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Effect of Vegetation Type on Soil Physical Properties at Lincoln University Living Laboratory

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Abstract: The aim of this investigation was to study surface soil physical properties of Lincoln University Living Laboratory (LULL) as affected by vegetation type. The LULL is a forested area on Lincoln University campus which resulted rock mining activities that took place prior to 1950. Soil samples were collected at 56 locations in each of two portions of LULL dominated by a forest and grass. The coordinates of each sampling location were recorded using Global Positioning System (GPS) and LULL was also mapped. Soil samples were analyzed for several soil physical properties and the data was transferred to GS+ 5.0; ARCGIS 9.2 and Statistix 9.0 for variogram modeling, mapping and correlation analysis. Results showed that the forest portion of LULL had higher soil bulk density (ρ_b), gravimetric (θ_g) and volumetric (θ_v) water contents while the grass had higher total soil pore space (TPS) and air content (f_a). Within each plot, soil physical properties correlated significantly among themselves with correlation coefficients (r) ranging from 0.44 to 0.90. However, no significant correlation existed for soil properties between plots (grass vs forest). Soil physical properties responded to several variogram models. However, except for TPS which fitted to a linear variogram model in both forest ($R^2 = 0.95$) and grass ($R^2 = 0.95$), all other soil properties variograms differed. Most of soil physical properties followed a similar and consistent distribution pattern in both forest and grass plots. Further studies are underway to better understand the effect of land use history on soil properties of LULL.

Key words: Soil physical properties, grass, forest, Living Lab

INTRODUCTION

Soils exhibit tremendous variability with regard to their biological, chemical and physical properties. In fact, soils evolve under the action of biological, climatic, geologic and topographic influences. Pedologists have identified five fundamental soil formation processes that influence soil properties: parent material, topography, climate, time and organisms (Soil Survey Staff, 2006). The parent material from which soils develop is a key factor that in many cases determines the kinds and contents of secondary minerals of soils, therefore determines its texture and chemical properties (IUSS Working Group WRB, 2006). However, living organisms such as vegetation also have an important role in a number of

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processes involved in soil formation including organic matter accumulation, profile mixing and biogeochemical nutrient cycling. Through litterfall and the process of vegetation decomposition, plants add humus and nutrients to the soil which influences soil structure and fertility (NRCS, 2007). Soil biological, chemical and physical properties are modified by plants by means of root exudation, uptake of nutrients, contaminants and root growth (Marcet *et al*., 2006). In fact, under equilibrium conditions, vegetation and soil are closely linked with each other that different vegetation type exhibit different physical properties (Wilson and Sellers, 1985). Studies have also showed that vegetation, production of organic matter, quality of forest floor and availability of nutrient elements, are strongly combined with the local precipitations, the physical properties of the soil as well as the history of land use (Wezel *et al*., 2000; Epstein *et al*., 1998; Burke *et al*., 1997). The Living Laboratory is a forested area near Lincoln University main campus which resulted from rock mining activities that took place prior to 1950. The property is now owned by Lincoln University and has been dedicated to faculty research and teaching activities. The Living Laboratory is located in a position where it receives runoff from a 3-acre city park. The past mining history of the site and the runoff water it receives might have an effect on the vegetation type and soil physical properties. The objective of this study was therefore to compare soil-surface physical properties between the forest and grass areas inside the Living Laboratory.

MATERIALS AND METHODS

The Study Area

The Living Laboratory is located in Jefferson City, Missouri on the campus of Lincoln University at 38° 33' N and 92° 10' W with an elevation of 155 m. This 2.66 hectare plot of land resulted from rock quarry activities that took place more than 60 years ago. The Living Laboratory consists mainly of a hardwood forest on a shallow-soiled hilly terrain. Within the Living Laboratory there are two clear-cut trails along which we moved while collecting soil samples and recording geographic coordinates. Figure 1 shows the area covered by this study in the Living Laboratory.

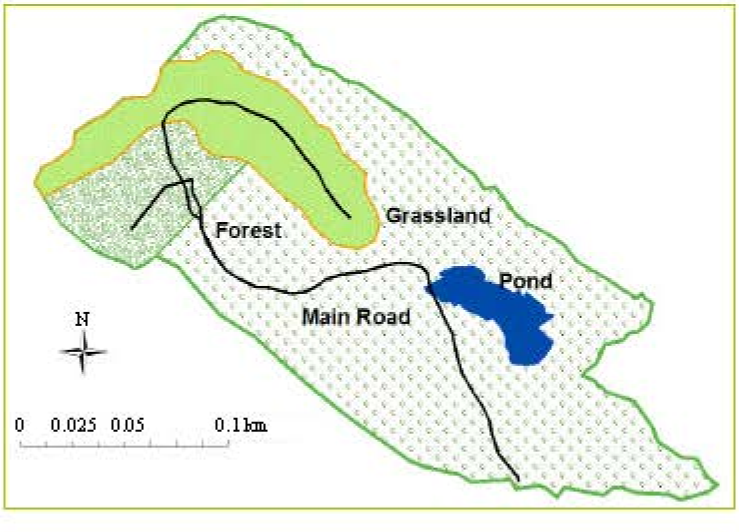

Fig. 1: Experimental field (Lincoln University Living Lab)

