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USING THE BULK DENSITY AND PARTICLE SIZE COMPOSITION OF SOIL AS SUSTAINABILITY INDICATORS TO CHARACTERIZE A SILVOARABLE ECOSYSTEM OF ROMANIA

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Abstract

The aim of the study was to identify the values of several soil parameters (particle size composition and bulk density) in a silvoarable ecosystem combining two types of plant cultures: a plantation of no-tilled hybrid poplar (Populus spp.*) trees and a conventional tilled rapeseed crop (Brassica napus). The studied parameters have been chosen because these are sustainability indicators used in the monitoring of the agricultural ecosystems in general, but in particular to characterize a rare type of agricultural ecosystems in Romania, the agroforestry ecosystems, and in this case a silvoarable ecosystem, because these are poorly studied and described in this country. The results have shown in the 0-10 cm topsoil of the poplar plantation negative Pearson's correlations between soil bulk density and respectively silt, colloidal clay and physical clay, and positive Pearson's correlations between soil bulk density and respectively coarse sand and fine sand, and inverse correlations between the same factors in the 20-30 cm poplar soil. The coarse sand and the fine sand have negatively correlated with other textural fractions of the soil (silt, colloidal clay, physical clay) in both plant types, excepting the depth 20-30 cm in the poplar soil. The silt fraction was positively correlated with the clay fractions (colloidal and physical, respectively) in both plant types, excepting the depth 20-30 cm in the poplar soil, and a positive correlation has been found between the colloidal clay and the physical clay fractions in both plant types and for all soil depths. In this study, for the topsoil (0-10 cm) of the two components (poplar plantation and rapeseed crop) there were not found statistical significant differences between the proportions of the fractions coarse sand, colloidal clay and physical clay, but there were found for fine sand and silt fractions.*

Key words*: agroforestry, particle size distribution, texture, Populus, poplar, rapeseed.*

INTRODUCTION

The particle size composition of the soil is an indicator of soil sustainability by influencing several processes in soil, among which the soil permeability has been widely studied, because the proportion of the soil fractions, their size and arrangement determine several parameters of soil which are water-related (water retention, water infiltration), such as the permeability coefficient, internal seepage (Zhao et al., 2024), water evaporation, pore size characteristics of soil (Li et al., 2024), or are very important in assessing the sustainability of agroecosystems, such as nutrient cycling, fertility (Wang et al., 2022a; Azaryan et al., 2022) soil aggregate stability (structural stability), soil leaching, soil erosion (Wang et al., 2022b). However, the soil particle size distribution is a very important parameter for understanding the soil mechanics and geotechnics, which influence its productivity, its pollutant retention or leaching (Bari, 2023) and, generally, its resilience on long term to accomplish its role in the agroecosystems and give humanity the expected sustainable economic benefits (mainly food production). Besides the influence on the physico-chemical properties of the soil, the particle size distribution of soil was found to influence several biological features of the pedosphere, like the microbial biomass and decomposition (Wang et al., 2022c; Duan et al., 2024) and the morphological traits of the roots (Azaryan et al., 2022).

The bulk density of soil is also an important physical indicator of soil sustainability because this influences many characteristics of the soils which describe its sustainability: the soil fertility by influencing the nutrient cycles, such as the stocks of soil organic carbon (Fenton et al., 2024) and the microbial activity (Gui et al., 2023), the soil compaction by estimating the packing density (Panagos et al., 2024), the water retention (Liu et al., 2024), the water hygroscopy (Zheng et al., 2021), the soil CO_2 emissions (Gui et al., 2023), or the soil temperature (Qiao et al., 2023) and pollutant contamination (Korchagina et al., 2014). The main driver of the bulk density variations was reported to be the land cover type and respectively the crop type when the soil use is agricultural (Panagos et al., 2024), but other studies (Larsbo et al., 2024) revealed the implications of soil pedofauna (earthworms) in changing the vertical profiles of the bulk density. The relationships between the textural fractions of the soil and its bulk density is a subject insufficiently approached in agroecosystems. In Romania, the agroforestry ecosystems are low studied, and the information about the relations existing between the physical factors of the soil in the silvoarable systems are lacking. This study aims to provide information about these relationships considering the importance of the approached soil parameters (particle size composition and bulk density) in characterising the soil sustainability.

