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Comparing distinct soil test methods for available nitrogen, phosphorus and potassium for groundnut (*Arachis hypogaea* L.) and wheat (*Triticum aestivum* L.) grown in North Western India

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ABSTRACT

*An experiment was conducted during 2020-21 and 2021-22 in the tarai region of Uttarakhand in order to find simple, economical, effective, and plant uptake correlated soil test methods for determining the available nitrogen, phosphorous, and potassium. Before sowing of groundnut and wheat, soil samples were collected to evaluate available nitrogen, phosphorus, and potassium soil test methods. Wet oxidation was used for organic carbon, alkaline potassium permanganate ($KMnO_4$) was used for mineralizable nitrogen, Olsen's-P, ammonium bicarbonate-diethylene triamine penta acetic acid (AB-DTPA), Mehlich-1 and Morgan-P were used to extract phosphorus (P), and ammonium acetate (NH_4OAc), ammonium bicarbonate-diethylene triamine penta acetic acid (AB-DTPA), Mehlich-1 and Morgan-K were used to extract potassium (K). The suitability of these methods for various soil nutrients was assessed by comparing R^2 values (coefficients of determination) derived through regression analysis. The results showed that the R^2 values of the derived equations by using different combinations of soil test methods to determine available N, P, and K in soil were highly significant in both crops. Superior R^2 value for groundnut (0.853**) was observed with the combination of alkaline $KMnO_4$, Olsen's P, Mehlich-K and for wheat (0.515**) the combination of alkaline $KMnO_4$, Mehlich-P, NH_4OAc–K. It found that these combinations are more superior to other methods and more promising.*

Keywords: Available soil nitrogen, available soil phosphorus, available soil potassium, Groundnut, wheat, mollisol, regression, soil test method

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a significant oilseed crop and an important agricultural export crop in India. It is an important leguminous crop grown across the nation under various climatic conditions. India has the largest area of land (6.7 million hectares) among the Asian nations, followed by China (4.7 million ha), Indonesia, Myanmar, Pakistan, and Thailand. India harvests more than 25% of the world's groundnuts, followed by China with 20%. Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, Uttar Pradesh, and Rajasthan are the major groundnut-growing states in India. It serves as a significant amount of vegetable protein and edible oil (Prasad *et al.*, 2009). In general, legumes in the rotation improve available soil nitrogen because legumes are a widespread, diversified, and agriculturally important plant order (Heywood, 1971). Legumes are well-known for their advantages in cereal cropping systems. According to studies, legumes improve soil fertility and increase the production of succeeding crops (Jain *et al.*, 2005). Legumes have the ability to fix atmospheric nitrogen and transform it into a form that plants can utilise. Wheat (*Triticum aestivum* L.) is the world's leading cereal crop cultivated over an area of about 226.45 m ha with a production of 161.9 m tonnes. India is second-largest food crop after rice, it has reached a new high of 108.75 million tonnes in 2020-21 and it exceeds the average wheat production of 100.42 million tonnes by 8.32 million tonnes (PIB, 2021).It requires a good supply of nutrients especially nitrogen for its growth (Mandal *et al.*, 1992) and yield (Krylov and Pavlov, 1989). One objective of soil testing is to get advice for appropriate and efficient soil nutrient management utilizing the relationships between soil test results and crop response to applied nutrient. Distinct soil test methods have been employed to extract nutrients from the soil; however there may not be a calibration between the amount of extractable nutrient and plant

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growth for all available extractants. For determining soil nutrient status and calculating the quantity of nutrient application, soil testing methods are widely used. This will enable us to prescribe nutrients more precisely and to increase nutrient use efficiency. For evaluating the plant available nutrient, various soil testing methods are used. The majority of these is plant nutrient-specific and involves separate procedures of determination that are time consuming, tedious and expensive. Furthermore, they are not used in soil testing laboratory, since a large number of samples cannot be analyzed in a short amount of time.By considering this discussion, multi-nutrient extractants can be a great alternative because they can extract many nutrients simultaneously (Madurapperuma and Kumaragamage, 2008; Bibiso *et al.*, 2015). Multi-nutrient extractants enable the subsequent extraction of plant available macronutrients, secondary nutrients and micronutrients in soils, making them extremely helpful in soil testing laboratories (Alva, 1993). The table below shows some classic examples of universal extractants.

Extractants	Composition	Elements analyzed
Mehlich-3 (Mehlich, 1984)	A mixture of 0.2 M HOAc, 0.25 M NH_4NO_3, 0.015 M NH_4F,0.013 M HNO_3 and 0.001 M EDTA, pH 2.5	P, K, Ca, Mg, S, B, Zn, Fe, Cu, Mn
AB-DTPA (Soltanpour and Schwab, 1977)	A mixture of M NH_4HCO_3 and 0.5 M DTPA, pH 7.6	P, K, Zn, Fe, Cu, Mn
Morgan (Morgan, 1941)	A mixture of 0.73 M NaOAc and 0.025 M HCl, pH 4.8	P, K, Ca, Mg, B, Zn, Fe, Cu, Mn
Modified Morgan (McIntosh, 1969)	A mixture of 0.62 N NH_4OH and 1.25 N HOAc, pH 4.8	P, K, Ca, Mg, Zn, Fe, Cu, Mn
CDTA-Glycerol method (Seth *et al.*, 2017)	A mixture of 0.002 M CDTA + 0.05 M Glycerol + 0.1 M NH_4OAc + 0.01 M NH_4F, pH 4.8	P, K, Ca, Mg, S, B, Zn, Fe, Cu, Mn

The use of universal extractants, which enable measuring several elements with a single extraction, has been greatly favored by advancements in instrumentation and analytical methods. However, the suitability and accuracy of such extractants for determining the amount of available nutrients must be validated based on their interactions with the soil, ongoing analytical techniques, and ultimately the responses of the crops. The practice of prescribing nutrients based on soil testing is widely used. To effectively prescribe nutrients for the targeted yield, the soil's nutrient availability must be evaluated. The availability of nutrients in soils has been determined using a various methods, but none of them has been universally applicable as it relies on the properties of soil, including organic matter content, temperature, and mineral composition. Furthermore, 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 reliable result due to interaction effects of soil and applied nutrient. Furthermore, 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 reliable result due to interaction effects of soil and applied nutrient. As a result, multiple regression analyses that include all of the primary nutrients (N, P, and K) at the same time can be employed as an alternative method for evaluating the suitability of various soil test methods using R^2 values. Several soil testing methods have been evaluated for their suitability in field conditions (Velayuthan *et al.*, 1984). This type of screening procedure is crucial in determining the suitable soil test method (Mosi and Lakshminarayanan, 1985). There is little information on suitablity of soil test methods for nutrient evaluation in mollisols under groundnut and wheat.

