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Research Article

Post-harvest soil nutrient prediction in hybrid castor (*Ricinus communis* l.) cropping sequence using a multivariate analysis technique

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Abstract
In the era of precision agriculture, the fertilizer prescription based on the soil fertility status is much required. Analyzing the soil after each crop is necessary for fertilizer recommendation and developing an alternative technique to forecast the soil available nutrient value rather than analyzing the soil. Multiple linear regression (MLR) equation was developed using filed experiment data to predict the soil available nutrient in castor cropping sequence. The post-harvest soil available nutrient was considered as the dependent variable and the initially available soil nutrient values, fertilizer added, yield and nutrient uptake of castor as an independent variable. In general, the post-harvest soil nutrient model's prediction accuracy was notable and had a coefficient of determination of less than 0.90. By calculating the RMSE (root means square error), R^2 value, the ratio performance to deviation (RPD) and, RE (relative error) the performance of the MLR model was confirmed.Using the validated model, post-harvest soil available nutrients were predicted and compared with laboratory tested soil available nutreints. It turned out that the established model is more precisely effective and equally precise. Fertilizer recommendation could be made to subsequent crop after hybrid castor using the predicted soil available nutrients.

Keywords: Fertilizer prescription, Hybrid castor, Multivariate analysis, Post-harvest soil

INTRODUCTION

Castor is an important industrial non-edible crop cultivated in around 30 countries worldwide. Castor cultivation is mostly concentrated in Asian continent, around 89 per cent, where India plays a predominant role in cultivation and production. India is the world's leading producer, accounting 1.8 million tonnes of castor oil for about 65 percent of total worldwide castor seed production and meeting 80–90 percent of global demand for castor oil (https://www.fao.org/india/fao-in-india/india-at-a-glance/en/). The productivity of castor is lower than the world average because of poor soil fertility and inefficient, imbalanced use of fertilizers. Two approaches to overcome this situation are fertilizer application based on soil test values and plant nutrient status (santhi *et al*., 2011). The nutritional status of plants can be tracked through the use of several diagnostic methods. However, soil tests are based on an examination of the soil's nutrients and balanced recommendations to improve fertilizer effectiveness.

Soil test-based fertilizer recommendation approach requires systematic monitoring of soil available nutrient status before and after each crop, which requires well developed soil testing laboratory with soil chemist to determine the soil available nutrient status. Soil analysis of available nutrients i.e. available alkaline potassium permanganate ($KMnO_4$) nitrogen (N), Olsen phosphorus (P), and ammonium acetate (NH_4OAc) K are to intercept the terms of crop available form of nutrients and response of the crop to applied fertilizer. Environmental degradation of soil health and poor quality surface water affects the soil's available nutrient and become major concern in the soil testing industries. In this present climate change era, “Environmental Nutrient Tests” had become major demand to measure the bio available pools of nutrients and their environmental scope and impacts (Mahajan, 2019)

In India, the largest source of livelihood were agriculture, with 82 per cent of small and marginal farmers (FAO, 2022). Timely analysis of soil samples before each crop and application of fertilizers based on soil available nutrient status is labour-consuming and requires more well-equipped soil testing laboratories. Analyzing the post-harvest soil of castor and recommending the fertilizer for the sequence crop in short period of time is neither economical in the farmers point of view nor environmental friendly. Knowledge of soil available nutrient status is necessary for soil test-based recommendation; therefore, it is necessary to predict the post-soil test values after the hybrid castor harvest (Gangola, 2017). Post-harvest prediction equations can be developed by adopting method developed by Ramamoorty and Velayutham (1971).

Estimation of soil available nutrient status without soil testing is need of the farmers in the world. The best alternative to estimate the soil available nutrient status is by using statistical models to predict leftover nutrients. Prediction of soil available nutrients after the harvest of crops and recommendation of fertilizer based on the prediction data for individual crops and its following crops with the help of initial soil nutrient status data, yield harvested, inorganic fertilizer applied and organic manure. Ramamoorthy and Velayutham (1971) developed a methodology of predicting soil available nutrient and recommendation for next crop using the data above. Statistical model i.e., multiple regression analysis provides alternative choice to determine the available nutrient status of post-harvest soil without standard chemical analysis.

