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Evaluation of Soil Test Methods for Available Nitrogen, Phosphorus and Potassium in Direct-Seeded Rice–Wheat Cropping Sequence

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ABSTRACT

A study was carried out in an attempt to obtain simple and efficient soil test method(s) for determination of available nitrogen (N), phosphorus (P) and potassium (K) in Mollisols. Soil samples were collected before sowing of direct-seeded rice (DSR) and wheat in sequence to evaluate the soil test methods for available N, P and K. Methods used were wet-oxidation for organic carbon (OC); alkaline $KMnO_4$ for available N; Olsen's-P, AB-DTPA and Mehlich-I for available P; and NH_4OAc-K, AB-DTPA and Mehlich-I for available K. Suitability of these methods for given soil nutrients was evaluated by comparing the R^2 values (coefficient of determination) obtained from regression analysis. Results showed that the R^2 values of obtained equations by using different combinations of soil test methods for the determination of available N, P and K in soil were highly significant in both the crops. Highest R^2 value for DSR (0.442^{**}) and wheat (0.898^{**}) were observed with the combination of OC, Olsen's-P, ABDTPA-K, and OC, Olsen's-P, Mehlich-K, respectively. It showed that these combinations are more promising and superior over other methods.

KEYWORDS

Available soil nitrogen, Available soil phosphorus, Available soil potassium, Direct-seeded rice, Mollisols, Soil test method, Wheat

INTRODUCTION

Rice and wheat is important staple foods of Indian sub continent (Bharati and Singh, 2019; Meena et *al*., 2016). Nutrient is one of the crucial inputs for improving production (Kanaujia, 2016). One of the objectives of soil testing is to provide suitable guidance for efficient soil fertility management by using the relationships between soil tests and crop response to applied nutrients. A number of soil test methods haves been used to extract the nutrients from the soil, but the calibration between the extractable nutrient level and the plant growth may not be available for all the extractants. For diagnosing the nutrient status of soil and deciding the need for nutrient application, soil testing methods are widely used. Therefore, accurate determination of available nutrients by soil testing methods will pave the way for precise nutrient prescription and increased nutrient use efficiency. Several soil testing methods are used for determining the plant available nutrients in soils. Most of these are specific for one plant nutrient and involve separate procedures of determination which make them time consuming, laborious, cumbersome and costly. Besides, these are not being used in soil testing laboratories, as large number of samples can't be handled in a short period.

Therefore, an ideal soil test method is one that is simple, rapid, reliable, less expensive and easily adaptable to the situations. In this context, multi-nutrient extractants offer a suitable alternative, as more than one nutrient can be extracted at a time (Gartley *et al*., 2002; Rodriguez-Suarez *et al*., 2007; Madurapperuma and Kumaragamage, 2008; Bibiso *et al*., 2015). Multi-nutrient extractant allows the simultaneous extraction of plant available macro, secondary and micronutrients in soils and is highly useful for soil testing laboratories (Alva, 1993). The AB-DTPA is a multi-element soil test for alkaline soils developed by Soltanpour and Schwab (1977). AB-DTPA and Mehlich extraction reagents will increase laboratory productivity and concurrently decrease analytical costs. Improvements in instrumentation and analytical techniques have drastically favoured the use of universal extractant which allows measuring a number of elements with a single extraction. However, the suitability and accuracy of such extractants for determination of available nutrients must be verified on the basis of their relationships with soil, existing analytical methods, and finally the crop responses. Nutrient prescription based on soil testing is well accepted practice. Evaluation of nutrient availability in soil is necessary to make sound nutrient prescription for desired yield target. Various methods have been advocated by several workers to determine available nutrients in soils, but none of these has been found to be universally applicable as the availability of nutrients depends on its amount in the soil, soil characteristics, soil mineralogical composition, soil temperature and soil organic matter content etc.

However, when there is variation in more than one nutrient for both soil and applied nutrients in field conditions, the simple correlation coefficients between soil test value for single nutrient and crop yield may not give correct results due to the interaction effects of soil and applied nutrients. Therefore, multiple regression analyses including all the primary nutrients (N, P and K) at a time can be employed

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as an alternative approach for evaluating the suitability of different soil test methods using R^2 values. Various soil test methods have been evaluated for their suitability under field conditions (Velayutham *et al.*, 1985). Such a screening method is useful to select the most appropriate soil test method (Mosi and Lakshminarayanan, 1985). Information on screening of soil test methods for determination of nutrients under DSR–wheat cropping sequence in mollisols is meager. Therefore, this present study was undertaken to evaluate the suitability of soil test methods for determination of available N, P and K in soil under field conditions in DSR–wheat cropping sequence.

MATERIALS AND METHODS

Experimental site

The field experiments were conducted in B_2 block of Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (29°N latitude, 79°29' E longitude and 243.84 meters above MSL) during *rabi* 2016-17 to 2017-18 in two phases *viz*., soil fertility gradient experiment and test crop experiment as per the technical programme of All India Coordinated Research Project (AICRP) on Soil Test Crop Response (STCR).

Experimental details

In the first phase, the experimental field was divided into three equal strips, and graded doses of 0:0:0, 100:100:100 and 200:200:200 (N: P_2O_5: K_2O kg ha^{-1}) were applied in strip I, II and III, respectively and wheat was grown as an exhausting crop. To minimize the interference of soil and other management factors affecting crop yield for the successful conduct of soil test crop response study, appreciable variation in soil fertility was created artificially as per the fertility gradient approach plan of AICRP on STCR.