Therefore, the study was conducted to evaluate the suitability of soil test methods for determining available N, P, and K in soil under field conditions taking groundnut as test crop and wheat succeeding crop.

MATERIALS AND METHODS

The study area is situated in the *tarai* region, which has a subtropical-humid climate. The experiment was carried out in the D_7 block of the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, India (29 N latitude, $79^0 29^'$ E longitude, 243.84 m above MSL) during *Rabi* 2020-21 to 2021-22 in three phases *viz*., soil fertility gradient experiment, test crop experiment and residual crop experiment as per the technical programme of All India Coordinated Research Project (AICRP) on Soil Test Crop Response (STCR). 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 oat was grown during *rabi* 2020-21 as an exhausting crop. For the successful conduct of the soil test crop response study, significant variation in soil fertility was created artificially in accordance with the fertility gradient approach plan of the AICRP on STCR. This was done to minimize the interference of soil and other management factors affecting crop yield.

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 9 m (3 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 on groundnut was laid out during *kharif*, 2021 as per AICRP on STCR plan and design with treatments comprised of various selected combinations of four levels of N (0, 10, 20 and 30 kg ha^{-1}), P (0, 15, 30 and 45 kg ha^{-1}), K (0, 22.5, 45 and 67.5 kg ha^{-1}), and three levels of FYM (0, 5 and 10 t ha^{-1}). Fertilizer treatments and controls were randomly distributed in each strip. In the third phase, residual effects of nutrients were studied by growing wheat during *rabi*, 2021 on the same field and no fertilizers were applied to it. Before application of basal dose of fertilizers to test 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), Mehlich-I (Korcak and Fanning, 1978) and Morgan-P (Morgan, 1941) for available P; neutral normal ammonium acetate (NH_4OAc) (Hanway and Heidel, 1952), AB-DTPA (Soltanpour and Schwab, 1977), Mehlich-1 (Korcak and Fanning, 1978) and Morgan-K (Morgan, 1941) for available K. Moreover, representative soil samples collected before sowing of wheat also.Both the crops were harvested at maturity from net plots; groundnut pod and wheat grain yield was recorded and expressed as quintals per hectare (q ha^{-1}). Availability indices of N, P and K were determined by multiple regression equations using pod or 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 pod yield in case of groundnut and grain yield of wheat 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, Mehlich-1 and Morgan-P method (for P); and neutral normal NH_4OAc, AB-DTPA, Mehlich-1 and Morgan-K method (for K). Correlation analysis was also carried out between economic productions, different soil test methods and applied fertilizer N, P and K in both the crops.

RESULTS AND DISCUSSION

The Table 1 shows the range and mean values of distinct soil extractants methods for the available N, P, and K that for groundnut and wheat.

Table 1: Available nitrogen (N), phosphorus (P) and potassium (K) determined by different soil extractants for groundnut and wheat

Parameter	Available N (kg ha^{-1})		Available P (kg ha^{-1})				Available K (kg ha^{-1})			
	OC (%)	Alkaline $KMnO_4$	Olsen's	AB-DTPA	Mehlich	Morgan	NH_4OAc	AB-DTPA	Mehlich	Morgan
Groundnut										
Range	0.39-0.89	112.9-213.2	12.7-20.18	11.67-34.64	10.34-26.26	10.78-20.98	125.55-191.52	84.11-148.96	83.17-153.98	66.19-135.37
Mean	0.55	147.40	16.41	20.02	17.19	16.17	155.78	112.68	113.01	95.59
Median	0.56	137.98	14.20	24.56	17.45	14.46	183.46	112	112.85	91.34
SD (±)	0.10	23.88	1.99	4.51	3.36	2.35	17.12	16.59	15.97	18.63
CV (%)	18.91	16.20	14.03	18.36	19.29	16.26	10.99	14.73	14.13	19.49
Wheat										
Range	0.429-1.014	125.4-250.9	15.67-25.16	11.67-36.64	11.54-25.56	14.64-27.54	124.31-216.88	86.25-156.43	89.32-160.32	68.32-137.28
Mean	0.616	162.50	21.29	20.54	18.72	20.03	158.63	117.62	118.11	97.08
Median	0.624	150.52	20.92	23.53	20.10	18.54	178.85	116.61	115.49	96.32
SD (±)	0.110	29.129	2.16	4.55	3.47	2.70	19.14	18.45	16.16	17.97
CV (%)	17.92	17.14	10.33	19.35	17.27	14.57	12.07	15.82	13.99	17.72

The amounts of soil N, P, and K that were extracted from the same soil type using various extraction methods revealed substantial differences between them. Whereas organic carbon, an indirect measure of soil available N, ranged from 0.39 to 0.89% with a mean value of 0.55%, available N by the alkaline $KMnO_4$ method ranged from 112.90 and 213.20 kg ha^{-1} in groundnut. By Olsen's method, the range of available P was 12.70 to 20.18 kg ha^{-1}, with a mean value of 16.41 kg ha^{-1}. With the AB-DTPA method, available P had a range of 11.67 to 34.64 kg ha^{-1}, Mehlich-P had a range of 10.34 to 26.26 kg ha^{-1}, and Morgan-P had a range of 10.78 to 20.98 kg ha^{-1}, with a mean value of 16.17 kg ha^{-1}.The range of available K determined by the NH_4OAc method was 125.55 to 191.52 kg ha^{-1}, with a mean value of 155.78 kg ha^{-1}; by the AB-DTPA method, it was 84.11 to 148.96 kg ha^{-1}, with a mean value of 112.68 kg ha^{-1}; by the Mehlich-K method, it was 83.17 to 153.98 kg ha^{-1}, with a mean value of 113.01 kg ha^{-1}. The aforementioned data showed that the soil test results were affected by the application of graded levels of N, P, and K in strips for the fertility gradient experiment.

