Comparison of soil organic matter content, aggregate composition and water stability of gleyic fluvisol from adjacent forest and cultivated areas

B. Gajic[1], G. Dugalic[2] and N. Djurovic[1]

[1]Institute of Land Management, Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080 Belgrade, Serbia; e-mail: bonna@agrifaculty.bg.ac.yu
[2]The Faculty of Agronomy, Cacak, Serbia

Abstract. The paper includes the results of comparative investigation of soil organic matter (SOM) content, aggregate size distribution (ASD) and water-stability of structural aggregates (WSA) of humus horizon (0–30 cm) of non-carbonate silty clay gleyic fluvisol in the Kolubara river valley (West Serbia) under natural deciduous forest vegetation and the same gleyic fluvisol used for more than 100 years as arable soil.

Long-term cultivation significantly ($P < 0.01$) decreased the SOM content in the plough horizon (0–20 cm). Due to long-term anthropogenization, the ASD and WSA in plough and sub-plough (20–30 cm) horizons of cultivated gleyic fluvisol are significantly degraded. In plough and sub-plough horizons, the content of the agronomically most valuable fraction (0.25–10 mm) is decreased about twice (from 67.7–74.0% to 37.1–39.2%), while the content of very coarse aggregates (> 10 mm) is increased to the same degree (from 22.8–31.2 % to 48.3–62.1%).

The conversion of forest semigley to continuous cropping using conventional cultivation significantly ($P < 0.05$) decreased the water stability of soil aggregates in the plough horizon. The lowest water-stability is found in structure aggregates > 3 mm. Their content is 2–3 times lower in the plough horizon (12.6–15.6%) than in the same depth zone of forest gleyic fluvisol (31.9–42.3%). Due to anthropogenization, water-stability of micro-aggregates (< 0.25 mm) is decreased in the plough horizon. The content of these aggregates is about twice as high in this horizon (29.9–34.0%), as in the same depth zone of the forest gleyic fluvisol (16.7–17.2%).

Key words: forest, cultivated fields, soil organic matter, aggregate composition, water stability of aggregates, mean weight diameter

INTRODUCTION

At present, anthropogenic influences of various types and intensities, distributed within traditional appropriating of new arable lands, disturb complex ecosystems and change the character, direction and mutual relations of natural pedogenic processes.

The available experience shows that human activity mainly caused the degradation of soil and the soil cover as a whole. Increased anthropogenic influence on soil leads at first to its degradation, i.e. deformation and destruction of micro- and macro-aggregates. By soil tillage, structural aggregates are exposed to fragmentation during rapid and fast wetting due to the impact of rain drops and the direct influence of agricultural machines.

Soil structure varies in time and space as a function of soil properties, climatic conditions and land management practices (Angers, 1998). Perennial crops generally improve soil structure, while annual row cropping often results in structural degradation, mainly as a result of a loss of ground cover and organic matter losses from soil disturbance (Magdoff & van Es, 2000). Soil degradation is accelerated when perennial crops are converted to annual row crops, primarily due to increased soil disturbance from tillage (Karunatilake & van Es, 2002). Soil structure and aggregation are strongly influenced by processes such as tillage, cropping systems and climate (Guérif et al., 2001).

Soil organic matter is an essential, but transient, component of the soil that controls many physical, chemical and biological properties of the soil (Carter, 1996). Continuous cropping and cultivation of many of the world's soils, which had previously been under forest or grassland, has resulted in a substantial decline in SOM. Soil structure and SOM content are considered important indicators of soil in agricultural soils (Lal & Kimble, 1997). SOM binds mineral particles into stable aggregates (Tisdall & Oades, 1982). In many soils intensive cultivation degrades the soil structure which is reflected by a decrease in stability of soil aggregates. The lower stability is usually associated with a decrease in SOM content and significantly affects plant development. Soil structural stability and soil organic carbon (SOC) content usually decrease with cultivation (Eynard et al., 2004). Tillage practices and low residue inputs have caused rapid losses of SOM and stable aggregation worldwide from conventionally cultivated soils (Lal & Kimble, 1997). Six et al. (2000a) reported that cultivation reduces soil carbon content and changes the distribution and stability of soil aggregates.