In the second phase, each fertility gradient strip was divided into 24 plots (21 treatments + 3 controls) resulting in seventy-two (24×3) plots of 15 m^2 (5 m × 3 m) size in all three strips. Treatments comprising various selected combinations of N, P, K and farm yard manure (FYM) were randomly allocated in each of these three strips. Test crop experiment was laid out as per AICRP on STCR plan and design with treatments comprised of various selected combinations of four levels of N (0, 60, 120 and 180 kg ha^{-1}), P (0, 30, 60 and 90 kg ha^{-1}), K (0, 20, 40 and 60 kg ha^{-1}), and three levels of FYM (0, 5 and 10 t ha^{-1}) for both the crops (DSR and wheat). Fertilizer treatments and controls were randomly distributed in each strip.

Soil sampling and chemical analysis

Before application of basal dose of fertilizers to each crop, representative soil samples (0-15 cm depth) were collected from 72 plots and analyzed for available N, P and K. Methods used were wet-oxidation for organic carbon (Walkley and Black, 1934) (gives indirect estimate of soil available N) and alkaline $KMnO_4$ for available N (Subbiah and Asija, 1956); Olsen's (Olsen *et al.*, 1954), AB-DTPA (Soltanpour and Schwab, 1977) and Mehlich-I (Korcak and Fanning, 1978) for available P; neutral normal ammonium acetate (NH_4OAc) (Hanway and Hiedal, 1952), AB-DTPA (Soltanpour and Schwab, 1977) and Mehlich-I (Korcak and Fanning, 1978) for available K. After the application of FYM and fertilizers in plots, rice cultivar 'Narendra Dhan 359' was grown followed by wheat (var. WH 1105), following standard agronomic practices. Both the crops were harvested at maturity from net plots, and grain yield was recorded and expressed as quintals per hectare (q ha^{-1}).

Statistical analysis

Availability indices of N, P and K were determined by multiple regression equations using grain yield as dependent variable (Y), and soil test values and fertilizer doses as independent variables. The coefficient of determination (R^2) values was calculated for both the crops by different combinations of soil test methods with grain yield in presence of NPK doses and their interactions. Data were analyzed to find out multiple regression equations for different functions with selected soil test methods used for determining organic carbon; alkaline $KMnO_4$ (for N); Olsen's, AB-DTPA or Mehlich-I method (for P); and neutral normal NH_4OAc, AB-DTPA or Mehlich-I method (for K). Correlation analysis was also carried out between grain yield, and different soil test methods and applied fertilizer N, P and K in both the crops.

RESULTS AND DISCUSSION

Available N, P and K in soil

Range and mean values of different soil extractant methods for available N, P and K for DSR and wheat are given in Table 1. The amounts of soil available N, P and K by different extraction methods in the same soil type showed great differences between different methods. Available N by alkaline $KMnO_4$ method in DSR ranged from 125.44 to 200.70 kg ha^{-1} with a mean value of 168.82 kg ha^{-1}, while organic carbon (indirect indicator of soil available N) ranged from 0.314 to 0.971% with mean value of 0.616%. Available P by Olsen's method ranged from 14.37 to 21.74 kg ha^{-1} with mean value of 17.81 kg ha^{-1}. With ABDTPA method, available P ranged from 10.15 to 37.82 kg h^{-1} with mean value of 19.15 kg ha^{-1}, while Mehlich-P ranged from 10.88 to 25.82 kg ha^{-1} with mean value of 17.85 kg ha^{-1}. Available K by NH_4OAc method ranged from 122.08 to 173.60 kg ha^{-1} with mean value of 151.73 kg ha^{-1}, while with ABDTPA method it ranged from 85.57 to 155.90 kg ha^{-1} with mean value of 114.52 kg ha^{-1} and by Mehlich method it range from 96.32 to 159.04 kg ha^{-1} with mean value of 118.74 kg ha^{-1}.

Available N by alkaline $KMnO_4$ method in wheat following DSR ranged from 112.90 to 238.34 kg ha^{-1} with mean value of 173.87 kg ha^{-1}, while organic carbon ranged from 0.457 to 0.886% with mean value of 0.628%. Available P by Olsen's method ranged from 13.63 to 24.32 kg ha^{-1} with mean value of 19.10 kg ha^{-1}. By AB-DTPA method, available P ranged from 9.14 to 23.86 kg h^{-1} with mean value of 17.46 kg ha^{-1}, while Mehlich-P ranged from 12.54 to 23.06 kg ha^{-1} with mean value of 19.35 kg ha^{-1}. Available K by NH_4OAc method ranged from 133.28 to 212.80 kg ha^{-1} with mean value of 161.82 kg ha^{-1} and by ABDTPA method it ranged from 78.40 to 143.81 kg ha^{-1} with mean value of 116.61 kg ha^{-1} and Mehlich-K ranged from 91.28 to 165.20 kg ha^{-1} with mean value of 118.02 kg ha^{-1}.