In this research, post-harvest prediction equations were formed using data on initial soil available nutrients, nutrients applied through inorganic fertilizers and seed yield of hybrid castor in three fertility gradient experiment datasets, each consisting of 24 treatments. The core objective of the above investigation was: i) to develop a statistical model to predict post-harvest soil available nutrient for N, P and K using three different fertility gradient soil data and ii) to validate the prediction equations using dataset as cross- validation across all gradient soil test values.

MATERIALS AND METHODS

Field experiment details

The study site was located at the Tapioca and Castor Research Station, Yethapur Salem district, Tamil Nadu, India (11° 35’ N Latitude, 78° 29’ E Longitudes) at an altitude of 282 meters above mean sea level. Each plot is about 25 m^2 and is sown with the same hybrid YRCH -1 castor. The growing period for castor in present study was from June to November 2021. Experimental soil (0–15 cm deep) was red sandy clay loam texture having neutral pH 7.52, non-saline (EC 0.32 dS m^{-1}) with cation exchange capacity of 22.7 c mol (p^+) kg^{-1} and non-calcareous in nature. The initial experimental soil had 0.61% of organic carbon, 210 kg ha^{-1} available alkaline potassium permanganate ($KMnO_4$) oxidizable nitrogen (N), 16.3 kg ha^{-1} Olsen phosphorus (P), and 245 kg ha^{-1} neutral normal ammonium acetate (NH_4OAc) exchangeable potassium (K), respectively. The diethylenetriaminepentaacetic acid (DTPA) extractable micronutrient status, *i.e.* zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn) of experimental soil were in the sufficiency ranges.

Artificial fertility gradient experiment

Initially, the field was made into three artificial fertility gradients by applying three graded levels of fertilizers, *i.e.*, level 1($N_0P_0K_0$), level 2 ($N_1P_1K_1$), and level 3 ($N_2P_2K_2$), by adopting the inductive methodology developed by Ramamoorthy *et al*. (1967). An exhaustive crop of dual-purpose sorghum (*var*. CO 30) was sown during February to April to improve the soil fertility and stability and harvested at pre-flowering stage as fodder. The level of N was based on the recommendation of gradient crop. Based on the P and K fixing capacity of the experimental soils, the levels of P_2O_5 and K_2O were 100 and 80 kg ha^{-1}, respectively. Soil samples (0-15 cm) were collected from twenty-four plots each in all three strips after the harvest of fodder sorghum and analyzed for N, P and K to confirm the development of artificial gradient and confirmed by analyzing statistically.

Test crop experiment

After the development of the artificial fertility gradient, 24 plots (5*5 m^2) were formed in each strip, accommodating 24 treatments. Among these were 21 treatments and 3 controls in each strip, totalling 72 plots in three strips. Across the strips, three blocks were made in which farm yard manure (0, 6.25, 12.5 t ha^{-1}) levels were superimposed, comprised of 24 plots in each block. Treatments were laid out in fractional factorial randomized block design with three factors and four levels in each *i.e,* Nitrogen (0, 45, 90,135 kg ha^{-1}), Phosphorus (P_2O_5) (0, 20, 40, 60 kg ha^{-1}) and Potassium (K_2O) (0, 20, 40, 60 kg ha^{-1}). Treatments were randomized in such a way that in each strip, all 24 set treatments were present in either direction. Fertilizer phosphorus was applied basally and nitrogen and potassium were applied in three splits 50% @ basal and 25% @ 30 DAS and 60 DAS after sowing. Test crop, hybrid castor (YRCH-1) was grown from June to November 2021 on the artificial fertility gradient field.

Soil samples were collected in all the twenty-four plot in each strip before and after sowing the test crop experiment, and soil available N, P and K were analyzed. The crop was grown along with all the management practices. Castor capsules were harvested @ 90, 120 and 150 DAS, sun-dried capsules and seeds were dehulled. The samples from 120 DAS were processed and analyzed for plant N (Humphries, 1956), P, and K (Jackson, 1973), and the total uptake of NP and K was computed by multiplying the mineral content with the dry-matter yield.