There exists a closer inter-relation between SOC concentration and aggregation (Hermawan & Bomke, 1997). Aggregate stability is significantly correlated with SOC due to the binding action of humic substances and other microbial by-products (Haynes et al., 1997; Shepherd et al., 2001). In some cases, however, SOC may be only moderately (Skøien, 1993) or weakly (Holeplass et al., 2004) correlated with aggregate stability.

A good soil structure for crop growth depends on the presence of aggregates between 1 to 10 mm diameter. Such aggregates should be stable when wetted (Edwards, 1991; Tisdall, 1996).

The objectives of this research were to determine and to estimate the effects of long-term (more than 100 years) tillage on (1) the SOM content, (2) the dry aggregate size distribution, (3) the aggregate stability, and (4) some soil structural parameters such as mean weight diameter (MWD) and structure coefficient (Ks) of humus horizon in gleyic fluvisol.

MATERIALS AND METHODS

The investigations were carried out with one of Serbia's most important agricultural soils (gleyic fluvisol; FAO, 1998), i.e. non-carbonated silty-clayey semigley (according to local classification – Skoric et al., 1985) formed over poorly carbonated alluvial deposit, which occupies the area of 10000 ha in the Kolubara river valley (western Serbia). The depth of its humus (Ah) horizon is mostly 30–40 cm. This soil was formed over a plateau (the first dry terrace of the Kolubara river). During the summer, the soil is dried down to a great depth. The mean annual temperature of the region is about 11°C. The mean annual precipitation is 725 mm, 65% of which is received during the fall and winter.

The soil samples for determination of dry aggregate-size distribution, aggregate stability and chemical analysis were taken from 0–10 cm, 10–20 cm and 20–30 cm depths of 9 profiles under forest, as well as of 9 profiles under stubbles. The collection of soil samples from field profiles was performed immediately after wheat harvest. At the same time, in vicinity of the arable field profiles (about 150 m far), the profiles were opened under natural forest vegetation, comprised of common oak and common ash association (*As. Querceto-Fraxinetum serbicum, Rud.*). Gleyic fluvisol under natural forest vegetation served as a control, i.e. referent (virgin) soil for the establishment of the influence of long-term tillage on SOM content and on the changes of their aggregate size distribution and water stability of structural aggregates.

The total organic carbon content is obtained by wet oxidation using potassium dichromate in a sulphuric medium (Rowell, 1997). Organic matter was calculated by dividing the organic C using a conversion constant of 0.58.

The total N content was determined by modified Kjeldahl method (ISO 11261).

Macro-aggregate composition of the investigated soils was determined by dry sieving, and the water stability of structural aggregates, by wet sieving by the Savinov's method (Gajic, 2005). By dry sieving, 8 classes of structural aggregates were separated by their size (> 10; 10–5; 5–3; 3–2; 2–1; 1–0.5; 0.5–0.25 and < 0.25 mm); by the wet sieving procedure 6 classes were separated (> 3; 3–2; 2–1; 1–0.5; 0.5–0.25 and < 0.25 mm).

The coefficient (Ks) was calculated as the ratio between the content of the agronomically most valuable fraction (0.25–10 mm), and the total content of the aggregates > 10 mm and < 0.25 mm separated by dry sieving (Shein et al., 2001). The mean weight diameter (MVD) of the structural aggregates was calculated by the following equation (Hillel, 2004):

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

where x_i is the mean diameter of any particular size range of aggregates separated by sieving, and w_i is the weight of the aggregates in that size range as a fraction of the total dry weight of the sample analyzed.