MATERIALS AND METHODS

The studied ecosystem is a silvoarable ecosystem (FAO 2017) from Timiș County, Romania (45.45418°N, 20.90334°E) consisting of two components: a poplar plantation (Euro-American hybrid poplar trees: *Populus deltoides* × *Populus nigra*) which border an agricultural crop of rapeseed (*Brassica napus* L., the hybrid LG Architect).

The study aimed to characterize the soil (vertisol) of the two plant ecosystems (poplar and rapeseed) through physical parameters known as sustainability indicators of soil in agroecosystems: particle size composition (coarse sand (2.0-0.2 mm), fine sand (0.2-0.02 mm), silt (0.02-0.002 mm), colloidal clay (<0.002 mm), physical clay (<0.01 mm) and bulk density. The fractions of the particle size composition have been analyzed for three depths (0-10 cm, 10-20 cm, 20-30 cm) in the poplar soil and for one depth (0-10 cm) in the rapeseed soil. The argument for analyzing only one depth in rapeseed soil is represented by the different agricultural technologies applied for rapeseed soil, which consist of mechanical disturbance on a depth by 30 cm, as compared with the poplar plantation where the soil was not disturbed through mechanical workings for eight years. This is also the reason why the bulk density was not monitored in the rapeseed soil. The soil analyses have been performed according to the following methodology: the particle size composition has been established according to STAS 7184/10-79-PS-04 (Kaczynski's method for determination, the Atterberg scale for interpretation), and the bulk density according to ISO 11272:2017. The statistical interpretation was made using the software IBM SPSS 28.0.0.0.

RESULTS AND DISCUSSIONS

The fractions of the particle size composition of the studied soils (planted with rapeseed and respectively with poplar hybrids) analyzed for three depths (0-10 cm, 10-20 cm, 20-30 cm) in the poplar soil and for one depth (0-10 cm) in the rapeseed soil are shown in Table 1, respectively Figure 1.

Table 1. The proportions of the soil textural fractions (mean values) of the two components of the studied silvoarable ecosystem (*Populus* spp. plantation and *Brassica napus* crop)

Soil depth (cm)	Soil parameters in *Populus* spp. (hybrid poplar) plantation (mean values)					
	Coarse sand (2.0-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Colloidal clay (<0.002 mm)	Physical clay (<0.1 mm)	Bulk density (g/cm^3)
0-10 cm	6.10± 2.90	41.93± 1.77	23.93± 1.45	28.03± 2.77	41.00± 3.67	1.470± 0.026
10-20 cm	6.36± 2.59	42.10± 1.70	23.33± 1.92	28.20± 2.26	37.06± 9.42	-
20-30 cm	6.06± 3.09	35.06± 9.93	30.00± 10.05	28.86± 2.82	41.93± 2.91	1.473± 0.056
Soil depth (cm)	Soil parameters in *Brassica napus* (rapeseed) crop (mean values)					
	Coarse sand (2.0-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Colloidal clay (<0.002 mm)	Physical clay (<0.1 mm)	
0-10 cm	4.20± 2.51	40.63± 5.70	25.10± 2.98	30.06± 5.20	43.46± 6.67	

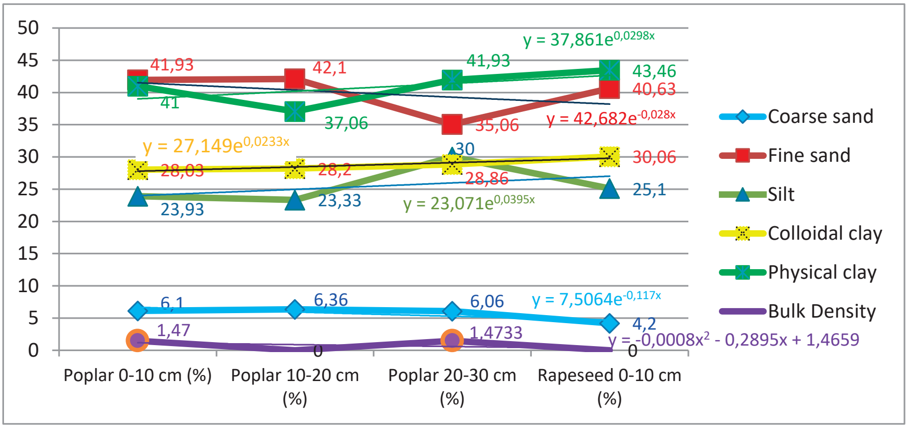

Figure 1. Particle size composition of the soil in the studied silvoarable ecosystem

