al.,* 2006).

$$\mathrm{SEP} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{A}_i - \mathrm{P}_i)^2}{n-1}} \quad \text{…. Eq.5}$$

$$\mathrm{RPD} = \frac{\mathrm{SD}}{\mathrm{SEP}} \quad \text{…. Eq.6}$$

Ratio of performance to deviation (RPD)

The RPD indicates the appropriateness of the prediction. The RPD is a ratio of standard deviation and the standard error of prediction (Williams and Norris, 1987). RPD values less than 1 suggest irrelevant prediction, 2-3 indicate appropriate screening procedure and more than 3 indicate suitable prediction or analytical approach (Malley *et al.,* 2000).

RESULTS AND DISCUSSION

Prediction of post-harvest soil available nutrient status for barnyard millet cropping sequence

The MLR model along with R^2 was used to progress the post-harvest soil test value prediction equation after barnyard millet are furnished in Table 1.

The prediction of $KMnO_4$-N showed good fitness by recording the high R^2 values of 96.8, 98.8 and 98.4 when accounted for the grain yield and 98.4, 96.8 and 97.8 when nitrogen uptake was considered under NPK alone, NPK+FYM 6.25 t ha^{-1} and NPK+FYM 12.5 t ha^{-1}, respectively. With respect to the prediction of Olsen-P, 96.8, 98.8 and 98.4 percent dependency were recorded for grain yield and 96.8, 98.4 and 98.2 percent for phosphorus uptake under NPK alone, NPK+FYM 6.25 t ha^{-1} and NPK+FYM 12.5 t ha^{-1} treatments, respectively. Likewise, in the case of NH_4OAc - K, the predictability was 96.9, 98.7 and 98.7 per cent while considering the grain yield and 97.7, 98.3 and 98.5 per cent for potassium uptake under NPK alone, NPK+FYM 6.25 t ha^{-1} and NPK+FYM 12.5 t $ha^{-1,}$ respectively. The higher percentage of dependency indicated the higher strength of the relationship between the two variables and the good fitness of the model for predicting the post-harvest nutrient status. Using the prediction model, the post-harvest soil test values were predicted for selected treatments and are given in Table 2 along with actual observed values.

The observed mean value for $KMnO_4$-N was 182.87 and the predicted mean values were 184 and 183.13 kg ha^{-1} while considering the yield and nitrogen uptake for prediction. The corresponding values for Olsen P were 27.33 kg ha^{-1}, 27.07 and 27.00 kg ha^{-1} and NH_4OAc – K were 499.60 kg ha^{-1}, 498.87 and 499.33 kg ha^{-1}. The respective mean variation between the observed and predicted values was 1.13 and 0.26 kg ha^{-1} for $KMnO_4$-N, 0.26 and 0.33 kg ha^{-1} for Olsen P and 0.73 and 0.46 kg ha^{-1} for NH_4OAc – K.

The results were concordant with those reported by Coumaravel *et al*. (2016) with the coefficient of the determination values greater than 0.65 referring to as best fit of the prediction. They evidenced significant (p < .01) and high correlation with r of 0.98, 0.94 and 0.95 for prediction of the N, P and K between the actual and predicted values after harvest of the maize crop on alfisols using multiple linear regression model (MLR). Ranjan *et al*. (2018) reported noticeably significant (p < .01) and high R^2 values for predicting post-harvest field N (0.95), P (0.98) and K (0.96) using MLR for field pea based cropping sequence in inceptisol and they suggested applying such prediction equations to make the soil test-based fertilizer recommendations for the succeeding crop.

