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AGGREGATE COMPOSITION AND STABILITY OF SOIL STRUCTURE OF RANKERS FROM MT. MALJEN, SERBIA

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Abstract

Soil structure is the natural organization of soil particles into different forms under the influence of pedogenic processes. The aim of this work is to determine the soil structure of ranker soils on Mount Maljen by analyzing the aggregate composition and water stability of structural aggregates, and to evaluate the soil structure using various soil aggregation indices. Thirteen soil profiles were studied and classified as ranker according to the national soil classification system. The following soil structure indices were determined: dry and wet mean weight diameter (dMWD and wMWD), dry and wet geometric mean diameter (dGMD and wGMD), structural stability index (SI), and structural coefficient (Kstr). The favorable aggregate composition of the studied ranker is illustrated by the wMWD/dMWD ratio of 0.81±0.10, the values of SI > 9% and Kstr > 2 in all soil profiles. The results indicate that the studied soils have favorable structure, high water stability and low risk of structural degradation, but various linear erosion processes observed in the field indicate that the study area is degraded and that soil structure is not the only factor stabilizing soil erosion.

Key words: *Soil structure, Rankers, aggregate composition, structural indices, soil degradation*

INTRODUCTION

Rankers belong to the order of automorphic soils in the National Soil Classification System. They belong to the class of humus accumulating soils and are characterized by the following soil horizon sequence: A - R, A - C, or A - C - R. They often have a well-developed humus accumulation horizon and are formed on non-calcareous parent material. These soils are usually formed on steep slopes in hilly mountainous regions. The natural vegetation on these soils consists mainly of grasses, rarely of forests, and they occur in all climatic conditions, from semi-arid to extremely humid. There are more than 400,000 ha of rankers in Serbia (Dugalić and

Gajić, 2012). Životić et al. (2021) noted that many authors in Serbia often associate rankers with the Leptosols Reference Soil Group (RSG) of the World Reference Base for Soil Resources (WRB), which is not always the case. Soil structure refers to the size, shape, and arrangement of solids and voids, their ability to store and transmit fluids and organic and inorganic matter, and their ability to support vigorous root growth and development (Lal, 1991). Soil aggregates are the basic structural elements of soil and are collections of mineral and organic soil components with microscopic and macroscopic dimensions. The presence, quantity, size, and stability of soil aggregates determine a number of soil properties (e.g., infiltration, water retention, hydraulic conductivity, etc.) and the performance of most soil functions (Pavlu et al., 2022). Soil aggregation is a complex process that results from the interaction between many different variables, including various soil properties, environmental and plant factors, and human intervention. Aggregate distribution and stability are often used as measures of soil structure (Six et al., 2000). Soil structure stability is one of the most important indicators of soil degradation, and some authors point out that it is one of the physical soil properties that can serve as an indicator of soil quality (Arshad and Coen 1992). In addition, soil structure directly affects soil erodibility and influences soil erosion. Favorable soil structure and high aggregate stability are very important because they affect many other soil properties and processes as well as plant growth. There are several indicators of soil aggregate stability, such as mean dry and wet weight diameter (dMWD and wMWD), mean dry and wet geometric diameter (dGMD and wGMD), structural stability index (SI), and structural coefficient (Kstr). Soil structure is not an easy measure to quantify, and there are numerous methods for its determination, all of which differ significantly in terms of precision and success (Životić et al., 2019). The most commonly used method for soil structure analysis in Serbia is Savinov's method (Savinov, 1931). Soil structure of different soil types has been studied by many authors (Gajić et al., 2006, Gajić et al., 2010; Ćirić et al., 2012; Životić et al., 2019) using this method.

The aim of this study is: a) to perform an analysis of the soil structure of rankers from the Maljen Mountains after dry and wet sieving, and b) to evaluate the aggregate composition and the stability of structural aggregates by different soil aggregation indices.

MATERIALS AND METHODS

Study area

The study was carried out in the eastern part of Maljen mountain, which is located in western Serbia. Maljen belongs to Dinaric Alps Mountain range and the most encountered bedrock are serpentinites and limestones. The mountain spreads about 25 km wide in western-eastern direction, and its highest peak is called Kraljev sto (1104 m a. s. l.).