In wheat grown after groundnut, available N determined using the alkaline $KMnO_4$ method ranged from 125.40 to 250.90 kg ha^{-1} with a mean value of 162.50 kg ha^{-1}, while organic carbon ranged from 0.429 to 1.014% with a mean value of 0.616%. By Olsen's method, the range of available P was 15.67 to 25.16 kg ha^{-1}, with a mean value of 21.29 kg ha^{-1}. By AB-DTPA method, available P ranged from 11.67 to 36.64 kg ha^{-1} with mean value of 20.54 kg ha^{-1}, Mehlich-P ranged from 11.54 to 25.56 kg ha^{-1}with mean value of 18.72 kg ha^{-1}and Morgan-P ranged from 14.64 to 27.54 kg ha^{-1} with mean value of 20.03 kg ha^{-1}. Available K analyzed using the NH_4OAc method ranged from 124.31 to 216.88 kg ha^{-1} with a mean value of 158.63 kg ha^{-1}; using the AB-DTPA method, it ranged from 86.25 to 156.43 kg ha^{-1} with a mean value of 178.85 kg ha^{-1}; using the Mehlich-K method, it ranged from 89.32 to 160.32 kg ha^{-1} with a mean value of 118.11 kg ha^{-1}. The combined use of chemical fertilizers and organic manure may have increased organic matter and further mineralization, resulting in an increase in available N, P, and K status. In addition, legumes such as groundnuts, can improve soil nitrogen (N) and be an important contributor of N fertility through symbiotic biological nitrogen fixation (Witcombe and Tiemann, 2022).

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 for groundnut and in table 3 for wheat. 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 ($p \leq 0.01$) under these particular soil and climatic conditions. The variability in grain yield accounted for 79.57 to

83.02 % and 37.05 to 39.71 % in groundnut 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 (Alkaline-$KMnO_4$, Olsen's-P, Mehlich-K, R^2=0.853**) > (Alkaline-$KMnO_4$, ABDTPA-P, Mehlich-K, R^2=0.845**)> (Alkaline-$KMnO_4$, Mehlich-P, Morgan-K, R^2=0.843**) > (Alkaline-$KMnO_4$, Mehlich-P, Mehlich-K, R^2=0.840**) > (Alkaline-$KMnO_4$, Morgan-P, Mehlich, R^2=0.839**) > (Alkaline-$KMnO_4$, ABDTPA-P, NH_4OAc-K, R^2=0.838**) = (Alkaline-$KMnO_4$, ABDTPA-P, Morgan-K, R^2=0.838**) > (Alkaline-$KMnO_4$, Morgan-P, Morgan-K, R^2=0.836**) >(Alkaline-$KMnO_4$, Olsen's-P, Morgan-K, R^2=0.835**) >(OC, Olsen's-P, NH_4OAc-K, R^2=0.827**) >(Alkaline-$KMnO_4$, Olsen's-P, NH_4OAc-K, R^2=0.823**) > (Alkaline-$KMnO_4$, Morgan-P, NH_4OAc-K, R^2=0.818**) = (Alkaline-$KMnO_4$, Mehlich-P, NH_4OAc -K, R^2=0.818**) >(OC, Mehlich-P, Mehlich-K, R^2=0.817**) > (OC, Morgan-P, NH_4OAc-K, R^2=0.815**)>(OC, ABDTPA-P, Mehlich-K, R^2=0.810**) >(OC, Mehlich-P, NH_4OAc-K, R^2=0.809**) > (OC, Olsen's-P, Mehlich-K, R^2=0.808**) = (OC, Morgan-P, Mehlich-K, R^2=0.808**) > (OC, ABDTPA-P, NH_4OAc-K R^2=0.805**) > (OC, Olsen-P, ABDTPA-K, R^2=0.793**) > (OC, Mehlich-P, Morgan-K, R^2=0.792**) > (OC, Morgan-P, Mehlich, R^2= 0.790**) > (OC, Olsen-P, Morgan-K, R^2=0.789**) >(OC,ABDTPA-P, Morgan-K, R^2=0.789**) > (OC, Morgan-P, ABDTPA-K, R^2=0.789**) >(Alkaline-$KMnO_4$, Morgan-P, ABDTPA-K, R^2=0.768**) > (Alkaline-$KMnO_4$, Mehlich-P, ABDTPA-K, R^2=0.765**) >(OC, Mehlich-P, ABDTPA-K, R^2=0.761**) >(Alkaline-$KMnO_4$, ABDTPA-P, ABDTPA-K, R^2=0.743**) >(OC, ABDTPA-P, ABDTPA-K, R^2=0.741**) >(Alkaline-$KMnO_4$, Olsen's-P, ABDTPA-K, R^2=0.738**) for groundnut. Similarly, the order of suitability for soil test methods in wheat on the basis of magnitude of R^2 values was (Alkaline-$KMnO_4$, Mehlich-P, NH_4OAc-K, R^2=0.515**) >(Alkaline-$KMnO_4$, Mehlich-P, Mehlich-K, R^2=0.491**) > (Alkaline-$KMnO_4$, Mehlich-P, ABDTPA-K, R^2=0.482**)> (Alkaline-$KMnO_4$, Mehlich-P, Morgan-K, R^2=0.477**) = Alkaline-$KMnO_4$, Morgan-P, NH_4OAc-K, R^2=0.477**) > (Alkaline-$KMnO_4$, Olsen-P, NH_4OAc-K, R^2=0.476**) > (Alkaline-$KMnO_4$, ABDTPA-P, NH_4OAc-K, R^2=0.473**) >(Alkaline-$KMnO_4$, ABDTPA-P, ABDTPA -K, R^2=0.449**) > (Alkaline-$KMnO_4$, Olsen-P, ABDTPA -K, R^2=0.448**) = (Alkaline-$KMnO_4$, Olsen-P, Morgan-K, R^2=0.448**) =(Alkaline-$KMnO_4$, ABDTPA-P, Morgan-K, R^2=0.448**) >(Alkaline-$KMnO_4$, Olsen-P, Mehlich-K, R^2=0.447**) = (Alkaline-$KMnO_4$, ABDTPA-P, Mehlich-K, R^2=0.447**) >(Alkaline-$KMnO_4$, Morgan-P, Morgan-K, R^2=0.445**) > (Alkaline-$KMnO_4$, Morgan-P, Mehlich-K, R^2=0.443**) > (Alkaline-$KMnO_4$, Morgan-P, ABDTPA-K, R^2=0.439**)>(OC, Olsen-P, NH_4OAc-K, R^2=0.311**)>(OC, Mehlich-P, NH_4OAc-K, R^2=0.298**) > (OC, Olsen's-P, ABDTPA-K, R^2=0.293**) > (OC, Morgan-P, NH_4OAc-K, R^2=0.273**) > (OC, ABDTPA-P, Mehlich-K, R^2=0.270**) = (OC, Olsen's-P, Mehlich-K, R^2=0.270**)> (OC, Olsen's-P, Morgan-K, R^2=0.265**) = (OC, ABDTPA-P, Mehlich-K, R^2=0.265**) > (OC, Morgan-P, ABDTPA-K, R^2=0.259**) > (OC, Mehlich-P, ABDTPA-K R^2=0.249**) > (OC, Mehlich-P, Mehlich-K, R^2=0.242**) > (OC, Morgan-P, Mehlich-K, R^2=0.223**) > (OC, Morgan-P, Mehlich, R^2=0.220**)> (OC, Morgan-P, Mehlich-K, R^2=0.223**) > (OC, Morgan-P, Mehlich, R^2=0.220**) > (OC, Mehlich-P, Morgan-K, R^2=0.206**) > (OC, ABDTPA-P, NH_4OAc, R^2=0.203**) > (OC, ABDTPA-P, ABDTPA-K, R^2=0.141**). The variation in the magnitude of the R^2 values obtained for both crops by combining various soil test methods is moderate among the combinations that were investigated. Alkaline $KMnO_4$, Olsen's-P and Mehlich-K combination in groundnut was found superior over other methods of determining available soil N, P and K under field condition as indicated by highest R^2 value (0.853**). While, for wheat, the combination of Alkaline $KMnO_4$, Mehlich-P and NH_4OAc-K, being highest in R^2 value (0.515**), was found to be superior over other methods. The suitability of the soil test method for the nutrients (N, P, or K) was assessed based on the magnitude of R^2 values or improvement in R^2 values by retaining the other two methods constant for particular nutrients in multiple regression equations. Furthermore, compared the two available N estimation methods (OC and alkaline $KMnO_4$), the alkaline $KMnO_4$ method was shown to be marginally superior to the organic carbon method, as reflected by a higher

