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Distributional Pattern of Tree Species in Response to Soil Variables in a Semi Natural Tropical Forest of Bangladesh

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Abstract

A plant community is a group of populations that coexist in space and interact directly or indirectly with the environment. In this paper, we determined the pattern of tree species composition in response to soil variables in Khadimnagar National Park (KNP), which is one of the least studied tropical forests in Bangladesh. Soil and vegetation data were collected from 71 sample plots. Canonical Correspondence Analysis (CCA) with associated Monte Carlo permutation tests (499 permutations) was carried out to determine the most significant soil variable and to explore the relationship between tree species distribution and soil variables. Soil pH and clay content (pH with $p<0.01$ and Clay content with $p<0.05$) were the most significant variables that influence the overall tree species distribution in KNP. Soil pH is related to the distribution and abundance of *Syzygium grande and Magnolia champaca*, which were mostly found and dominant species in KNP. Some species were correlated with clay content such as *Artocarpus chaplasha* and *Cassia siamea*. These observations suggest that both the physico-chemical properties of soil play a major role in shaping the tree distribution in KNP. Hence, these soil properties should take into account for any tree conservation strategy in this forest.

Key Words: Khadimnagar National Park, tree species distribution, soil variables, ordination, CCA

Introduction

A plant community is the aggregation of living plants coexisting in a common environment and shares directly or indirectly with a complicated mutual relationship among themselves and the environment (Chapman and Reiss 2003). Focusing on the distribution pattern of tree species along environmental variables can help us improve our understanding of the ecological diversity of tropical forests (Diekmann 2003). Several studies have mentioned the association between tropical species and environmental variables (Harms et al. 2001; Toledo et al. 2012). The impact of environmental variables on species distribution depends on which environmental variables are measured and how these are modeled (Potts et al. 2002). Various methods have been used to model the species distribution along with environmental variables. It can be done through ordination methods such as Canonical correspondence analysis (CCA) or Redundancy Analysis (RDA) (Legendre and Legendre 1998).

The variation in the diversity of species can be associated to several ecological patterns (Kessler 2000). The most important variables that influence species distribution are topography and soil (Jafari et al. 2004). Observing the inter-

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actions of different species and their relation with various soil variables could guide forest improvement (Tavili and Jafari 2009). Many studies demonstrated that soil pH, organic matter, sand and silt content are important factors that regulate tree species growth (Jafarian et al. 2010).

Tropical forests are the earth's most diverse ecosystem with a high deforestation rate (Malhi and Grace 2000). According to Sollins (1998), the study of community ecology became difficult in tropical forests due to a lack of information about soil, topography, geography and climate.

Bangladesh is located within the Indo-Burma region, which is a global biodiversity hotspot (Mittermeier et al. 1998). Because of its unique biophysical environment, Bangladesh is blessed with a high floral species diversity (Barua et al. 2001; Chowdhury 2001; Hossain 2001). The north-eastern forests of Bangladesh cover 40000 ha. area of which only 118.46 ha. comprises freshwater swamp forest (Hosen and Ahamed 2017) and the rest parts are the mixture of tropical evergreen and deciduous forests. Our present study is directed in Khadimnagar National Park (KNP) which is a tropical evergreen and semi-evergreen forest situated in the north-eastern part of Bangladesh. A comprehensive bibliographic search found very little ecological research about this forest (Mohammad et al. 2011; Sobuj and Rahman 2011; Redowan et al. 2014) and surprisingly no research was conducted to explain the impact of soil variables on the distribution of KNP tree species. In this regard, our study was conducted to find out the relationship between tree species distribution and soil variables in KNP using a multivariate statistical method. We were interested to see which soil variables do influence the tree species distribution in Khadimnagar National Park? We hypothesize that a single soil variable has very little chance to trigger the tree species distribution and hence, both the soil physico-chemical soil variables influence the distributional pattern of tree species in KNP.