The area is characterized by a mountain climate. The nearest mountain meteorological station (located on Rudnik mountain) recorded a mean annual temperature of 10.4°C and a mean annual rainfall of 965.1 mm in the period from 1997 to 2016. However, in the researched area, a lower average temperature and a higher annual amount of precipitation can be expected, given that it is located at a higher altitude. Study area is located between the municipalities of Gornji Milanovac, Mionica and Požega. The altitude of the terrain on which the soil was examined ranges between 767 and 898 m a. s. l. The relief of the study area is mountainous with moderately high and high slope gradients, and often long slopes.

The vegetation of the study area is mostly grassy and very dense, except on very steep slopes where it is very rare or non-existent. Exposure of bedrocks and coarse surface fragments are present on the top of the surface across the slopes, and sometimes on the flat terrain. Woody vegetation is also present on the flatter parts where the soil is deeper. The dominant land use in the study area is pastures used for extensive grazing.

Soil sampling and analyses

Field research was conducted in May of 2022. A total of 13 soil profiles were opened until the appearance of solid rock. Soil was described on field. Disturbed soil samples were collected from all soil horizons in profiles and a total number of 13 samples were analysed in the laboratory.

The main physical and chemical characteristics were determined by following methods: particle-size distribution of the soils was determined by combining sieving and pipette methods (Rowell, 1997); soil texture was classified using the USDA triangle (Natural Resource Conservation Service, 2004); soil organic matter (SOM) (Dugalić and Gajić, 2005); soil organic carbon concentration (SOC) was calculated = % of humus / 1.724.

Dry ASD (aggregate-size distribution) and water stability were determined by Savvinov's method (Savinov, 1936). This method uses dry and wet sieving procedures. Soil aggregates were separated on sieves of 11.2, 5, 3, 2, 1, 0.5, and 0.25 mm into eight dry aggregate size classes. As for the wet sieving, the samples were originally sieved through a column of 3, 2, 1, 0.5 and 0.25 mm sieves, but considering the fact that the highest percentage of aggregates (on average 23.1±6.9%) retained on a 3 mm sieve, upon drying these aggregates were again sieved through 11.2, 8 and 5 mm sieves in order to obtain more reliable results of the water resistance of the aggregates.

Structure indices and coefficients

The following soil structure indices were calculated: dMWD, wMWD, dGMD, wGMD, Kstr and SI. The weights of different aggregate size classes (ASCs) obtained after dry and wet sieving were used to calculate dMWD, wMWD, dGMD and wGMD. Both dMWD and wMWD were calculated by the following equation (Van Bavel, 1949):

$$MWD = \frac{\sum_{i=1}^{n} xi*mi}{\sum_{i=1}^{n} mi} \quad (1)$$

Where: xi is the mean diameter of each ASC (mm), mi is the weight of each ASC (g) with respect to the total sample and n is the number of separated ASCs.

Geometric mean diameter was calculated as the index of Mazurak (1950) after dry and wet sieving using the following equation:

$$GMD = exp\left|\frac{\sum mi*log\,xi}{\sum mi}\right| \quad (2)$$

Where: mi is the weight of the aggregates of each size class (g) and xi is the mean diameter of its size class (mm).

Structural stability index (SI) proposed by Pieri (1992) was determined as a way of assessing the risk of structural degradation as per the following equation:

$$SI = \frac{1.274*SOC}{(silt+clay)} * 100 \quad (3)$$

Where: SOC (%) represents soil organic carbon content and (silt + clay) (%) represents the combined silt and clay content of the soil. SI is expressed in % and a value higher than 9% indicates that the soil has a stable structure, values between 7% and 9% indicate that there's a low risk of structural degradation, values between 5% and 7% indicate a high risk of degradation and finally a value lower than, or equal to 5% indicates a structurally degraded soil (Pieri, 1992).

Another way of assessing the quality of soil structure is through the coefficient of structure given by Shein et al. (2001) which was calculated using the formula given below:

$$Kstr = \frac{A}{B} \qquad (4)$$

Where: A is the content of aggregates of size 0.25-10 mm (%) and B represents the content of aggregates <0.25 mm and >10 mm (%). Kstr is used for evaluating aggregate composition where soils have a good structure if Kstr values are > 1.5; satisfactory structure if Kstr ranges from 0.67 to 1.5; and unsatisfactory for Kstr < 0.67.