Table 1: Available nitrogen (N), phosphorus (P) and potassium (K) obtained with different soil extractant methods for direct-seeded rice and wheat

Parameters	Available N (kg ha^{-1})		Available P (kg ha^{-1})			Available K (kg ha^{-1})		
	OC (%)	Alkaline KMnO 4	Olsen's	AB-DTPA	Mehlich	NH 4 OAc	AB-DTPA	Mehlich
Direct -seeded rice								
Range	0.314 – 0.971	125.44 – 200.70	14.37 – 21.74	10.15 – 37.82	10.88 – 25.82	122.08 – 173.60	85.57 – 155.90	96.32 – 159.04
Mean	0.616	168.82	17.81	19.15	17.85	151.73	114.52	118.74
Median	0.593	169.34	17.68	18.91	18.45	153.44	111.10	115.92
SD (±)	0.132	18.71	1.42	5.57	3.41	13.77	17.65	14.96
CV (%)	21.39	11.08	7.99	19.08	19.13	9.08	15.41	12.60
Wheat								
Range	0.457 – 0.886	112.90 – 238.34	13.63 – 24.32	9.14 – 23.86	12.54 – 23.06	133.28 – 212.80	78.40 – 143.81	91.28 – 165.20
Mean	0.628	173.87	19.10	17.46	19.35	161.82	116.61	118.02
Median	0.629	175.62	18.79	17.39	19.92	161.28	120.74	115.36
SD (±)	0.099	28.28	3.08	3.50	2.72	17.16	17.10	17.02
CV (%)	15.84	16.38	16.13	19.06	14.05	10.68	14.66	14.43

For P, both AB-DTPA method and Olsen's tests remove soil P with HCO_3^- ions and mainly from Ca- phosphates (Elrashidi *et al*., 2001). For available K, ammonium acetate (NH_4OAc) extracted the highest amounts of K, followed by AB-DTPA and Mehlich-I, which was attributed to the presence of higher concentration of NH_4^+ ions in NH_4OAc. Ammonium ions are known to efficiently replace exchangeable K as well as K from specific sites (Sharma *et al*., 2018). Pant (2010) and Arya (2019) found similar range and mean values of available soil N in similar type of soil using these soil test methods. In case of P and K, the extractability was maximum with Olsen's and neutral normal NH_4OAc, respectively in these soil and climatic conditions. Similar types of results were also observed by Gangola (2016), Kumar (2016) and Luthra (2019) for different crops in same type of soils.

Significance of combination of different availability indices of N, P and K

Various combinations of different availability indices of N, P and K are given in Table 2 and 3. The R^2 values obtained for both the crops by different combinations of soil test methods indicated that all the combinations of soil test methods were significant ($p \leqslant 0.01$) under these particular soil and climatic conditions. The variability in grain yield accounted for 30.9 to 44.2% and 86.8 to 89.8% in DSR and wheat, respectively. The suitability of the used soil test methods for available N, P and K was selected from the magnitude of R^2 values or improvement in R^2 values. The order of suitability on the basis of magnitude of R^2 values was (OC, Olsen's-P, ABDTPA-K, $R^2 = 0.442^{**}$) > (OC, Olsen's-P, NH_4OAc-K, $R^2 = 0.418^{**}$) > (OC, Olsen's-P, Mehlich-K, $R^2 = 0.416^{**}$) > (OC, ABDTPA-P, ABDTPA-K, $R^2 = 0.414^{**}$) > (OC, Mehlich-P, ABDTPA-K, $R^2 = 0.410^{**}$) > (OC, ABDTPA-P, Mehlich-K, $R^2 = 0.405^{**}$) > (OC, Mehlich-P, Mehlich-K, $R^2 = 0.403^{**}$) > (OC, Mehlich-P, NH_4OAc-K, $R^2 = 0.396^{**}$) > (OC, ABDTPA-P, NH_4OAc-K, $R^2 = 0.388^{**}$) > (Alkaline-$KMnO_4$, Olsen's-P, ABDTPA-K, $R^2 = 0.367^{**}$) > (Alkaline-$KMnO_4$, Olsen's-P, Mehlich-K, $R^2 = 0.355^{**}$) > (Alkaline-$KMnO_4$, ABDTPA-P, ABDTPA-K, $R^2 = 0.345^{**}$) = (Alkaline-$KMnO_4$, Mehlich-P, Mehlich-K, $R^2 = 0.345^{**}$) > (Alkaline-$KMnO_4$, Olsen's-P, NH_4OAc-K, $R^2 = 0.341^{**}$) > (Alkaline-$KMnO_4$, ABDTPA-P, Mehlich-K, $R^2 = 0.339$) > (Alkaline-$KMnO_4$, Mehlich-P, ABDTPA-K, $R^2 = 0.337$) > (Alkaline-$KMnO_4$, Mehlich-P, NH_4OAc-K, $R^2 = 0.323^{**}$) > (Alkaline-$KMnO_4$, ABDTPA-P, NH_4OAc-K, $R^2 = 0.309^{**}$) for DSR. Similarly, the order of suitability for soil test methods in wheat on the basis of magnitude of R^2 values was (OC, Olsen's-P, Mehlich-K, $R^2 = 0.898^{**}$) > (OC, ABDTPA-P, NH_4OAc-K, $R^2 = 0.897^{**}$) = (OC, Olsen's-P, NH_4OAc-K, $R^2 = 0.897^{**}$) > (OC, Olsen's-P, ABDTPA-K, $R^2 = 0.896^{**}$) = (OC, ABDTPA-P, Mehlich-K, $R^2 = 0.896^{**}$) = (OC, Mehlich-P, NH_4OAc-K, $R^2 = 0.896^{**}$) > (OC, Mehlich-P, ABDTPA-K, $R^2 = 0.894^{**}$) = (OC, Mehlich-P, Mehlich-K, $R^2 = 0.894^{**}$) > (OC, ABDTPA-P, ABDTPA-K, $R^2 = 0.893^{**}$) > (Alkaline-$KMnO_4$, Olsen's-P, NH_4OAc-K, $R^2 = 0.888^{**}$) > (Alkaline-$KMnO_4$, ABDTPA-P, NH_4OAc-K, $R^2 = 0.884^{**}$) > (Alkaline-$KMnO_4$, Olsen's-P, ABDTPA-K, $R^2 = 0.882^{**}$) = (Alkaline-$KMnO_4$, Olsen's-P, Mehlich-K, $R^2 = 0.882^{**}$) > (Alkaline-$KMnO_4$, Mehlich-P, NH_4OAc-K, $R^2 = 0.881^{**}$) > (Alkaline-$KMnO_4$, Mehlich-P, ABDTPA-K, $R^2 = 0.872$) = (Alkaline-$KMnO_4$, ABDTPA-P, ABDTPA-K, $R^2 = 0.872$) > (Alkaline-$KMnO_4$, ABDTPA-P, Mehlich-K, $R^2 = 0.868^{**}$) = (Alkaline-$KMnO_4$, Mehlich-P, Mehlich-K, $R^2 = 0.868^{**}$).