Materials and Methods

Study site

Khadimnagar National Park (N 24°56'-24°58' latitude and E 91°55'-91°59' longitude) is situated in Sylhet Forest Division under the tropical evergreen and semi-evergreen bio-geographical area (Sobuj and Rahman 2011). In 2006, it was declared as National Park which was previously known as Khadimnagar Reserve Forest (Fig. 1). The total area of Khadimnagar National Park is 679 ha. The forest is characterized with low to gentle slope hills and the soil texture is clay loam and acidic in nature (Sobuj and Rahman 2011).The climate is tropical in general and subject to heavy rainfall with a mean annual rainfall of 3931 mm. The minimum average temperature of these areas is 18.9°C and

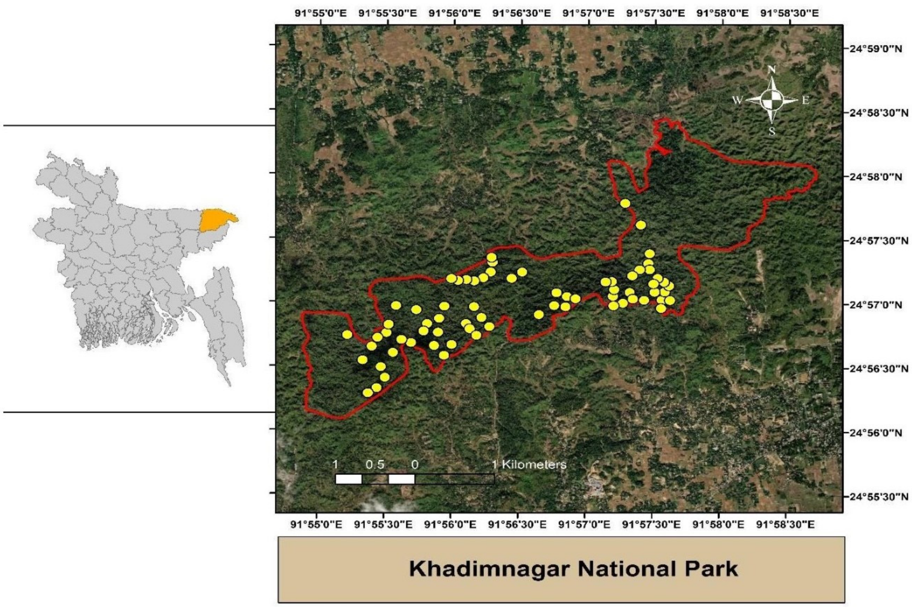

Fig. 1. Map of the Study area (Khadimnagar National Park, Bangladesh). Small yellow circles represent the sample plots (Shapefile Source: www.protectedplanet.net).

the average maximum temperature is 30.7°C (BBS 2005; Rahman et al. 2011). During December, the relative humidity is about 74%, while during July-August it is over 90% in Khadimnagar National Park (Choudhury et al. 2004). The common growing tree species are *Dipterocarpus turbinatus* (Garjan), *Artocarpus chaplasha* (Chapalish), *Chukrasia tabularis* (Chickrasi), *Aquilaria agallocha* (Agar), *Toona ciliate* (Toon), *Aphanamixis wallichii* (Rata), *Gmelina arborea* (Gamari), *Tectona grandis* (Teak), *Syzigium grande* (Dhakijam), *Cassia siamia* (Minjiri), *Artocarpus heterophyllus* (Kathal), *Mangifera indica* (Aam) and Bamboos.

Vegetation survey

For the present study, a total of 71 sampling plots were selected arbitrarily without preconceived biases (McCune et al. 2002). The study was conducted during November and December of 2018. The 15 m×15 m plot size was taken to conduct a quantitative field survey for tree species. All the trees ≥5 cm diameter at breast height (dbh, 1.3 m height) were recorded and their dbh were measured using a diameter tape on each plot. If the tree were branched at breast height, the diameter was measured separately for each of the branches and averaged. Heights of the trees were measured by Haga-altimeter. Tree species were identified with the help of the local guide and forest officials. But still some of the species which were not possible to identify in the field, photographs were taken and samples of those unidentified species were taken from the field. Then the unidentified species were identified with the help of different books from the seminar library of the Department of Forestry and Environmental Science, Shahjalal University of Science and Technology, Sylhet.

