Original scientific paper

A comparative study of the winter wheat and maize effects on the changes in structural properties of Chernozem

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Abstract

In order to study aggregate fraction distribution and structure stability of the Haplic Chernozem soils from different cropping systems of winter wheat and maize were analyzed. Cropping systems were situated in a long-term experiment carried out at the Rimski Sancevi experimental station, Novi Sad. Soils from different cropping systems were analyzed in depths: 0-20, 20-40 and 40-60 cm with wet and 0-20 cm for dry sieving procedure. The following indicators of soil structure were analyzed: dry geometric mean diameter (dGMD), structure coefficient (K_s), wet mean weight diameter (wMWD) and water stable aggregates (WSA). Based on the aggregate size fraction arrangement after dry and wet sieving significant difference was found between crops - winter wheat and maize. After dry sieving both crops showed relatively stable structure, although dry geometric mean diameter (dGMD) and structure coefficient (K_s) differ in explanation of cropping system effects on structure. After wet sieving small macroaggregates (250-2000 µm) showed greater structural stability and large marcroaggregates were lower. To preserve structure it is necessary to apply proper tillage operation and to allow soil to naturally build biological maturity that facilitate favourable aggregates and affects soils properties.

Key words: soil structure, dry sieving, wet sieving, winter wheat, maize, cropping systems

Introduction

Physical properties of the soil are related to the intensity of the agricultural management and a various vegetative factors combined in environmental conditions of the production site. In the soil structure analysis particular attention is given to the fact that this property directly or indirectly affects water, air and soil thermal regime, and also serves as an indicator of the soil quality (Dexter, 1997; Pagliai et al., 2004; Hillel, 1998; Belic et al., 2004). It is important to emphasize that the soil structure is not static but very dynamic soil property with pronounced temporal dynamic. However, in respect to the changes over time, soil management must be focused to create optimal structure for early stages of plant growth and development. The agricultural soil with a favourable structure provides less resistance to field machinery, leads to a less water loss by evaporation, creating weaker and thinner crust. From the agronomic point of view, soil structure stability can be explained considering the size and the relationship of aggregate fractions, but can be conceded that formation of macro-aggregates is presumption for a favourable water-air and thermal regime of the soil (Vučić, 1987). Change of the soil structure by crops is related with morphological and physiological characteristics of roots, amount of incorporated crop residues, and the number and intensity of applied agricultural operations. Roots exudates and other gelatinous substance secreted by roots into the soil play an important role in the stabilization of soil aggregates (Chan and Heenan, 1996; Traoré et al., 2000). Proper soil tillage, use of organic fertilizers and mixed crop sequence (Kay 1990), are the presumption for preserving a favourable soil structure. However, it should be noted that the structure that is created using different tools for soil preparation is only a form of "transient cluster" in the aggregate arrangement that is very unstable and changeable. Pressure caused by various management practices (including tillage and traffic with agricultural machines) as well as natural stress such as rainfall, could accelerate aggregate breakdown and inhibit aggregate formation (Birkás, 2008). Balesdent et al. (2000) explained that tillage, by affecting the life-time and amount of aggregates wherein SOC is sequestered, is naturally suspected to influence the extent of physical protection. Therefore, aggregate distribution and arrangement must be preserved in order to protect soil physical, chemical and microbiological properties. Analysis of the stability of soil structure of Chernozem in Vojvodina begins in 1960-ies when 3-year crop rotation and winter wheat was confirm to exerts a positive effects on aggregation and stability of aggregates (Vučić, 1960). Considering temporal processes of structure formation and stabilization, that repeats in cycles, it is necessary to consider the long-term cumulative effect of different cropping systems and role of a particular crops. The aim or our research is to compare long-term effects of winter wheat and maize on aggregate distribution and structure stability of the Haplic Chernozem by using dry and wet sieving procedure.