Among the combinations evaluated, the variation in the magnitude of R^2 values obtained for both the crops by using the combinations of different soil test methods is meager. But OC, Olsen's-P and ABDTPA-K combination in DSR was found superior over other methods of determining available soil N, P and K under field condition as indicated by highest R^2 value (0.442^{**}). While, for wheat, the combination of OC, Olsen's-P and Mehlich-K, being highest in R^2 value (0.898^{**}), was found to be superior over other methods. Among the individual methods, the suitability of soil test method for the nutrients (N or P or K) was evaluated from the magnitude of R^2 values or improvement in R^2 values by keeping the other two methods constant for specific nutrients in multiple regression equations. Among the individual methods, the alkaline $KMnO_4$-N had R^2 values of 0.341^{**} and 0.888^{**} and these were 0.418^{**} and 0.897^{**} in case of organic carbon for DSR and wheat, respectively, when Olsen's-P was used for available P and NH_4OAc-K for available K estimation. Organic carbon method was found slightly superior to alkaline $KMnO_4$ as indicated by higher R^2 values for both the crops in Mollisols. The R^2 values for different methods (Olsen's P, AB-DTPA P and Mehlich-I P) of available P estimation was 0.418^{**} for Olsen's P, 0.414^{**} for AB-DTPA P and 0.396^{**} for Mehlich-I P in DSR. While, for wheat, the R^2 value for Olsen's P was 0.897^{**}, 0.897^{**} for AB-DTPA P and 0.896^{**} for Mehlich-I P, when organic carbon method and NH_4OAc method were used for available N and K determination, respectively. Likewise, R^2 values for different methods (Olsen's P, AB-DTPA P and Mehlich-I P) of available P estimation was 0.341^{**} for Olsen's P, 0.309^{**} for AB-DTPA P and 0.323^{**} for Mehlich-I P in case of DSR. While, for wheat, R^2 value for Olsen's P was 0.888^{**}, 0.884^{**} for AB-DTPA P and 0.881^{**} for Mehlich-I P, when alkaline $KMnO_4$ method for available N and NH_4OAc method for available K were used. Therefore, it can be inferred that Olsen's method in both the crops was superior compared to other two methods as a measure of available P as indicated by higher R^2 values. The R^2 values for different methods of available K estimation (NH_4OAc-K, AB-DTPA-K and Mehlich-I-K) was 0.418^{**} for NH_4OAc-K, 0.442^{**} for AB-DTPA K and 0.416^{**} for Mehlich-I K in DSR. While, for wheat, R^2 value for NH_4OAc-K was 0.897^{**}, 0.896^{**} for AB-DTPA K and 0.898^{**} for Mehlich-I K, when organic carbon and Olsen's method were used for available N and P determination, respectively. The R^2 values for different methods of available K estimation (NH_4OAc-K, AB-DTPA-K and Mehlich-I-K) was 0.341^{**} for NH_4OAc-K, 0.367^{**} for AB-DTPA K and 0.355^{**} for Mehlich-I K in DSR. While, for wheat, R^2 value for NH_4OAc-K was 0.888^{**}, 0.882^{**} for AB-DTPA K and 0.882^{**} for Mehlich-I K, when alkaline $KMnO_4$ method and Olsen's method were used for available N and P determination, respectively. Thus, it can be concluded that AB-DTPA method in DSR and NH_4OAc method in wheat crop were superior to other methods as a measure of available K in soil as indicated by higher R^2 values. It was found that among the individual soil test methods, soil organic carbon and Olsen's method for determination of available N and P in soil, respectively, for both the crops were found more promising and superior over other methods as indicated by higher R^2 values, keeping other two methods constant for specific nutrient in equations. Alkaline $KMnO_4$ method used for extracting available N was found suitable for predicting its availability as reported by Lakshminarayana and Rajgopoal (2000). While, ABDTPA and NH_4OAc methods were superior for the determination of available K in soil for DSR and wheat, respectively.

Table 2: Multivariate regression equations representing the relationship among the soil test values, fertilizer doses, their interactions and grain yield in direct-seeded rice (n = 72)