Soil analysis

Among the different soil variables, we selected and measured only soil pH, moisture content, bulk density, organic matter, and soil texture (sand, silt, clay content). Five soil samples were taken from each corner and the center of the plot. Each of the samples was taken at 10 cm depth using a core soil sampler. Then five soil samples from each plot were mixed up well together in the field and marked as one sample used to measure soil variables. Thereafter, the samples were taken to the Soil Laboratory of Forestry and Environmental Science, Shahjalal University of Science and Technology for analysis, and all the coarse materials like stones, branches, undecomposed materials, roots were removed by passing through a sieve (2 mm). Soil pH was measured with Kelway Soil Tester. Soil moisture content was measured with a digital moisture meter. For bulk density, the weight of the moist soil samples were measured and later oven-dried for 24 hours at 105-degree Celsius temperature. After measuring the dry weight of the soil, Bulk Density (g/cm^3) was calculated. Organic matter was measured by using loss ignition method. Maffle furnace was used to burn the soil. The percentage of sand, silt, and clay content were measured by using the Hydrometer method.

Data analysis

Ordination is a method for community data analysis. Community ecologists used it to analyze the relationship between species community with environmental variables by ordination method. It is a multivariate statistical approach which is also a part of gradient analysis. A Unimodal ordination technique was performed to conduct the study. The structure of the species dataset was "tree abundance x sample plot" and the environmental dataset was "environmental variables x sample plot".

According to Leps and Smilauer (2003), Detrended Correspondence Analysis (DCA) is usually used to determine whether a dataset is unimodal or linear. Detrending by segments (Hill and Gauch 1980) approach was used to observe the length of the axis in the species data. If the first axis of DCA has a gradient length >4 then a unimodal method should be performed (Leps and Smilauer 2003). In this study, species data were used to determine the length of the gradient and the length of the gradient was >4; hence, the linear method was not appropriate.

Canonical Correspondence Analysis was used in this study to explore the pattern of variation in species distribution along with environmental variables (Ter Braak 1986). CCA is a multivariate statistical analysis which is a simple method for studying species along with environmental variables (Ter Braak 1987). In CCA, species raw data were used. Seven soil variables were used as explanatory variables (environmental variables) such as soil pH, moisture content, bulk density, organic matter and soil texture (sand, silt and clay). We performed CCA using

CANOCO 5.1 to observe the variation pattern of tree species distribution explained by the soil variables. The first constrained axis test and all constrained axes test were done to determine the significance of first and all CCA axes. Forward selection of environmental variables along with Monte Carlo Permutation test (499 Permutations) was done to find out the statistically significant soil variables that are responsible for overall species compositional variation in KNP (Ter Braak and Smilauer 2002). The relationship between tree species community and soil variables were shown by Biplots and Triplots. We used abbreviated species scientific names of each tree by using first three letters each from genus and species. For example, *Art cha* was an abbreviation for *Artocarpus chaplasha* (Appendix 1).

Results

While performing CCA the collinearity among the explanatory variables was detected (Table 1). Subsequently strongly inter-correlated variables were removed from further analysis to solve the collinearity problem (Ter Braak 1986). For this reason, the silt was excluded from the analysis because of its strong correlation with sand (r=0.899) and clay content (r=0.416) (Appendix 2).

The CCA ordination showed that eigenvalues for the first four axes were 0.511, 0.270, 0.243, 0.119 and pseudo-canonical correlations for these four axes were 78%, 64%, 60% and 44% in the respective form (Table 2). These results indicate that a gradual decrease in eigenvalues for the first four successive axes of the CCA which ensure that the dataset was well structured. It also ensured that the performance of the CCA analysis was good in describing the relationship between tree species community and soil variables (Sharmin et al. 2016) presented in the biplot (Fig. 2). The CCA result also revealed that 13.3% of the variance in species data and 89.6% of the variance of fitted data (species-environmental relation) was explained by first four axes cumulatively. The higher value of species-environmental relationship (89.6%) indicated that species data were strongly related to the measured soil variables.

In CCA Ordination, the dominant soil variables which were correlated with the first axis were pH, clay content, and bulk density showed in the intraset correlation coefficient. On the other hand, with the second axis moisture content, organic matter, and sand were related (Table 3). Our CCA ordination model was statistically significant

Table 1. Descriptive statistics of soil variables

Soil variables	Plot number	Mean	Standard deviation	Minimum	Maximum
pH	71	5.23	0.36	4.5	5.8
Moisture content (%)	71	24.82	3.53	16.53	31.87
Bulk density (g/cm^3)	71	1.17	0.15	0.93	1.52
Organic matter (%)	71	18.27	3.68	11.13	25.51
Sand (%)	71	93.28	1.74	88.6	96.7
Silt (%)	71	5.42	1.92	0.7	9.6
Clay (%)	71	1.29	0.84	0	3.1

Table 2. Results of CCA ordination

Axes	1	2	3	4
Eigenvalues	0.511	0.270	0.243	0.119
Pseudo-canonical correlations	0.783	0.648	0.607	0.444
Cumulative percentage variance of				
Response data	5.9	9.1	11.9	13.3
Fitted response data	40.0	61.2	80.2	89.6

Total inertia=8.597.

