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The Colloid Fraction and Cation-Exchange Capacity in the Soils of Vojvodina, Serbia

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Summary: The colloidal complex of soil consists of humus and clay, the most important acidoids which are able to create the bonds between oppositely charged ions (cations) through the forces strong enough to provide protection from leaching, and also weak enough to enable absorption through the plant root. This ability becomes more pronounced if the degree of dispersity is higher, i.e. if particles have smaller diameters. Total of 435 soil samples were collected from the surface horizon in 2011, for the purpose of soil fertility control in Vojvodina and prevention of its possible degradation in broader terms. This paper presents a part of study through selected representative soil samples, related to the research results of mechanical composition, basic chemical properties, and cation-exchange capacity in the most frequent types of soils in North Bačka and Banat (chernozem, fluvisol, semiglay, humoglay, solonchak, solonetz), due to the fact that soil fertility and its ecological function in environment protection largely depend on the studied properties. The average content of clay was 25.26%, ranging from 5.76 to 49.44%, the average content of humus was 3.10%, ranging between 1.02 and 4.30%, while the average value of CEC was 27.30 cmol/kg, ranging between 12.03 and 46.06 cmol/kg. Soils with higher content of clay and humus have greater cation-exchange capacity. According to the established average values of CEC in cmol/kg, the order of soil types is as follows: solonetz (40.06), semiglay (31.98), humoglay (30.98), solonchak (26.62), chernozem (22.72), and fluvisol (22.40). Research results have shown that cation-exchange capacity depends on clay fraction and humus content. Higher correlation coefficient between CEC and clay, compared to CEC and humus, indicates that clay content compared to humus content has greater effect on cation-exchange capacity.
Keywords: CEC, clays, humus, mechanical composition, soils

Abbreviations: Cation-exchange capacity (CEC)

Introduction

Knowledge about the physical and chemical soil properties is of great importance for agricultural practice given the fact that soil fertility and yield directly depend on these traits. Obtaining knowledge about these traits is highly significant since agricultural practice relies on the results of theoretical studies in its attempt to solve problems. We are witnessing more intense pollution of not only soil but all the other ecosystems. The ability of soil to resist these degrading changes depends on its content of clay and humus, i.e. cation-exchange capacity.

Cation-exchange capacity (CEC) is one of the most important soil properties, as it affects soil fertility through prevention from leaching, and losses of cations as a result of binding with soil colloids. Cation exchange in soils is a reversible reaction. It prevents nutrient losses and leaching of soil, affects accessibility of nutrients for plants, and also serves as a basis for determination of the required quantity of fertilizers. Cation-exchange capacity depends primarily on the content of clay minerals and organic matter in soils (Hadžić et al. 1995). Organic matter is the main source of CEC in sandy soils (Johnson 2002).

Minerals belonging to the illite group are the most frequent clay minerals in soils of Vojvodina, Serbia. Cation-exchange capacity is most accurately presented by the fact that 1 g of montmorillonite has an active surface area of 700 m² with a negatively charged centre. Such a vast surface can bind large quantities of nutrient cation and positively charged radicals from organic compounds, where they are first retained and then subjected to microbiological degradation (Nešić et al. 2013).

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The average humus content in the soils of Vojvodina is 3% (Manojlović 2008). There is an important requirement to study and define physical and chemical properties of soils, not only in order to preserve the present state of soils but also to determine the course of activities with the purpose of soil improvement.

Since cation-exchange capacity is one of the essential factors of soil fertility, the aim of this paper was to define the exchange capacity of specific soil types in Vojvodina, and determine the correlation between clay and humus content and cation exchange capacity in the tested soils. These data are significant considering that soil fertility and its ability to resist degrading changes largely depend on clay and humus content, i.e. the cation-exchange capacity.