Soil Sampling

This study was conducted in summer and fall 2006. GeoExplorer Pathfinder 3-Global Positioning System (GPS) was used to map the Living Laboratory, its pond and the two trails. Composite soil samples were collected at 56 points in each of forest and grass dominated portions of the forest. Each sampling location's longitude and latitude were recorded. Additional measurements of soil temperature and thermal properties were recorded, but this data is handled in another study. Soil samples were collected with a 5 cm height and 5 cm diameter cylinders for a total 100 cm per sample. Three composite samples were collected on the surface at each location. The samples were kept in plastic bags to avoid moisture loss and were brought to Dickinson Research Center Laboratory (which is adjacent to the forest) where soil fresh weights were measured, then samples were transferred into an oven to be dried at 105^{0}C for 72 h. After drying, soil bulk density (ρ_b), air-filled porosity (f_a), gravimetric water content (θ_g), volumetric water content (θ_v), Total Pore Space (TPS), Water Filled Pore Space (WFPS), the relative gas diffusion coefficient (D_s/D_o) and the pore tortuosity factor (τ) were calculated according to Nkongolo *et al.* (2007).

GIS and Statistical Analysis

The data collected with Geo-Explorer Pathfinder 3-Global Positioning System (GPS) was directly transferred to ArcGIS 9.2 software where map of the Living Laboratory and its forest and grass portion were produced. The data on soil physical properties was first recorded into an excel spreadsheet, then transferred to GS$^+$ 5.0 and ArcGIS 9.2 where variograms and interpolated maps portraying the spatial distribution of soil properties were produced using ArcGIS 9.2. Spatial Analyst Extension. The interpolation method used was Inverse Distance Weighed (IDW). Inverse Distance Weighing is an exact interpolation method based on the assumption that the nearby values contribute more to the interpolated values than distant observations (Chang, 2010; Price, 2004). Statistix 9.0 statistical software (Analytical Software, 2009) was used to calculate the summary of simple statistics given in Table 1 and 2 for the forest and grass plots.

Table 1: Summary of simple statistics for soil physical properties in the forest plot

Simple statistics	f_a ($m^3 m^{-3}$)	ρ_b ($kg m^{-3}$)	θ_g ($kg kg^{-1}$)	θ_v ($m^3 m^{-3}$)	TPS ($m^3 m^{-3}$)	D_s/D_o ($m^2 sec^{-1} m^{-2} sec$)	WFPS (%)	τ ($m m^{-1}$)
Mean	0.29	1.05	0.31	0.32	0.60	0.09	52.49	3.61
SD	0.01	0.04	0.03	0.02	0.02	0.01	2.26	0.15
CV	3.76	4.07	9.20	6.24	2.80	6.93	4.30	4.23
Min.	0.25	1.00	0.17	0.23	0.50	0.06	46.00	3.29
Med.	0.29	1.05	0.30	0.31	0.60	0.09	52.25	3.60
Max.	0.31	1.31	0.38	0.37	0.62	0.10	59.71	4.12
Skew	-0.92	3.86	-1.41	-0.69	-3.95	-1.21	0.70	1.32
Kurt.	2.37	20.83	8.72	6.09	21.46	3.07	2.40	3.29

f_a: Air content, ρ_b:Bulk density, θ_g: Gravimetric water content, θ_v: Volumetric water content, TPS: Total pore space, D_s/D_o: Relative gas diffusion coefficient, τ: Pore tortuosity factor, WFPS: Water filled pore space

Table 2: Summary of simple statistics for soil physical properties in the grass plot

Simple statistics	f_a ($m^3 m^{-3}$)	ρ_b ($kg m^{-3}$)	θ_g ($kg kg^{-1}$)	θ_v ($m^3 m^{-3}$)	TPS ($m^3 m^{-3}$)	WFPS (%)	D_s/D_o ($m^2 sec^{-1} m^{-2} sec$)	τ ($m m^{-1}$)
Mean	0.44	0.90	0.25	0.22	0.66	33.49	0.20	2.46
SD	0.04	0.06	0.02	0.03	0.02	5.15	0.03	0.43
C.V.	9.37	6.32	8.88	12.13	3.25	15.37	14.40	17.45
Min.	0.18	0.81	0.17	0.16	0.56	22.87	0.03	1.90
Med.	0.44	0.90	0.26	0.22	0.66	33.43	0.20	2.44
Max.	0.54	1.16	0.33	0.38	0.69	67.14	0.29	5.41
Skew	-4.27	2.88	-0.37	3.37	-2.87	4.90	-3.27	5.90
Kurt.	26.89	10.84	4.04	20.15	10.79	31.28	21.29	38.65

f_a: Air content, ρ_b:Bulk density, θ_g: Gravimetric water content, θ_v: Volumetric water content, TPS: Total pore space, D_s/D_o: Relative gas diffusion coefficient, τ: Pore tortuosity factor, WFPS: Water filled pore space