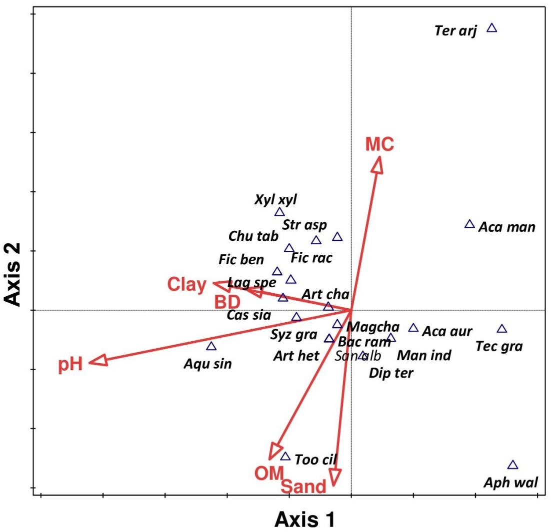

Fig. 2. Ordination-biplot of CCA. The arrows indicate soil variables and the triangles represent tree species. The length of the arrow is proportional to its importance and the angle between two vectors reflects the degree of correlation between variables. CCA, canonical correspondence analysis; BD, bulk density; MC, moisture content; OM, organic matter. For tree species abbreviation see Appendix 1.

as the result of the constrained axes test implied that the first CCA axis (Pseudo-F=0.7, p=0.002) and all CCA axes (Pseudo-F=1.9, p=0.002) both were statistically significant.

Forward selection of environmental variables results showed that pH and clay content were the two significant variables (pH with $p<0.01$ and Clay content with $p<0.05$) that explained most of the variance of the ordination model. The marginal and conditional effects of the explanatory variables table also indicated the same result (Table 4). In this case, the variables were selected based on their variance without taking into account the other variables (marginal effect) and to be included in the model after selecting the most important variables successively (conditional effect).

Tree species distribution patterns when constrained by soil variables were reflected in the biplot (Fig. 2). CCA ordination results revealed that in the study area soil pH was negatively correlated with moisture content. *Syzygium*

Table 3. Canonical coefficients and intraset correlations of the first two axes among the site scores and the soil variables

Variables	Canonical coefficients (Standardized)		Correlation coefficients (Intraset)	
	Axis 1	Axis 2	Axis 1	Axis 2
pH	-0.8061	-0.0468	-0.8439	-0.1788
MC	-0.1414	0.5977	0.0914	0.5176
BD	-0.4835	0.4737	-0.3424	0.0726
OM	-0.0103	-0.6547	-0.2629	-0.5043
Sand	0.0119	-0.4910	-0.0569	-0.5917
Clay	-0.3729	0.2980	-0.4427	0.0913

MC, moisture content; BD, bulk density; OM, organic matter.

Table 4. Variables explaining tree species-soil relation by the marginal and conditional effect of CCA using forward selection

Marginal Effects		Conditional Effects			p
Variables	Explains (%)	Variables	Explains (%)	Pseudo-F	
pH	4.8	pH	4.8	3.5	0.002**
Clay	2.8	Clay	2.4	1.8	0.038*
OM	2.0	BD	2.1	1.5	0.104
MC	1.9	OM	2.0	1.5	0.102
Sand	1.7	MC	2.1	1.6	0.074
BD	1.5	Sand	1.4	1.1	0.358

*$p<0.05$, **$p<0.01$.