In this study, for the two components (poplar plantation and rapeseed crop) of the researched silvoarable ecosystem, there were not found statistical significant differences between the proportions of the following textural (particle size composition) fractions of the topsoil (0-10 cm): coarse sand, colloidal clay, and physical clay. These findings show that, despite the different agricultural technology and land use, the particle size distribution of the rapeseed soil is not statistically different as coarse sand, colloidal clay and physical clay from that of the poplar soil. Considering that the poplar plantation has been established eight years earlier, a possible explication for these not significant differences could be the time necessary to produce changes in a vertisol by introducing a woody species. Another reason could be the higher stability of the clay due to its mineral-organic association with the organic matter (Chen et al., 2018) as compared with other particle fractions of the soil. The plant root biomass in the rapeseed topsoil and the litter input in the poplar topsoil could action as equivalent factors in maintaining the supply with organic matter of the soil and could explain the achieved result. The coarse sand is considered a non-erodible soil element (Lipiec et al., 2016) and a contributor to the internal spatial architecture of the soil which promote plant root penetration and thus its stability and low migration along soil profile.

Statistical significant differences (paired samples t-test, $p<0.05$) were however found for the finer fractions of the soil particles, i.e. for the fine sand, which in the poplar topsoil was with 3.11% higher than in the rapeseed topsoil, respectively for the silt, which in the rapeseed topsoil was with 4.88% higher than in the poplar topsoil, at 0-10 cm depth (Figure 2).

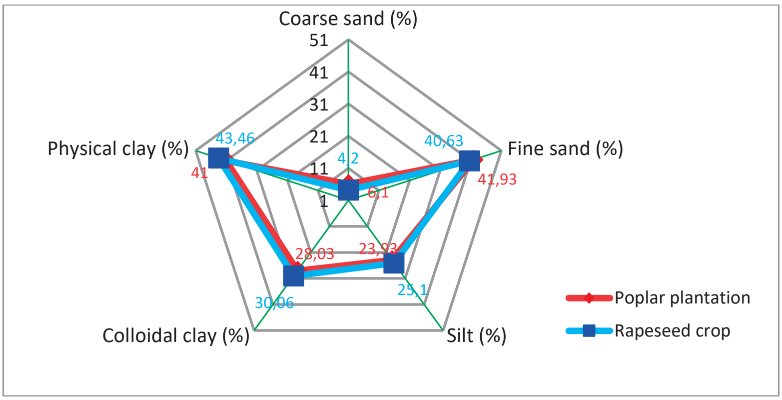

Figure 2. Particle size composition of the topsoil (0-10 cm) in the studied silvoarable ecosystem

Although these differences are small, these could have important impacts at soil level since other studies (Liang et al., 2020) showed that small variations (0-25%) of the clay fraction can considerably impact several soil properties such as the critical hydraulic gradient, the critical flow velocity and the internal erosion by influencing the behaviour of the find sand in the analyzed soil. Several researches showed that the finer particles of the soil texture are more susceptible to vary due to the particle breakdown during the mechanical agricultural workings and farming practices (Birhanu et al., 2016; Jacobs et al., 2024), or due to their susceptibility to contribute to soil losses through erosion (Ampontuah et al., 2006).

The Pearson's correlations ($p<0.05$) have been calculated to identify the relationships existing between all fractions of the particle size composition both for the soil planted with rapeseed and poplar (Table 2).