Bulk density was determined on 5 replicate samples by the core method (Gajic, 2005).

Conventional statistics (ANOVA) were used to assess treatment differences (SPSS 10.0 for Windows).

RESULTS AND DISCUSSION

In Table 1 the results are presented of the determination of average SOM (humus) content, organic C, total N, bulk density and particle size distribution of the investigated gleyic fluvisol. The detailed presentation of physical and chemical characteristics of these soils is given previously (Gajic, 1998).

Table 1. Some physical and chemical properties of the soil.

Soil use	Depth	Bulk density	Organic C	Total N	C/N	SOM	Particle size distribution[A]			Textural classes[B]
							%			
	cm	Mgm^{-3}	gkg^{-1}	gkg^{-1}		$Mgha^{-1}$	sand	silt	clay	
Forest	0–10	1.01	44.7	3.69	12.1	77.8	5.1	47.8	47.1	S. C.[C]
(*n* = 9)	10–20	1.32	18.6	1.68	11.0	42.3	6.5	49.2	44.3	S. C.
	20–30	1.47	10.4	0.98	10.6	26.4	7.9	50.6	41.5	S. C.
Crop	0–10	1.31	16.8	1.60	10.5	37.9	6.8	51.8	41.4	S. C.
(*n* = 9)	10–20	1.44	15.1	1.65	9.2	37.5	9.1	49.6	41.3	S. C.
	20–30	1.50	8.7	0.94	9.3	22.5	10.2	50.3	39.5	S. C.

[A] Sand 50–2000 µm; Silt 50–2 µm; Clay < 2 µm.
[B] USDA Classification (Soil Survey Staff 1996).
[C] S. C. – Silty clay.

The results presented in Table 1 show that all analyzed samples, according to the American soil texture classification (Hillel, 2004), belong to silty clays, with almost the same portions of silt fraction and clay.

Bulk density was significantly greater in the plough horizon than in the surface part (0–10 cm and 10–20 cm) of the humus horizon of the forest soil, but this effect was not present at 20–30 cm depth. Bulk density was negatively correlated with organic matter attributes, as organic matter generally lowers the mean density of soils (Hillel, 1998). Gülser (2006) reported that bulk density gave the significant negative correlation with SOM. According to Idowu (2003) the negative relationship of bulk density to aggregate stability is reflecting the extent of soil degradation that occurs over time, which in turn has influenced factors such as organic matter, which contribute directly to the formation of stable soil aggregates.

Soil organic matter

The data in Table 1 clearly show that due to long-term tillage, the average SOM content ($Mgha^{-1}$) in surface samples (0–10 cm) of the plough horizon is decreased about 2 times in comparison with gleyic fluvisol under forest vegetation. The differences were found at 10–20 cm; no significant differences were found at 20–30 cm. Our results are in general agreement with Reeves (1997) who found decreasing SOM in intensively cultivated soils. Conventional agriculture has caused large losses of SOM from cultivated land worldwide (Francis et al., 2001; Pulleman et al., 2005). The lower carbon content in cultivated soils can be attributed to lower residue return to the soil, as a significant portion of dry matter production is removed in harvested material (Golchin et al., 1995).

As expected, the forest gleyic fluvisol soil had significantly greater organic C content and total N content through the sampled depths compared with the cultivated soil (Table 1). The cultivated soil had a lower C/N than forest through the sampled depths (Table 1). Our results are in general agreement with Martens et al. (2003) who found decreasing organic C content, total N content and aggregate stability in cultivated soils.

Research has shown that plant residue additions in forests can increase soil aggregation and, concomitantly, soil C content (Bossuyt et al., 2002). The loss of C with cropped land use has been linked to soil disturbance (Bremer et al., 1994) and change in plant litter C composition (Martens, 2000).