Materials and methods

The present study was performed on a long–term experiment "Plodoredi" carried out at the Rimski Šančevi Experimental Field of the Institute of Field and Vegetable Crops in Novi Sad. Our investigation was performed on *Haplic Chernozem* (*CHha*) according to the IUSS Working Group WRB (2006). The study treatments were as follows: fertilized 3–year crop rotation (wheat–maize–soybean) D3; fertilized 2–year crop rotation (wheat–maize) D2; fertilized wheat monoculture MO; unfertilized 3–year rotation (wheat–maize–soybean), N3 and unfertilized 2–year rotation (wheat–maize) N2. The unfertilized treatments were established 1946/47, and fertilized started in 1969/70. Maize and winter wheat growing was based on conventional tillage including mouldboard ploughing and seed bed preparation with a germinator manufactured by Kongskilde. Row cultivator for maize and herbicide application was used according to recommended technology. Maize sowing took place in April at a seeding rate of 17 kg ha^{-1}, and a distance between and in rows: 70 × 25 (57.142 plants per ha). Winter wheat sowing was in October (25-30) with seeding rate of 230 kg ha^{-1}. Fertilization scheme and crop rotation sequence was described in Šeremešić (2005). The soil structure was accessed in the winter wheat (NS40S) and maize (NSSC640) cropping. Soil samples were taken in the 2008-2010 period in undisturbed state and kept in laboratory for analyses. Dry sieving was conducted on soil samples from 0-20 cm soil depth and for wet sieving 0-60 cm soil dept was analyzed. Dry aggregate size classes (ASC) was determined by the dry-sieving method (Savinov, 1936). Briefly, 500 g of air-dried, undisturbed sample is sieved through a nest of sieves having 10, 5, 3, 2, 1, 0.5, and 0.25 mm square openings so eight aggregate size classes were obtained (>10, 10-5, 5-3, 3-2, 2-1, 1-0.5, 0.5-0.25 and <0.25 mm). Dry GMD (mm) is calculated as (Hillel, 2004):

$$\mathrm{dGMD} = \exp\left[\sum_{i=1}^{n} \frac{(w_i \log(x_i))}{w_i}\right]$$

where w_i is the weight percentage of each ASC with respect to the total sample and x_i is the mean diameter of each ASC (mm).

Aggregate size distribution, expressed as the structure coefficient (Ks), is calculated according to (Shein et al., 2001):

$$Ks = a / b$$

where a represents the weight percentage of aggregates 0.25-10 mm and b represents the weight percentage of aggregates <0.25 mm and >10 mm.

Using the weights of these ASC, dMWD (mm) is calculated (Hillel, 2004):

$$\mathrm{dMWD} = \sum_{i=1}^{n} x_i w_i$$

where w_i is the weight percentage of each ASC with respect to the total sample and x_i is the mean diameter of each ASC (mm).

Water stable aggregates were calculated as the mass of aggregates (>250 μm) divided by the total aggregate (stable + unstable) mass, and expressed as the percentage of water-stable aggregates according to the method described by Kemper and Rosenau (1986). In the formula, M_s represents the mass of stable aggregates, and M_u is the mass of unstable aggregates:

$$\mathrm{WSA} = \{\mathrm{M_s}/(\mathrm{M_s} + \mathrm{M_u})\} \times 100$$

Using the weights of these wet aggregate fractions, wMWD (mm) is calculated

$$\mathrm{wMWD} = \sum_{i=1}^{n} x_i w_i$$

The significance of treatments was determined using ANOVA. Fisher's LSD test was used to separate means at the $p < 0.05$ level of significance.

Results and discussion

Analysis of dry aggregate size distribution

The largest difference between cropping systems were observed within the dry aggregate size classes of5-10 mm and <0.25 mm.(Figure 1). The soil samples in maize based cropping systems were abundant with the 5-10 mm aggregates whereas soils after winter wheat had more dispersed soil structure and smaller fractions. Interestingly, soil under both crops had comparable amount of 1-2 mm size aggregates. Considering the concentration of the favourable aggregate size classes, from the agronomic point (0.25 to 2 mm), soils after winter wheat had better effects on structure compared with the maize cropping. Differences between crops could be explained with root development and soil cover during the year. Winter wheat covers the soil in the most of the year and implies less supplementary soil operation after sowing that facilitates processes of soil stabilization. On the other hand maize requires tillage operation in spring that usually disperses aggregates and allows traffic induced soil compaction.

Among the maize cropping systems differences in concentration of aggregate size classes appears in >10mm, 3-5mm and 0.5-1 mm (Figure 1). The soil has more large aggregates (clods) as a consequence of compaction by agricultural machinery in long term tillage, (Wiesmeier et al., 2012). Maize monoculture had different arrangement of soil aggregates after being exposed to long-term compaction (weeding, row cultivator, herbicide application) compared with rotations. In addition to that, 2 and 3-year crop rotation showed only small difference in concentration of ASC which indicate that soil structure more depended on preceding crop (winter wheat) and less on the fertilization.