Statistical analysis

Following fertility gradient trial, descriptive statistical analysis of post-harvest soil available nutrients data were performed strip-wise. Using analysis of variance artificial fertility gradient for N, P and K in three different strips were assessed and confirmed. The multiple linear regression (MLR) analysis was done considering post-harvest soil test nutrient value as dependent variable and castor seed yield, amount of nutrient applied through fertilizer and initial soil test values of nutrient as an independent variable. The accuracy of MLR calibration model was measured using the coefficient of determination (R^2),the ratio of performance to deviation (RPD), the root mean square error (RMSE, Eq. 2), and the relative error (RE, Eq. 3) using methodology followed by Mahajan *et al*. (2019) and Selvam *et al*. (2021),

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(Ai-Pi)^2}}{n} \quad (1)$$

$$RE = \frac{\sqrt{\sum_{i=1}^{n}((Ai-Pi/Ai)^2}}{n} \times 100 \quad (2)$$

$$RPD = \frac{SD}{SEP} \quad (3)$$

where

$$SEP = \frac{\sqrt{\sum_{i=1}^{n}(Ai-Pi)^2}}{n-1} \quad (4)$$

RESULTS

Descriptive statistics of the fertility gradient experiment

The establishment of the artificial gradient in three various strips was analyzed for variance, considering three levels of strips as three treatments with eight replications. Artificial fertility gradient establishment was observed for N, P and K (Table 1). Post-harvest soil test values of N, P and K were the highest in strip III, followed by strip II and the lowest was recorded in the strip I. In strip III, the mean N, P and K values were 220, 24.3 and 253 kg $ha^{-1,}$ respectively. Descriptive statistics of initial soil available nutrient values with respect to grain yield and its nutrient uptake are furnished in Table 2. Coefficient of variation (CV = 18.57%) was observed for grain yield in strip I. The CV of 14.33% for strip II and 14.41% for strip III, and 19.40% for grain yield of overall strips were recorded.

Prediction of post- harvest available soil nutrient in hybrid castor

The prediction of available-N by the multiple linear regression model exhibited higher accuracy by recording high R^2 values of 98.4, 98.0 and 97.9 when accounted for the castor seed yield and 98.1, 97.4 and 98.7 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 available-P, 91.1, 93.6 and 91.4 per cent dependency was recorded for grain yield and 92.0, 92.6 and 90.3 per cent for phosphorus uptake under NPK alone, NPK+FYM 6.25 t ha^{-1} and NPK+FYM 12.5 t ha^{-1} treatments, respectively. Similarly, in the case of NH_4OAc - K, the predictability was 97.5, 97.6 and 95.2 per cent while considering the grain yield and 96.4, 96.8 and 94.2 per cent for potassium uptake under NPK alone, NPK+FYM 6.25 t ha^{-1} and NPK+FYM 12.5 t ha^{-1}, respectively.

Prediction of post-harvest soil available NPK in NPK fertilizer alone treated plot

The MLR analysis was performed to develop for prediction of post-harvest soil NPK after hybrid castor from independent variables like initial soil available nutrient, applied fertilizer and nutrient uptake and grain yield (Table 3). The prediction of available nitrogen by the prediction model equations with yield provided very good performance with $R^2 \geq 0.98$ ($p < .01$), RMSE ≤ 2.787 kg N and RE ≤ 1.289% and RPD= 7.858, which indicated the satisfactory prediction of post-harvest soil

Table 1. Results of fertility gradient experiment with fodder sorghum

Treatment	Soil available nitrogen (kg ha^{-1})		Soil available phosphorus (kg ha^{-1})		Soil available potassium (kg ha^{-1})	
	Pre-sowing	Post-harvest	Pre-sowing	Post-harvest	Pre-sowing	Post-harvest
Strip I	202	176	14.6	10.6	232	214
Strip II	205	203	14.4	17.8	230	239
Strip III	202	220	15.2	24.3	228	253
SE(d)		3.7		0.5		4.6
C.D.		10		1.4		13

