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EFFECT OF ORGANIC PRODUCTION ON SOIL STRUCTURE

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Abstract

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Organic agriculture is a production system, which avoids the use of synthetic fertilizers, pesticides, growth regulators, and additives and relies on natural principles that contribute to the growth, development, and health of plants. Its aim is safe production of quality produce and maintenance and improvement of the sanitary condition and quality of soil and the environment. Soil structure is most important among the physical soil properties due to its large impact on the water, air and thermal status, chemical and biological properties of the soil, soil tilth and the growth of plant roots. It is an indicator of soil fertility and productivity. The objective of this study was to determine the contribution of organic agriculture to soil structure improvement by comparing soil structure indicators from organic farms and conventionally tilled production plots. The study was conducted in Vojvodina Province, Serbia. Organic farms in 8 locations (Kelebija, Orom, Pančevo, Crepaja, Bajmok, Ljutovo, Totovo Selo, and Kisač) were compared against Rimski Šančevi experiment station in which the conventional soil tillage system has been employed for several decades. Soil samples were collected from soil depth of 0-30 cm. The conventionally tilled soils had a better structure than the soils in organic agriculture. Their structure coefficients were Ks = 5.50 and Ks = 2.60, respectively. Soil aggregate stability was better in organic farms than with conventional tillage, MWD = 0.95 and MWD = 0.73, respectively. OM content was higher in all classes of stable aggregates in the organic farms compared with the conventional tillage system. The organic agriculture deteriorated the distribution of soil structural aggregates, improved soil aggregate stability, and increased the soil OM content.

Key words: organic agriculture, soil structure, aggregate size distribution, aggregate stability, soil organic carbon

Abbreviations: OM – organic matter, MWD – mean weight diameter

Introduction

Presently, the conventional agricultural production causes imbalance among various pedogenetic factors. Human activity may increase or reduce the natural resistance of the soil to various forms of degradation. Soil degradation can be defined as a set of processes caused by human activity. These processes reduce the present and future soil potential which is a requirement for the survival of the plant and animal life on our planet. Thematic Strategy for Soil Protection (CEC, 2006/232) defined the concept of soil degradation as loss of arable land or loss of soil capacity to perform specific functions.

The term ‘organic agriculture’ refers to a production system which avoids or minimizes the use of synthetic fertilizers, pesticides, and growth regulators in crop growing and additives in animal feed. Organic agriculture maximizes the use of crop rotation, crop residues, animal manure, legumes, green manure, off-farm organic waste and biological pest control in order to maintain soil productivity, supply plants with necessary nutrients, and control insects, weeds and other pests (USDA, 1980; cited in Lampkin, 1990). The role of organic agriculture is to maintain or improve soil quality and sanitary condition (Ekwue, 1992), i.e., to maintain the quality of agricultural produce without jeopardizing the environment. In that context it is important for all cultural practices to be aimed at the maintenance and improvement of soil fertility, i.e., the prevention of soil degradation. The last but not the least, organic agriculture contributes to biodiversity improvement (Paoletti et al., 1992).

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Crop rotation as a key segment of organic agriculture is a cultural practice whose application varies in dependence of type of production and soil fertility (Bengtsson, 2005). In its turn, crop rotation determines types of soil tillage and fertilization. Unlike the conventional production in which crop rotation is not always rigorously followed, the organic agriculture applies strict field crop, field crop-vegetable crop, field crop-forage crop, vegetable crop, and other rotations, with legumes and grass-clover mixtures becoming a requisite part of the rotations. Soil tillage is typically reduced, but care is taken to use a soil tillage method that will not deteriorate but rather improve soil properties, especially its fertility. Therefore, subsoilers that only loosen the soil are preferred in organic agriculture over moldboard plows that turn over the topsoil. Finally, organic agriculture makes use of organic fertilizers and natural mineral fertilizers while plant diseases, pests and weeds are controlled by biological protectants (Babović et al., 2005).