Analyses of dry aggregate size classes after winter wheat showed similar arrangement of aggregates. Similar to maize cropping systems, fertilization had less effect to concentration of dry aggregates compared with preceding crop. Topsoil of wheat monoculture has the highest concentration of the aggregates which are considered as indicators of good structure (0.25 to 2 mm). This can be explained with the possibility to perform agro-technical measures at the optimum time, the longest soilcover under crop, and proper stubble mulching and residue incorporation. As a consequence of long-term winter wheat monoculture maintenance of organic matter occurred compared with rotations (Seremesic, 2011). Regular incorporation of the crops residue is important for the maintenance of the humus level in the soil (Franzluebbers et al., 2002), which is a prerequisite for preservation of the favourable soil structure (Seremesic, 2011).

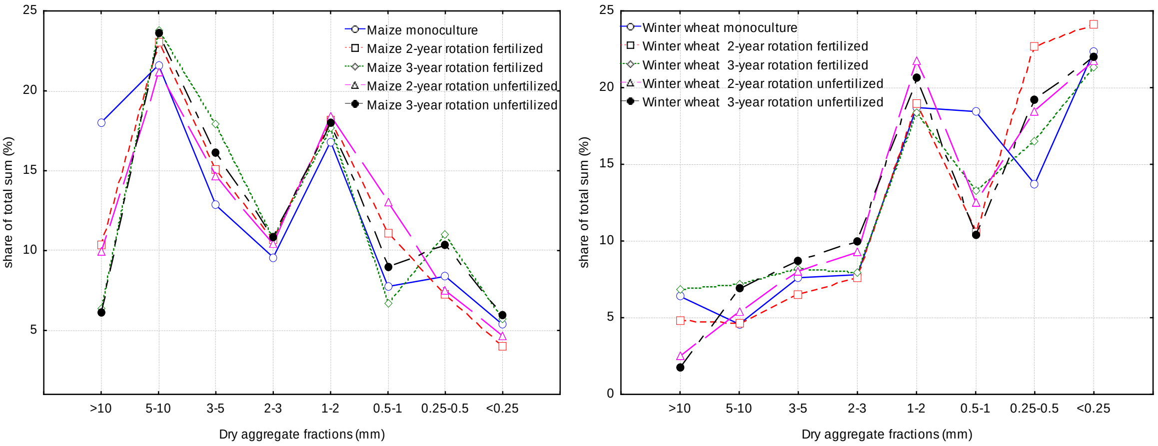

Figure 1. Aggregate size classes after dry sieving after maize (left) and winter wheat (right)

The concept of soil aggregates stability of different sizes depends on the strength of the forces which connect particles of soil, including the volume, nature and scope of activities destructive processes that are present in the soil (Beare and Bruce, 1993). Alteration in soil texture can have an effect on soil structure, although this depends also on humus and Ca^{2+}concentration (Table 1).

Table 1. Indicators of soil structure in maize and winter wheat cropping

	Cropping systems									
	MO		D2		D3		N2		N3	
	M	WW	M	WW	M	WW	M	WW	M	WW
Indicators										
Soil Texture (0-20 cm)										
Total sand	36.74	35.12	34.2	41	40	38.32	40.6	43.5	36.98	40.38
Silt	30.36	37.07	32.52	33.18	25.9	39.19	26.3	38.08	30.8	39.07
Clay	32.6	27.71	33.22	25.83	34.1	22.41	33.1	16.37	32.3	20.51
dMWD mm (0-20 cm)	7.23	2.96	5.58	2.5	4.72	3.26	5.33	2.12	4.61	2.06
K_s (+/- SD) (0-20 cm)	3.29 ±2.12	2.46 ±1.94	7.3 ±1.89	2.54 ±1.38	5.95 ±1.89	2.44 ±1.23	5.86 ±1.54	3.11 ±0.58	7.28 ±1.47	3.19 ±0.88
wMWD mm (+/- SD)										
0-20 cm	0.79 ±0.10	0.68 ±0.20	0.90 ±0.04	0.76 ±0.13	0.57 ±0.20	0.67 ±0.14	0.78 ±0.10	1.01 ±0.20	1.37 ±0.08	1.18 ±0.23
20-40 cm	1.13 ±0.38	0.63 ±0.15	0.86 ±0.19	0.82 ±0.20	0.77 ±0.04	0.70 ±0.10	0.64 ±0.10	0.92 ±0.28	1.62 ±0.10	1.11 ±0.33
40-60 cm	1.03 ±0.18	0.78 ±0.21	0.53 ±0.11	0.83 ±0.14	0.57 ±0.09	0.86 ±0.20	0.70 ±0.30	0.66 ±0.05	1.01 ±0.06	0.89 ±0.10
Average	*0.98*	*0.69*	*0.76*	*0.80*	*0.63*	*0.74*	*0.70*	*0.86*	*1.33*	*1.06*

