ASSESSMENT OF THE INTERDEPENDENCE OF SOIL PROPERTIES AND NUTRIENTS OF DISTRICT MIRZAPUR (U.P), INDIA

Abstract

In present paper assessment of the interdependence of the soil characteristics and nutrients through Multiple Regression analysis and Path coefficient analysis was done. For this soil characteristic data related to the farmers of sampled villages of different blocks of Mirzapur district of Uttar Pradesh was used. The study reveals that pH has significant positive correlation with Sulphur and Boron and significant negative correlation with Nitrogen, Manganese and Iron. EC has shown significant positive correlation with Potassium, Sulphur and Boron and significant negative correlation with Iron, Manganese and Zinc. Moreover, OC is found to have positive and significant correlation with all the nutrients except Nitrogen. Path coefficient analysis reveals that EC, OC, Sulphur, Copper and Boron have positive direct effects on soil pH and remaining have negative direct effects on soil pH. Multiple Linear Regression Models are developed for estimating soil properties (pH, EC, OC) on the basis of given values of soil nutrients. These models are found to be quite efficient for the said purpose on the basis of large value of R^2 and small value of Root Mean Square Error.

Keywords: Path coefficient, Correlation Coefficient, Multiple Linear Regression, Coefficient of determination, Root Mean Square Error.

Introduction

Soil acts as an engineering medium, a home for soil organisms, a recycling system for nutrients and organic wastes, a regulator of water quality and a medium for plant growth, making it a critically important supplier of ecosystem services. Since soil has a tremendous variety of available organisms and habitats, it comprises most of the Earth's genetic diversity. Soil characteristics and properties are determining factors for the growth of plants. Vijaykumar *et al.* (2011) studied fertility status of some tsunami affected areas of Negapattinam taluk of Tamilnadu and revealed a positive correlation of zinc and copper with pH and EC and a negative correlation of iron with pH and EC respectively. In soil data analysis, several authors like Gosling and Shepherd (2005), Sarwar *et al.* (2007), Yadav and Meena (2009), Kumar and Babel (2011), Kumari *et al*. (2014), Mishra and Kumar (2020) and others have widely utilized these statistical methods in different sample studies to illustrate their results more precisely. According to Lauber *et al.* (2008), variability in soil pH within and across land-use types can have a significant effect on microbial community structure and should not be ignored.

In view of the importance of the subject matter, the present study was undertaken to study the effect of soil nutrients (N, P, K, S, Fe, Zn, Mn and B) on soil properties (pH, EC and OC) and to study the direct and indirect effects of other soil characteristic contents on pH. Determining the characteristics of soils will eventually help to determine how to manage them effectively. The soil pH may depend on EC, OC, nitrogen, phosphorus etc. Similar dependence may exist among other soil characteristics and nutrients. Such study may help the farmers in knowing the amount of water and fertilizers needed for the proper growth of plants. Considering all the above properties and nutrients, a study was made to statistically analyze the interdependence of soil characteristics and soil nutrients.

Materials and methods

Study Region and Data Description

The study area for the present work was Mirzapur district of Uttar Pradesh (UP) which is situated between latitude 23.52º to 23.32º and longitude 82.72º to 83.33º. It covers an area of 4521 sq. km. Mirzapur is divided into 4 thesils, 12 blocks and 973 gram sabhas consisting of 1698 villages. The study is confined to four tehsils of Mirzapur district namely Mirzapur (Sadar), Marihan, Lalganj and Chunar, having 12 blocks namely Sikhar, Narayanpur, Jamalpur, Kon, Majhwa, Nagar, Rajgarh, Chinnoway, Marhian, Lalganj, Halia and Pahari.

Figure 1: Map of Mirzapur district

Secondary data on important soil characteristics viz. pH, Electrical Conductivity, Organic Carbon, Nitrogen, Phosphorus, Carbon, Potassium, Zinc, Boron, Iron, Magnesium and Sulphur were obtained from the "Regional Soil Testing Laboratory, Varanasi, Government of Uttar Pradesh and AICRP (All India Coordinated Research Projects), Varanasi Centre sponsored by Ministry of Agriculture, Government of India".