Some additional parameters of SOM (humified organic carbon, polysaccharides, etc.) can describe in more detail the relationship between SOM and aggregate composition. Hot-water soluble carbon and acid hidrolysable carbohydrate fractions are considered to be more informative in determining aggregate stability. However, it is not possible at this moment to determine and assess these parameters in our laboratory.

Saroa and Lal (2001) reported that the SOM concentration decreased with decreasing aggregate size and was statistically higher in aggregates > 0.5 mm than < 0.5 mm. Skøien (1993) did not find any significant differences in the SOM concentration in different aggregate size fractions, although there was a slight trend of a decrease in SOM concentration with decreasing aggregate size. Holeplass et al. (2004) find a trend of increasing SOM concentration with decreasing aggregate size for > 0.25 mm fraction.

Dry aggregate size distribution

The results obtained from the dry sieving analysis, in Table 2 show that, due to a long-term use of gleyic fluvisol as arable field soil, i.e. due to human activity, there occurred a substantial change of its dry aggregate size distribution in comparison with the gleyic fluvisol under natural forest vegetation. The agronomically most valuable fractions of structural aggregates with the diameters between 0.25 and 10 mm prevail in all investigated depth zones of the humus horizon of forest gleyic fluvisol. Due to increased dispersion during the tillage, as well as to the compaction caused by threading, the plough horizon (0–10 and 10–20 cm) shows lower (37.1–39.2%) content of the agronomically most valuable aggregates (by their size) than the forest gleyic fluvisol (67.7–74.0%). On the basis of the content of these aggregates, and according to the classification by Shein et al. (2001), the arable gleyic fluvisol does not have satisfactory aggregate composition, while the gleyic fluvisol under forest vegetation is well structured in dry state. Soil structural changes under cropping were mainly related to a decline in the > 5 mm sized aggregates (Carter et al., 2002).

Due to the application of various agrotechnical measures, in the plough (0–20 cm) and sub-plough (20–30 cm) horizons, the total content of very coarse- (> 10 mm) and micro-aggregates (< 0.25 mm) is increased approximately twice. The content of these aggregates in humus horizon of forest gleyic fluvisol varies within a rather narrow interval, from 26.0 to 32.3%, and in the arable soils within a much wider interval, from 49.2 to 62.9%. Hakansson et al. (1988) made similar observations. They reported that the size of soil aggregates increases under intensive cultivation as a result of increased clodding.

Both structure coefficient (Ks) and MWD values of dry aggregates support the conclusion that the aggregate size distribution of arable gleyic fluvisol during long-term tillage suffered from significant qualitative changes (Table 2). In the humus horizon of the forest gleyic fluvisol, the Ks is about 2.5–4 times higher than in the cultivated one. The values of Ks in the profiles of forest gleyic fluvisol are regularly > 1.5, i.e. they vary between 2.09 and 2.85. According to the classification of Shein et al. (2001), the values Ks are characteristic for the soils of good structure. In the plough horizon (0–10 and 10–20 cm) the values Ks vary between 0.59 and 0.64, which is, according to the mentioned classification, a characteristic of soils with unsatisfactory structure. Sub-plough horizon (20–30 cm) of the investigated profiles, by its Ks value (1.03), shows satisfactory structure.

Table 2. Effects of different gleyic fluvisol use on dry aggregate size distribution.

Soil use	Depth (cm)	Dry aggregate size distribution (%)							Ks[A]	MWD
		> 10 mm	5–10 mm	3–5 mm	2–3 mm	2–0.25 mm	< 0.25 mm	10–0.25 mm		
Forest	0–10	22.8	34.9	15.4	10.5	13.2	3.2	74.0	2.85	7.09
(*n* = 9)	10–20	31.2	37.2	13.4	7.8	9.3	1.1	67.7	2.09	8.53
	20–30	26.5	36.9	15.1	9.0	10.5	2.0	71.5	2.51	7.71
Crop	0–10	57.6	25.5	5.8	3.1	4.8	0.7	39.2	0.64	11.02
(*n* = 9)	10–20	62.1	26.3	5.6	2.7	2.5	0.8	37.1	0.59	11.62
	20–30	48.3	31.3	9.9	5.1	4.5	0.9	50.8	1.03	10.19

[A] Ks–structure coefficient.