RESULTS AND DISCUSSION

Soil Physical Properties in the Forest and Grass Plots

Soil bulk density (ρ_b), volumetric (θ_v) and gravimetric (θ_g), Water-Filled Pore Space (WFPS) and the pore tortuosity factor (τ) were highest in the forest plot (Table 1) while air content (f_a), Total Pore Space (TPS) and the relative gas diffusion coefficient (D_s/D_0) were highest in the grass portion (Table 2) of the Living Laboratory. Overall, all soil physical properties measured in both forest and grass plots had little variability as showed by low Standard Deviations (SD) ranging from 0.01 to 2.26 in the forest and 0.02 to 5.15 in the grass plot. The Coefficients of Variation (CV) were also very low and ranged from 2.80 to 6.93% in the forest and from 3.25 to 17.45% for the grass plot. Although, soil physical properties were measured at only 56 locations in each plot, the data approached normality as showed by means which are all equal or nearly equal to their medians in each of the forest and grass portions of the Living Laboratory. However, with the exception of only ρ_b and TPS, data for all soil physical properties in the forest had low kurtosis, implying that their normal curve had a flat top near the mean. In contrary, except for θ_g, data for all soil physical properties in the grass had high kurtosis values, implying that their normal curve had a sharp peak near the mean. Except θ_v, D_s/D_0 and WFPS, all other soil physical properties had the same direction of skewness (left or write) in both forest and grass plot. Soil air in both forest and grass plots was above 0.10 $m^3\ m^{-3}$, the minimum soil air content suggested by several researchers to sustain plant growth and other soil processes (Glinski and Lipiec, 1990). However, the grass plot was dryer and had 56% more air, but 45% less water (volumetric) content than the forest. In fact, soil sampling for this study was conducted during Summer and early fall, certainly the exuberant forest cover during Summer and early fall months better protected the soil from the sun, therefore reducing evaporation and helping the forest soil to keep its water. This can explain the difference in soil air and water in these adjacent plots. Total Pore Space (TPS) was 10% higher and the relative gas diffusion coefficient (D_s/D_0) even more than 100% higher in grass as compared to the forest. These results agree with those reported by Kodešová *et al.* (2007) who found that soil porous system in the organic matter horizon (top horizon) under the grass vegetation consisted of one cluster of pores with the larger diameters and isolated pores with the smaller diameter. Therefore, the retention ability of the organic matter horizon under the grass vegetation was higher than the retention ability of the organic matter horizon under the spruce forest. These results can also explain the soil bulk and the pore tortuosity factor which were, respectively 17 and 47% lower in grass as compared to the forest. In fact, it has been reported that increase in soil organic matter content is related to a decrease in soil bulk density and an increase in soil air content (Rivenshield and Bassuk, 2007; Nadian *et al.*, 2005) as found in this study. However, conflicting results have also been reported on the difference in bulk densities of a same soil, but under different vegetation cover or management types. Tate *et al.* (2004) studied the influence of oak canopy, topographic position and livestock concentration activities on bulk density of savanna Rangeland in the Southern Sierra Nevada Foothills. They found that soil-surface bulk density was 19% lower under oak canopy than in adjacent open grass. Assaeed (1982) observed higher bulk densities on grazed swale sites (1.38 g cm^{-3}) compared to 10 year ungrazed swale sites (1.22 g cm^{-3}). However, Assaeed (1982) also found no difference in bulk density between grazed and ungrazed areas located on hill-slope positions. Dahlgren *et al.* (2003) compared soil under blue oaks and savanna in California. They reported finding evidence of improved soil quality under blue oaks for physical, chemical and biological soil properties. They conclude that the type of vegetation (oak versus annual grasses) has a much stronger influence on soil organic matter and nutrient pools than does soil parent material.

Table 3: Correlation matrix between soil physical properties in the forest plot

Soil properties	f_a (m^3 m^{-3})	ρ_b (kg m^{-3})	θ_g (kg kg^{-1})	θ_v (m^3 m^{-3})	TPS (m^3 m^{-3})	WFPS (%)	D_s/D_o (m^2 sec^{-1} m^{-2}sec)
ρ_b	0.0967						
p-value	0.4782						
θ_g	-0.4957	-0.9090					
	0.0001	0.0001					
θ_v	-0.6311	-0.8319	0.9810				
	0.0001	0.0001	0.0001				
TPS	-0.0771	-0.9994	0.9007	0.8202			
	0.5721	0.0001	0.0001	0.0001			
WFPS	-0.8468	-0.6037	0.8686	0.9439	0.5869		
	0.0001	0.0001	0.0001	0.0001	0.0001		
D_s/D_o	0.9889	0.0607	-0.4571	-0.5987	-0.0394	-0.8225	
	0.0001	0.6570	0.0004	0.0001	0.7732	0.0001	
τ	-0.9877	-0.1606	0.5386	0.6785	0.1415	0.8801	-0.9783
	0.0001	0.2371	0.0001	0.0001	0.2983	0.0001	0.0001

f_a: Air content, ρ_b:Bulk density, θ_g: Gravimetric water content, θ_v: Volumetric water content, TPS: Total pore space, D_s/D_o: Relative gas diffusion coefficient, τ: Pore tortuosity factor, WFPS: Water filled pore space