Statistical Techniques Used

Regression analysis is used to model the relationship between soil characteristics and nutrients. Meersmans *et al.* (2008) and Regar and Singh (2014) presented a multiple regression model to predict the soil organic carbon value of a particular land use. Shukla *et al.* (2016) studied the chances of deficiency of micronutrients (Zn and Fe) in future in the soil of Araziline Block of Varanasi.

Let y_i denotes the i^{th} value of response variable which is linearly related to n independent variables $x_1, x_2, \ldots\ldots\ldots, x_n$ then

$$y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_k x_{ik} + e_{i,} \quad i = 1,2,.....,n \qquad ..(1)$$

Equation (1) is called Multiple Linear Regression Model. Where, β_0 is the regression constant term and the parameters $\beta_1, \beta_2, \ldots, \beta_k$ are the Partial Regression Coefficients relating the explanatory variables $x_1, x_2, \ldots, x_n$ and *e* is the residual term defined as the difference between observed and predicted values of response variable. Here soil nutrients were taken as independent variables and properties of soil (pH, EC and OC) as dependent variables.

Then overall significance of regression coefficients were tested using F-test and the significance of individual regression coefficients was tested by using t-test. Efficiency of model was tested on the basis of high value of Coefficient of Multiple Determination (R^2) and low value of Root Mean Square Error (RMSE).

Path Coefficient Analysis

Path coefficient analysis is a standardized partial regression coefficient that allows partitioning of correlation coefficient into direct and indirect effects of various variables towards dependent variable. Ige *et al.* (2007) performed path coefficient analysis to distinguish between direct and indirect effects of soil properties on Potassium retention. Here the path coefficient analysis shows the cause and effect relation between the pH and other soil characteristics and partitions the association into direct and indirect effect through other independent variables.

The path coefficient was estimated by solving following sets of simultaneous equations indicating the basic relationship between correlation and path coefficients.

$$r_{iy} = P_{iy} + r_{i1}P_{1y} + r_{i2}P_{2y} + \ldots + r_{i(i-1)}P_{iy} ; \qquad i = 1,2,3\ldots\ldots,n$$

Where, *n* is the number of independent characters (causes); r_{1y} to r_{iy} denote coefficients of correlation between causal factors 1 to *i* and dependent character *y*, r_{12} to $r_{i(i-1)}$ the coefficients of correlation among all possible combinations of causal factors and P_{1y} to P_{iy} denote the direct effects of character 1 to i on the character y. The indirect effect of i^{th} variable through j^{th} variable on y the dependent variable is computed as $P_{jy} \times r_{ji}$.

Results and Discussion

Path coefficient analysis of soil characteristics on pH

Correlation among the growth parameters

Correlation analysis was carried out to determine the nature and degree of relationship between soil properties and nutrients. The various soil characteristics under study were found to be associated with each other ultimately affecting the pH. Table 1 shows correlation between soil properties and nutrients.

pH: pH was significantly and positively correlated with Sulphur (0.081) and Boron (0.323) and negatively correlated with Nitrogen (-0.122), Iron (-0.537) and Manganese (-0.502). On the other hand pH showed no significant correlation with Phosphorus (-0.006), Potassium (0.05) and Zinc (0.043). It means that pH increases with increase in Sulphur and Boron contents whereas decreases with increase in Nitrogen, Iron and Manganese. Moreover pH remains unaffected with the change in Phosphorus, Potassium and Zinc.

Table 1: Correlation between soil properties and nutrients

Nutrients	Soil properties		
	pH	EC	OC%
N (kg/ha)	-0.122**	-0.026	0.064
P (kg/ha)	-0.006	0.066	0.158**
K (kg/ha)	0.05	0.097**	0.238**
S (ppm)	0.081*	0.244**	0.131**
Fe (ppm)	-0.537**	-0.179**	0.187**
Cu (ppm)	-0.063	-0.009	0.256**
Mn (ppm)	-0.502**	-0.137**	0.091*
Zn (ppm)	0.043	-0.076*	0.249**
B (ppm)	0.323**	0.261**	0.3**

** Significant at 1 % level, * Significant at 5 % level

Electrical Conductivity: EC showed significant positive correlation with Potassium (0.097), Sulphur (0.244) and Boron (0.261). It showed significant negative correlation with Iron (-0.179), Manganese (-0.137) and Zinc (-0.076) and showed no significant correlation with Phosphorus (0.066) and Copper (-0.009). It shows that EC increases with increase in Potassium, Sulphur and Boron and decreases with increase in Iron, Manganese and Zinc. Moreover EC remains unaffected with change in phosphorus and Copper contents.