RESULTS AND DISCUSSIONS

Soil properties, aggregate-size distribution and aggregate stability.The studied soils are located at elevations between 767and 898 m a.s.l. The soil profiles were opened at sites with varying degrees of slope (from sites with gently sloping terrain to slopes with 20-30% inclination). The micro relief around the profiles is mainly characterized by the occurrence of skeletons and rocks on the soil surface, which led to the fact that the soil profiles were opened in non-representative places. The basic characteristics of the studied soils are listed in Table 1. It can be noted that the silt fraction dominates the grain size distribution in all samples with an average value of 63.7±7.0%. The lowest silt fraction of 45.0% was found in profile No. 8, while in the other twelve profiles the silt fraction exceeds 55%. All the studied soils have a very high percentage of particles smaller than 0.05 mm (71.5-92.8%). Twelve of the thirteen samples belong to the same texture class - silty loam, while the sample from profile 8 belongs to the loamy texture class. All the samples studied have a very high SOM content. The average SOM content is 14.19±2.29%. The soil organic carbon content is also high, varying from 5.59% in profile 6 to 10.75% in profile 12. In addition to the characteristics listed in Table 1, the studied soils have a moderately acidic to neutral response, high cation exchange capacity, and high base saturation. Twelve of the thirteen soil profiles belong to the leptosols RSG of the WRB classification. Profile 10 belongs to the leptic pheozems because its thickness is more than 25 cm.

Table 1 Particle size distribution and soil organic matter of investigated Rankers

Soil sample number	Depth (cm)	Horizon	Particle size distribution (%, mm)			Soil texture	SOM (%)	SOC (%)
			Total sand 2–0.05	silt, 0.05–0.002	clay, <0.002			
1	0-15	A	16.9	65.2	17.9	Silty loam	13.11	7.60
2	0-20	A	17.5	64.7	17.8	Silty loam	16.19	9.39
3	0-20	A	15.3	66.5	18.2	Silty loam	13.67	7.93
4	0-21	A	19.8	60.4	19.8	Silty loam	11.32	6.57
5	0-11	A	19.3	63.8	16.9	Silty loam	15.09	8.75
6	0-22	A	22.1	63.9	14.0	Silty loam	9.64	5.59
7	0-17	A	14.3	67.1	18.6	Silty loam	14.31	8.30
8	0-18	A	28.5	45.0	26.5	Loam	13.71	7.95

9	0-24	A	28.0	56.8	15.2	Silty loam	12.73	7.38
10	0-29	A	9.5	70.1	20.4	Silty loam	15.79	9.16
11	0-14	A	7.2	74.6	18.2	Silty loam	13.29	7.71
12	0-20	A	15.1	63.9	21.0	Silty loam	18.53	10.75
13	0-22	A	8.3	65.5	26.2	Silty loam	17.04	9.89

Table 2 shows the results obtained by dry sieving. The content of microaggregates is higher than 10% only in profiles 10 and 13. In the studied soils, structural aggregates with size from 3 to 5 mm are the most represented with average content of 19.2±4.4%. Aggregates with a size of 0.5-1 mm are the least represented with an average of 5.1±0.8%. The results of dry sieving indicate that the studied soils have a favourable aggregate composition, which is best illustrated by the fact that the content of agronomically valuable fractions (0.25 to 10 mm) in all soil samples is over 70%. Among these aggregates, fine and medium aggregates predominate. Structural aggregates with large diameters (larger than 10 mm) are not conducive to water conservation and plant growth, while aggregates with too small diameters (called microaggregates, smaller than 0.25 mm) can clog pores and affect soil permeability (Wu and Hong, 1999). Aggregate stability is defined as resistance to external destructive agents such as rain, runoff (drainage), and wind (Pavlu et al., 2022). The results of wet sieving and the distribution of particle size classes obtained afterwards are presented in Table 3. It should be noted again that the aggregates were originally sieved through a series of 3-, 2-, 1-, 0.5-, and 0.25-mm sieves during wet sieving. However, because the highest percentage of aggregates remained on a 3-mm sieve, they were re-sieved through 11.2-, 8-, and 5-mm sieves after drying to obtain more accurate results for the indices. Thus, we obtained nine aggregate size classes, one more than with dry sieving. The content of water-stable macroaggregates (5-8 mm) ranged from 2.7% to 11.5% (6.2±3.1% on average). Megaggregates (< 11.2 mm) are present in every soil sample and the average content is 7.9±5.0%. The presence of these aggregates in wet sieving shows that the soils have high water stability. The percentage of water stable aggregates larger than 1 mm of 67.9±5.3% is also an indicator of high aggregate stability. Pavlu et al. (2022) state that soil structure stability is one of the most important indicators of soil degradation. The presence of water-stable aggregates plays a very important role in maintaining the stability of soil structure.