Soil structure is a key determinant of soil fertility and agricultural productivity, and is thus of great ecological significance. Structural status (shape, size) and stability of structural aggregates are key factors of soil fertility, which significantly affect the sustainability of crop production (Amezketa 1999, Bronicki and Lal 2005). Effect of soil structure on crusting, root penetration, soil water and air flow, CO_2 emission, erosion, retention of nutrients and biological activity is well known (Savin et al., 2011). Soil structure formation is a complex process which depends on interactions among soil type, cementing agents, land management and environmental conditions (Tisdall and Oades, 1982; Oades and Waters, 1991; Bronicki and Lal, 2005). Soil structure is typically expressed as aggregate stability and it is measured by indices such as MWD and GMD. Soils with stable aggregates have a high resistance to water and wind erosion and nutrients leaching.

Soil structure deterioration has local, regional, and global effects on the economy, environmental quality and sustainability of natural resources and it causes soil compaction and decrease in the concentration of OM (Lal, 1991). Intensification of soil tillage causes loss of macroaggregates in favor of microaggregates. As the former have a higher concentrations of OM that the latter, the result is the overall loss of OM (Six et al., 2000). Organic matter is more stable in microaggregates than in macroaggregates (Puget et al., 2000). Aggregate stability and preservation of OM concentration depend largely on soil texture. The impact of OM on structural stability is even more pronounced in soils containing low levels of clay fraction (Wuddivira and Camps-Roach, 2007). Such soils also have a low OM concentration in the microaggregate fraction because most of the sand particles are part of this fraction.

The objective of this paper was, based on the analysis of distribution of soil structural units, their stability, and their OM content, to determine whether the cultivation practices applied in organic agriculture improve soil structure. Results of earlier studies conducted on chernozem soil under conventional agricultural production at Rimski Šančevi experiment station (Ćirić, 2008) were used for comparison.

Materials and Methods

Site description

This study was conducted in Vojvodina Province, northern Serbia, which covers an area of 2,150,600 hectares. Vojvodina Province occupies the southern part of the Pannonian (Carpathian) basin (46º 11’-46º 37’ N, 18º 51’-21º 33’ E) and it is the warmest and driest part of the basin (Marković et al., 2008). Specific features of the Vojvodina or Pannonian climate are: the distribution of rainfall characterized by large variations in monthly rainfall, the impact of the Azores anticyclone in summer bringing a fairly stable weather with occasional local showers, and prevalence of northwestern and southeastern winds. Vojvodina has the mean annual rainfall of 602 mm and the mean annual temperature of 11.0°C.

Vojvodina has 1 648 000 hectares of prime quality arable land. The portion of land suitable for tillage (chernozems, meadow soils, hydromorphic black soils, fluvisols) amounts to 91%. The various subtypes, varieties, and forms of chernozem take 42.37%, meadow soils 16.46%, hydromorphic black soils 15.50%, and fluvisols 8.64% (Republic Agency for Spatial Planning, 2009)

Sampling design

Samples for soil property testing were taken in 8 locations (Kelebija, Orom, Pančevo, Crepaja, Bajmok, Ljutovo, Totovo Selo, Kisač), from farms engaged in organic agriculture (3-10 years). Seven of these locations are situated on the chernozem soil, one on the arenosol soil. The soils from these organic farms were compared against the conventionally tilled soil sampled at Rimski Šančevi experiment station near Novi Sad. Soil samples were collected from the depth of 0-30 cm, in undistrurbed and disturbed condition. The former samples were taken with Kopecky cylinders.

Soil analysis

The collected samples were analyzed at the Laboratory for Soil Science and Irrigation, Faculty of Agriculture, University of Novi Sad, using the following methods:

Soil texture was determined by the pipette method. Sample preparation for analysis was done with Na-pyrophosphate, after Thun. Soil texture class was determined according to Tommerup's classification;

Particle density was determined by the xylol pycnometer method;

Soil bulk density was determined by means of the Kopecky cylinder ($100cm^3$);

Filtration coefficient (K-Darcy, cm/s) was determined in undisturbed soil samples (in Kopecky cylinders), using an apparatus that provided constant water pressure;

Total soil porosity was determined by calculation;

Dry sieving, i.e., distribution of aggregates, was done by the method of Savinov (1936). Wet sieving, i.e., aggregate stability against dissolving in water, was done by the modified method of Elliot (1986);

OM content was determined by the wet combustion method (Tyurin, 1931) modified by Simakov (1957).