Organic Carbon: OC showed significant positive correlation with Phosphorus (0.158), Potassium (0.238), Sulphur (0.131), Iron (0.187), Copper (0.256), Manganese (0.091), Zinc (0.249) and Boron (0.3). Soil OC showed no significant correlation with Nitrogen (0.064). It means that the soil OC increases with the increase in nutrients other than Nitrogen. It remains unaffected with the change in Nitrogen content.

Further Path coefficient analysis revealed the relative contribution of different soil characteristics towards soil pH in Mirzapur district. Considering soil pH as the main variable and the other characteristics (EC, OC, N, P, K, S, Fe, Cu, Mn, Zn and B) as the causal factors, the correlation coefficients of these causal factors with soil pH is partitioned into direct and indirect effects and are presented in Table 2.

Table 2: Direct and indirect effects of other soil characteristics on soil pH

	Y(pH)	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
	r_{yX}	EC (dS m-1)	OC%	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)
r_{y1}	0.257	**0.069**	-5E-04	0.002	-8E-05	-0.006	0.027	0.062	-4E-04	0.04	0.007	0.058
r_{y2}	-0.025	-0.0016	**0.019**	-0.005	-2E-04	-0.015	0.015	-0.065	0.011	-0.026	-0.023	0.066
r_{y3}	-0.122	-0.002	0.001	**-0.081**	-5E-05	-0.008	-1E-03	-0.034	0.005	-0.019	-0.003	0.02
r_{y4}	-0.006	0.005	0.003	-0.003	**-0.001**	-0.004	0.009	-0.049	0.008	9E-04	-0.016	0.043
r_{y5}	0.05	0.007	0.005	-0.011	-9E-05	**-0.064**	0.014	0.016	0.008	0.02	-0.018	0.074
r_{y6}	0.081	0.017	0.003	7E-04	-1E-04	-0.008	**0.111**	-0.05	0.012	-0.021	-0.009	0.026
r_{y7}	-0.537	-0.012	0.004	-0.008	-2E-04	0.003	0.016	**-0.346**	0.011	-0.17	0.006	-0.039
r_{y8}	-0.063	-6E-04	0.005	-0.008	-2E-04	-0.012	0.031	-0.085	**0.044**	-0.034	-0.04	0.036
r_{y9}	-0.502	-0.009	0.002	-0.005	4E-06	0.004	0.008	-0.204	0.005	**-0.289**	0.018	-0.032
r_{y10}	0.043	-0.005	0.005	-0.003	-2E-04	-0.012	0.011	0.022	0.019	0.057	**-0.091**	0.04
r_{y11}	0.323	0.018	0.006	-0.007	-2E-04	-0.021	0.013	0.062	0.007	0.042	-0.016	**0.221**

Table 3: List of direct and indirect effects of different soil characteristics on soil pH

	EC (dS m-1)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)
Direct effect	0.069	0.019	-0.081	-0.001	-0.064	0.111	-0.346	0.044	-0.289	-0.091	0.221
Indirect effect	0.188	-0.044	-0.041	-0.005	0.114	-0.03	-0.191	-0.107	-0.213	0.134	0.102

Direct effects of various characteristics on soil pH

It is clear from the Table 3 that five out of eleven characteristics have positive and direct effect on soil pH. The characteristics which have positive direct effect are electrical conductivity (0.069), organic carbon (0.019), sulphur (0.111), copper (0.044) and boron (0.221). Six characteristics nitrogen (-0.081), phosphorus (-0.001), potassium (-0.064), iron (-0.346), manganese (-0.289) and zinc (-0.091) have negative direct effects on soil pH.