Table 2: Empirical equations representing the relationship among the soil test values, fertilizer doses, their interactions and grain yield in groundnut (n = 72)

Sr. No.	Regression equation	R^2	Parameters	Sr. No.	Regression equation	R^2	Parameters
1	Y = -2.7767 + 4.8517 * OC - 0.0046 * SP + 0.0751 * SK - 0.1390 * FN - 0.0090 * FP - 0.1397 * FK + 0.0045 * FN2 - 0.0025 * FP2 - 0.0009 * FK2 + 0.0476 * FNSN + 0.0125 * FPSP + 0.0012 * FKSK	0.827**	OC (%), Olsen's-P, NH_4OAc-K	15	Y = -0.1343 + 3.9294 * OC + 0.0869 * SP + 0.0721 * SK - 0.1317 * FN - 0.0254 * FP - 0.0825 * FK + 0.0031 * FN2 - 0.0024 * FP2 - 0.0005 * FK2 + 0.1028 * FNSN + 0.0138 * FPSP + 0.0010 * FKSK	0.808**	OC (%), Morgan-P Mehlich-K
2	Y = -1.5169 + 4.4135 * OC + 0.2020 * SP + 0.0662 * SK - 0.1316 * FN - 0.0094 * FP - 0.0657 * FK - 0.0036 * FN2 - 0.0018 * FP2 - 0.0036 * FK2 + 0.0712 * FNSN + 0.0105 * FPSP + 0.0008 * FKSK	0.793**	OC (%), Olsen's-P, ABDTPA-K	16	Y = 2.3261 + 4.4355 * OC + 0.1602 * SP + 0.0460 * SK - 0.0896 * FN - 0.0257 * FP - 0.1091 * FK + 0.0033 * FN2 - 0.0018 * FP2 - 0.0008 * FK2 + 0.0050 * FNSN + 0.0115 * FPSP + 0.0014 * FKSK	0.790**	OC (%), Morgan -P Morgan-K
3	Y = -3.1333 + 3.8918 * OC + 0.2917 * SP + 0.0692 * SK - 0.1440 * FN + 0.0377 * FP - 0.0794 * FK - 0.0005 * FN2 - 0.0018 * FP2 - 0.0005 * FK2 + 0.1280 * FNSN + 0.0073 * FPSP + 0.0010 * FKSK	0.808**	OC (%), Olsen's-P, Mehlich-K	17	Y = -3.1298 + 0.0196 * SN + 0.0909 * SP + 0.0713 * SK - 0.1455 * FN + 0.0145 * FP - 0.1285 * FK + 0.0026 * FN2 - 0.0020 * FP2 - 0.0010 * FK2 + 0.0003 * FNSN - 0.0089 * FPSP + 0.0012 * FKSK	0.823**	Al.-$KMnO_4$, Olsen's-P, NH_4OAc-K
4	Y = 2.1060 + 3.1729 * OC + 0.2383 * SP + 0.0433 * SK - 0.1368 * FN + 0.0241 * FP - 0.1241 * FK - 0.0033 * FN2 - 0.0017 * FP2 - 0.0009 * FK2 + 0.0834 * FNSN + 0.0079 * FPSP + 0.0015 * FKSK	0.789**	OC (%), Olsen's-P, Morgan-K	18	Y = -2.5986 + 0.0254 * SN + 0.2647 * SP + 0.0619 * SK - 0.0722 * FN + 0.0094 * FP - 0.0530 * FK + 0.0013 * FN2 - 0.0005 * FP2 - 0.0005 * FK2 + 0.0003 * FNSN - 0.0085 * FPSP + 0.0007 * FKSK	0.738**	Al.-$KMnO_4$, Olsen's-P, ABDTPA-K
5	Y = -5.1559 + 3.2333 * OC - 0.0993 * SP + 0.0844 * SK - 0.2476 * FN + 0.02599 * FP - 0.1899 * FK + 0.0071 * FN2 - 0.0031 * FP2 - 0.0010 * FK2 + 0.1251 * FNSN - 0.0018 * FPSP + 0.0015 * FKSK	0.805**	OC (%), ABDTPA-P, NH_4OAc-K	19	Y = -3.0741 + 0.0317 * SN + 0.1619 * SP + 0.0727 * SK - 0.2695 * FN + 0.0665 * FP - 0.0801 * FK - 0.0030 * FN2 - 0.0026 * FP2 - 0.0004 * FK2 + 0.3103 * FNSN + 0.0074 * FPSP + 0.0009 * FKSK	0.853**	Al.-$KMnO_4$, Olsen's-P, Mehlich-K
6	Y = -1.3568 + 4.0708 * OC - 0.0993 * SP + 0.0823 * SK - 0.2239 * FN + 0.2487 * FP - 0.1072 * FK + 0.0060 * FN2 - 0.0025 * FP2 - 0.0042 * FK2 + 0.1381 * FNSN - 0.0024 * FPSP + 0.0011 * FKSK	0.741**	OC (%), ABDTPA-P, ABDTPA-K	20	Y = -1.1535 + 0.0393 * SN + 0.1490 * SP + 0.0601 * SK - 0.2205 * FN + 0.0626 * FP - 0.0853 * FK - 0.0026 * FN2 - 0.0021 * FP2 - 0.0007 * FK2 + 0.2243 * FNSN + 0.0058 * FPSP + 0.0011 * FKSK	0.835**	Al.-$KMnO_4$, Olsen's-P, Morgan-K
7	Y = 0.2352 + 2.8250 * OC - 0.0498 * SP + 0.7819 * SK - 0.1517 * FN + 0.0806 * FP - 0.0706 * FK - 0.0031 * FN2 - 0.0005 * FP2 - 0.1327 * FK2 + 0.1327 * FNSN + 0.0161 * FPSP + 0.0093 * FKSK	0.810**	OC (%), ABDTPA-P, Mehlich-K	21	Y = -5.1036 + 0.0120 * SN - 0.2172 * SP + 0.0725 * SK - 0.2718 * FN + 0.2545 * FP - 0.1311 * FK + 0.0039 * FN2 - 0.0029 * FP2 - 0.0001 * FK2 + 0.0010 * FNSN - 0.0028 * FPSP + 0.0012 * FKSK	0.838**	Al.-$KMnO_4$, ABDTPA-P, NH_4OAc-K
8	Y = 4.4103 + 3.3685 * OC + 0.0322 * SP + 0.0508 * SK - 0.1066 * FN - 0.1055 * FP - 0.1055 * FK + 0.0029 * FN2 - 0.0008 * FP2 - 0.0008 * FK2 + 0.0472 * FNSN + 0.0155 * FPSP + 0.0014 * FKSK	0.786**	OC(%), ABDTPA-P Morgan-K	22	Y = -4.4293 + 0.0278 * SN - 0.2142 * SP + 0.0752 * SK - 0.1749 * FN + 0.2893 * FP - 0.0858 * FK + 0.0041 * FN2 - 0.0023 * FP2 - 0.0004 * FK2 + 0.0002 * FNSN - 0.0055 * FPSP + 0.0009 * FKSK	0.743**	Al.-$KMnO_4$, ABDTPA-P, ABDTPA-K