Table 4: Correlation matrix between soil physical properties in the grass plot

Soil properties	f_a (m^3 m^{-3})	ρ_b (kg m^{-3})	θ_g (kg kg^{-1})	θ_v (m^3 m^{-3})	TPS (m^3 m^{-3})	WFPS (%)	D_s/D_o ($m^2$$sec^{-1}$ m^{-2} sec)
ρ_b	-0.8004						
p- value	0.0001						
θ_g	-0.5294	-0.0683					
	0.0001	0.6168					
θ_v	-0.8721	0.4056	0.8643				
	0.0001	0.0019	0.0001				
TPS	0.7984	-0.9999	0.0720	-0.4027			
	0.0001	0.0001	0.5981	0.0021			
WFPS	-0.9570	0.5993	0.7231	0.9713	-0.5969		
	0.0001	0.0001	0.0001	0.0001	0.0001		
D_s/D_o	0.9934	-0.8080	-0.5267	-0.8558	0.8060	-0.9377	
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
τ	-0.9733	0.7234	0.5551	0.8946	-0.7214	0.9723	-0.9421
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

f_a: Air content, ρ_b;Bulk density, θ_g; Gravimetric water content,θ_v:Volumetric water content, TPS: Total pore space, D_s/D_o: Relative gas diffusion coefficient, τ: Pore tortuosity factor, WFPS: Water filled pore space

Correlation Between Soil Physical Properties in the Forest and Grass Plots

The correlation matrices between soil physical properties in the forest and grass plots are showed in Table 3 and 4, respectively. In the forest, out of 28 correlations computed between soil physical properties, five were not significant, mainly f_a versus ρ_b, D_s/D_o and τ; ρ_b versus D_s/D_o and τ and finally TPS versus D_s/D_o and τ. For the 21 significant correlations between soil physical properties, correlation coefficient (r) ranged from 0.46 to 0.99. Except for the only one positive relationship between f_a and D_s/D_o, Air-filled porosity (f_a) and soil bulk density (ρ_b) were negatively correlated to all other soil physical properties (Table 3). In contrary, except their only negative relationships with D_s/D_o, all θ_g, θ_v, TPS and WFPS correlated positively with all other soil physical properties. In the grass plot however (Table 4), only two correlations were not significant, i.e., between θ_g and TPS and θ_g and ρ_b. Correlation coefficients (r) ranged from 0.40 to 0.99. The trend observed in the forest between D_s/D_o and other soil physical properties was not pronounced for the grass plot, except for θ_g and TPS for which a positive or negative correlation with D_s/D_o led to an opposite correlation with all other soil physical properties. Finally, none of the soil physical properties measured in the forest was significantly correlated to those in the grass.

Variogram Models for Soil Physical Properties in the Forest and Grass Plots

Variogram models for selected soil physical properties are showed in Fig. 2a and b- 4a and b. Table 5 gives model parameters of variogram not showed, mainly θ_g, TPS, WFPS,

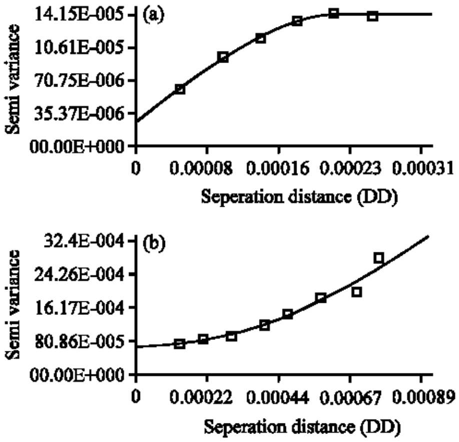

Fig. 2: Variogram models for soil air content in the forest and grass. (a) Spherical model: C_0 = 0.0000; C_0+C = 0.0001; A_0 = 0.00022700; r^2 = 0.997; RESS = 1.538E-11. (b) Gaussian model: C_0 = 0.0007; C_0+C = 0.0126; A_0 = 0.001800000; r^2 = 0.691; RSS = 1.300E-07

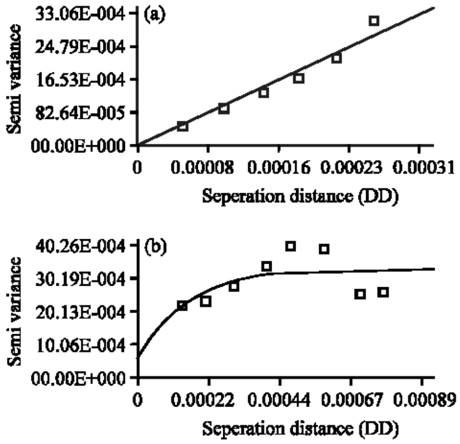

Fig. 3: Variogram models for soil bulk density in the forest and grass. (a) Linear model: C_0 = 0.0000; C_0+C = 0.0066; A_0 = 0.00062300; r^2 = 0.967; RSS = 2.125E-06. (b) Exponential model: C_0 = 0.0005; C_0+C = 0.0333; A_0 = 0.000150000; r^2 = 0.350; RSS = 2.345E-06