Regression equations	R^2	Parameters
$Y = -11.9298 + 6.0160\ OC + 0.7354\ SP + 0.1939\ SK + 0.1126\ FN - 1.0868\ FP + 1.0831\ FK - 0.0008\ FN^{2*} + 0.0140\ FP^2 - 0.0072\ FK^2 + 0.1509\ FNOC + 0.0240\ FPSP - 0.0043\ FKSK$	0.418^{**}	OC% Olsen's-P NH_4OAc-K
$Y = -13.8569 - 2.1002\ OC + 0.0316\ SP + 0.5221\ SK + 0.0931\ FN - 1.6246\ FP + 1.5655\ FK^{**} - 0.0010\ FN^{2*} + 0.0151\ FP^{2*} + 0.0057\ FK^2 + 0.2097\ FNOC + 0.0544\ FPSP - 0.0167\ FKSK^{*}$	0.442^{**}	OC% Olsen's-P ABDTPA-K
$Y = -3.5666 + 3.2474\ OC - 0.1089\ SP + 0.3330\ SK + 0.1172\ FN - 1.2581\ FP + 0.8024\ FK - 0.0009\ FN^{2*} + 0.0077\ FP^2 - 0.0083\ FK^2 + 0.1648\ FNOC + 0.0485\ FPSP - 0.0041\ FKSK$	0.416^{**}	OC% Olsen's-P Mehlich-K
$Y = 0.4240 + 4.3605\ OC - 0.0007\ SP + 0.2051\ SK + 0.0877\ FN - 0.5876\ FP + 1.0026\ FK - 0.0008\ FN^{2*} + 0.0133\ FP^2 - 0.0076\ FK^2 + 0.1846\ FNOC - 0.0013\ FPSP - 0.0038\ FKSK$	0.388^{**}	OC% ABDTPA-P NH_4OAc-K
$Y = -19.1012 - 5.7105\ OC - 0.3324\ SP + 0.6720\ SK^{*} + 0.0421\ FN - 0.6187\ FP + 1.5812\ FK^{**} - 0.0008\ FN^{2*} + 0.0131\ FP^2 + 0.0090\ FK^2 + 0.2523\ FNOC + 0.0048\ FPSP - 0.0192\ FKSK^{*}$	0.414^{**}	OC% ABDTPA-P ABDTPA-K
$Y = -13.6346 + 3.5198\ OC - 0.4476\ SP + 0.4747\ SK + 0.0909\ FN - 0.2614\ FP + 0.6823\ FK - 0.0007\ FN^{2*} + 0.0053\ FP^2 - 0.0085\ FK^2 + 0.1855\ FNOC + 0.0021\ FPSP - 0.0041\ FKSK$	0.405^{**}	OC% ABDTPA-P Mehlich-K
$Y = -5.3242 + 6.7352\ OC + 0.1335\ SP + 0.2226\ SK + 0.0981\ FN - 0.3567\ FP + 1.0168\ FK - 0.0008\ FN^{2*} + 0.0156\ FP^2 - 0.0076\ FK^2 + 0.1602\ FNOC - 0.0182\ FPSP - 0.0038\ FKSK$	0.396^{**}	OC% Mehlich-P NH_4OAc-K
$Y = -19.5224 - 3.8583\ OC - 0.2009\ SP + 0.6310\ SK + 0.0587\ FN - 0.5228\ FP + 1.5766\ FK^{**} - 0.0009\ FN^{2*} + 0.0122\ FP^2 + 0.0062\ FK^2 + 0.2322\ FNOC + 0.0004\ FPSP - 0.0177\ FKSK^{*}$	0.410^{**}	OC% Mehlich-P ABDTPA-K
$Y = -12.6441 + 8.6685\ OC - 0.5795\ SP + 0.4387\ SK + 0.1195\ FN - 0.1410\ FP + 0.8269\ FK - 0.0008\ FN^{2*} + 0.0021\ FP^2 - 0.0107\ FK^2 + 0.1388\ FNOC + 0.0029\ FPSP - 0.0040\ FKSK$	0.403^{**}	OC% Mehlich-P Mehlich-K
$Y = -13.3668 - 0.0072\ SN + 0.8787\ SP + 0.2167\ SK + 0.2288\ FN - 1.2218\ FP + 1.0913\ FK - 0.0007\ FN^2 + 0.0161\ FP^{2*} - 0.0058\ FK^2 - 0.0003\ FNSN + 0.0283\ FPSP - 0.0046\ FKSK$	0.341^{**}	Alk. $KMnO_4$-N Olsen's-P NH_4OAc-K

Y = – 27.5505 + 0.0039 SN + 0.0538 SP + 0.6498 SK* + 0.2416 FN - 1.7401 FP + 1.5957 FK* - 0.0007 FN^{2*} + 0.0168 FP^{2*} + 0.0091 FK^{2} – 0.0003 FNSN + 0.0578 FPSP – 0.0187 FKSK*	0.367**	Alk. $KMnO_4$-N Olsen's-P ABDTPA-K
Y = – 5.8053 – 0.0362 SN – 0.0474 SP + 0.4149 SK + 0.2431 FN – 1.2334 FP + 0.6627 FK – 0.0007 FN^{2} + 0.0074 FP^{2} – 0.0101 FK^{2} – 0.0003 FNSN + 0.0475 FPSP – 0.0026 FKSK	0.355**	Alk. $KMnO_4$-N Olsen's-P Mehlich-K
Y = – 8.2089 + 0.0572 SN – 0.1912 SP + 0.2354 SK + 0.3210 FN – 0.7823 FP* + 1.1298 FK – 0.0006 FN^{2} + 0.0088 FP^{2} – 0.0077 FK^{2} – 0.0010 FNSN + 0.0180 FPSP – 0.0044 FKSK	0.309*	Alk. $KMnO_4$-N ABDTPA-P NH_4OAc-K
Y = – 38.6115 + 0.0625 SN – 0.6912 SP + 0.8056 SK* + 0.2977 FN – 0.8759 FP* + 1.5918 FK* – 0.0005 FN^{2} + 0.0064 FP^{2} + 0.0110 FK^{2} – 0.0010 FNSN + 0.0314 FPSP – 0.0206 FKSK*	0.345**	Alk. $KMnO_4$-N ABDTPA-P ABDTPA-K
Y = – 17.2592 – 0.0214 SN – 0.6094 SP + 0.5827 SK + 0.2738 FN – 0.3646 FP + 0.6966 FK – 0.0006 FN^{2} + 0.0011 FP^{2} – 0.0093 FK^{2} – 0.0006 FNSN + 0.0156 FPSP – 0.0043 FKSK	0.339**	Alk. KMnO4-N ABDTPA-P Mehlich-K
Y = – 23.3414 + 0.0159 SN + 1.4735 SP + 0.2310 SK + 0.3042 FN – 0.1487 FP + 0.9244 FK – 0.0007 FN^{2} + 0.0270 FP^{2*} – 0.0066 FK^{2} – 0.0007 FNSN – 0.0606 FPSP – 0.0034 FKSK	0.323*	Alk. $KMnO_4$-N Mehlich-P NH_4OAc-K
Y = – 42.3524 + 0.0016 SN + 0.8210 SP + 0.7093 SK* + 0.2589 FN – 0.3136 FP + 1.5041 FK* – 0.0006 FN^{2} + 0.0213 FP^{2} + 0.0083 FK^{2} – 0.0005 FNSN – 0.0357 FPSP – 0.0181 FKSK*	0.337**	Alk. $KMnO_4$-N Mehlich-P ABDTPA-K
Y = – 20.1170 – 0.0403 SN + 0.7227 SP + 0.4555 SK + 0.2685 FN + 0.0783 FP + 0.5913 FK – 0.0007 FN^{2} + 0.0115 FP^{2} – 0.0132 FK^{2} – 0.0004 FNSN – 0.0375 FPSP – 0.0012 FKSK	0.345**	Alk. $KMnO_4$-N Mehlich-P Mehlich-K