Materials and Methods

Soil samples used in this survey were collected from the territory of the Vojvodina Province, Serbia, and they represent the most frequent soil types of this region. Representative samples including various geomorphological units, types and lower level units were selected for analysis, as well as different types of soil use. GPS technology was used in order to select the sampling locations (Figure 1). The exact coordinates of sampling locations, county, altitude, sample number and type of soil are presented in Table 2. Soil samples were collected in disturbed condition, according to the regulations of Soil Fertility and Fertilizer Use Control System with the agrochemical probe at the depth of 0-30 cm, according to the round control lot system, in a network of squares sized 4×4 km. Laboratory tests were conducted at the Laboratory for Soil and Agroecology of the Institute of Field and Vegetable Crops, and the Laboratory of Pedology of the Faculty of Agriculture in Novi Sad (according to the methods for this type of research accepted by Yugoslavian Soil Research Society (JDZP 1966, 1997)).

The selected samples in this study determine the following:

- Basic chemical properties (pH in H_2O and 1M KCl, % $CaCO_3$ using Scheibler calcimeter, and content of humus according to the Turin method),
- Mechanical content using the international B method- Pipette method, sample were prepared for analysis using Na-pyrophosphate according to Thun, and texture was classified according to Tommerup,
- Cation-exchange capacity (CEC) was measured by cation extraction with sodium acetate and ammonium acetate; concentration of Na+ ions in extract was measured by ICP (inductively coupled plasma ICP-OES Vista Pro Varian).