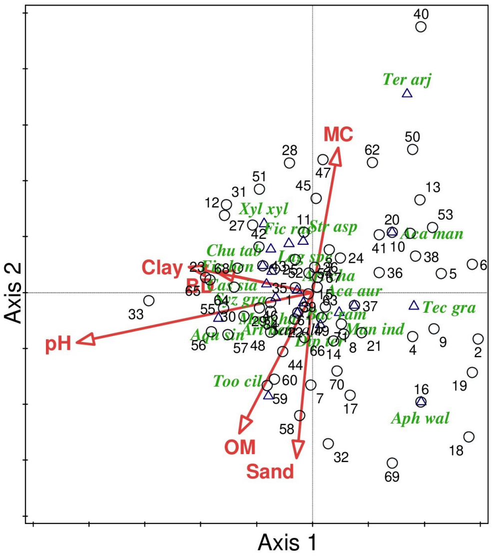

Fig. 3. Ordination-triplot of CCA. The arrows indicate soil variables whereas circles and triangles represent sample plots and tree species respectively. The length of the arrow is proportional to its importance and the angle between two arrows reflects the degree of correlation between variables. CCA, canonical correspondence analysis; BD, bulk density; MC, moisture content; OM, organic matter. For tree species abbreviation see Appendix 1.

grande and *Aquilaria sinensis* were positively correlated with pH and negatively correlated with moisture content. Some species were highly correlated with clay content and bulk density such as *Artocarpus chaplasha* and *Cassia siamea* but negatively related to *Dipterocarpus turbinatus* and *Tectona grandis*. Species like *Magnolia champaca*, *Baccaurca ramiflora*, *Artocarpus heterophyllus*, and *Toona ciliate* were positively correlated with organic matter and their distribution was also influenced by pH and sand. The biplot of CCA ordination indicated that most of the species variation was due to soil pH, clay content and bulk density (Fig. 2).

The tri-plot of CCA ordination showed the relationship between soil variables and their contribution to the tree species distribution along with sample sites (Fig. 3).

Discussion

In tropical forests, the diversity of the soil affects tree species distribution, abundance, richness, structure, and growth (Jones et al. 2008). The growth of plants and vegetation is influenced by soil properties (Molles 2002). From this analysis, it can be seen that pH and clay content are strongly correlated with CCA axis 1 (Table 2). That means in KNP tree species distribution is influenced by more than one soil variable. The forward selection method using CANOCO also revealed that pH and clay content are the significant variables that explain most of the variation of tree species distribution in KNP which was in line with our expectations. A study in the Harran Plain observed a link between pH and clay content in the soil (Sakin et al. 2011). The strong relation between pH and soil texture was also found in the tree species distribution of the Brazilian Atlantic rain forest (Guilherme et al. 2012).

Soil pH is the most important variable regulating other soil variables (Joshi and Ghose 2003). Evidence from previous study suggested that soil pH has an impact on tropical species distribution (Islam et al. 2001). In KNP, the soil is usually acidic (Table 1). The presence of pre-weathered parent materials and extreme leaching of basic cations during heavy rainfall in monsoon lead to this kind of acidity in the forest soil (Islam and Weil 2000, Akhtaruzzaman et al. 2020). The ranges of soil pH influence the strength of the correlation of other soil variables (Sollins 1998). Soil pH affects plant growth very importantly by changing nutrients availability (Joshi and Ghose 2003). The biplot of the CCA reveals that pH influenced the distribution and abundance of *Syzygium grande* and *Magnolia champaca* which is mostly found and dominant species in KNP (Fig. 2). Clay content is another factor that influences the distribution of tree species in the studied area. Clay content provides cohesion to the soil which increases the shear strength of the soil. Clay content has a broad specific-surface, mostly negatively charged, which preserves nutrients against leaching and interacts with hydrogen and aluminium ions while at the same time buffering the soil against drastic pH changes. When it degrades, the clay itself can be a source of nutrients to the plants (Newman 1984). Species like *Artocarpus chaplasha* and *Cassia siamia* were related to clay content which is shown by the CCA biplot (Fig. 2).

The tropical region lacks in bulk density (Bernoux et al. 1998). In this study, bulk density was moderately related to CCA axis 1 and there is a little influence of bulk density in tree species distribution. However, the impact of bulk density is not alone in tree species distribution but with the combination of the clay content in KNP. The impact of soil texture is well observed in bulk density (Jones 1983). Though some studies reported the influence of soil organic matter on tree species distribution in tropical forests, we didn't find any strong relationship. The possible reason may be the organic matter loss due to water erosion caused by heavy rainfall during monsoon. Moreover, enhanced oxidation, animal grazing and trampling which may be responsible for greater compaction, reduced porosity and low structural stability of soils (Islam et al. 2001; Sarker et al. 2013). Other variables such as moisture content and sand could improve the CCA ordination but the contribution is not so high. Soil moisture content is one of the most prominent determinants of expiring compositional species variation among different soil types and their dynamics and distribution (Russo et al. 2005). However, Moisture content was negatively correlated with most of the tree species in KNP.