Table 2. Pearson`s correlations ($p<0.05$) between the textural (particle size composition) fractions of the soil in *Populus* spp. plantation and *Brassica napus* crop

Plant type/Soil depth (cm)	Soil textural fraction	Pearson's correlation coefficient (*p<0.05)					
		Coarse sand (2.0-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Colloidal clay (<0.002 mm)	Physical clay (<0.1 mm)	Bulk density (g/cm^3)
Populus spp. (hybrid poplar) 0-10 cm	Coarse sand (2.0-0.2 mm)	-	0.599	-0.902*	-0.958*	-0.948*	0.923*
	Fine sand (0.2-0.02 mm)	-	-	-0.886*	-0.804*	-0.822*	0.860*
	Silt (0.02-0.002 mm)	-	-	-	0.988*	0.992*	-0.998*
	Colloidal clay (<0.002 mm)	-	-	-	-	0.999*	-0.994*
	Physical clay (<0.1 mm)	-	-	-	-	-	-0.997*
Populus spp. (hybrid poplar) 10-20 cm	Coarse sand (2.0-0.2 mm)	-	0.882*	-0.971*	-0.987*	-0.783	-
	Fine sand (0.2-0.02 mm)	-	-	-0.968*	-0.944*	-0.983*	-
	Silt (0.02-0.002 mm)	-	-	-	0.996*	0.907*	-
	Colloidal clay (<0.002 mm)		-	-	-	0.870*	-
Populus spp. (hybrid poplar) 20-30 cm	Coarse sand (2.0-0.2 mm)	-	-0.157	0.127	-0.998*	-0.994*	-0.994*
	Fine sand (0.2-0.02 mm)	-	-	-0.999*	0.215	0.257	-0.273
	Silt (0.02-0.002 mm)	-	-	-	-0.186	-0.229	0.301
	Colloidal clay (<0.002 mm)	-	-	-	-	0.999*	0.880*
	Physical clay (<0.1 mm)	-	-	-	-	-	0.858*
Brassica napus (rapeseed) 0-10 cm	Coarse sand (2.0-0.2 mm)	-	0.971*	-0.963*	-0.994*	-0.996*	-
	Fine sand (0.2-0.02 mm)	-	-	-0.999*	-0.991*	-0.988*	-
	Silt (0.02-0.002 mm)	-	-	-	0.986*	0.983*	-
	Colloidal clay (<0.002 mm)	-	-	-	-	0.999*	-

The proportions and associations of the differently sized physical fractions of the soil are important features because these determine the soil capacity to retain the water, its hygroscopy (Arthur et al., 2021), and therefore this study aimed to identify the possible relationships existing between the textural fractions of the researched soil and between these and soil bulk density. It was found a negative correlation between the factors coarse sand and silt both in poplar soil and in the rapeseed soil, excepting the soil depth 20-30 cm in poplar plantation, where the correlation was not statistically significant. Also, the factor coarse sand was negatively correlated with the clay content (colloidal clay and physical clay) for all soil depths in both plant types. The correlation between soil coarse sand and bulk density has been studied only in poplar plantation and there was found to be positive in the soil layer 0-10 cm and negative in the soil layer 20-30 cm. Negative correlations of the coarse sand with soil silt and clay have been previously found in an Entisol (Gubiani et al., 2021). The same study reported also a negative correlation between the fine sand and silt fractions of the soil. Negative correlations between the clay content and the coarse sand content of the soil have been previously reported by other researches (Xi et al., 2015; Valladares et al., 2006), which found that the clay content is associated, to some extent, with the content of organic carbon of soil (Xi et al., 2015), whereas the coarse sand content has been associated with a low content of organic carbon (Wang et al., 2019).

The soil textural fraction fine sand was negatively correlated with silt in all soil depth for both plant types. This finding is consistent with other researches regarding the particle size distribution of soil (Erktan et al., 2016) which have found that the fine sand and silt act as drivers upon the soil aggregate stability, the fine sand enhancing it whereas the silt content was associated with its decrease, emphasizing the importance of the factors fine sand and silt in determining the structural stability of soils especially in the early stages of the ecological succession of the disturbed sites, when the content of the organic matter of soil is low, resulting that the soil aggregate stability is relying also on physical and mechanical factors, such as soil particle size distribution or fine root network.