Soil texture analyses showed that clay fraction is lower in soil after winter wheat compared with the maize cropping systems. This could be explained with the rainfall effects on the topsoil of the winter wheat plots that washout finest soil aggregates in deeper layer. In contrary, silt fraction is higher in top soil after winter wheat compared with the maize. This indicate that the dry aggregate size classes >0.5 mm depends more on a silt concentration in top soil, since clay is ether washout or implicated in creation of the organo-mineral complex.

Unlike total dry fraction evaluation dMWD and K_S showed different result (Table 1.) Higher dMWD indicate more cohesive soil conditions and less susceptible to wind erosion (Gajić et al., 2010). In our study soil samples analyzed after maize had values of dMWD that were higher compared with winter wheat. Similar values for dMWD presented Ćirić et al. (2012) for cultivated Chernozem in temperate conditions. Higher structure coefficient (K_s) is an indicator of a better structure (Table 1). According to our study Ks was higher in maize cropping due to differences in <0.25 mm aggregate size class which is represented with more than 20% in winter wheat. Contrary to the analyses of total dry aggregate size classes, where aggregates from 0.25 to 2 mm are indicators of good structure, K_s showed different results. Higher values of Ks were found in soil of a 3-year rotation for both, winter wheat and maize, compared with 2-year rotation and monoculture. Crop rotation had more effects on this indicator compared to fertilization.

Analysis of aggregate stability following wet sieving procedure

Higher values of wMWD imply greater aggregate stability. Within the 0-20 cm soil depth maize had higher values for wMWD at the MO, D2 and N3 compared with winter wheat and remaining D3 and N2 had opposite aggregate diameter display. The results for 20-40 cm soil depth generally showed larger aggregate diameter of maize in most cropping systems. Soil at N2 plot after winter wheat is more compacted that caused increase in wMWD in 20-40 cm soil depth. Within the 40-60 cm depth higher values of wMWD was observed in soil of the maize MO and N2 as a result of larger root development that increases the aggregate cohesion. Differences among crops, in the 0-20 cm, could be attributed to the tillage, however in the subsoil compaction or deterioration of a soil structure is related with the root activity.

We determine that the biggest difference between maize and winter wheat across all cropping systems and depths was found in 250-2000 µm and <53 µm (Table 2). Small macroaggregates (250-2000µm) in our study, represented with 46.60 and 36.55%, were found to be dominant in most cropping systems (Dameni et al., 2010). Within the two crops statistical differences between aggregate fractions of wet aggregate was found when cropping systems were compared.

Table 2. Concentration of the soil aggregate fraction after wet sieving

		Aggregate fraction (µm)			
Field crop	System	>2000	250-2000	53-250	<53
Winter wheat	D2	3.78c	50.30a	34.36b	11.56bc
	D3	3.29c	45.47c	38.55a	12.69ab
	MO	2.50c	47.92b	37.12a	12.44ab
	N2	6.88b	41.07d	38.50a	13.55a
	N3	9.18a	48.22ab	31.53c	11.03bc
	Average	*5.13*	*46.60*	*36.01*	*12.25*
Maize	D2	6.21c	33.29c	52.41a	8.03d
	D3	4.00d	34.55c	30.84c	30.68b
	MO	7.88b	47.92a	34.70b	9.48d
	N2	6.54bc	29.68d	28.47d	35.39a
	N3	17.28a	37.31b	23.53e	21.45c
	Average	*8.38*	*36.55*	*33.99*	*21.01*

$^{a-c}$Values in columns of each crop followed by similar letters do not differ significantly at $P \leq 0.05$

In average, aggregate size class of 250-2000 µm dominated in winter wheat, and >53µm aggregate fraction was marginally represented, opposite to dry sieving. Higher concentration of aggregate fraction in different maize cropping systems was observed between 53-2000 µm, contrary to dry sieving where >2000 µm fractions dominate. Based on the obtained results soil after maize is less resistant to slaking and wet sieving. Also, long-term continuous tillage had resulted with increase in 53-250 µm and <53 µm aggregates that is prerequisite for formation of the surface crusts in the 0-20 cm soil layer. According to Le Bissonnias (1996) wMWD values for fertilized treatments indicate unstable soil that could be characterized by the frequent appearance of crust.