9	Y = -4.1123 + 5.7642 * OC - 0.0083 * SP + 0.0823 * SK - 0.1708 * FN + 0.1555 * FP - 0.2009 * FK + 0.0065 * FN2 - 0.0030 * FP2 - 0.0009 * FK2 + 0.0222 * FNSN - 0.0038 * FPSP + 0.0016 * FKSK	0.809**	OC (%), Mehlich-P NH_4OAc-K	23	Y = -2.864 + 0.0331 * SN - 0.0656 * SP + 0.0805 * SK - 0.2519 * FN + 0.00093 * FP - 0.0560 * FK - 0.0030 * FN2 - 0.0029 * FP2 - 0.0003 * FK2 + 0.2721 * FNSN + 0.0128* FPSP + 0.0006 * FKSK	0.845**	Al.-$KMnO_4$, ABDTPA-P, Mehlich-K
10	Y = -1.5676 + 5.6698 * OC + 0.0554 * SP + 0.0812 * SK - 0.1574 * FN + 0.1358 * FP - 0.1155 * FK + 0.0056 * FN2 - 0.0025 * FP2 - 0.0003 * FK2 + 0.0308 * FNSN - 0.0037 * FPSP + 0.0011 * FKSK	0.761**	OC (%), Mehlich-P ABDTPA-K	24	Y = -0.4779 + 0.0411 * SN + 0.0503 * SP + 0.0651 * SK - 0.2021 * FN - 0.0076 * FP - 0.0671 * FK + 0.0025 * FN2 - 0.0023 * FP2 - 0.0006 * FK2 + 0.1884 * FNSN + 0.0106 * FPSP + 0.0009 * FKSK	0.838**	Al.-$KMnO_4$, ABDTPA-P Morgan-K
11	Y = -0.4362 + 3.3035 * OC + 0.1045 * SP + 0.0748 * SK - 0.1258 * FN - 0.0509 * FP - 0.0932 * FK + 0.0026 * FN2 - 0.0025 * FP2 - 0.0005 * FK2 + 0.1094 * FNSN - 0.0150 * FPSP + 0.0011 * FKSK	0.817**	OC (%), Mehlich-P, Mehlich-K	25	Y = -7.0048 + 0.0273 * SN - 0.1624 * SP + 0.0821 * SK - 0.1817 * FN + 0.2153 * FP - 0.1610 * FK + 0.0038 * FN2 - 0.0026 * FP2 - 0.0009 * FK2 + 0.0004 * FNSN - 0.0014 * FPSP + 0.0013 * FKSK	0.818**	Al.-$KMnO_4$, Mehlich-P NH_4OAc-K
12	Y = 3.8438 + 3.6422 * OC + 0.0848 * SP + 0.0468 * SK - 0.0931 * FN - 0.0777 * FP - 0.1254 * FK + 0.0026 * FN2 - 0.0019 * FP2 - 0.0008 * FK2 + 0.0351 * FNSN - 0.0190 * FPSP + 0.0015 * FKSK	0.792**	OC (%), Mehlich-P Morgan-K	26	Y = -5.8240 + 0.0416 * SN + 0.2230 * SP + 0.0767 * SK - 0.0842 * FN + 0.1918 * FP - 0.0965 * FK + 0.0038 * FN2 - 0.0021 * FP2 - 0.0004 * FK2 + 0.0003 * FNSN - 0.0003 * FPSP + 0.0010 * FKSK	0.765**	Al.-$KMnO_4$, Mehlich-P ABDTPA-K
13	Y = -3.9538 + 5.7642 * OC + 0.0370 * SP + 0.0770 * SK - 0.1599 * FN + 0.0906 * FP - 0.1493 * FK + 0.0062 * FN2 - 0.0025 * FP2 - 0.0008 * FK2 + 0.0214 * FNSN - 0.0070 * FPSP + 0.0012 * FKSK	0.815**	OC (%), Morgan-P NH_4OAc-K	27	Y = -3.2315 + 0.0336 * SN + 0.1212 * SP + 0.0767 * SK - 0.2386 * FN - 0.0137 * FP - 0.0844 * FK + 0.0024 * FN2 - 0.0028 * FP2 - 0.0003 * FK2 + 0.2763 * FNSN - 0.0114 * FPSP + 0.0009 * FKSK	0.840**	Al.-$KMnO_4$, Mehlich-P, Mehlich-K
14	Y = -1.8725 + 6.2282 * OC + 0.1236 * SP + 0.0713 * SK - 0.1242 * FN - 0.0522 * FP - 0.0653 * FK + 0.0054 * FN2 - 0.0020 * FP2 - 0.0003 * FK2 + 0.0007 * FNSN - 0.0079 * FPSP + 0.0007 * FKSK	0.773**	OC (%), Morgan-P ABDTPA-K	28	Y = -0.6679 + 0.0410 * SN + 0.0958 * SP + 0.0607 * SK - 0.1969 * FN - 0.0085 * FP - 0.0924 * FK + 0.0021 * FN2 - 0.0023 * FP2 - 0.0006 * FK2 + 0.1978 * FNSN - 0.0097 * FPSP + 0.0011 * FKSK	0.843**	Al.-$KMnO_4$, Mehlich-P Morgan-K
29	Y = -3.2694 + 0.0231 * SN + 0.0353 * SP + 0.0754 * SK - 0.1758 * FN + 0.0468 * FP - 0.1204 * FK + 0.0039 * FN2 - 0.0021 * FP2 - 0.0009 * FK2 + 0.0004 * FNSN - 0.0076 * FPSP + 0.0011 * FKSK	0.818**	Al.-$KMnO_4$, Morgan-P NH_4OAc-K	31	Y = -1.8091 + 0.3185 * OC + 0.0581 * SP + 0.0757 * SK - 0.2625 * FN - 0.0124 * FP - 0.0727 * FK + 0.0029 * FN2 - 0.0027 * FP2 - 0.0004 * FK2 + 0.3066 * FNSN + 0.0119 * FPSP + 0.0008 * FKSK	0.839**	Al.-$KMnO_4$, Morgan-P Mehlich-K
30	Y = -1.7774 + 0.0322 * SN + 0.1251 * SP + 0.0666 * SK - 0.099 * FN - 0.0038 * FP - 0.0469 * FK + 0.0038 * FN2 - 0.0015 * FP2 - 0.0004 * FK2 + 0.0001 * FNSN - 0.0089 * FPSP + 0.0006 * FKSK	0.768**	Al.-$KMnO_4$, Morgan-P ABDTPA-K	32	Y = -0.6770 + 0.0395 * SN + 0.1065 * SP + 0.0617 * SK - 0.2132 * FN - 0.0348 * FP - 0.0768 * FK + 0.0006 * FN2 - 0.2116 * FP2 - 0.0006 * FK2 + 0.2116 * FNSN + 0.0079 * FPSP + 0.0009 * FKSK	0.836**	Al.-$KMnO_4$, Morgan -P Morgan-K