D_s/D_0 and τ. All soil physical properties studied at Lincoln University Living Laboratory (LULL) fitted to either linear, exponential, spherical or a Gaussian variogram model. However, among all soil physical properties, only D_s/D_0 fitted to the same spherical variogram model in both forest and grass plots. Except for soil bulk density (R^2 = 0.35) and total pore space (R^2 = 0.12) in the grass which had less developed structure and water filled pore space (R^2 = 0.71) in the forest with moderate spatial structure, all variogram models had highly developed structure as showed by R^2 ranging from 0.90 to 0.99. In the forest, the range of spatial variability was the same for θ_g, TPS and ρ_b (A_0 = 0.00062) and closer for

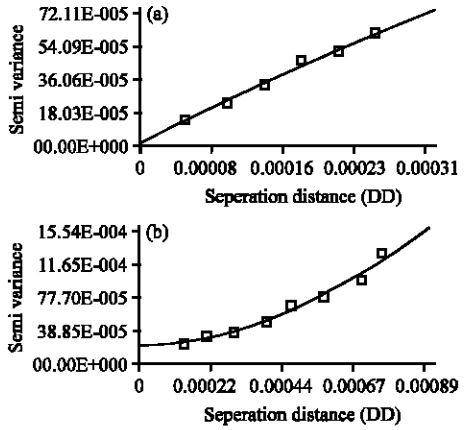

Fig. 4: Variogram models for volumetric water content in the forest and grass. (a) Spherical model: C_o = 0.0000; C_o+C = 0.0011; A_o = 0.00065800; r^2 = 0.993; RSS = 1.150E-09. (b) Gaussian model: C_o = 0.0002; C_o+C = 0.006; A_o = 0.001790000; r^2 = 0.982; RSS = 1.680E-08)

Table 5: Parameters of variogram models for soil physical properties in grass and forest

Variogram parameters	θ_g ($m^3 m^{-3}$)	TPS ($m^3 m^{-3}$)	WFPS (%)	D_s/D_o ($m^2sec^{-1} m^{-2}sec$)	τ ($m m^{-1}$)
Forest					
Model	LIN	LIN	SPH	SPH	SPH
C_o	0.00	0.00	2.97	0.00	0.0075
C_o+C	0.0029	0.0010	8.12	0.0001	0.0281
A_0	0.00062	0.00062	0.00177	0.00026	0.00026
R^2	0.99	0.95	0.71	0.99	0.98
Grass					
Model	SPH	EXP	LIN	SPH	EXP
C_o	0.00	0.0003	0.10	0.0001	0.0010
C_o+C	0.0006	0.0007	51.20	0.0022	1.71
A_0	0.00056	0.00145	0.00096	0.00207	0.00449
R^2	0.93	0.12	0.92	0.92	0.90

LIN: Linear, EXP: Exponential, SPH: Spherical, C_o: Nugget variance, C_o+C: Model variance, A_0: Range of spatial variability, R^2: Model fir

θ_v(A_0 = 0.00065). Similarly, D_s/D_o, f_a and τ also had the same range of spatial variability in the forest and could therefore be sampled at the same distance. However, in the grass, only θ_v and f_a had the same range of spatial variability (A_0 = 0.0018).

Spatial Distribution of Soil Properties Across the Forest and Grass Plots

Maps portraying the spatial distribution of some of these properties in the forest and grass plots are showen in Fig. 5-8. Overall, Fig. 5-7 show that soil air content, bulk density and volumetric water content followed a similar and consistent pattern in both forest and grass plots: an homogenous zone of moderate or high values with pockets of higher or lower values spread across the plot. These hot spots occurred at three points near the pond and one at the entrance of the Living Laboratory for soil air content in the forest. At these locations there was less forest, which allowed sunlight to heat the soil and evaporate the soil moisture. However, the area under intense forest canopy had lower air-content. In the grass, however, there were few spots of higher air contents as compared to the forest. The distribution of soil bulk density in the forest is even more apparent with about 90% of the