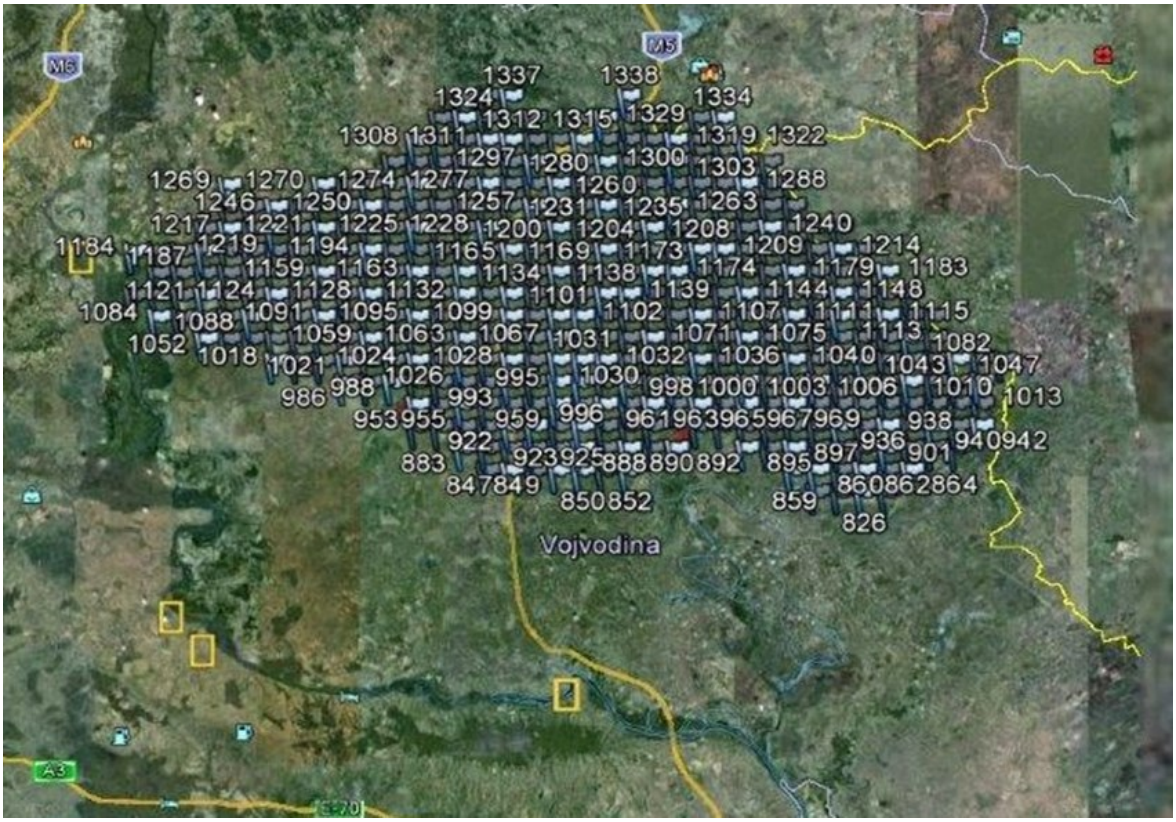


Figure 1. Soil sampling locations in Northern Vojvodina

Data were processed using the program Statistica 8. Correlation analysis was used to determine the correlation coefficient, in order to confirm how the changes in clay fractions and humus content modify the exchange capacity. Statistically significant correlation was determined between clay and CEC (r = 0.42), and humus and CEC (r = 0.30), at the level of r < 0.05 (Table 1). CEC was positively correlated with both elements, based on which we conclude that the rise in the percentage of clay and humus in soil increases the CEC.

Results and Discussion

Thirty-two selected soil samples represent six types of soil at the tested area. The most widespread type of soil is chernozem which occupies 40.63%, followed by semiglay and humoglay each occupying 18.75%, fluvisol 9.36%, and finally solonchak and solonetz, each occupying 6.25% (Figure 2). Regarding soil use, the area mainly consists of arable land 81.25%, meadows 9.36%, gardens 6.25% and pastures 3.13%.

Clay content ranged between 19.44 to 40.75% (Table 3). The highest average clay content was found in humoglay 40.75%, solonetz 26.2%, fluvisol 25.61%, semiglay 23.04%, solonchak 21.88%, with the lowest clay content found in chernozem 19.44%.

Clay or colloid fraction represents the most active part of the solid phase of soil, thus physical and chemical soil properties and soil fertility are largely dependent on its presence. The main property of colloid fraction is its large active surface, where adsorption and substitution of ions and solution molecules occur (Resulović & Čustović 2002).

Heavy clay soils are better supplied with nutrients compared to lighter sandy soils which are poor in nutrients. Therefore, physical properties of soil such as mechanical content affect its chemical properties and plant nutrition (Bogdanović & Ubavić 1995).

Humus content ranged between 2.69 to 3.45% (Table 1). All soil types can be considered as humus rich soils. The highest percentage of humus was found in semiglay 3.45%, humoglay 3.25%, chernozem 3.05%, solonchak 2.90%, solonetz 2.78%, and the lowest in fluvisol 2.69%.

Cation-exchange capacity in the tested soil types varied in the interval from 22.41 to 40.06 cmol/kg, which is within the average values (Table 1). The highest CEC was found in solonetz 40.06 cmol/kg, semiglay 31.99 cmol/kg, humoglay 30.97 cmol/kg, solonchak 26.61 cmol/kg, and the lowest in chernozem 22.72 cmol/kg and fluvisol 22.41cmol/kg.

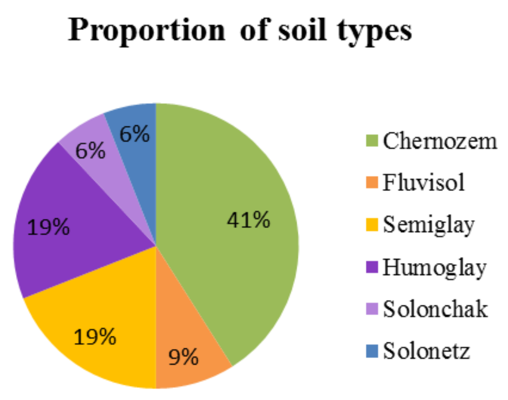
Cation exchange capacity varies in different soil types in wide intervals from 1-2 cmol/kg to more than 100 cmol/kg of soil. The most frequent level of CEC is 25-35 cmol/kg. In the arable horizon of Serbian loam and clay soils, which are low in humus, CEC varies between 20 to 40 cmol/kg of soil (Dugalić & Gajić 2012).