*Y, grain yield (q ha^{-1}); OC, organic carbon (%); SN, SP & SK, soil available (kg ha^{-1}) N (alkaline $KMnO_4$-N), P (Olsen's-P, ABDTPA-P and Mehlich-P), and K (NH_4OAc-K, ABDTPA-K, Mehlich-K); FN, FP and FK, fertilizer N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) in elemental forms; **Significant at 1%; *Significant at 5%*

Table 3: Multivariate regression equations representing the relationship among soil test values, fertilizer doses, their interactions and grain yield in wheat (n = 72)

Regression equations	R^2	Parameters
Y = – 9.1479 + 23.6028 OC + 0.3434 SP + 0.0202 SK + 0.3937 FN** – 0.0842 FP – 0.2743 FK – 0.0010 FN^{2**} + 0.0018 FP^{2} – 0.0004 FK^{2} – 0.0328 FNOC – 0.0016 FPSP + 0.0015 FKSK	0.897**	OC% Olsen's-P NH_4OAc-K
Y = – 13.3930 + 27.6948 OC + 0.3019 SP + 0.0520 SK + 0.4037 FN** – 0.1241 FP + 0.1108 FK – 0.0010 FN^{2**} + 0.0003 FP^{2} + 0.0005 FK^{2} – 0.0391 FNOC + 0.0041 FPSP – 0.0017 FKSK	0.896**	OC% Olsen's-P ABDTPA-K
Y = – 5.7057 + 24.6908 OC + 0.4069 SP – 0.0154 SK + 0.3524 FN** – 0.1246 FP + 0.1520 FK – 0.0009 FN^{2**} + 0.0014 FP^{2} + 0.0028 FK^{2} + 0.0023 FNOC + 0.0014 FPSP – 0.0024 FKSK	0.898**	OC% Olsen's-P Mehlich-K
Y = – 17.2070 + 32.2607 OC + 0.4318 SP + 0.0376 SK + 0.4364 FN** – 0.1530 FP – 0.2202 FK – 0.0011 FN^{2**} + 0.0029 FP^{2} – 0.0014 FK^{2} – 0.0796 FNOC – 0.0050 FPSP + 0.0016 FKSK	0.897**	OC% ABDTPA-P NH_4OAc-K
Y = – 19.9780 + 35.9597 OC + 0.3986 SP + 0.0639 SK + 0.4373 FN** – 0.0412 FP + 0.0659 FK – 0.0011 FN^{2**} + 0.0001 FP^{2} – 0.0005 FK^{2} – 0.0702 FNOC – 0.0040 FPSP – 0.0010 FKSK	0.893**	OC% ABDTPA-P ABDTPA-K
Y = – 19.0244 + 38.9004 OC* + 0.7326 SP – 0.0036 SK + 0.4087 FN** – 0.0771 FP + 0.3109 FK – 0.0010 FN^{2**} + 0.0035 FP^{2} + 0.0021 FK^{2} – 0.0575 FNOC – 0.0127 FPSP – 0.0032 FKSK	0.896**	OC% ABDTPA-P Mehlich-K
Y = – 13.7609 + 29.5440 OC + 0.2984 SP + 0.0361 SK + 0.3976 FN** + 0.1675 FP – 0.2874 FK – 0.0010 FN^{2**} + 0.0030 FP^{2} – 0.0004 FK^{2} – 0.0449 FNOC – 0.0181 FPSP + 0.0017 FKSK	0.896**	OC% Mehlich-P NH_4OAc-K
Y = – 17.2362 + 28.4153 OC + 0.4821 SP + 0.0562 SK + 0.3929 FN** + 0.3624 FP – 0.0746 FK – 0.0011 FN^{2**} + 0.0006 FP^{2} – 0.0004 FK^{2} – 0.0130 FNOC – 0.0231 FPSP + 0.0001 FKSK	0.894**	OC% Mehlich-P ABDTPA-K
Y = – 8.4235 + 30.5677 OC + 0.5759 SP – 0.0394 SK + 0.3589 FN** + 0.1342 FP + 0.011714 FK – 0.0009 FN^{2**} + 0.0038 FP^{2} + 0.0017 FK^{2} – 0.0008 FNOC – 0.0192 FPSP – 0.0013 FKSK	0.894**	OC% Mehlich-P Mehlich-K
Y = – 3.0834 + 0.0075 SN + 0.5647 SP + 0.0260 SK + 0.4144 FN** – 0.0099 FP – 0.4648 FK – 0.0010 FN^{2**} + 0.0012 FP^{2} – 0.0004 FK^{2} – 0.0002 FNSN – 0.0025 FPSP + 0.0028 FKSK	0.888**	Alk. $KMnO_4$-N Olsen's-P NH_4OAc-K