**, significance at 0.05 probability level; SE, standard error; SE(d), standard error of mean

Descriptive Statistics	Initial soil available nutrient (kg ha^{-1})			Castor seed yield and uptake (kg ha^{-1})			
	$KMnO_4$-N	Olsen-P	NH_4OAc-K	Grain Yield	N uptake	P uptake	K uptake
Strip I							
Min-Max	171-179	9.6- 12.6	204- 215	1080-2317	42.8- 81.4	5.8- 13.3	40.4- 69.4
Range	8	3	11	1237	38.6	7.5	29
Mean ±SD	173±3.08	10.8±0.7	211±2.89	1860±3.45	61.7±11.47	9.6±2.14	53.2±7.5
CV%	1.77	6.51	1.37	18.57	18.59	22.19	14.07
Strip II							
Min-Max	199-207	16.3- 21.1	232- 247	1234- 2752	44.9- 89.3	6.5- 15.7	45.6- 75.1
Range	8	4.8	15	1518	44.4	9.2	30.5
Mean ±SD	202±3.99	17.9±14.84	241±2.24	2128±8.24	68.2±3.13	11.4±1.20	57.5±4.15
CV%	18.75	21.77	19.74	14.33	1.55	6.72	1.72
Strip III							
Min-Max	218- 227	22.4- 27.2	250- 263	1360- 2730	46.2- 89.9	5.9- 15.7	47.3- 85.3
Range	9	4.8	13	1370	43.7	9.8	38
Mean ±SD	221±3.75	24.1±13.09	255±2.51	22.5±9.20	70.1±3.59	12.6±1.26	63.8±3.07
CV%	16.62	18.67	19.84	14.41	1.62	5.22	1.2
Overall strip							
Min-Max	171-227	9.6-27.2	204-263	1080-2752	42.85-89.97	5.84-15.78	40.4- 85.3
Range	56	17.6	59	1672	47.12	9.94	44.9
Mean ±SD	199.14±19.83	17.60±5.56	236.18±19.04	20.81±4.04	66.68±13.51	11.21±2.58	58.20±9.31
CV%	9.96	31.61	8.06	19.40	20.27	23.05	15.99

Min-Max, minimum-maximum; SD, standard deviation; CV, coefficient of variation (standard deviation/mean) expressed in %.

test nitrogen with yield. When nitrogen uptake was considered, the prediction model showed higher RMSE ≤ 2.869 kg N and RE ≤ 1.409% and a lower RPD value (7.353). Although the yield and uptake based calibration model showed higher R^2 value > 0.98 the yield calibration model showed closer values of R^2, and the prediction accuracy was higher than that uptake-based model, which is indicated by lower RMSE and RE values of yield-based model. With respect to the prediction of Olsen-P, prediction model showed good performance with R^2 ≥ 0.91 (p < .01), RMSE ≤ 2.089 kg P and RE ≤ 13.243% and RPD= 3.217, which indicated the satisfactory prediction of post-harvest soil test phosphorus with yield. When phosphorus uptake was considered, the prediction model showed higher RMSE ≤ 1.987 kg P and RE ≤ 13.631% and a higher RPD value (3.398). Uptake based calibration model showed a higher R^2 value than the yield-based calibration model, the prediction accuracy was higher than that yield-based model, which was indicated by lower RMSE and higher RPD value. Likewise, in the case of available potassium, the predictability was very good with R^2 ≥ 0.97 (p < .01), RMSE ≤ 3.105 kg K and RE ≤ 1.363% and RPD= 6.307, which indicated the satisfactory prediction of post-harvest soil test potassium with yield. Uptake based calibration model showed lower R^2 value than the yield-based Calibration model. The prediction accuracy was lower than that of the yield-based model, which was indicated by higher RMSE and lower RPD value.

Prediction of post-harvest soil available NPK in NPK fertilizer + FYM @ 6.25 t ha^{-1} treated plot

Prediction equation model based on independent variable of soil available nutrient, fertilizer applied, yield and nutrient uptake showed good performance in the post-harvest soil nutrient prediction in NPK + 6.25 t ha^{-1} FYM treated plots. The prediction of available nitrogen by the

Table 3. Prediction equations for post-harvest soil test values of available N, P and K for Hybrid castor under NPK alone