Table 2 Dry aggregate size distribution analysis

Soil sample	Depth (cm)	Dry aggregate size distribution (mm, in %)							
		>11.2	11.2–5	5–3	3–2	2–1	1–0.5	0.5–0.25	<0.25
1	0–15	12.2	20.0	22.5	12.7	10.5	5.4	7.5	9.2
2	0–20	18.8	19.7	19.6	12.5	9.8	4.3	6.7	8.6
3	0–20	5.2	8.6	20.1	23.6	19.2	5.3	9.8	8.2
4	0–21	6.2	10.1	22.5	25.0	18.3	4.2	7.6	6.1
5	0–11	14.0	15.0	21.5	15.0	11.7	4.8	8.8	9.1
6	0–22	17.6	16.6	20.0	13.8	13.0	4.7	8.0	6.3
7	0–17	16.4	9.7	26.7	9.2	15.2	5.0	9.0	8.9

8	0–18	17.6	16.4	21.8	17.9	12.8	4.3	5.5	3.6
9	0–24	22.1	14.0	16.3	11.9	13.0	4.6	9.3	8.8
10	0–29	4.2	6.5	13.9	18.5	21.5	7.4	14.5	13.5
11	0–14	8.5	20.5	20.0	13.8	13.5	5.9	10.4	7.5
12	0–20	11.5	6.3	10.3	18.6	21.3	4.9	18.7	8.5
13	0–22	20.8	12.7	14.4	12.6	14.2	4.9	9.7	10.6

Table 3 Soil aggregate stability to water analysis

Soil sample	Depth (cm)	Soil aggregate stability to water (mm, in %)								
		>11.2	11.2–8	8–5	5–3	3–2	2–1	1–0.5	0.5–0.25	<0.25
1	0-15	9.5	3.9	6.3	22.6	9.6	15.2	10.6	2.6	19.8
2	0-20	12.1	8.8	11.1	25.6	3.7	9.4	7.2	2.1	20.1
3	0-20	1.8	9.1	11.3	11.9	10.9	24.4	11.4	2.6	16.5
4	0-21	1.8	5.4	3.2	41.1	6.6	13.2	8.1	1.7	19.0
5	0-11	10.0	0.3	4.1	41.5	4.5	11.1	7.4	4.1	17.0
6	0-22	13.7	9.1	5.3	36.1	3.9	8.7	7.5	2.1	13.6
7	0-17	5.2	3.3	4.8	40.2	6.1	9.2	5.4	1.2	24.6
8	0-18	8.4	5.8	6.6	41.0	4.7	11.1	6.3	1.4	14.7
9	0-24	18.4	8.1	4.7	22.4	5.3	11.3	9.4	2.0	18.5
10	0-29	3.1	2.4	2.7	22.9	9.2	20.2	10.6	2.5	26.3
11	0-14	4.8	7.1	5.5	8.4	11.3	23.0	14.9	1.8	23.1
12	0-20	4.0	4.4	3.2	10.5	4.3	23.9	16.1	3.0	30.5
13	0-22	9.1	5.8	11.5	20.9	5.6	15.4	7.5	1.5	22.5