Based on the obtained weight of stable aggregates, MWD of structural aggregates was calculated by the following equation (Hillel, 2004):

$$\mathbf{MWD} = \sum_{i=1}^{n} x_i w_i ,$$

where w_i was the weight percentage of stable aggregates in relation to the total sample weight, and x_i was the average diameter of stable aggregates (µm).

Soil structure was evaluated by the structural coefficient of Shein et al. (2001), according to which soils with a coefficient value above 1.5 have a good structure. The structure coefficient is calculated as:

$K_s = a / b$

where a is the content of structural aggregates in the range from 0.25 mm to 10 mm, and b the content of structural aggregates <0.25 mm and >10 mm.

Results and Discussion

Basic soil properties

The chernozems in the studied region belong to the subtype chernozem on loess and loess-like sediments (Škorić et al., 1985), i.e., they had been formed on the loess terrace (redeposited loess) as the native substrate, whose loamy mechanical composition, favorable mineralogical composition, and high $CaCO_3$ content make it an ideal substrate for soil formation (Gaudenyi et al., 2008).

Most of the analyzed chernozems were slightly alkaline in the upper part of the profile to moderately alkaline in the lower part. The Amo,p horizon was calcareous while the others horizons were highly calcareous, with the highest $CaCO_3$ content in the C horizon. The humus content was medium. The total nitrogen was medium, while available phosphorus and potassium contents were high (Nešić et al., 2011). The chernozems had mainly a loamy mechanical composition (Table 1) and favorable water-air properties (Table 2).

Soils formed on aeolian sand such as arenosols have light texture, low OM content, and a low potential for OM content increase due to their sandy texture, good aeration, and the humus accumulation layer, which is not allowed to pass the initial stage of formation due to continual wind erosion (Belić et al, 2013). About 85% of agricultural land in Vojvodina is affected by wind erosion with an annual loss of more than 0.9 tons of material per hectare (Vidojević and Manojlović, 2007).

Aggregate size distribution

The relationship between aggregation and soil type is a complex one. Soil structure is the result of joint effects of several factors. Distribution of structural aggregates depends largely on soil type and the method of its use (Ćirić

Table 1
Soil texture (0-30 cm) at the analyzed organic farms

Location	Soil type	Particles, %			Texture according to Tommerup
		Total sand	Silt	Clay	
		2-0.02	0.02-0.00	<0.002	
		mm	mm	mm	
Kelebija	Arenosol	71.96	16.96	11.08	Coarse sand loam
Orom	Chernozem	54.32	31.76	13.92	Loam
Pančevo	Chernozem	40.52	36.32	23.16	Clay loam
Crepaja	Chernozem	39.72	36.28	24.00	Silty clay loam
Bajmok	Chernozem	45.44	33.96	20.60	Clay loam
Ljutovo	Chernozem	70.44	16.04	13.52	Coarse sand loam
T. Selo	Chernozem	51.16	29.40	19.44	Clay loam
Kisač	Chernozem	37.24	37.08	25.68	Loamy clay