PHSTVs Prediction equations	R^2	RMSE	RE	RPD
NPK Alone				
YPHN=-4.516+0.9525**SN+0.0404**FN-0.0079** yield	0.98**	2.687	1.289	7.858
YPHN=-4.409+1.036**SN+0.139**FN-0.1358**uptake	0.98**	2.869	1.409	7.353
YPHP= -6.713+0.987**SP+0.1041*FP+0.0026** yield	0.91**	2.089	13.243	3.217
YPHP=-7.311+0.86**SP+0.049*FP+0.9306** uptake	0.92**	1.987	13.631	3.398
YPHK=4.315+1.0879**SK+0.2804**FK-0.0078** yield	0.97**	3.105	1.363	6.307
YPHK=6.141+0.892**SK+0.3543**FK-0.154**uptake	0.96**	3.717	1.611	5.239
NPK + FYM 6.25 t ha^{-1}				
YPHN=-2.780+0.930**SN+0.0103**FN+0.0114 yield	0.98**	2.719	1.305	7.129
YPHN=2.9849+1.025**SN+0.1397**FN-0.175 uptake	0.97**	3.103	1.498	6.227
YPHP=-9.9878+1.0022**SP+0.0744*FP+0.0048 yield	0.92**	1.692	11.326	3.839
YPHP= -8.295+0.8405**SP+0.0462*FP+1.054 uptake	0.92**	1.819	10.414	3.551
YPHK=-1.165+0.935**SK+0.277**FK+0.0061yield	0.97**	2.929	1.239	6.463
YPHK=-3.621+0.984**SK+0.3525**FK+0.017**uptake	0.97**	3.400	1.441	5.545
NPK + FYM 12.5 t ha^{-1}				
YPHN=-7.022+0.9721**SN+0.0535*FN+ 0.0091yield	0.97**	3.073	1.502	6.903
YPHN=12.040+1.1382**SN+ 0.3234**FN-0.786uptake	0.98**	2.415	1.151	8.821
YPHP=-7.760+0.9938**SP+0.097*FP+0.0040*yield	0.91**	2.130	10.667	3.265
YPHP=-5.106+0.9795**SP+0.1012**FP+0.499 uptake	0.90**	2.257	12.742	3.063
YPHK=13.2323+0.880**SK+0.2626**FK+0.0072 yield	0.95**	5.946	2.481	3.241
YPHK=-13.5281+0.938**SK+0.348**FK-0.0287 uptake	0.94**	4.824	1.975	4.059
YPHN=-7.022+0.9721**SN+0.0535*FN+ 0.0091yield	0.97**	3.073	1.502	6.903

*Significant at P = 0.05; **Significant at P = 0.01; PH = Post-Harvest; FN, FP and FK = fertiliser 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}.

prediction model equations with yield provided very good performance with $R^2 \geq 0.98$ ($p < .01$), RMSE ≤ 2.719 kg N and RE ≤ 1.305% and RPD= 7.129, which indicated the satisfactory prediction of post-harvest soil test nitrogen with yield. When nitrogen uptake was considered, the prediction model showed higher RMSE ≤ 3.103 kg N and RE ≤ 1.498% and a lower RPD value (6.227). With respect to the prediction of Olsen-P, prediction model showed good performance with $R^2 \geq 0.93$ ($p < .01$), RMSE ≤ 1.692 kg P and RE ≤ 11.326% and RPD= 3.839, which indicated the satisfactory prediction of post-harvest soil test phosphorus with yield. When phosphorus uptake was considered, the prediction model showed higher RMSE ≤ 1.819 kg P and RE ≤ 10.414% and a lower RPD value (3.551). Uptake based calibration model showed higher prediction accuracy than the yield-based calibration model, which is indicated by higher RMSE and lower RPD value. Likewise, in the case of available potassium, the predictability was very good with $R^2 \geq 0.97$ ($p < .01$), RMSE ≤ 2.929 kg K and RE ≤ 1.239% and RPD= 6.463, which indicated the satisfactory prediction of post-harvest soil test potassium with yield. Uptake-based calibration model showed lower R^2 value than the yield-based calibration model. The prediction accuracy was lower than that yield-based model indicated by RMSE and RPD value.

Prediction of post-harvest soil available NPK in NPK fertilizer + FYM @ 12.5 t ha^{-1} treated plot

Post-harvest soil nutrient prediction in the NPK fertilizer + FYM @ 12.5 t ha^{-1} based on independent variables of soil available nutrient, fertilizer applied, yield and nutrient uptake showed good performance in the post-harvest soil nutrient prediction. The prediction of available nitrogen by the prediction model equations with yield provided very good performance with $R^2 \geq 0.97$ ($p < .01$), RMSE ≤ 3.073 kg N and RE ≤ 1.502% and RPD= 6.903, which indicate the satisfactory prediction of post-harvest soil test nitrogen with yield. When nitrogen uptake was considered, the prediction model showed lower RMSE ≤ 2.415 kg N and RE ≤ 1.151% and a higher RPD value (8.821). With respect to the prediction of Olsen-P, prediction model showed good performance with $R^2 \geq 0.91$ ($p < .01$), RMSE ≤ 2.130 kg P and RE ≤ 10.667% and RPD= 3.265, which indicated the satisfactory prediction of post-harvest soil test