Table 4 shows average values of active and substitutional acidity, the average content of calcium carbonate, nitrogen, easily accessible phosphorus and potassium.

Mineral nutrition of plants is affected by numerous biotic and abiotic factors. Belonging to the group of abiotic factors, soil reaction or soil pH has a very important role. Since pH value affects the transport of matter and energy, as well as plant growth and development, it also affects yield (Kastori 2011).

Active acidity of the tested soil samples had an average value of 8.17, so these soils are neutral to slightly alkaline, and pH values in H_2O ranged from 7.86 to 8.92. The highest pH value was found in solonchak (8.92), and the lowest in humogley (7.86). The average value of substitutional acidity (pH in 1MKCl) was 7.46, the highest was found in solonchak 7.94 and the lowest in humogley 7.13.

Calcium carbonate plays an important role in soils, since Ca ion affects the physical and chemical properties of soil in the form of Ca-humates acidity neutralizer or buffer. The content of $CaCO_3$ ranged from 1.25 to 23.45% and the average value was 8.92%, so these are carbonate soils.



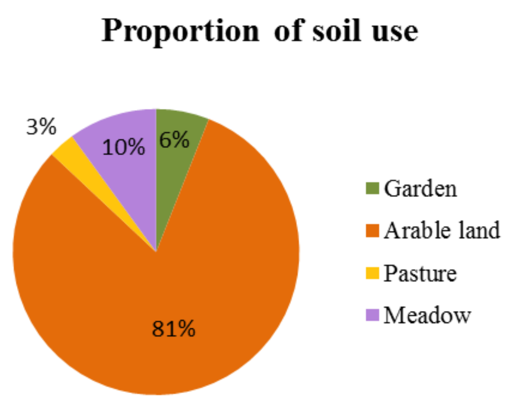


Figure 2. Proportion of soil types and soil use

Nitrogen, phosphorus and potassium are among the essential plant nutrients. Nitrogen mainly affects plant growth, and being a part of humic acids, nitrogen and humus content are in close correlation. Total nitrogen content was balanced and ranged in a small interval between 0.20-0.24%, whereas the average value was 0.21%, so these soils are well supplied with nitrogen.

Easily accessible phosphorus (P_2O_5) ranged in interval from 8.15 mg/100 g in solonchak to 89.30 mg/100 g in solonetz. Average value of phosphorus was 30.17 mg/100 g, so these soils are well supplied with phosphorus.

Easily accessible potassium (K_2O) ranged from 17.70 mg/100 g in solonchak, to 63.15 mg/100 g in solonetz. The average value was 34.21 mg/100 g which indicates high potassium supplies in these soils.

Table 1. Average values of clay, humus and CEC according to soil types

Soil type	Clay (%)	Humus (%)	CEC (cmol/kg)
Chernozem	19.44	3.05	22.72
Fluvisol	25.61	2.69	22.41
Semiglay	23.04	3.45	31.99
Humoglay	40.75	3.25	30.97
Solonchak	21.88	2.90	26.61
Solonetz	26.2	2.78	40.06
Average value	26.15	3.02	29.13

Table 2. Average values of chemical properties in the tested soil types

Soil type	pH in 1M KCl	pH in H_2O	$CaCO_3$ %	Total N %	P_2O_5 (mg/100g)	K_2O (mg/100g)
Chernozem	7.48	8.16	11.16	0.21	31.72	30.79
Fluvisol	7.37	7.90	2.79	0.20	21.33	29.67
Semiglay	7.54	8.18	12.93	0.24	16.82	27.77
Humoglay	7.13	7.86	1.95	0.23	13.75	36.23
Solonchak	7.94	8.92	23.45	0.21	8.15	17.70
Solonetz	7.30	8.03	1.25	0.21	89.30	63.15
Average value	7.46	8.17	8.92	0.21	30.17	34.21