Distribution of WSA in the analyzed treatments of the both crops indicates that the addition of mineral fertilizers and crop residue incorporation was not sufficient for soil structure preservation (Figure 2). Šimanský (2011) evaluated water stable aggregates at the Haplic Luvisol and also found that fertilization did not influence size fraction of WSA. Wagner et al. (2007) explained that crop residues are less important for structural stability, as the main role of the residue are to act as a physical protection on soil surface and as a nucleus for organo-clay aggregations. Concentration of WSA (%) showed no clear pattern among rotations. Unger et al. (1998) also noted that WSA distribution was affected with cropping system and depth but few differences were significant. Obtained results indicate that the higher concentration of WSA (%) in 0-20 cm soil after winter wheat is found in N3, whereas soil samples after maize MO and N3 were higher in stable aggregates. Accordingly, concentration of WSA is probably most affected with tillage and soil texture. These data supports the Mahboubi and Lal (1998) study in which structural changes were attributed to tillage and sampling period. Cultivation during unfavourable soil moisture content usually results with the structure deterioration in condition when period for structure consolidation is reduced (Birkás, 2009). In circumstances when optimal water content in soil is not attained tillage could amplify processes of structure impairment. It also appears that, in the temperate regions with plowing in autumn, there was no sufficient wetting and drying, freezing and thawing cycles during the winter for re-aggregation. Therefore, moldboard plowing and following soil preparation significantly contributes to deterioration of a soil structure. In a long-term this represents a considerable pressure for soil structure stability.

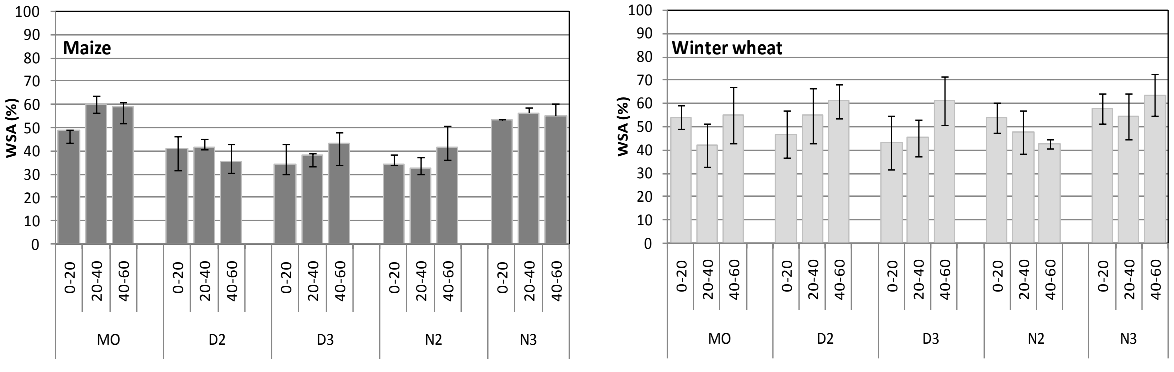

Figure 2. Concentration of WSA in winter wheat and maize cropping systems

Regardless to the dispersion induced with soil tillage the hierarchical model of soil aggregates has been observed (Šeremešić, 2012). This involves creation of the stable macroaggregateswhen microaggregates are bound together by additional organic matter (Tisdall and Oades, 1982; Oades and Waters, 1991).

Conclusion

The obtained results show relatively stable structure in the surface layer after dry sieving. Higher dGMD for maize was found under monoculture and for winter wheat in 3-year rotation. Higher structure coefficient (K_s) had 2-year rotation and unfertilized 3-year rotation for maize cropping systems and unfertilized 3-year and 2-year rotation after winter wheat. Wet sieving resulted with higher wMWD after unfertilized 3-year rotation. Small macroaggregates (250-2000 µm) were found to be dominant in most cropping systems, represented with 46.60% after winter wheat and 36.55% after maize and large macroaggregates were least stable to water treatment. Concentration of WSA % ranged from 42.2-63.56% in winter wheat and 32.57-60.32% after maize. The differences in aggregate stability between dry and wet sieving method demonstrate the sensitivity of the procedure to the initial moisture content of the soil. Significant differences was found between investigated crops and appears that tillage operation (time and soil moisture), also length of the stabilization period for soil could have primary effects of structure stabilization and preservation.

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