Indirect effects of various characteristics on soil pH

The characteristics which have positive indirect effect are electrical conductivity (0.188), potassium (0.114), zinc (0.134) and boron (0.102). Organic carbon (-0.044), nitrogen (-0.041), phosphorus (-0.005), sulphur (-0.03), iron (-0.191), copper (-0.107) and manganese (-0.213) are found to have negative indirect effects on soil pH.

Electrical Conductivity (EC): Electrical conductivity has positive indirect influence on soil pH through N (0.002), S (0.027), Fe (0.062), Mn (0.04), Zn (0.007) and B (0.058). On the other hand, it has influence on soil pH in negative direction viz. OC (-5E-04), P (-8E-05), K (-0.006) and Cu (-4E-04).

Organic Carbon: Organic carbon has positive indirect influence on soil pH through S (0.015), Cu (0.011) and B (0.066). On the other hand, it has negative indirect influence on soil pH through EC (-0.0016), N (-0.005), P (-2E-04), K (-0.015), Fe (-0.065), Mn (-0.026) and Zn (-0.023).

Nitrogen: Nitrogen has positive indirect influence on soil pH through OC (0.001), Cu (0.005) and B (0.02). On the other hand, it has negative indirect influence on soil pH through EC (-0.002), P (-5E-05), K (-0.008), S (-1E-03), Fe (-0.034), Mn (-0.019) and Zn (-0.003).

Phosphorus: Phosphorus has positive indirect influence on soil pH through EC (0.005), OC (0.0030, S (0.009), Cu (0.008), Mn (9E-04) and B (0.043). On the other hand it has influence on soil pH in negative direction viz. N (-0.003), K (-0.004), Fe (- 0.049) and Zn (-0.016).

Potassium: Potassium has positive indirect influence on soil pH through EC (0.007), OC (0.005), S (0.014), Fe (0.016), Cu (0.008), Mn (0.002) and B (0.074). On the other hand it has influence on soil pH in negative direction viz. N (-0.011), P (-9E-05) and Zn (-0.018).

Sulphur: Sulphur has positive indirect influence on soil pH through EC (0.017), OC (0.003), N (7E-04), Cu (0.012) and B (0.026). On the other hand it has influence on soil pH in negative direction viz. P (-1E-04), K (-0.008), Fe (-0.05), Mn (-0.021) and Zn (-0.009).

Iron: Iron has positive indirect influence on soil pH through OC (0.004), K (0.003), S (0.016), Cu (0.011) and Zn (0.006). On the other hand it has influence on soil pH in negative direction viz. EC (-0.012), N (-0.008), P (-2E-04), Mn (-0.17) and B (-0.039).

Copper: Copper has positive indirect influence on soil pH through OC (0.005), S (0.031) and B (0.036). On the other hand it has influence on soil pH in negative direction viz. EC (-6E-04), N (-0.008), P (-2E-04), K (-0.012), Fe (-0.085), Mn (-0.034) and Zn (-0.04).

Manganese: Manganese has positive indirect influence on soil pH through OC (0.002), P (4E-06), K (0.004), S (0.008), Cu (0.005) and Zn (0.018). On the other hand it has influence on soil pH in negative direction viz. EC (-0.009), N (-0.0050, Fe (-0.204), B (-0.032).

Zinc: Zinc has positive indirect influence on soil pH through OC (0.005), S (0.011), Fe (0.022), Cu (0.019), Mn (0.057) and B (0.04). On the other hand it has influence on soil pH in negative direction viz. EC (-0.005), N (-0.003) and K (0.012).

Boron: Boron has positive indirect influence on soil pH through EC (0.018), OC (0.006), S (0.0130, Fe (0.0620, Cu (0.0070 and Mn (0.042). On the other hand it has influence on soil pH in negative direction viz. N (-0.007), P (-2E-04), K (-0.021), Zn (-0.016).