As we know, the relationship between tree species distribution and soil variables has been demonstrated in various studies of tropical forests in the world, our study only shows the result based on a few soil properties. A study in the submontane rainforests of Tanzania showed that the development and existence of vegetation depend on both soil physical and chemical properties (Munishi et al. 2007). So, to explore the most important driving factors that influence tree species distribution in KNP, soil chemical properties (i.e. soil nutrient content) may also help. Moreover, altitude and topography may also have an influence over tree species distribution in any area (Teixiera et al. 2008). Anthropogenic disturbance is also an important issue for any forest but from the field inspection very minimal amount of forest disturbance activity was observed. Thus, the disturbance may not be influencing the tree species distribution in KNP.

Conclusion

This study examined the distributional pattern of tree species in response to soil variables in KNP. The analysis revealed that pH and clay content are the most influential variables responsible for tree species compositional variation in this forest. We strongly believe that the findings will assist forest managers to determine which species to plant where to optimize the local and regional diversity. The outputs we present here provide an important baseline evaluation on species and soil association. However, we suggest future researches with an integrated approach combining both plant functional traits and physiological measurements in relation to environmental variables to improve our mechanistic understanding of tree species distribution in KNP.

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Appendix 1. List of tree species in Khadimnagar National Park

Local name	Scientific name	Abbreviation	Height (m)		Diameter (cm)	
			Max	Min	Max	Min
Aam	*Mangifera indica*	*Man ind*	8.5	5.5	41.5	18
Agor	*Aquilaria sinensis*	*Aqu sin*	8	6	17.2	6.8
Arjun	*Terminalia arjuna*	*Ter arj*	16	12	49.5	22
Akashmoni	*Acacia auricuiformis*	*Aca aur*	15	15	24.5	24.5
Bot	*Ficus benghalensis*	*Fic ben*	7.5	7.5	18	18
Champa	*Magnolia champaca*	*Mag cha*	16.5	5	38.5	7.5
Chapalish	*Artocarpus chaplasha*	*Art cha*	18	7	64.5	13
Chikrashi	*Chukrasia tabularis*	*Chu tab*	21.5	9	52	12
Dhakijam	*Syzygium grande*	*Syz gra*	20	11.9	60	7
Dumur	*Ficus racemosa*	*Fic rac*	14	5.5	24	11
Garjan	*Dipterocarpus turbinatus*	*Dip tur*	21	8.3	52	11
Jarul	*Lagerstroemia speciose*	*Lag spe*	11	7.1	50	19
Kathal	*Artocarpus heterophyllus*	*Art het*	14.5	14	38	34
Lohakath	*Xylia xylocarpa*	*Xyl xyl*	20	18.5	42	38
Lotkon	*Baccaurca ramiflora*	*Bac ram*	5.5	5.5	21.6	21.6
Mangium	*Acacia mangium*	*Aca man*	17.5	12.5	32	14
Minjiri	*Cassia siamea*	*Cas sia*	11	6	34	15
Rata	*Aphanamixis wallichii*	*Aph wal*	6.5	6.5	10	10
Shegun	*Tectona grandis*	*Tec gra*	19	5	107	10
Sheto Chandan	*Santalum album*	*San alb*	11.5	6	33.5	14
Shewra	*Streblus asper*	*Str asp*	7	5.5	32	6
Toon	*Toona ciliate*	*Too cil*	10	7.5	25	16

Appendix 2. Relationship between all variables from pearson's correlation analysis

	pH	MC	BD	OM	Sand	Silt	Clay
pH	1						
MC	-0.187	1					
BD	-0.053	-0.098	1				
OM	0.087	0.068	0.262*	1			
Sand	0.047	-0.130	0.120	0.131	1		
Silt	-0.150	0.203	-0.026	-0.116	-0.899**	1	
Clay	0.244*	-0.192	-0.191	-0.008	-0.025	-0.416**	1

*$p < 0.05$, **$p < 0.01$.