Y, pod yield (q ha^{-1}); OC, organic carbon (%); SN, SP & SK, soil available (kg ha^{-1}) N (alkaline KMnO4 -N), P (Olsen's-P, ABDTPA-P and Mehlich-P), and K (NH4OAc-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: Empirical equations representing the relationship among the soil test values, fertilizer doses, their interactions and grain yield in wheat (n = 72)

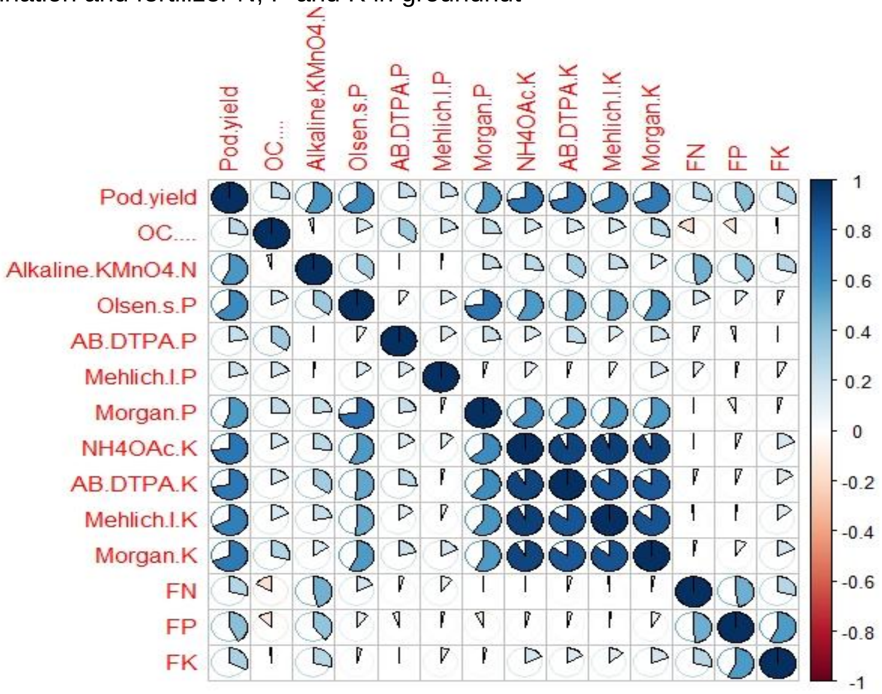
Sr. No.	Regression equation	R^2	Parameters	Sr. No.	Regression equation	R^2	Parameters
1	Y = -235.17 - 45.5446 * SN + 2.7942 * SP + 2.9723 * SK + 16.0584 * SNSP - 1.9913 * SNSK - 0.0720 * SPSK	0.311**	OC (%), Olsen's-P, NH_4OAc-K	11	Y = -89.0968 - 40.6647 * SN + 2.0451 * SP + 1.6727 * SK + 7.1994 * SNSP - 0.8307 * SNSK - 0.0477 * SPSK	0.242**	OC (%), Mehlich-P, Mehlich-K
2	Y = -175.649 - 95.4594 * SN + 3.5446 * SP + 3.1214 * SK + 13.7435 * SNSP - 1.7963 * SNSK - 0.0969 * SPSK	0.293**	OC (%), Olsen's-P, ABDTPA-K	12	Y = -19.8478 - 71.9124 * SN - 0.0860 * SP + 1.3605 * SK + 7.3229 * SNSP - 0.7056 * SNSK - 0.0382 * SPSK	0.206**	OC (%), Mehlich-P Morgan-K
3	Y = -130.613 - 35.6824 * SN - 3.7107 * SP + 2.7260 * SK + 14.1137 * SNSP - 2.3180 * SNSK - 0.0521 * SPSK	0.270**	OC (%), Olsen's-P, Mehlich-K	13	Y = -257.198 + 62.8109 * SN + 4.2882 * SP + 2.7348 * SK + 10.7110 * SNSP - 1.8736 * SNSK - 0.0668 * SPSK	0.273**	OC (%), Morgan-P NH_4OAc-K
4	Y = -86.2852 - 131.823 * SN - 0.0041* SP + 3.0045 * SK + 14.7060 * SNSP - 2.0132 * SNSK - 0.0757 * SPSK	0.265**	OC (%), Olsen's-P, Morgan-K	14	Y = -201.681 - 18.2702 * SN + 4.3607 * SP + 3.2303 * SK + 11.4292 * SNSP - 1.9362 * SNSK - 0.0907 * SPSK	0.259**	OC (%), Morgan-P ABDTPA-K
5	Y = -71.8187 + 72.2576 * SN + 0.1361 * SP + 0.8372 * SK + 1.5698 * SNSP - 0.7701 * SNSK - 0.0043 * SPSK	0.203**	OC (%), ABDTPA-P, NH_4OAc-K	15	Y = -204.618 + 81.4263 * SN + 1.7820 * SP + 3.0617 * SK - 10.4270 * SNSP - 2.5306 * SNSK - 0.0623 * SPSK	0.223**	OC (%), Morgan-P Mehlich-K
6	Y = -25.9955 + 77.4535 * SN - 1.1699 * SP + 0.6727 * SK + 0.9193 * SNSP - 0.9479 * SNSK - 0.0078 * SPSK	0.141**	OC (%), ABDTPA-P, ABDTPA-K	16	Y = -142.021 - 11.6648 * SN + 1.9620 * SP + 3.1713 * SK + 10.5430 * SNSP - 2.2039 * SNSK - 0.0799 * SPSK	0.220**	OC (%), Morgan -P Morgan-K
7	Y = -130.61 - 35.6824 * SN - 0.7107 * SP + 2.7260 * SK + 14.1137 * SNSP - 2.3180 * SNSK - 0.0521 * SPSK	0.270**	OC (%), ABDTPA-P, Mehlich-K	17	Y = -161.03 - 0.4509 * SN + 0.6756 * SP + 1.5005 * SK + 0.0248 * SNSP - 0.0043 * SNSK - 0.0274 * SPSK	0.476**	Al.-$KMnO_4$, Olsen's-P, NH_4OAc-K