Regression analysis of soil properties (pH, EC&OC) on soil nutrients (N, P, K, S, Fe, Zn, Mn&B)

Multiple regression analysis was carried out to see the effects of soil nutrients on soil properties. While fitting the multiple regression equation, we have considered nine soil nutrients (N, P, K, S, Fe, Cu, Mn, Zn and B) as independent variables and the soil properties (pH, EC and OC) as dependent variables.

Estimation of soil pH

Regression analysis was carried out to know the effect of various soil nutrients in estimating soil pH. It is concluded that the regression model is significant. Table 4 shows the equation of Multiple Linear Regression plane of pH on all above said soil nutrients along with the value of coefficient of determination (R^2) and corresponding Root Mean Square Error (RMSE).Further to know the effects of various soil characteristics individually, t-test was carried out and the results are presented in Table 5.

Table 4: MLR model to estimate pH taking all soil nutrients as predictors

Multiple Linear Regression Model	R^2(adj.)	RMSE
pH=7.428**+0.003N**+0.025P**─0.013K**+0.025S** +0.031Fe**+0.099Cu**─0.197Mn**+0.002Zn─0.117B**	0.861	0.07030

Table 5: Partial Regression Coefficients and corresponding t values

Model	Unstandardized Coefficients		Standardized Coefficients	t	p-value
	B	Std. Error	Beta		
(Constant)	7.428	.033		228.324	.000
N	.003	.000	.298	11.204	.000
P	.025	.001	.818	19.466	.000

K	-.013	.000	-.861	-36.248	.000
S	.025	.001	.365	18.795	.000
Fe	.032	.004	.425	7.141	.000
Cu	.100	.006	.331	16.092	.000
Mn	-.197	.015	-.812	-13.370	.000
Zn	.002	.006	.006	.277	.782
B	-.117	.005	-.837	-23.721	.000

It is evident from the Table 5 that the effects of all soil nutrients except Zinc on soil pH is found to be highly significant. Further since the effect of Zinc on soil pH is insignificant; we have obtained the multiple regression equation of soil pH on all soil nutrients except Zinc, which is given in Table 6.

Table 6: MLR model to estimate pH taking all soil nutrients except Zinc as predictors

Multiple Linear Regression Model	**R^2(adj.)**	**RMSE**
$pH=7.434^{**}+0.003N^{**}+0.025P^{**}-0.013K^{**}+0.025S^{**}+0.032Fe^{**}+0.099Cu^{**}-0.197Mn^{**}-0.116B^{**}$	0.861	0.07026

Developed MLR model is presented in Table 6. Coefficient of multiple determination of this model is significant and sufficiently high (R^2= 0.861) and RMSE of this model is (0.07026), which is very low. 86.1% of the total variation in soil pH can be explained by these soil nutrients of Mirzapur district. Hence this model can be regarded as a good prediction model to estimate soil pH if we are given with the data of above soil nutrients.

Estimation of soil EC

Taking soil EC as dependent variable and soil nutrients as independent variables Regression analysis was carried out to estimate effect of soil nutrients on EC and it is concluded that the regression model is highly significant. The equation of the regression plane of soil EC on soil nutrients is given in Table 7. Further, we have tested the significance of individual Partial Regression Coefficients and the results are presented in Table 8.

Table 7: MLR model to estimate EC taking all soil nutrients as predictors

Multiple Linear Regression Model	**R^2(adj.)**	**RMSE**
$EC=0.538^{**}-0.002N^{**}-0.005P^{**}+0.003K^{**}-0.015S^{**}-0.033Fe^{**}+0.001Cu+0.029Mn^{**}+0.042Zn^{**}+0.017B^{**}$	0.927	0.0161

Table 8: Partial Regression Coefficients along with the corresponding t-values

Model	Unstandardized Coefficients		Standardized Coefficients	t	p-value
	B	Std. Error	Beta		
(Constant)	.538	.009		62.646	.000
N	-.002	.000	-.670	-33.850	.000
P	-.005	.000	-.525	-14.313	.000
K	.003	.000	.656	37.240	.000
S	-.015	.000	-.629	-42.681	.000
Fe	-.033	.001	-1.132	-23.462	.000
Cu	.001	.001	.008	.525	.600
Mn	.029	.004	.295	6.996	.000
Zn	.042	.001	.504	31.036	.000
B	.017	.002	.381	11.100	.000

It is evident from the Table 8 that all the soil nutrients except Copper have significant effect on Electrical Conductivity (EC) of soil. Further, the multiple regression equation of soil EC on all the soil nutrients except Copper has been obtained and is given in Table 9.