Table 4. Observed and predicted post-harvest soil available $KMnO_4$-N, Olsen-P and NH_4OAc-K for Hybrid castor

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									
$N_0P_0K_0$	165	167	167	9.5	8.6	9.0	198	197	200
$N_0P_2K_2$	225	226	224	28.1	26.0	26.7	259	256	259
$N_1P_1K_1$	234	229	229	26.4	23.3	24.0	255	253	253
$N_2P_2K_2$	214	214	214	21.3	20.2	20.0	252	249	248
$N_3P_3K_3$	208	212	209	21.4	23.5	23.4	245	249	249
NPK + FYM @ 6.25 t ha^{-1}									
$N_0P_0K_0$	168	170	170	8.4	6.4	8.2	201	198	199
$N_0P_2K_2$	236	232	232	24.3	23.5	24.5	266	265	268
$N_1P_1K_1$	227	224	222	27.4	25.3	26.6	263	261	263
$N_2P_2K_2$	216	215	217	20.6	19.7	18.3	248	248	248
$N_3P_3K_3$	211	216	214	25.2	26.6	25.7	244	245	241
NPK + FYM @ 12.5 t ha^{-1}									
$N_0P_0K_0$	169	171	170	7.4	8.7	9.8	201	204	204
$N_0P_2K_2$	228	225	227	32.2	29.0	30.0	259	261	261
$N_1P_1K_1$	231	228	234	22.6	26.1	25.9	272	261	268
$N_2P_2K_2$	213	211	217	22.2	21.3	20.5	252	250	245
$N_3P_3K_3$	222	227	221	26.4	30.3	29.5	260	263	256
Mean	**211**	**211**	**211**	**21.6**	**21.2**	**21.5**	**245**	**244**	**244**
'r' value		**0.98****	**0.99****		**0.92****	**0.93****		**0.98****	**0.98****