The fine sand fraction was also negatively correlated with the colloidal clay and with the physical clay in both plant types (excepting the soil depths 20-30 cm in poplar plantation, where the correlation was not statistically significant). Other studies (Liang et al., 2020) indicated that the relations of the fine sand with the clay in soils influence the internal erosion and the hydraulic conductivity of it. Also, the clay was found to be responsible for the increasing of the soil cohesion which depends on the ratio of cohesive (clay)/non-cohesive (sand) particles in the soil and on the fine particles of the soil rather than on the coarse particles of it (Wibisono et al., 2017). The fraction fine sand in the poplar soil showed a positive correlation with the bulk density only in the 0-10 cm topsoil. Similar relationship has been also found by Așkin and Özdemir (2003) in a grassland soil and it indicated that the sand content was the soil fraction with the higher direct effects on soil bulk density than any other particle fraction and also with indirect effects through other soil properties on the bulk density of the analyzed soil.

The soil fraction silt has shown positive correlations with the clay (both colloidal and physical) in both plant types, excepting the soil depths 20-30 cm in poplar plantation, where the correlation was not statistically significant. The soil silt was negatively correlated with the bulk density only in the 0-10 cm poplar topsoil. Similar relationship between soil silt and soil bulk density has been also found by Așkin and Özdemir (2003), which found in a grassland soil of hot Mediterranean climate the following order of direct influence of the soil particle fractions on the soil bulk density: sand, clay, silt, organic matter, fine sand.

In this study, positive correlations between the soil fractions coarse sand and fine sand were noticed only for the superior soil layers, respectively 10-20 cm in the poplar soil and 0-10 cm in the rapeseed soil. The main difference between the properties of the coarse and fine sand in soils consists on their influence on soil liquid permeability because of the porosity resulted from their arrangement along the soil profile (Wang et al., 2022a). In our study, in the poplar soil, the positive correlations between coarse and fine sand have been found in the soil layer with the largest amount of coarse sand and respectively of fine sand (10-20 cm).

The correlations between the soil textural fractions colloidal clay and physical clay were positive for both plant types and for all studied soil depths.

The relations of soil bulk density with the clay (both colloidal and physical) in the poplar soil were found to be negative in the soil layer 0-10 cm and positive in the soil layer 20-30 cm. A study regarding the bulk density of the European soils (Panagos et al., 2024) made on three depth intervals (0-10, 10-20, 20-30 cm) showed that, generally, the values of this parameter increase with the depth, with approximately 16% for the depth 20-30 cm as compared with the soil depth 0-10 cm. The same study revealed that the disturbed soils (arable lands) have the bulk density higher with 44-60% than the woodlands. In the present study, the difference between the same depth layers (0-10 and 20-30 cm) of the poplar soil was lower than 1% for bulk density. We consider this is a consequence of the no tillage technologies for eight years in the poplar plantation. Another direction to explain this low difference between the bulk densities of the soil layers was to investigate the earthworm presence in this soil, which revealed in the poplar soil the massive presence of the epigeic earthworms, which not contribute through their feeding behaviour to the variations of the bulk density, but this data is not published in this study. Positive correlations between the bulk density and the colloidal clay and the direct dependence of the bulk density on the colloidal clay content have been found previously by Suzuki et al. (2015) in the same range of soil depth. In our study, the bulk density has been measured only in the poplar soil and it has been positively correlated with the colloidal clay only for the depth 20-30 cm, because for the depth 0-10 cm the correlation has been negative. Other studies showed that the variation of the values of bulk density between the soil layers is associated with the various amount of organic matter, the biological activity or the different architecture of the plant roots.

CONCLUSIONS

In this study, for the topsoil (0-10 cm) of the two components (poplar plantation and rapeseed crop) of the researched silvoarable ecosystem there were not found statistical significant differences between the proportions of the fractions coarse sand, colloidal clay and physical clay, but there were found for fine sand and silt.

The results have shown in the 0-10 cm topsoil of the poplar plantation negative Pearson's correlations between soil bulk density and respectively silt, colloidal clay and physical clay, and positive Pearson's correlations between soil bulk density and respectively coarse sand and fine sand, and inverse correlations between the same factors in the 20-30 cm poplar soil.

The coarse sand and the fine sand have negatively correlated with other textural fractions of the soil (silt, colloidal clay, physical clay) in both plant types, excepting the depth 20-30 cm in the poplar soil.

The silt fraction was positively correlated with the clay fractions (colloidal and physical, respectively) in both plant types, excepting the depth 20-30 cm in the poplar soil.

A positive correlation has been found between the colloidal clay and the physical clay fractions in both plant types and for all analyzed soil depths.

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