Calibration of the predicted model

NPK alone

While considering the yield for prediction of post-harvest available N, the lowest RMSE value of 3.013 kg N, excellent RE value of 1.738 percent and RPD of 6.804 were observed under NPK alone treatments. Similarly, for phosphorus and potassium, the lowest

Table 1. Prediction equations for post-harvest soil test value for barnyard millet

NPK Alone				
PHSTVs Prediction equations	**R^2**	**RMSE**	**RE**	**RPD**
YPHN=23.53+0.90**SN+0.29**FN-0.00959** yield	0.9788**	3.013	1.738	6.804
YPHN= 11.96+1.0084**SN+ 0.2487**FN-0.4976** uptake	0.9849**	2.549	1.452	8.089
YPHP= -0.37932+0.935**SP+0.1217*FP+0.0004922yield	0.9687**	1.683	7.720	5.561
YPHP=-0.0387+0.93**SP+0.13*FP+0.048 uptake	0.9686**	1.685	7.747	5.555
YPHK=-1.510+1.0016**SK+0.2627**FK-0.0069261yield	0.9697**	4.435	0.870	5.657
YPHK=-12.77 +1.0387**SK+0.30**FK-0.462**uptake	0.9771**	3.848	0.760	6.540
NPK + FYM 6.25 t				
PHSTVs Prediction equations	**R^2**	**RMSE**	**RE**	**RPD**
YPHN=-17.486 +0.8799**SN+0.2675**FN-0.001918 yield	0.9675**	7.006	3.564	3.652
YPHN=10.548+0.9692**SN+ 0.2909**FN-0.26626 uptake	0.9684**	3.886	1.940	5.53
YPHP=-4.1235+1.0056**SP+0.101406*FP+0.00222 yield	0.9886**	1.166	4.862	9.317
YPHP= -3.2184+0.9788**SP+0.12218*FP+0.3467 uptake	0.9849**	1.196	5.037	9.043
YPHK=3.2211+0.9980**SK+0.2671**FK-0.0051yield	0.9800**	3.479	0.682	7.001
YPHK=0.4254+1.018**SK+0.2714 **FK-0.3470**uptake	0.9835**	3.163	0.619	7.720
NPK + FYM 12.5 t				
PHSTVs Prediction equations	**R^2**	**RMSE**	**RE**	**RPD**
YPHN=-9.3725+0.9033**SN+0.0775*FN+ 0.0133yield	0.9764**	4.175	2.02	6.436
YPHN=-17.879+1.177**SN+ 0.3487**FN-0.4055uptake	0.9782**	4.079	2.081	6.591
YPHP=-8.57328+1.0466**SP+0.1302*FP+0.00363*yield	0.9849**	1.426	4.695	8.088
YPHP=-6.4201+1.0391**SP+0.1770**FP+0.4245 uptake	0.9823**	1.547	5.230	7.445
YPHK=-1.3599+0.9799**SK+0.1626**FK+0.004756 yield	0.9873**	3.579	0.702	7.658
YPHK=-19.2339+1.0362**SK+0.2237**FK-0.0338 uptake	0.9851**	3.802	0.749	7.205

*Significant at P = 0.05; **Significant at P = 0.01; PH = Post-Harvest; FN, FP and FK = fertilizer N, $P_2O_5$and K_2O respectively in kg ha^{-1}; SN, SP and SK = Soil available N, P and K, respectively in kg ha^{-1}.

RMSE values of 1.683 and 4.435 kg, RE values of 7.720 and 0.870 percent and RPD values of 5.561 and 5.567 were recorded, which indicated the satisfactory prediction. Considering phosphorus and potassium, nutrient uptake-based model calibration, the RMSE values were 2.549, 1.685 and 3.848, RE values were 1.452, 7.747 and 0.760 and RPD values were 28.089, 5.555 and 6.540 respectively for available N, P and K. This indicated a satisfactory prediction by this analytical model.

NPK+ FYM @ 6.25 t ha^{-1}

With respect to yield-based prediction, the RMSE values of 7.006, 1.166 and 3.479 were recorded for $KMnO_4$-N, Olsen P and NH_4OAc – K. The parallel values for RE were 3.564, 4.862 and 0.682 and RPD were 3.652, 9.317 and 7.001. A similar trend of results was registered while taking in to account the uptake for prediction.