Table 9: MLR model to estimate EC taking all soil nutrients except Copper as predictors

Multiple Linear Regression Model	R^2(adj.)	RMSE
EC=0.540**–0.002N**–0.005P**+0.003K**–0.015S** –0.033Fe**+0.028Mn**+0.042Zn**+0.017B**	0.928	0.01613

Developed MLR model for soil EC is depicted in Table 9. Coefficient of multiple determination of this model is significant and sufficiently high (R^2= 0.928) and RMSE of this model is very low (0.01613). High R^2 value indicates that soil nutrients can explain 92.8% variability in soil EC of Mirzapur district.

Estimation of soil OC

Regression analysis was carried out to know the effect of various soil nutrients in estimating soil OC and it was concluded that the regression model is highly significant. The equation of multiple regression plane of OC on soil nutrients along with the values of R^2 and RMSE is given in Table 10. Further, to know the effects of various soil characteristics individually on OC, t-test is carried out and the results are presented in Table 11.

Table 10: MLR model to estimate OC taking all soil nutrients as predictors

Multiple Linear Regression Model	R2(adj.)	RMSE

OC=0.717**─0.004N**─0.011P**+0.003K**─0.013S** ─0.015Fe** ─0.073Cu**+0.102Mn**─0.045Zn**+0.061B**	0.693	0.0442

Table 11: Partial Regression Coefficients along with corresponding t-value

Model	Unstandardized Coefficients		Standardized Coefficients	T	p-value
	B	Std. Error	Beta		
(Constant)	.717	.020		35.052	.000
N	-.004	.000	-.889	-22.404	.000
P	-.011	.001	-.866	-13.800	.000
K	.003	.000	.456	12.859	.000
S	-.013	.001	-.450	-15.497	.000
Fe	-.015	.003	-.481	-5.418	.000
Cu	-.073	.004	-.573	-18.661	.000
Mn	.102	.009	1.001	11.044	.000
Zn	-.045	.004	-.403	-11.971	.000
B	.061	.003	1.032	19.576	.000

It is evident from the Table 11 that all the soil nutrients have significant effect in estimating Organic Carbon (OC) of soil. None of them showed insignificant relationship with soil OC. Coefficient of multiple determination of this model is significant (R^2=0.693) and RMSE of this model is 0.0442. Hence the model can be used to predict soil OC of Mirzapur district. If we are given the values of nutrients and 69.4% of the total variability in soil OC can only be explained by soil nutrients.

Conclusion

In this study, Correlation analysis between soil properties and nutrients shows that pH is significantly and positively correlated with Sulphur and Boron and negatively correlated with Nitrogen, Iron and Manganese. EC has shown significant positive correlation with Potassium, Sulphur and Boron and significant negative correlation with Iron, Manganese and Zinc. OC shows significant positive correlation with Phosphorus, Potassium, Sulphur, Iron, Copper, Manganese, Zinc and Boron. Soil pH is a determining factor for the growth of crops. It is a complex character and controlled by many other soil characteristics. Path coefficient analysis reveals that for the optimum growth of any crop in a particular soil our choice should not be restricted to soil pH alone but other components related to soil pH should also be considered. Path Coefficient analysis was carried out for partitioning the correlation coefficient between soil pH and other soil characteristics (EC, OC, N, P, K, S, Fe, Zn, Mn, Cu and B). Direct and indirect effects on soil pH are estimated. To estimate soil properties (pH, EC and OC) of Mirzapur district on the basis of soil nutrients Multiple Linear Regression models are developed using all the nine soil nutrients (N, P, K, S, Fe, Cu, Mn, Zn and B). The soil characteristics are important for optimum growth of plants therefore these analysis and interdependence of soil characteristics can help the farmers to estimate the amount of water and fertilizers needed for proper plant growth.

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