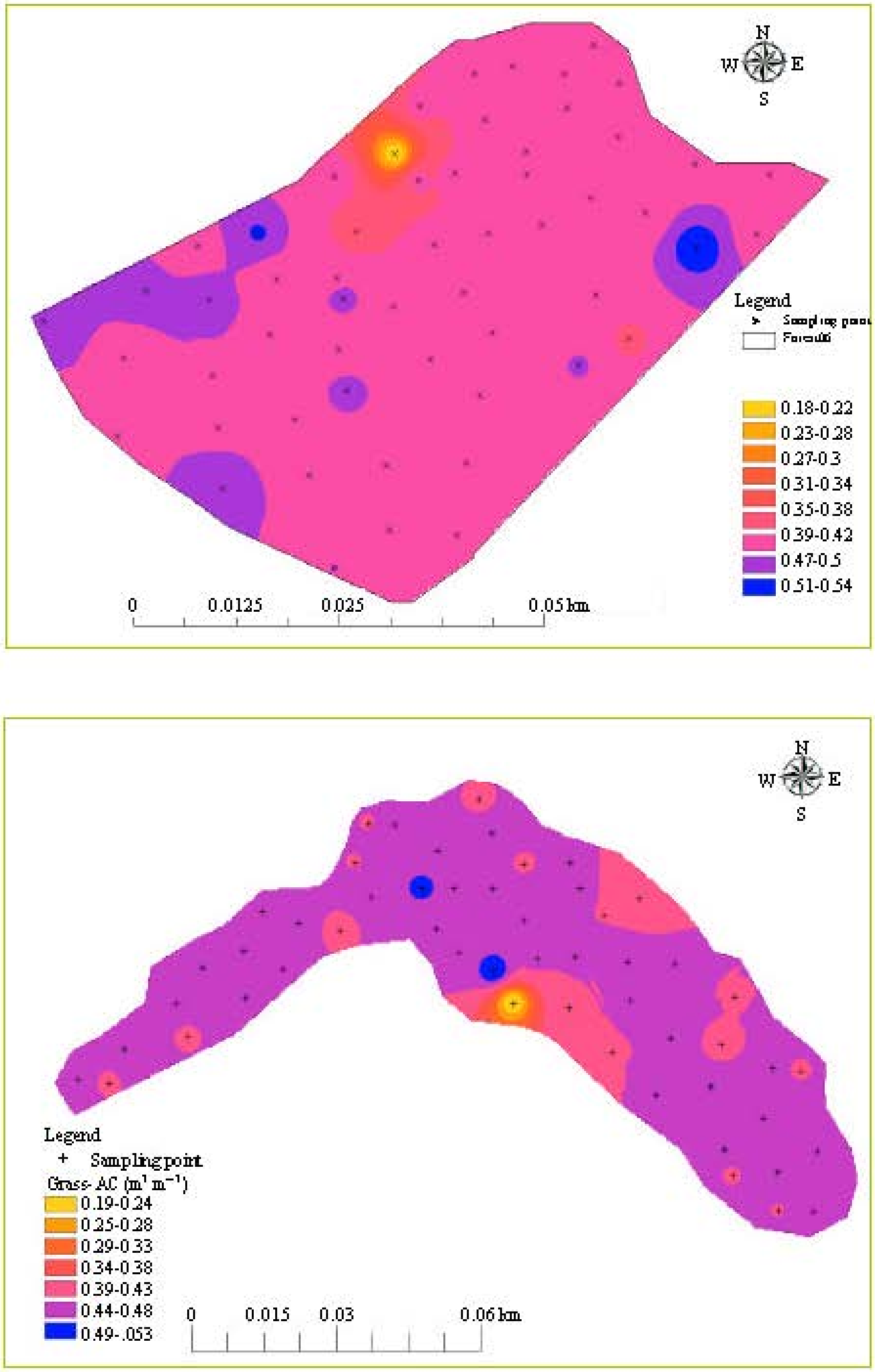

Fig. 5: Spatial distribution of soil air content in the forest and grass

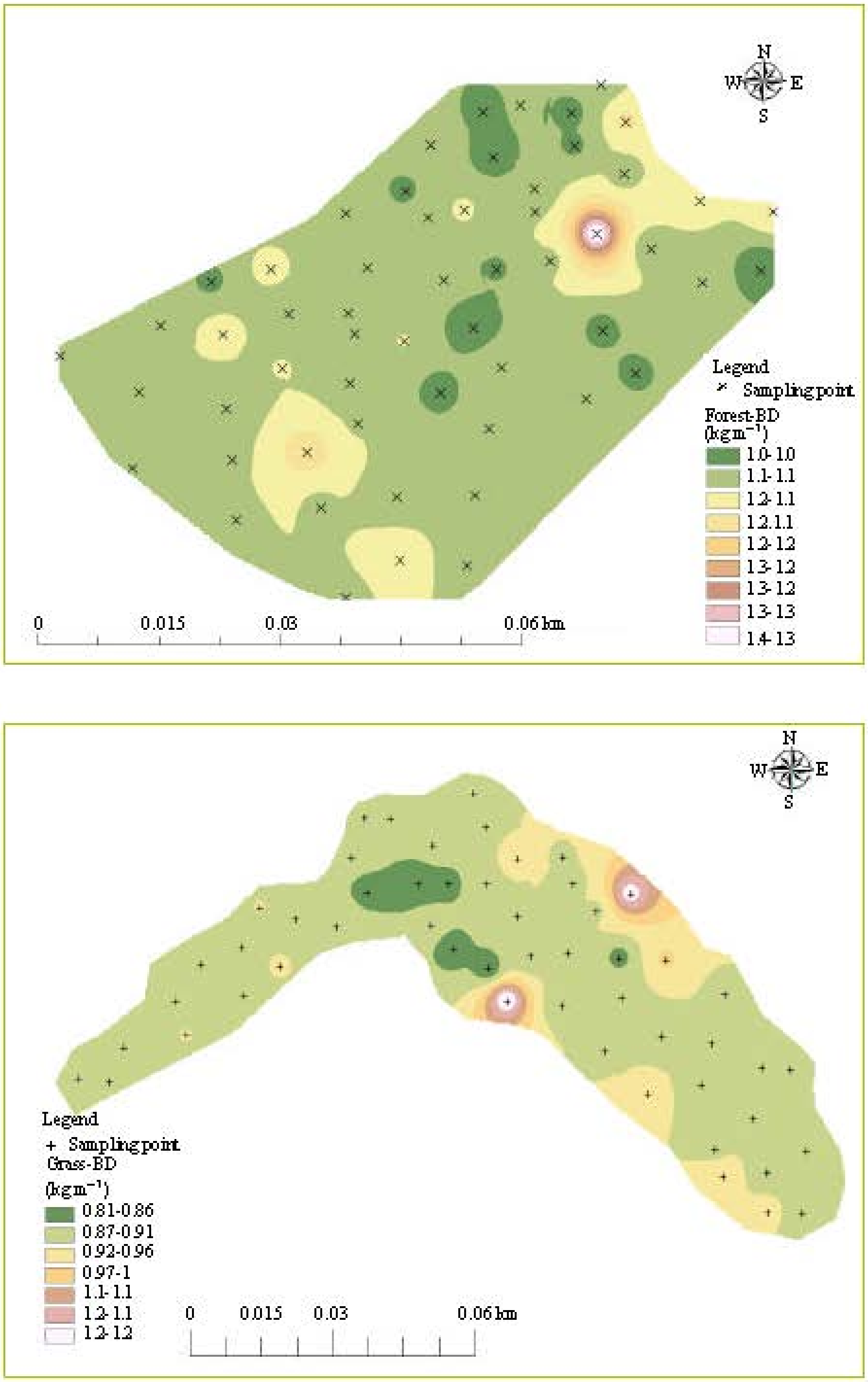