8	Y = -86.2852 - 131.823 * SN - 0.0041 * SP + 3.0045 * SK + 14.7060 * SNSP - 2.0132 * SNSK - 0.0751 * SPSK	0.265**	OC (%), ABDTPA-P Morgan-K	18	Y = -131.833 - 0.3142 * SN + 3.1482 * SP + 1.3233 * SK + 0.0127 * SNSP - 0.0028 * SNSK - 0.0369 * SPSK	0.448**	Al.-KMnO4, Olsen's-P, ABDTPA-K

9	Y = -127.528 - 78.8431 * SN - 4.3038 * SP + 1.5973 * SK + 8.1915 * SNSP - 0.5091 * SNSK - 0.0550 * SPSK	0.298**	OC (%), Mehlich-P NH_4OAc-K	19	Y = -122.692 - 0.6324 * SN - 0.9203 * SP + 1.0595 * SK + 0.0062 * SNSP - 0.0042 * SNSK - 0.0104 * SPSK	0.447**	Al.-$KMnO_4$, Olsen's-P, Mehlich-K
10	Y = -73.7657 - 94.107 * SN + 2.7169 * SP + 1.6653 * SK + 8.1788 * SNSP - 0.5438 * SNSK + 0.0594 * SPSK	0.249**	OC (%), Mehlich-P ABDTPA-K	20	Y = -86.2852 - 131.823 * SN - 0.0041* SP + 3.0045 * SK + 14.7060 * SNSP - 2.0132 * SNSK - 0.0757 * SPSK	0.448**	Al.-$KMnO_4$, Olsen's-P, Morgan-K
21	Y = -110.844 + 0.8984 * SN - 1.4060 * SP + 0.6593 * SK + 0.0018 * SNSP - 0.0041 * SNSK - 0.0085 * SPSK	0.473**	Al.-$KMnO_4$, ABDTPA-P, NH_4OAc-K	27	Y = -161.909 + 0.9428 * SN + 2.5711 * SP + 0.9806 * SK - 0.0072 * SNSP - 0.0045 * SNSK - 0.0040 * SPSK	0.491**	Al.-$KMnO_4$, Mehlich-P, Mehlich-K
22	Y = -37.5689 + 0.7054 * SN - 2.2018 * SP + 0.1290 * SK - 0.0015 * SNSP - 0.0031 * SNSK + 0.0232 * SPSK	0.449**	Al.-$KMnO_4$, ABDTPA-P, ABDTPA-K	28	Y = -116.985 + 0.7430 * SN - 2.0092 * SP + 0.8103 * SK - 0.005 * SNSP - 0.0038 * SNSK - 0.0038 * SPSK	0.477**	Al.-$KMnO_4$, Mehlich-P Morgan-K
23	Y = -122.692 + 0.6324 * SN - 0.9203 * SP + 1.0585 * SK + 0.0062 * SNSP - 0.0042 * SNSK - 0.0143 * SPSK	0.447**	Al.-$KMnO_4$, ABDTPA-P, Mehlich-K	29	Y = -175.916 + 0.7531 * SN + 0.1773 * SP + 1.4786 * SK + 0.0166 * SNSP - 0.0052 * SNSK - 0.0208 * SPSK	0.477**	Al.-$KMnO_4$, Morgan-P NH_4OAc-K
24	Y = -111.767 + 0.3552 * SN - 1.9696 * SP + 1.3857 * SK + 0.0114 * SNSP - 0.0035 * SNSK - 0.0327 * SPSK	0.448**	Al.-$KMnO_4$, ABDTPA-P Morgan-K	30	Y = -150.384 + 0.5372 * SN + 3.2925 * SP + 1.4368 * SK + 0.0068 * SNSP - 0.0034 * SNSK - 0.0375 * SPSK	0.439**	Al.-$KMnO_4$, Morgan-P ABDTPA-K
25	Y = -220.889 + 0.9290 * SN + 4.6722 * SP + 1.2598 * SK - 0.0004 * SNSP - 0.0041 * SNSK - 0.0240 SPSK	0.515**	Al.-$KMnO_4$, Mehlich-P NH_4OAc-K	31	Y = -180.568 + 0.8517 * SN + 3.0763 * SP + 1.4489 * SK - 0.0014 * SNSP - 0.0046 * SNSK - 0.0249 * SPSK	0.443**	Al.-$KMnO_4$, Morgan-P Mehlich-K
26	Y = -159.123 + 0.8050 * SN + 4.0266 * SP + 0.9916 * SK - 0.0060 * SNSP - 0.0035 * SNSK - 0.0182 * SPSK	0.482**	Al.-$KMnO_4$, Mehlich-P ABDTPA-K	32	Y = -136.205 + 0.5776 * SN + 2.4343 * SP + 1.5436 * SK + 0.0049 * SNSP - 0.0041 * SNSK - 0.0351 * SPSK	0.445**	Al.-$KMnO_4$, Morgan -P Morgan-K