The values of MWD (Table 2) of the dry aggregate size distribution in plough and sub-plough horizons are significantly increased ($P< 0.01$) (10.19–11.02 mm) compared to the forest gleyic fluvisol (7.09–8.53 mm). Similar to the data reported by Shepherd et al. (2001).

Water stable aggregates

Soil aggregate stability is a crucial soil property affecting soil sustainability and crop production (Amezketa, 1999). The data presented in Table 3 show that, under the influence of long-term tillage, there occurred a significant decrease of WSA in plough and sub-plough horizons. Laffan et al. (1996) made similar observations. The lowest stability in the investigated semigley is found in structural aggregates with the diameter > 3 mm (Table 3). The content of these aggregates in humus horizon (0–30 cm) of the forest gleyic fluvisol is about 2–3 times greater than in the same depth zone of cultivated soils. The virgin soils had a greater aggregate stability than the cultivated sites (Golchin, 1995). The stability of soil aggregates generally increases with increased levels of soil organic carbon (Tisdall & Oades, 1982). The consequent decrease in SOM reduces the percentage of water-stable aggregates (Lal, 1993). The low WSA in the cultivated soils may be due to more mechanical disturbance by tillage, raindrop impact and harvest traffic (Holeplass et al., 2004).

Comparative analysis shows that under the influence of anthropogenic factors, there occurred a significant decrease in water stability of aggregates, indicated by an increase of micro-aggregates, (< 0.25 mm) in plough horizon (0–20 cm). Their content (29.9–34.0%) in the mentioned horizon is about 15% higher than in the same depth zone of the humus horizon of the forest gleyic fluvisol (16.7–17.2%). The difference in the content (29.7%) of water-stable aggregates < 0.25 mm between the sub-plough horizon (20–30 cm) and the same depth zone in the forest horizon is much narrower, about 4%, but it is also statistically significant ($P < 0.05$). Many studies have shown that cultivation leads to a decline in water-stable macro-aggregates (> 250 μm), resulting in a rapid loss of SOM that binds micro-aggregates (< 250 μm) into macro-aggregates (Tisdall & Oades, 1982; Elliott, 1986).

Table 3. Effects of different gleyic fluvisol use on size distribution of water-stable aggregates.

Soil use	Depth (cm)	% of water-stable aggregates of size (mm)						MWD (mm)
		> 3	3–2	2–1	1–0.5	0.5–0.25	< 0.25	
Forest	0–10	42.3	10.5	17.1	9.1	3.8	17.2	2.32
(*n* = 9)	10–20	31.9	10.4	22.9	12.7	5.4	16.7	2.02
	20–30	17.5	10.7	26.5	13.9	5.8	25.6	1.52
Crop	0–10	12.6	7.3	22.0	15.6	8.5	34.0	1.21
(*n* = 9)	10–20	15.6	9.2	22.8	14.9	7.6	29.9	1.37
	20–30	9.8	10.5	27.7	15.0	7.2	29.7	1.25

Soil disturbance from tillage is a major cause of reduction in the number and stability of soil aggregates when native ecosystems are converted to agriculture (Six et al., 2000b).

The tendency of the decrease of WSA under different land use in agricultural production was established by Koposov et al. (1994). Soil aggregate stability declined rapidly in the first year after ploughing, but more slowly after that (Francis et al., 2001). The main cause of the decrease of WSA in arable field soils after deforestation and soil tillage is, according to Hamblin (1985) and Lal (1993), the decrease of the content of humus and some of its components (Caron et al., 1992).