Fig. 6: Spatial distribution of soil bulk density in the forest and grass

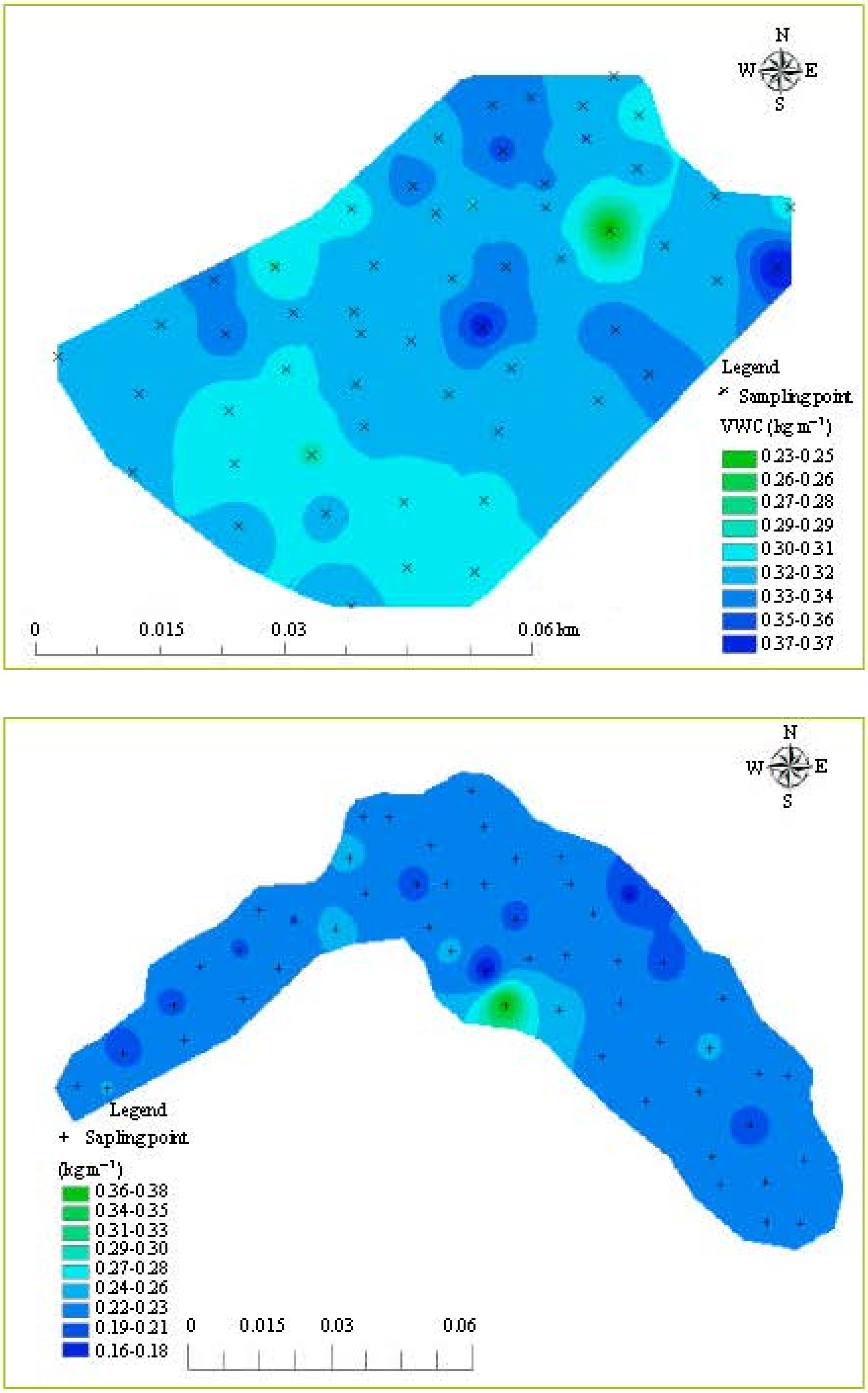

Fig. 7: Spatial distribution of soil volumetric water content in the forest and grass