**=significant at P=0.01

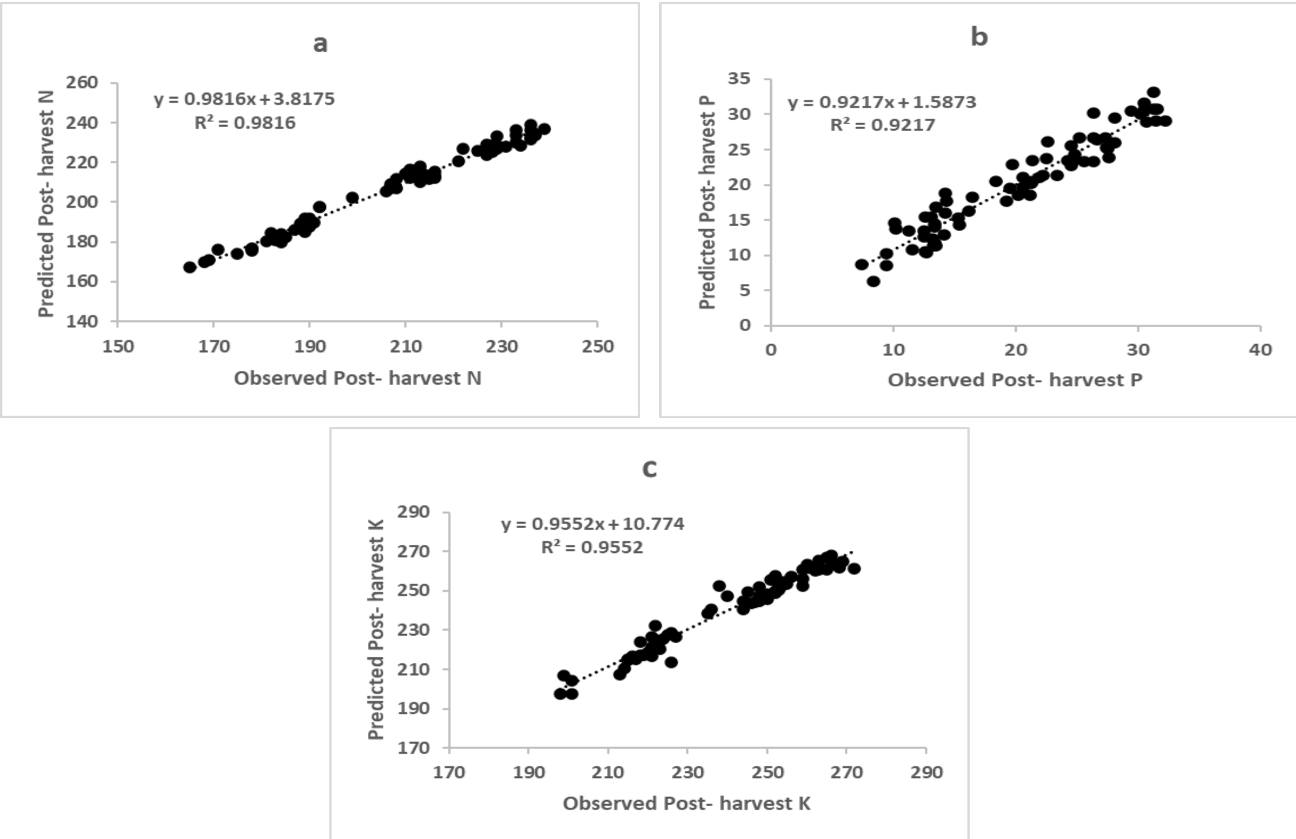

Fig. 1. *Comparison between observed and predicted post-harvest soil test values of (a)* $KMnO_4$*-N, (b) Olsen-P and (c)* NH_4OAC*-K (using yield data)*