NPK+ FYM @ 12.5 t ha^{-1}

Under NPK+ FYM @ 12.5 t ha^{-1}, the RMSE values of 4.175, 1.426 and 3.579 were registered for available N, P and K. The respective RE values were 2.02, 4.695 and 0.702 and RPD values were 6.436, 8.088 and 7.658. Similar results were recorded for the uptake-based model prediction. In all the situations, the lowest RMSE values along with RE values of less than 10 per cent and RPD values of more than three were recorded, which shows that the prediction model was found to be excellent and satisfactory while considering the yield and uptake for prediction. The results were corroborated with Mahajan *et al*. (2019) who developed post-harvest prediction equation for rice-wheat cropping sequence on Typic Haplustept by using multivariate analysis technique at Delhi.

As a result, the soil test results for $KMnO_4$-N, Olsen-P and NH_4OAc-K were predicted and compared to the observed values in the current study (actually tested). Fig. 1 and 2 show a comparison of observed and predicted soil test values of available N, P, and K after barnyard millet using a 1:1 regression line, where all points stayed close to the regression line and the values were in good agreement with each other as evidenced by highly significant R^2 = 0.9614**, 0.9820** and 0.9784** respectively with yield; 0.9778**, 0.9807**

Table 2. Observed and predicted post-harvest soil $KMnO_4$-N, Olsen-P and NH_4OAc-K for barnyard millet

Treat-ments	$KMnO_4$-N (kg ha^{-1})			Olsen-P (kg ha^{-1})			NH_4OAc-K (kg ha^{-1})		
	Observed	Predicted based on		Observed	Predicted based on		Observed	Predicted based on	
		Yield	Uptake		Yield	Uptake		Yield	Uptake
NPK alone									
$N_0P_0K_0$	148	155	152	11	12	12	464	468	468
$N_0P_2K_2$	207	204	203	37	37	37	531	527	528
$N_1P_1K_1$	207	205	204	38	39	39	521	522	522
$N_2P_2K_2$	185	184	186	32	32	32	512	511	513
$N_3P_3K_3$	190	193	191	33	34	34	509	508	507
NPK + FYM @ 6.25 t ha^{-1}									
$N_0P_0K_0$	152	153	152	12	12	12	460	467	466
$N_0P_2K_2$	182	192	184	33	31	32	522	519	520
$N_1P_1K_1$	200	197	192	34	33	32	518	511	513
$N_2P_2K_2$	168	166	170	17	19	18	479	478	479
$N_3P_3K_3$	174	169	174	20	20	20	478	478	477
NPK + FYM @ 12.5 t ha^{-1}									
$N_0P_0K_0$	152	153	153	11	11	11	462	465	466
$N_0P_2K_2$	150	158	155	19	18	18	478	474	475
$N_1P_1K_1$	168	164	165	18	17	17	475	470	471
$N_2P_2K_2$	228	230	231	46	42	42	544	540	540
$N_3P_3K_3$	233	237	235	49	49	49	541	545	545
Mean	182.87	184	183.13	27.33	27.07	27.00	499.60	498.87	499.33
'r' value		0.98**	0.99**		0.99**	0.99**		0.99**	0.99**

Table 3. Fertilizer prescriptions for barnyard millet - blackgram based cropping sequence based on initial soil test values under NPK alone and IPNS

Yield target (t ha^{-1})	First crop (Barnyard millet)						Yield target (q ha^{-1})	Second crop (Blackgram)		
	Fertilier doses (kg ha^{-1})			PHSTV (kg ha^{-1})				Fertilizer doses* (kg ha^{-1})		
	N	P_2O_5	K_2O	N	P	K		N	P_2O_5	K_2O
NPK alone										
2.50	37	23	18	185	24	503	8	12.5*	25*	12.5*
2.75	57	30	29	190	26	506	8.5	12.5*	25*	12.5*
3.00	77	37	40	195	28	509	9	12.5*	25*	12.5*
IPNS (NPK+FYM @ 12.5 t ha^{-1})										
2.50	37	23	18	185	24	503	8	12.5*	25*	12.5*
2.75	57	30	29	190	26	506	8.5	12.5*	25*	12.5*
3.00	77	37	40	195	28	509	9	12.5*	25*	12.5*