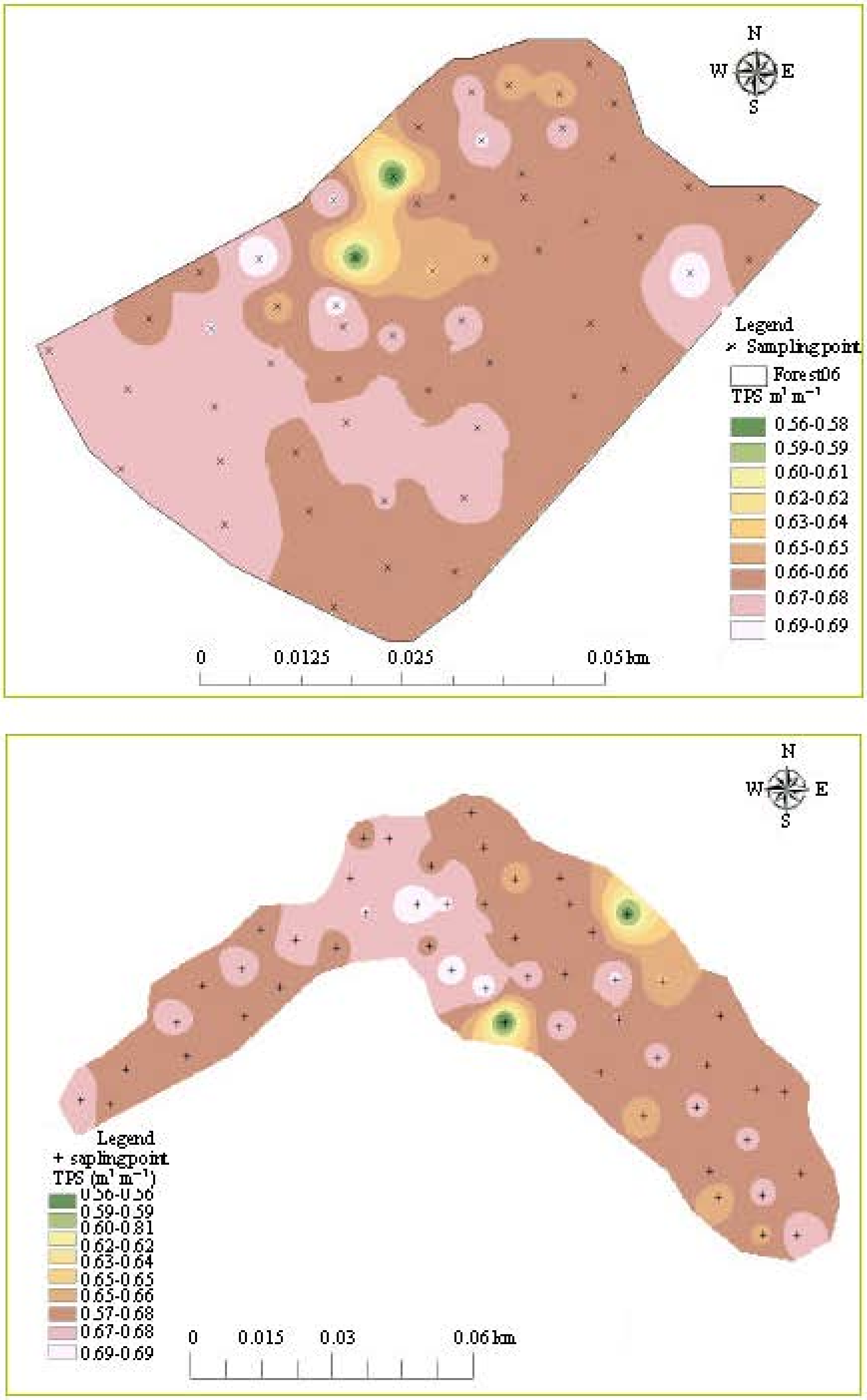

Fig. 8: Spatial distribution of soil total pore space in the forest and grass

plot covered with ρ_b between 1.0 to 1.1 with five spots of ρ_b between 1.1. and 1.3. The grass plot showed similar pattern even though the zone with higher was bigger than that in the forest. Soil volumetric water content in the forest had its pockets of high values concentrated in the northern part of the forest plot. In the grass, however, four pockets of low water content represented less than 10% of the plot (Fig. 7). Two zones of total pore space (Fig. 8) were observed in each of the forest and grass.

CONCLUSIONS

The effect of vegetation type on soil physical properties was investigated at Lincoln University Living Laboratory (LULL) in its forest and grass portions. Despite the position of LULL and its history, surface soil physical properties were in the range of values reported in similar ecosystems. Although, soil physical properties differed in both forest and grass, their spatial distribution followed a similar trend. These preliminary results will be useful to future studies at this forested area devoted to students and faculty research on the main campus of Lincoln University of Missouri.

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