$Y = -4.5287 + 0.0134\,SN + 0.5676\,SP + 0.0389\,SK + 0.4010\,FN^{**} - 0.0199\,FP - 0.0200\,FK - 0.0010\,FN^{2**} - 0.0015\,FP^2 - 0.0005\,FK^2 - 0.0001\,FNSN + 0.0044\,FPSP - 0.0002\,FKSK$	0.882^{**}	Alk. $KMnO_4$-N Olsen's-P ABDTPA-K
$Y = 0.8425 + 0.0373\,SN + 0.6181\,SP - 0.0412\,SK + 0.3852\,FN^{**} - 0.1306\,FP + 0.0032\,FK - 0.0009\,FN^{2**} + 0.0006\,FP^2 + 0.0007\,FK^2 - 0.0002\,FNSN + 0.0057\,FPSP - 0.0004\,FKSK$	0.882^{**}	Alk. $KMnO_4$-N Olsen's-P Mehlich-K
$Y = -7.2586 + 0.0525\,SN + 0.3208\,SP + 0.0432\,SK + 0.4527\,FN^{**} - 0.1506\,FP - 0.4968\,FK - 0.0010\,FN^{2**} + 0.0001\,FP^2 - 0.0018\,FK^2 - 0.0005\,FNSN + 0.0038\,FPSP + 0.0036\,FKSK$	0.884^{**}	Alk. $KMnO_4$-N ABDTPA-P NH_4OAc-K
$Y = -6.7729 + 0.0616\,SN + 0.3383\,SP + 0.0404\,SK + 0.4239\,FN^{**} + 0.0614\,FP - 0.2260\,FK - 0.0011\,FN^{2**} - 0.0048\,FP^2 - 0.0031\,FK^2 - 0.0003\,FNSN + 0.0036\,FPSP + 0.0025\,FKSK$	0.872^{**}	Alk. $KMnO_4$-N ABDTPA-P ABDTPA-K
$Y = -8.4548 + 0.1018\,SN + 0.7345\,SP - 0.0470\,SK + 0.4205\,FN^{**} - 0.0239\,FP + 0.1600\,FK - 0.0010\,FN^{2**} + 0.0002\,FP^2 - 0.0017\,FK^2 - 0.0004\,FNSN - 0.0060\,FPSP - 0.0004\,FKSK$	0.868^{**}	Alk. $KMnO_4$-N ABDTPA-P Mehlich-K
$Y = -4.2871 + 0.0202\,SN + 0.4054\,SP + 0.0421\,SK + 0.4172\,FN^{**} + 0.1096\,FP - 0.5307\,FK - 0.0010\,FN^{2**} + 0.0023\,FP^2 - 0.0012\,FK^2 - 0.0002\,FNSN - 0.0119\,FPSP + 0.0035\,FKSK$	0.881^{**}	Alk. $KMnO_4$-N Mehlich-P NH_4OAc-K
$Y = -8.2194 - 0.0138\,SN + 0.8216\,SP + 0.0690\,SK + 0.3845\,FN^{**} + 0.5220\,FP - 0.1987\,FK - 0.0012\,FN^{2**} - 0.0011\,FP^2 - 0.0021\,FK^2 + 0.0002\,FNSN - 0.0268\,FPSP + 0.0017\,FKSK$	0.872^{**}	Alk. $KMnO_4$-N Mehlich-P ABDTPA-K
$Y = 1.7713 + 0.0468\,SN + 1.0450\,SP - 0.1159\,SK + 0.3938\,FN^{**} + 0.1390\,FP - 0.2066\,FK - 0.0010\,FN^{2**} + 0.0048\,FP^2 - 0.0026\,FK^2 - 0.0002\,FNSN - 0.0215\,FPSP + 0.0027\,FKSK$	0.868^{**}	Alk. $KMnO_4$-N Mehlich-P Mehlich-K

*Y, grain yield (q ha^{-1}); OC, organic carbon (%); SN, SP & SK, soil available (kg ha^{-1}) N (alkaline $KMnO_4$-N), P (Olsen's-P, ABDTPA-P and Mehlich-P), and K (NH_4OAc-K, ABDTPA-K, Mehlich-K); FN, FP and FK, fertilizer N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) in elemental forms; **Significant at 1%; *Significant at 5%*

Suitability of these methods for given soil nutrient was evaluated by comparison of the magnitude of R^2 values of regression equations. A similar type of evaluation of soil test methods for available N, P and K for French bean and maize was also carried out by Gangola *et al.* (2017). These observations are in accordance with the findings reported by Dhawan *et al.* (1992) and Prasad (1994). Various soil test methods were evaluated for their suitability under field conditions (Velayutham *et al.*, 1985) and such a screening of method was considered useful to select the most appropriate soil test method (Mosi and Lakshminarayanan, 1985). ABDTPA extractant was also found suitable for the determination of available K in all soil pH ranges (Malathi and Stalin, 2018). A highly significant correlation was also observed between NH_4OAc- K and ABDTPA-K for neutral and alkaline soils, as also reported by Malathi and Stalin (2018). Similar results were also observed by Sharma *et al.* (2018).