*Y, grain yield (q ha^{-1}); OC, organic carbon (%); SN, SP & SK, soil available (kg ha^{-1}) N (alkaline KMnO4 -N), P (Olsen's-P, ABDTPA-P and Mehlich-P), and K (NH4OAc-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%*

R^2 value for both crops in Mollisols. Among different methods of available P (Olsen's P, ABDTPA-P, Mehlich-I P and Morgan-P), Olsen's method for groundnut and Mehlich-P for wheat were superior as reflected by higher R^2 value. The Mehlich-I technique in groundnut and NH_4OAc method in wheat were superior to others among the different K estimate methods (NH_4OAc-K, ABDTPA-K, Mehlich-I-K, and Morgan-K), as evidenced by greater R^2 values when the other methods were held constant for particular nutrients in equations. Singh *et al.* (2020) also conducted a similar evaluation of soil test methods for available N, P, and K for DSR and wheat and found that NH_4OAc-K was highly suitable for wheat in Mollisols. According to Lakshminarayana and Rajgopoal (2000), the alkaline $KMnO_4$ method for extracting available N was found to be suitable. While, Olsen's and Mehlich-I methods were superior for the determination of available P in soil for groundnut and wheat, respectively.

Figure 1: Pearson's correlation coefficient (r) correlogram among pod yield, different methods of N, P and K determination and fertilizer N, P and K in groundnut



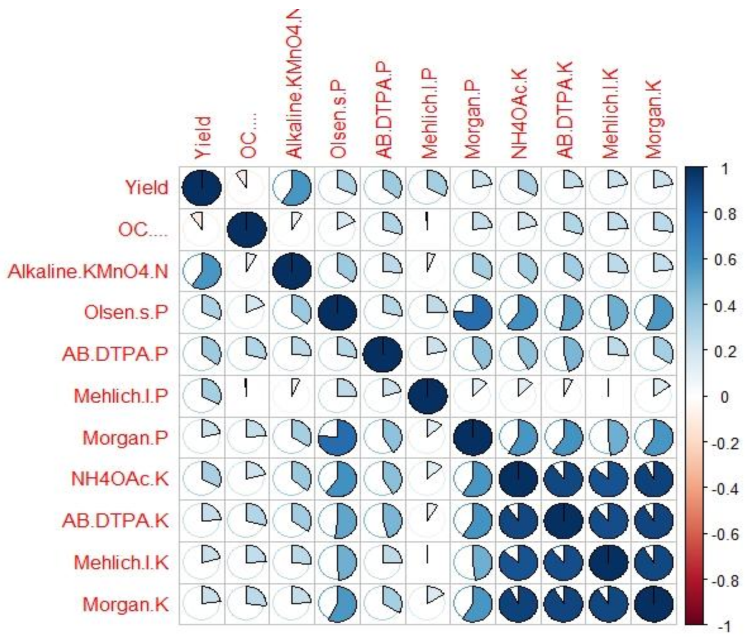
Y, pod yield (q ha^{-1}); OC, organic carbon (%);N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) in elemental forms FN, FP and FK, fertilizer

Arya (2019) conducted a similar type of study of soil test methods for available N, P, and K for cauliflower. These findings are similar to those reported by Dhawan *et al.* (1992) and Prasad (1994). Various soil test methods were evaluated for their suitability under field conditions (Velayutham *et al.*, 1984), and such method screening was thought useful in choosing the most suitable soil test method (Mosi and Lakshminarayanan, 1985).

Relationship among pod/grain yields, different extraction methods and fertilizer N, P and K in groundnut and wheat

Alkaline $KMnO_4$ and pod yield (0.572**), Olsen's P and pod yield (0.634**), and all methods of K and pod yield all indicated positive and highly significant correlations in groundnut (Figure 1). Furthermore, there was a significant correlation between the yield of groundnut pods and fertilizers N (0.289), P (0.418), and K (0.312). Similarly, alkaline $KMnO_4$ (0.675**), Olsen's (0.403**), Mehlich-P (0.281*), NH_4OAc-K (0.393**), and ABDTPA (0.304**) were all significantly correlated with grain yield in wheat (Figure 2). Also, Sharma *et al.* (2018) and Singh *et al.* (2020) reported a similar type of correlation.

Figure 2: Pearson's correlation coefficient (r) correlogram among grain yield, different methods of N, P and K determination and fertilizer N, P and K in wheat



Y, grain yield (q ha^{-1}); OC, organic carbon (%);N (kg ha^{-1}), P (kg ha^{-1}) and K (kg ha^{-1}) in elemental forms

CONCLUSION

It may be concluded that among the methods used to determine available N, P, and K, the difference between any two combinations was low, despite considerable variability in R^2 values were found. However, the highest R^2 values were found with the combination of alkaline KMnO4, Olsen's-P, and Mehlich-K for groundnut, and alkaline KMnO4, Mehlich-P, and NH4OAc-K for wheat. Among the individual soil test methods, alkaline $KMnO_4$ was shown to be more promising than OC method for determining available N for both crops. Olsen's-P for groundnut and NH4OAc-K for wheat were found to be suitable. Meanwhile, the Mehlich-I approach was found to be suitable for available K in groundnut and available P in wheat.Therefore, in the groundnut and wheat cropping sequences in North Western India, these combinations may be considered as availability indices for determining N, P, and K, respectively.

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