et al., 2012). The distribution of aggregates obtained by dry sieving was relatively uniform in the samples from the organic farms (Table 3). In the locations of Pančevo, Crepaja and Kisač, the portion of large aggregates (> 5 mm) mm was more than 40%. This was due to the high clay contents in the soil in these locations, higher that in the others. Clay minerals have a high impact on the distribution of aggregates, acting as a cementing substance, so that the clay content is highly correlated with the distribution of different aggregate classes (Ćirić et al., 2012). Similar views were presented by Skidmore and Layton (1992). The formation of large and stable aggregates (pseudo-aggregates or clods) is characteristic for fine textured soils exposed to intensive cultivation, and their effectiveness in assuaging wind erosion is high (Colazo and Buschiazzo, 2010). Large aggregates do not improve soil structure, because they are associated with high bulk density values and low moisture retention capacity (Boix-Fayos et al., 2001). In the locations Ljutovo, Kelebija, and Orom, the content of aggregates <0.5 mm was > 20%. This makes them sensitive to wind erosion, which is a consequence of the fact that we recorded largest amounts of sand in the soil fraction >50% in these locations. In all locations except Kisač, the aggregates desirable from the agronomic point were present in the amounts >70%, which is typical for chernozem soils.

When the average values of the distribution of structural aggregates for the organic farms were compared against the values for the chernozem soil at Rimski Šančevi experiment station, which was conventionally tilled for several decades, we observed differences which indicated that long-term tillage affected the soil structural aggregates (Figure 1). The conventionally tilled soil had a substantially smaller portion of large aggregates (>10 mm) as well as a substantially smaller portion of the smallest aggregates than the soils at the organic farms. Furthermore, the former tillage method produced a much larger portion of desirable aggregates (2-0.5 mm) than the latter method, which indicated that the former method ensured a better structural condition of the soil. This was confirmed by Ks, which was more than double for the conventionally tilled soil (5:50) compared with the soils at the organic farms (2.60).

Table 2
Basic physical soil properties (0-30 cm) at the analyzed organic farms

Location	Soil type	Density of soil particles	Bulk density	Porosity	K-Darcy, cm s^{-1}
		g cm^{-3}	g cm^{-3}	%	
Kelebija	Arenosol	2.53	1.50	40.71	$2.89\ 10^{-3}$
Orom	Chernozem	2.38	1.08	54.62	$2.39\ 10^{-2}$
Pančevo	Chernozem	2.06	1.32	35.92	$1.70\ 10^{-3}$
Crepaja	Chernozem	2.20	1.37	37.77	$3.32\ 10^{-3}$
Bajmok	Chernozem	2.02	1.18	41.58	$1.54\ 10^{-2}$
Ljutovo	Chernozem	2.98	1.37	54.03	$1.78\ 10^{-2}$
Totovo Selo	Chernozem	2.10	1.13	46.19	$5.00\ 10^{-3}$
Kisač	Chernozem	2.44	1.28	47.54	$1.87\ 10^{-2}$

Table 3
Soil dry aggregate size distribution (0-30 cm) at the analyzed organic farms

Effect	Aggregate size, mm							
	>10	10–5	5–3	3–2	2–1	1-0.5	0.5-0.25	<0.25
Kelebija	18.5	19.6	13.1	8.0	11.4	8.1	10.5	10.9
Orom	11.4	14.4	11.2	8.3	14.1	5.2	20.7	14.7
Pančevo	19.0	21.2	12.8	8.8	14.4	4.7	14.2	4.9
Crepaja	24.5	22.9	13.7	8.5	13.3	8.5	5.7	2.9
Bajmok	15.4	15.6	15.9	10.8	16.6	8.0	9.6	8.1
Ljutovo	11.0	13.1	12.4	8.1	12.4	4.9	22.4	15.7
Totovo Selo	18.9	19.2	10.8	7.5	12.8	11.6	9.7	9.6
Kisač	44.1	22.1	10.3	6.2	8.3	0.0	7.0	2.0