NB: PHSTV: Post-harvest soil test value; Initial soil test value (ISTV): $KMnO_4$-N=175 kg ha^{-1}; Olsen-P=20 kg ha^{-1} and NH_4OAc-K=500 kg ha^{-1}. Blanket doses for blackgram (varieties): 25:50:25 kg N, P_2O_5 and K_2O kg ha^{-1}. computed using the already existing fertilizer prescription equations for blackgram (varieties) on Periyanaickenpalayam soil series * maintenance dose (50 percent of the blanket dose)

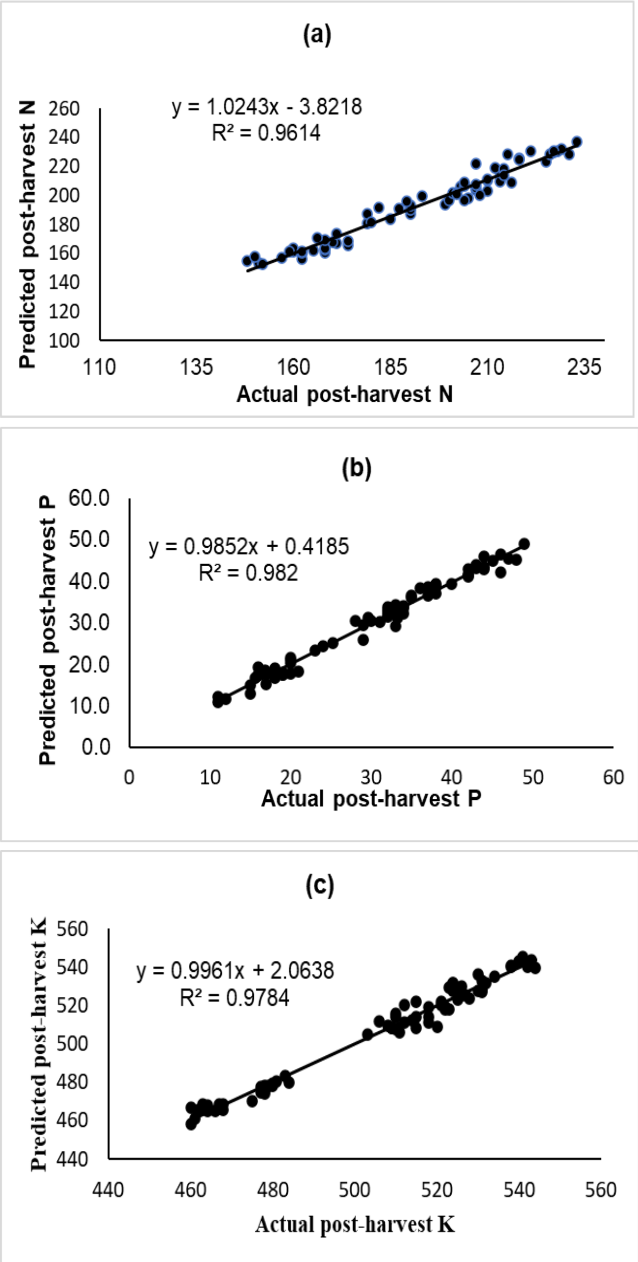

Fig.1. *comparison between observed and predicted postharvest soil test values of (a) $KMnO_4$-N, (b) Olsen-P and (c) NH_4OAC-K (using yield data)*