According to the results of the determination of MWD of water-stable aggregates presented in Table 3, it may be seen that due to long-term cultivation, there occured a very significant decrease of WSA. The values of MWD (1.21–1.37 mm) are about 1.5–2 times lower in the plough horizon than in the surface part (0–10 cm and 10–20 cm) of the humus horizon of the forest gleyic fluvisol (2.02–2.32 mm). Similar results were reported by Skøien (1993). Golchin et al. (1995) reported that the virgin sites and sites which had been under long-term pasture had a greater aggregate stability than the cultivated sites. Statistically significant ($P < 0.05$) differences in the values of MWD water-stable aggregates, although somewhat smaller, are found also in the third depth zone (20–30 cm) of the investigated gleyic fluvisol.

The decrease in MWD was mostly due to a decrease in the proportion of water-stable aggregates > 1 mm. It appeared that macro-aggregates of larger sizes are more sensitive to cultivation than smaller sizes when a virgin soil is brought under long-term cultivation.

CONCLUSION

On the basis of the results of comparative investigation of SOM content, dry aggregate size distribution and water-stable aggregates in humus horizons (0–30 cm) of noncarbonate, silty clay gleyic fluvisol in the Kolubara river valley, under native forest vegetation and the long-term (more than 100 years) cultivated areas, the following conclusions may be formed:

The average SOM content in surface samples (0–10 cm) of the plough horizon is about 2.5 times decreased in comparison with gleyic fluvisol under forest vegetation.

Long-term tilled areas, in the absence of regular crop rotation, lead to a strong impairment of aggregate composition of plough (0–10 and 10–20 cm) and sub-plough (20–30 cm) horizons. The content of very coarse, poorly porous aggregates (> 10 mm) in the plough and sub-plough horizons is increased by about twice, and the agronomically most valuable aggregate (0.25–10 mm) content is significantly decreased, also about twice in comparison with the gleyic fluvisol under natural forest cover.

The values of Ks in the plough horizon are 2.5–4 times lower than in the forest gleyic fluvisol, which also shows a degradation of the aggregate composition of cultivated gleyic fluvisol after deforestation.

Under the influence of anthropogenization, there occured a great decrease of WSA > 3 mm. The content of these aggregates is 2–3 times lower in the plough horizon (0–10 and 10–20 cm) than in the same depth zone of the forest gleyic fluvisol.

The content of water-stable micro-aggregates (< 0.25 mm) in the plough horizon (0–20 cm) of long-term cultivated gleyic fluvisol is about twice as low as in the same depth zone of forest gleyic fluvisol.

ACKNOWLEDGEMENTS. We thank prof. dr Miodrag Zivkovic for useful discussions and dr Dragan Nikolic for statistical advice.

REFERENCES

Amezketa, E. 1999. Soil aggregate stability: A review. *J. of Sustain. Agric.* **14**, 83–151.

Angers, D. A. 1998. Water-stable aggregation of Québec silty clay soils: some factors controlling its dynamics. *Soil Till. Res.* **47**, 91–96.

Bossuyt, H., Six, J. & Hendrix, P. F. 2002. Aggregate-protected carbon in no-tillage and conventional tillage agroecosystems using carbon-14 labeled plant residue. *Soil Sci. Soc. Am.J.* **66**, 1965–1973.

Bremer, E., Janzenm, H. H. & Johnston, A. M. 1994. Sensitivity of total, light fraction and mineralizable organic matter on management practices in a Lethbridge soil. *Can. J. Soil Sci.* **74**, 131–138.

Caron, J., Kaz, B., D. & Perfect, E. 1992. Short-term decrease in soil stuctural stability following bromegrass establishment on a clay loam. *Soil Till. Res*. **25**, 167–185.

Carter, M. R. 1996. Analysis of soil organic matter storage in agroecosystems. In Carter, M. R. & Stewart, B. A., (eds): S*tructure and organic matter storage in agricultural soils*, pp. 3–14. (Advances in soil science) CRC Pres, Inc.