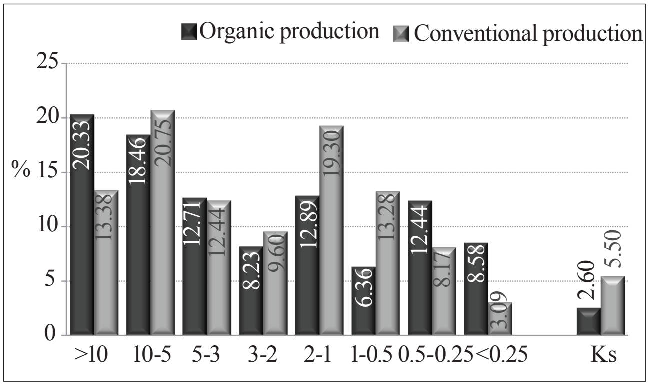

Fig. 1. Comparision of soil dry aggregate size distribution and Ks (0-30 cm) in organic farms and conventionally tilled soil

Aggregate stability

The stability of structural aggregates is determined on the basis of aggregate resilience to dissolution in water. The obtained results showed that the studied soil types differed in the portion of stable structural aggregates (Table 4). In the locations Orom and Pančevo, we found the largest portion of the aggregates >2 mm. Highest OM contents in the soil were also determined in these locations. The level of OM in the soil is closely associated with soil structure. OM contect in the soil is one of major factors of aggregation (Bronicki and Lal, 2005). Aggregates provide physical protection to OM, while OM acts as the cementing agent in the process of aggregation. Our results also showed that, in all locations, the portions of small macroaggregates and microaggregates (2-0.053 mm) were considerably larger than the portions of macroaggregates >2 mm and the fraction of silt and clay (<0.053 mm).

A comparison of the average values of aggregate stability at the organic farms and at the experiment station under conventional tillage showed that the soils at the organic farms had higher contents of large macroaggregates and microaggregates, while small macroaggregates and the fraction of silt and clay predominated in the conventionally tilled soil. Agricultural mechanization is typically used in conventional production systems, and its unfavorable impact on soil is larger than in organic agriculture. In consequence, in the former systems, the value of bulk density is increased, water and air balance deteriorates, and the stability of large macro-aggregates is reduced. Large macro-aggregates crumble, increasing the portion of silt and clay.

The value of MWD as an indicator of the degree of stability of structural aggregates is most influenced by the content of large macroaggregates, which in its turn is determined by the method of land use and the method of soil tillage. The obtained values clearly indicated that the stability of soil aggregates was higher in the soils at the organic farms (Figure 2). The average MWD value was 0.95at the organic farms, and it was lower (0.73) in the conventionally tilled soil. Šeremešić (2011) reported that the MWD value for the chernozem soil at Rimski Šančevi varied in the range from 0.54 to 1.18 mm, in dependence of tillage method, while Ćirić et al. (2013) reported the value of 0.67 mm for the same location.

Aggregate-associated carbon

The stability of soil OM is determined by the chemical nature of organic matter, adsorption and absorption on and in the mineral part of the soil, and OM participation in the formation of structural microaggregates (Travnikova et al., 2002). OM content in different classes of stable aggregates at the studied organic farms is shown in Table 4. OM contents were higher in the large and small macroaggregates than in the microagregates and the fraction of silt and clay in all locations except Kelebija and Ljutovo which had highest OM contents in the fraction of silt and clay. The different arrange-

Table 4
Soil aggregate stability and aggregate-associated OM (0-30 cm) at the analyzed organic farms

Effect	Aggregate size, mm							
	>2	2-0.25	0.25-0.053	<0.053	>2	2-0.25	0.25-0.053	<0.053
	Weight percent of aggregates				Aggregate-associated OM (%)			
Kelebija	4.84	25.21	53.60	16.35	2.62	2.15	1.03	2.73
Orom	21.12	39.36	28.28	11.24	5.49	5.77	4.41	3.5
Pančevo	10.31	32.40	33.67	23.62	4.17	3.70	3.83	2.82
Crepaja	8.44	38.13	26.73	26.70	4.45	3.82	3.24	2.66
Bajmok	4.60	45.07	34.17	16.16	4.28	3.99	2.79	3.2
Ljutovo	4.63	50.53	39.98	4.86	3.56	2.97	1.98	5.14
Totovo Selo	8.62	33.33	35.75	22.30	4.79	4.86	3.34	3.89
Kisač	14.80	27.74	37.06	20.40	5.14	4.96	3.92	3.64