Table 3.Average values of clay, humus and CEC according to the type of soil use

Type of soil use	Clay (%)	Humus (%)	CEC (cmol/kg)
Garden	18.7	2.31	22.51
Arable land	27.09	3.23	27.15
Pasture and meadow	21.64	2.65	30.58

Table 4.Correlation analysis

Variables	Correlations (Spreadsheet1) Marked correlations are significant at $p < .05000$ N=32 (Casewise deletion of missing data)									
	pH in 1M KCl	pH in H_2O	$CaCO_3$ %	Humus %	Total N %	P_2O_5	K_2O	Clay	Dust and clay	CEC
pH in 1M KCl	1.00	0.82*	0.74*	-0.23	-0.24	0.00	-0.41*	-0.58*	-0.48*	-0.33
pH in H_2O	0.82*	1.00	0.69*	-0.22	-0.21	-0.20	-0.39*	-0.36*	-0.28	-0.19
$CaCO_3$ %	0.74*	0.69*	1.00	0.08	0.08	-0.04	-0.26	-0.52*	-0.34	-0.13
Humus %	-0.23	-0.22	0.08	1.00	0.99*	0.18	0.22	0.16	0.44*	0.30
Total N %	-0.24	-0.21	0.08	0.99*	1.00	0.19	0.21	0.17	0.46*	0.33
P_2O_5	0.00	-0.20	-0.04	0.18	0.19	1.00	0.59*	-0.32	-0.19	0.20
K_2O	-0.41*	-0.39*	-0.26	0.22	0.21	0.59*	1.00	0.08	0.12	0.44*
Clay	-0.58*	-0.36*	-0.52*	0.16	0.17	-0.32	0.08	1.00	0.87*	0.42*
Dust and clay	-0.48*	-0.28	-0.34	0.44*	0.46*	-0.19	0.12	0.87*	1.00	0.38*
CEC	-0.33	-0.19	-0.13	0.30	0.33	0.20	0.44*	0.42*	0.38*	1.00

Correlation coefficient indicates a slight positive, statistically significant correlation of 0.30 between CEC and humus, the organic component of soil composition, and a statistically significant correlation of 0.42 between CEC and clay, the inorganic counterpart in soil (Table 4). Higher coefficient correlation was found between CEC and clay than CEC and humus, therefore clay, or the mechanical composition of soil, had greater effect on the cation exchange. Similar results were obtained by Gajić et al. (2007). CEC had the highest correlation coefficient with easily accessible potassium K_2O. Potassium is a cation whose increase affects the increase of CEC. Easily accessible potassium can be found in illite, a clay mineral, indicating that the higher content of clay in soil increases the content of K_2O and the CEC.

When it comes to soil use, the highest cation-exchange capacity was found in soils utilized as meadows and pastures (30.58 cmol/kg), a slightly lower CEC is found in arable land (27.15 cmol/kg), while the lowest sorption ability was observed in gardens (22.51 cmol/kg) (Table 3).

Conclusions

Based on the 32 analysed samples, collected in the region of Northern Bačka and Northern Banat in Vojvodina, Serbia, at the depth of 0-30 cm in different systematic soil units, the following conclusions are drawn:

According to the Pedological Map of Vojvodina (scale 1:50,000), the tested samples belong to the following soil types: chernozem, fluvisol, semiglay, humoglay, solonetz and solonchak. The most widespread soil type is chernozem which occupies 40.63% of the area, semiglay and humoglay each with 18.75%, fluvisolwith 9.36%, and the least frequent are solonchak and solonetz, each with 6.25%. According to the soil use, soils were classified as arable land, meadows, pastures and gardens. The area has the highest percent of arable land 81.25%, followed by meadows 9.36%, gardens 6.25%, and pastures 3.13%.