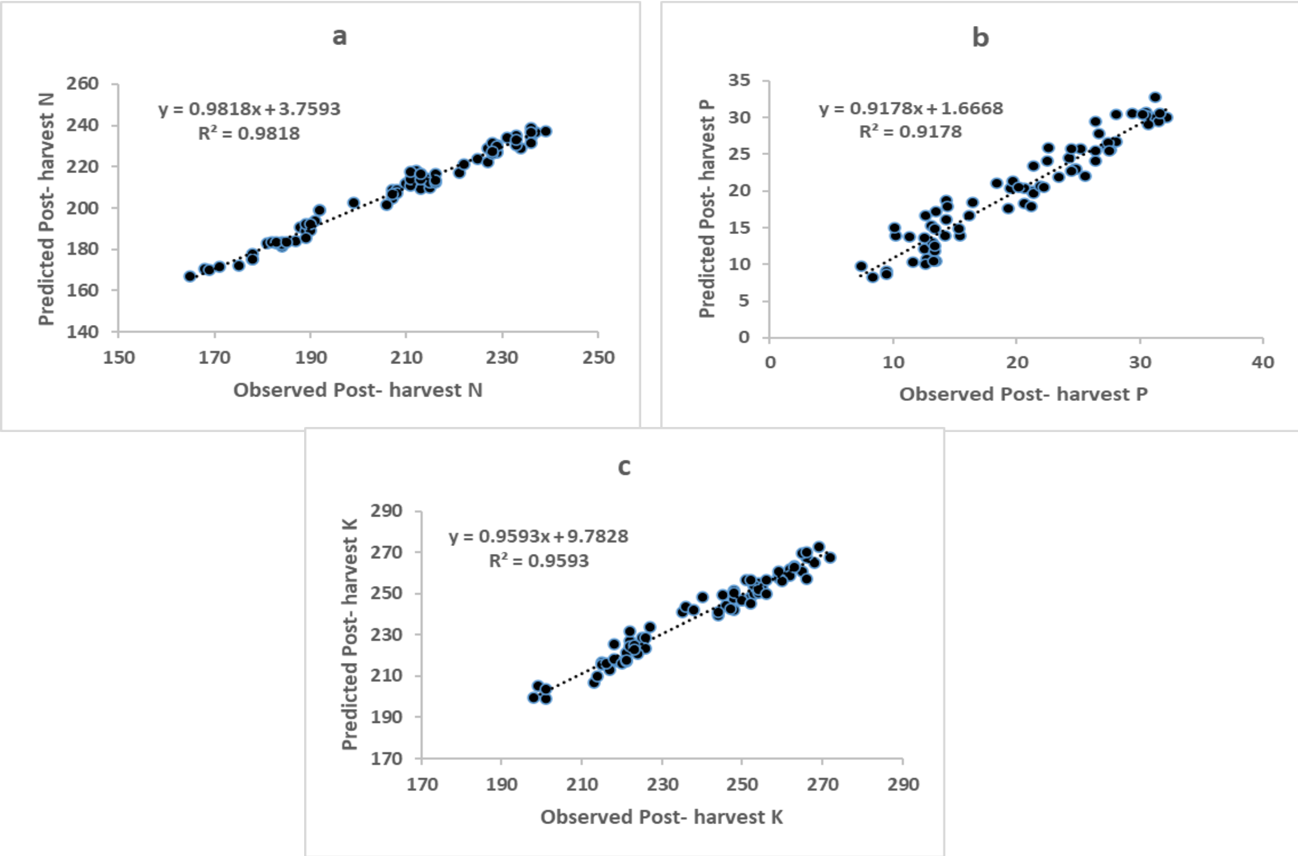

Fig. 2. *Comparison between observed and predicted post-harvest soil test values of (a) $KMnO_4$-N, (b) Olsen-P and (c) NH_4OAC-K (using uptake data)*

phosphorus with yield. When phosphorus uptake was considered, the prediction model showed higher RMSE ≤ 2.257 kg P and RE ≤ 12.742% and a lower RPD value (3.063). Likewise, in the case of available potassium, the predictability was very good with $R^2 \geq 0.95$ ($p < .01$), RMSE ≤ 5.946 kg K and RE ≤ 2.481% and RPD= 3.241 which indicated the satisfactory prediction of post-harvest soil test potassium with yield. Uptake-based calibration model showed lower R^2 value than the yield-based calibration model. The prediction accuracy was lower than that yield-based model indicated by RMSE and RPD value.

The prediction model showed higher accuracy considering the uptake and yield and the model predictability was supported by the low RMSE values, less than 10 per cent RE values along with RPD values of more than three. The results were corroborated with Mahajan *et al*. (2019) and Selvam *et al*. (2021) who developed post-harvest prediction equation for rice-wheat cropping sequence on *Typic Haplustept* and barnyard millet based cropping sequence on *Vertic Ustropept* respectively by using multivariate analysis.

Using the multiple linear regression equation prediction model, the post-harvest soil test values were predicted for selected treatments and are given in Table 4 along with observed values. The observed mean value of selected fifteen treatments for $KMnO_4$-N was 211 and the predicted mean values while considering the yield and nitrogen uptake were 211 and 211 kg ha^{-1}, respectively. The Olsen P corresponding values were 21.6 kg ha^{-1}, 21.2 and 21.5 kg ha^{-1} and NH_4OAc – K were 245 kg ha^{-1}, 244 and 244 kg ha^{-1}. The variation between the observed and predicted mean values was 0.4 and 0.1 kg ha^{-1} for Olsen-P and 1 kg ha^{-1} for NH_4OAc – K, respectively. The results concordant with those reported by Coumaravel et al. (2016) in of tomato crop on Alfisols using multiple linear regression model (MLR). Ranjan *et al*. (2018) reported high R^2 values for predicting soil available NPK in pea-based cropping sequence in Inceptisol and they suggested fertilizer recommendations for the following crop using the prediction equation.

The predicted soil available nutrients for $KMnO_4$-N, Olsen-P and NH_4OAc-K were compared with the analyzed values. Using 1:1 regression line observed and predicted soil test values of available N, P, and K were compared and result (Fig. 1 and 2) showed all points remained close to the regression line with high significant R^2= 0.9816**, 0.9217** and 0.9552** , respectively with yield; and 0.9818**, 0.9178** and 0.9593** , respectively with uptake. Suresh and Santhi (2019) reported using a similar approach for hybrid maize to compare the experimental and estimated data.

Conclusion

The present study concluded that the multiple linear regression models to predict post-harvest soil N, P and K after hybrid castor crop using initial soil available nutrients, applied fertilizer nutrients, seed yield and nutrient uptake by the plant can predict post-harvest soil available N, P, and K of hybrid castor-based cropping sequences. As soil testing of nutrients by farmers after every crop is not practical, the prediction models proposed in the present study can eliminate the need for soil testing of nutrients after every harvest.

Conflict of interest

The authors declare that they have no conflict of interest.

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