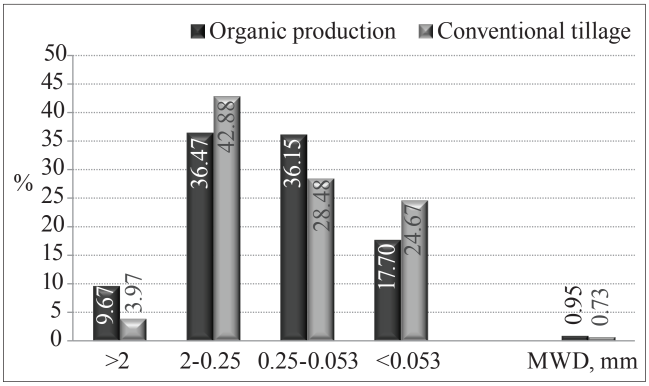

Fig. 2. Comparision of soil aggregate stability and MWD (0-30 cm) at organic farms and in conventionally tilled soil

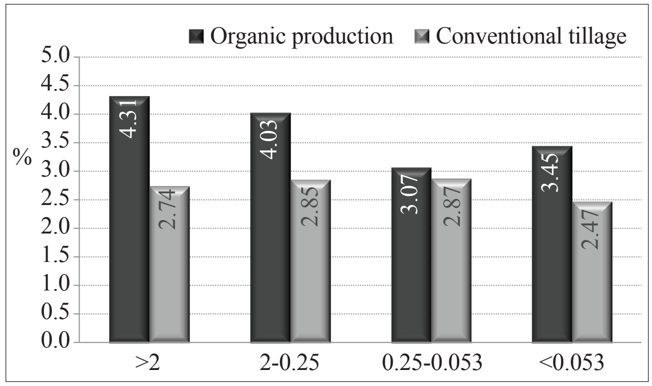

Fig. 3. Comparision of aggregate-associated OM (0-30 cm) at organic farms and in conventionally tilled soil

ments in the OM content per aggregate classes in Kelebija and Ljutovo were due to the high content of sand (>70%) in the soils of these two locations. Low levels of adsorption and aggregation in sandy soils cause a higher percentage of OM to be retained in the silt and clay fraction.

A comparison of the average OM contents in the different classes of stable aggregates found at the organic farms and at the experiment station showed that the OM content was significantly lower in the latter location (Figure 3). The largest reduction in the OM content was found in the class of large macroaggregates, the smallest in the class of microaggregates. The increased OM contents at the organic farms were a consequence of the applied soil management system, which included large OM inputs into the soil as well as the incorporation of crop residues. Organic production systems are based on OM management aimed at improving the chemical, biological and physical properties of the soil, all in order to optimize the crop production (Watson et al., 2002). Prolonged use of agricultural machines causes OM exposure and oxidation, i.e., degradation processes that affect crop yield and soil biological activity. In that way, soil OM content and aggregate stability decline in consequence to tillage (Tisdall and Oades, 1982).

Conclusions

The results of dry sieving showed that the soils under organic agriculture had a relatively uniform distribution of structural aggregates, which could be largely associated with soil texture. Also, this production method contributed to the forming of large clods (aggregates > 10 mm), which resulted in a poor structural status expressed via the structure coefficient (Ks = 2.60), poorer than the one recorded for the conventional tillage system (Ks = 5.50).

At the organic farms, the stability of structural aggregates depended largely on the OM content. The stability of structural aggregates was higher at the organic farms than in the case of conventional tillage (MWD = 0.95 and MWD = 0.73, respectively).

OM contents in the different classes of stable aggregates, which depended on soil texture, were significantly higher at the organic farms than at the experiment field under conventional tillage. The largest difference in OM content was found for the fraction of large macroaggregates, the smallest for the fraction of microaggregates. Organic agriculture deteriorated the distribution of structural aggregates, improved aggregate stability, and led to an increase in soil OM content.

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