Average values of the tested parameters indicated that soils from the area of survey mostly have a loam or clay composition, neutral to slightly alkaline reaction, belong to the carbonate group, with an average supply of humus and total nitrogen, and a high supply of easily accessible phosphorus and potassium. Clay content ranged from 19.44 to 40.75%. The highest average content of clay was found in humoglay 40.75%, solonetz 26.2%, fluvisol 25.61%, semiglay 23.04%, solonchak 21.88%, and the lowest in chernozem 19.44%. The average clay fraction content in all the tested samples was 26.15%. Humus content ranged from 2.69 to 3.45%. The average content of humus in the tested samples was 3.02%. It can be concluded that all soil types are medium humic. The highest percentage of humus was found in semiglay (3.45%), humoglay (3.25%), chernozem (3.05%), solonchak (2.90%), solonetz (2.78%) and the lowest humus content in fluvisol (2.69%).

Cation exchange capacity in the tested soil samples ranged in the interval from 22.41 to 40.06 cmol/kg. Average CEC in the tested soils was 29.13 cmol/kg. The highest CEC was found in solonetz 40.06 cmol/kg, then semiglay 31.99 cmol/kg, humoglay 30.97 cmol/kg, solonchak 26.61 cmol/kg, and the lowest in chernozem 22.72 cmol/kg and fluvisol 22.41 cmol/kg. Significant correlation between CEC and clay fraction content, presented by the correlation coefficient (r), was found at the level of 0.42 in the tested soils. The correlation between CEC and humus content, presented by the correlation coefficient, was statistically significant in most of the tested samples at the level of 0.30.

Overall study results indicate that cation-exchange capacity depends on the clay fraction and humus content. Larger correlation coefficient was established between CEC and clay than CEC and humus, indicating that the clay content has a greater effect on cation-exchange capacity.

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Koloidna frakcija i kapacitet adsorpcije katjona u nekim zemljištima Vojvodine

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Sažetak: Koloidni kompleks zemljišta sadrži humus i glinu kao najvažnije acidoide putem kojih ima sposobnost vezivanja jona suprotnog naelektrisanja (katjoni) silama dovoljno snažnim za zaštitu od ispiranja, a istovremeno dovoljno slabim za prijem putem korena biljke. Ova sposobnost je utoliko jače izražena ukoliko je stepen disperznosti veći, tj. ukoliko je prečnik čestica manji. U cilju kontrole plodnosti zemljišta Vojvodine i sprečavanja njihove eventualne degradacije u širem smislu, u toku 2011. prikupljeno je 435 uzoraka zemljišta iz površinskog horizonta. U ovom radu je prikazan deo istraživanja u izabranim reprezentativnim uzorcima, koja se odnose na rezultate istraživanja mehaničkog sastava, osnovnih hemijskih svojstava kao i kapaciteta adsorpcije katjona u najzastupljenijim tipovima zemljišta sa područja severne Bačke i Banata (černozem, fluvisol, semiglej, humoglej, solončak, solonjec), s obzirom da plodnost zemljišta kao i njegova ekološka funkcija u zaštiti životne sredine u velikoj meri zavise od ispitivanih osobina. Srednji sadržaj gline iznosio je 25,26% i kretao se u granicama od 5,76 do 49,44%, srednji sadržaj humusa 3,10% i kretao se u granicama od 1,02 do 4,30%, dok je srednja vrednost CEC -a iznosila 27,30 cmol/kg i kretala se u granicama od 12,03 do 46,06 cmol/kg. Većim kapacitetom adsorpcije katjona odlikuju se zemljišta koja sadrže više gline i humusa. Prema utvrđenim srednjim vrednostima CEC-a u cmol/kg, redosled ispitivanih tipova zemljišta je sledeći: solonjec (40,06), semiglej (31,98), humoglej (30,98), solončak (26,62), černozem (22,72) i fluvisol (22,40). Rezultati istraživanja u celini su pokazali da kapacitet adsorpcije katjona zavisi od sadržaja frakcije gline i sadržaja humusa. Veći koeficijent korelacije između CEC-a i gline nego između CEC-a i humusa ukazuje da sadržaj gline ima veći uticaj na kapacitet adsorpcije katjona od sadržaja humusa.

Ključne reči: CEC, glina, humus, mehanički sastav, zemljište