Table 4: Pearson's correlation coefficient (r) among grain yield, different methods of N, P and K determination and fertilizer N, P and K in direct-seeded rice

Parameters	Y	OC	Alkaline $KMnO_4$-N	Olsen's-P	AB-DTP A-P	Mehlich -P	NH_4OA c-K	AB-DTP A-K	Mehlich -K	FN	FP	FK
Y	1											
OC	0.401^{**}	1										
Alkaline $KMnO_4$-N	NS	NS	1									
Olsen's-P	NS	NS	NS	1								
ABDTPA-P	NS	0.396^{**}	NS	NS	1							
Mehlich-P	NS	0.351^{**}	NS	NS	0.504^{**}	1						
NH_4OAc-K	NS	NS	NS	NS	NS	NS	1					
ABDTPA-K	0.311^{**}	0.379^{**}	NS	NS	0.553^{**}	NS	NS	1				
Mehlich-K	0.259^{*}	0.344^{**}	NS	NS	0.554^{**}	0.426^{**}	NS	0.622^{**}	1			
FN	0.389^{**}	0.702^{**}	NS	NS	0.449^{**}	0.437^{**}	NS	0.298^{**}	NS	1		
FP	0.259^{**}	0.419^{**}	NS	NS	0.599^{**}	0.757^{**}	NS	0.509^{**}	0.431^{**}	0.582^{**}	1	
FK	0.298^{**}	0.319^{**}	NS	NS	0.269^{**}	0.480^{**}	NS	0.758^{**}	0.746^{**}	0.449^{**}	0.545^{**}	1

*Y, grain yield (q ha^{-1}); OC, organic carbon (%); FN, FP and FK, fertilizer N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) in elemental forms; **Significant at 1%; *Significant at 5%*

Relationship among grain yields, different extraction methods and fertilizer N, P and K in DSR and wheat

Correlation analysis in DSR (Table 4) revealed positive and highly significant correlation between soil organic carbon and grain yield (0.401**). Significant and positive correlation was recorded between grain yield and Mehlich-K (0.259*), and grain yield and ABDTPA-K (0.311**). Furthermore, rice grain yield was positively correlated with fertilizer N (0.389**), fertilizer P (0.259*) and fertilizer K (0.298*). Similarly, grain yield was positively correlated with soil organic carbon (0.582**), alkaline $KMnO_4$ (0.675**) and Mehlich-P (0.251*) in wheat (Table 5). Highly significant positive correlation existed between wheat grain yield and fertilizer N (0.886**), P (0.539**) and K (0.427**). Similar type of correlation was also reported by Sharma *et al.* (2018) and Malathi and Stalin (2018). Khan *et al.* (2007) and Njukeng *et al.* (2013) also reported significant correlations between AB-DTPA extractable and NH_4OAc extractable K. Similar results have been reported for acidic and alkaline upland soils by Elrashidi *et al.* (2003).

Table 5: Pearson's correlation coefficient (r) among grain yield, different methods of N, P and K determination and fertilizer N, P and K in wheat

Parameters	Y	OC	Alkaline KMnO4-N	Olsen's-P	AB-DTPA-P	Mehlich-P	NH4OAc-K	AB-DTPA-K	Mehlich-K	FN	FP	FK
Y	1											
OC	0.582**	1										
Alkaline KMnO4-N	0.675**	0.541**	1									
Olsen's-P	NS	0.485**	0.290*	1								
ABDTPA-P	NS	0.365**	0.293*	0.371**	1							
Mehlich-P	0.251*	0.505**	0.486**	0.526**	0.508**	1						
NH4OAc-K	NS	0.372**	0.334**	0.552**	NS	0.529**	1					
ABDTPA-K	NS	0.280**	0.294*	0.399**	NS	0.386**	0.342**	1				
Mehlich-K	NS	NS	0.266*	NS	0.343**	0.371**	NS	0.513**	1			
FN	0.886**	0.472**	0.721**	NS	0.284**	0.239**	NS	NS	NS	1		
FP	0.539**	0.482**	0.441**	NS	0.608**	0.475**	NS	NS	NS	0.582**	1	
FK	0.427**	0.369**	0.351**	NS	NS	0.296**	NS	0.484**	0.401**	0.449**	0.545**	1

*Y, grain yield (q ha^{-1}); OC, organic carbon (%); FN, FP and FK, fertilizer N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) in elemental forms; **Significant at 1%; *Significant at 5%*

CONCLUSION

It can be concluded that among the methods used for determination of available N, P and K, the difference, although variation existed between R^2 values, between any two methods for specific nutrients was meager. But, the highest R^2 values were found with the combination of OC, Olsen's-P and ABDTPA-K, and OC, Olsen's-P and Mehlich-K for DSR and wheat, respectively. Among the individual soil test methods, soil organic carbon and Olsen's method for available N and P determination for both the crops were found promising over other methods, respectively. While, ABDTPA and NH_4OAc method were found suitable for available K determination in soil for DSR and wheat, respectively. The final recommendations on suitability of Olsen/AB-DTPA/ Mehlich-I for soil testing would require studies on correlation between the nutrient's uptake (N, P and K) by different crops and the nutrients extracted/applied based on soil analysis with Olsen/AB-DTPA/ Mehlich-I extractants. Thus, these combinations may be used as availability indices for determination of N, P and K, respectively in DSR–wheat cropping sequence in Mollisols of *tarai* regions.

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