Soil structure indices

The values of the structural coefficient, mass weight, and mean geometric diameter, as well as the index of structural stability, are shown in Table 4. These indices, along with aggregate size distribution (ASD) and stability of soil aggregates to water (WAS), are critical to understanding the structural condition of soils. Mean weight diameters were calculated using dry (dMWD) and wet (wMWD) sieving results; the same is true for geometric mean diameters (GMD). The dry MWD of the studied soils has values ranging from 2.56 mm to 5.40 mm (average 4.36±0.92 mm). Wet MWD values range from 2.21 mm to 4.77 mm (3.52±0.84). In general, the higher the wMWD value, the more stable the soils and vice versa. High values mean greater aggregate stability, while high values of aggregates < 0.25 mm mean low aggregate stability (Životić et al., 2019). The ratio of wMWD and dMWD has an average value of 0.81±0.10, indicating little change in aggregate size after wet sieving. This ratio is a good indicator of aggregate stability. The least significant change between wMWD and dMWD was observed in profile 3, while the largest difference was observed in profile 11. The stability of the soil aggregates can also be expressed by the dry and wet geometric mean diameter. The values of dry GMD range from 1.13 mm in soil profile 10 to 1.67 mm in profile 8, while wGMD has values between 0.95 mm (profile 12) and 1.49 mm (profile 6). The relationship between wGMD and dGMD indicates that the mean geometric diameters changed very little after wet sieving, with the average value of wGMD being 0.87±0.06 of dGMD. All the studied soils have a structural stability index (SI) higher than 9.14%, with an average value of 12.65±1.91%. This means that all soil samples have a stable to very stable structure, with minimal to no risk of structural deterioration. High SI values are correlated with very high SOC values of the studied soils. The structural coefficient also shows very high values. In all 13 profiles, the value of this parameter is greater than 2. The highest value of Kstr was measured in profile 4 (Kstr = 7.17), and the lowest in profile 13 (Kstr = 2.18). In accordance with the classification given by Shein et al. (2001), we can conclude that the studied soils have a good structure.

Table 4 Various structural indices of Rankers from Maljen mountain

Soil sample	Depth (cm)	dMWD (mm)	wMWD (mm)	wMWD/dMWD	dGMD (mm)	wGMD (mm)	wGMD/dGMD	SI (%)	Kstr
1	0-15	4.69	3.51	0.75	1.5	1.23	0.82	11.65	3.68
2	0-20	5.4	4.47	0.83	1.6	1.37	0.85	14.5	2.65
3	0-20	3.16	3.04	0.96	1.31	1.22	0.93	11.93	6.49
4	0-21	3.51	3.04	0.86	1.41	1.25	0.89	10.44	7.17
5	0-11	4.57	3.65	0.80	1.47	1.31	0.89	13.81	3.34
6	0-22	5.09	4.74	0.93	1.58	1.49	0.95	9.14	3.18
7	0-17	4.57	3.28	0.72	1.46	1.22	0.83	12.34	2.96
8	0-18	5.23	4.06	0.78	1.67	1.42	0.85	14.17	3.71
9	0-24	5.29	4.77	0.90	1.53	1.38	0.90	13.06	2.24
10	0-29	2.56	2.39	0.93	1.13	1.05	0.93	12.89	4.67
11	0-14	4.23	2.76	0.65	1.44	1.09	0.76	10.58	5.28
12	0-20	3.35	2.21	0.66	1.23	0.95	0.78	16.13	3.99
13	0-22	4.98	3.79	0.76	1.46	1.25	0.86	13.74	2.18

CONCLUSION

After performing quantitative analyses, we can conclude that all studied rankers have favourable aggregate composition and water-stable soil structure. The values of various structural indices and coefficients indicate that the studied soils have a low risk of degradation. The favourable aggregate composition is best illustrated by the content of the most agronomically valuable aggregates (0.25-10 mm), which is 78.2±6.1% in our study. The size ratio of structural aggregates after wet sieving ranges from 0.65to 0.96, or 0.81±0.10 on average, which is also an indicator of water-stable structural aggregates. The structural stability index (SI) has a value above 9.14% for all the soils studied, indicating that there is very little to no risk of structural deterioration, since all the samples have a very stable soil structure. The favourable structure of these soils is also reflected in the values of the structural coefficient (Kstr), which is on average above 2 in all profiles (3.96±1.55). The studied rankers are characterised by a good structure, with a high content of agronomically suitable aggregates, which are very resistant to water. The studied rankers have a favourable aggregate composition and water-stable aggregates. Therefore, various linear erosion processes, such as gullies along the entire length of the slope and soil creep on the slope shoulders, were observed during the field research. These phenomena are common in soils developed on serpentinite rocks. The study area is degraded despite the favourable soil structure, which also indicates that soil structure is not the only factor stabilising soil erosion.

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