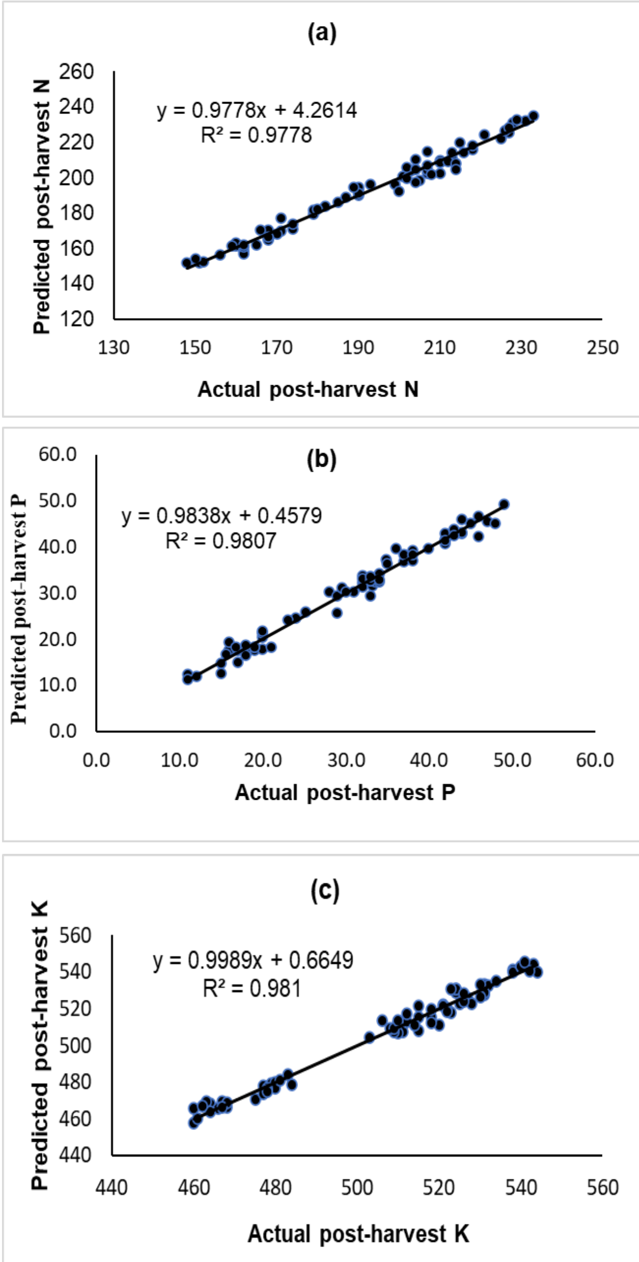

Fig.2. *Comparison between observed and predicted post-harvest soil test values of (a) $KMnO_4$-N, (b) Olsen-P and (c) NH_4OAC-K (using yield data)*

and 0.9810** respectively with uptake. Bera *et al.* (2006) reported for the rice using MLR, and Suresh and Santhi (2019) reported using a similar approach for hybrid maize to compare the observed and anticipated data.

Fertilizer prescriptions for specific yield target of blackgram in barnyard millet- blackgram cropping sequence

After the barnyard millet, The fertilizer doses were prescribed for the succeeding crop through the predicted post-harvest soil test values and furnished in table 3. This implies that the fertilizer doses for blackgram to get the targeted yield of 8,8.5 and 9 q ha^{-1} were 17, 21 and 26 kg N ha^{-1}; 33, 36, and 39 kg P_2O_5 ha^{-1} and 22, 24 and 27 kg K_2O ha^{-1}, respectively under NPK alone. Fertilizer requirement for blackgram to get the yield target of 8, 8.5 and 9 q ha^{-1} were 12.5, 12.5 and 12.5 kg N ha^{-1}; 25, 25 and 39 kg P_2O_5 ha^{-1} and 12.5, 12.5 and 12.5 kg K_2O ha^{-1}, respectively under NPK+ FYM @ 12.5 t ha^{-1}. Similar results were reported by Singh *et al.* (2015) in maize-based sequences using multiple regression model. In most of the studies addressed here, the coefficient of determination or correlation coefficient has been used to assess predictability, but the current study employs RMSE, RE and RPD, in addition to R^2, in determining predictability.

Conclusion

The multivariate analysis used to develop models to predict post-harvest soil N, P and K after barnyard millet crop using initial soil available nutrients, applied nutrients through fertilizers, and grain yield, can predict post-harvest soil available N, P, and K of barnyard millet-based cropping sequences with confidence. Because soil testing of nutrients by farmers after each crop is impractical, the prediction models described in this work can eliminate the necessity for soil testing of nutrients after each crop.

Conflict of interest

The authors declare that they have no conflict of interest.

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