Carter, M. R., Skjemstad, J. O. & MacEwan, R. J. 2002. Comparison of structural stability, carbon fractions and chemistry of krasnozem soils from adjacent forest and pasture areas in south-western Victoria. *Aust J. Soil Res.* **40**, 283–297.

Edwards, W. M. 1991. Soil structure: Processes and management. In Lal, R. & Pierce, F. J., (eds): *Soil Management for Sustainability*, pp. 7–14. Soil and Water Conservation Society, Ankeny, Iowa.

Eynard, A., Schumacher, T. E., Lindstrom, M. J., Malo, D. D. & Kohl R. A. 2004. Wettability of soil aggregates from cultivated and uncultivated ustolls and usterts. *Aust. J. Soil Res.* **42**, 163–170.

Eynard, A., Schumacher, T. E., Lindstrom, M. J. & Malo, D. D. 2004. Aggregate size and stability in cultivated south Dakota prairie ustolls and usters. *Soil Sci. Soc. Am.J.* **68**, 1360–1365.

FAO 1998. *World Reference Base for Soil Resources*. World Soil Resources Reports. FAO, ISRIC, ISSS, Rome, 87 pp.

Francis, G. S., Tabley, F. J. & White, K. M. 2001. Soil degradation under cropping and its influence on whet yield on a weakly structured New Zealand silt loam. *Aust. J. Soil Res.* **39**, 291–305.

Gajić, B. 1998. Comparative investigations of physical properties in various varieties of meadow black soils of the Kolubara valley. *Review of Research Work at the Faculty of Agriculture* **43**, 25–38.

Gajic, B. 2005. *Soil physics. Laboratory manual*. Grafoprint, Zemun-Belgrade; 185 pp. (in Serbian).

Golchin, A., Clarke, P., Oades, J. M. & Skjemstad, J. O. 1995. The effects of cultivation on the composition of organic matter and structural stability of soils. *Aust. J. Soil. Res.* **33**, 975–993.

Guérif, J., Richard, G., Dürr, C., Machet, J. M., Recous, S. & Roger-Estrade, J. 2001. A review of tillage effects on crop residue management, seedbed conditions, and seedling establishment. *Soil Till. Res*. **61**, 13–32.

Gülser, C. 2006. Effect of forage cropping treatments on soil structure and relationships with fractal dimensions. *Geoderma* **131**, 33–44.

Hakansson, I., Voorhees, W. B. & Riley, H. 1988. Vehicle and wheel factors influencing soil compaction and crop response in different traffic regimes. *Soil Till. Res*. **11**, 239–282.

Hamblin, A. 1985. The influence of soil structure on water movement, crop root growth, and water uptake. *Adv. Agron.* **38**, 95–158.

Haynes, R. J., Swift, R. S. & Stephen, K. C. 1997. Influence of mixed cropping rotations (pasture-arable) on organic matter content, water-stable aggregation and clod porosity in a group of soils. *Soil Till. Res.* **19**, 77–81.

Hermawan, B. & Bomke, A. A. 1997. Effects of winter cover crops and successive spring tillage on soil aggregation. *Soi Till. Res.* **44**, 109–120.

Hillel, D. 1998. *Environmental Soil Physics*. Academic Press, San Diego, 771 pp.

Hillel, D. 2004. *Introduction to Environmental Soil Physics*. Elsevier Academic Press, Amsterdam, 494 pp.

Holeplass, H., Singh, B. R. & Lal, R. 2004. Carbon sequestration in soil aggregates under different crop rotation and nitrogen fertilization in an inceptisol in southeastern Norway. *Nutr. Cycl. Agroecosyst.* **70**, 167–177.

ISO 11261. 2005. Soil quality. Determination of total nitrogen modified Kjeldahl method.

Karunatilake, U. P. & van Es, H. M. 2002. Rainfall and tillage effects on soil structure after alfalfa conversion to maize on a clay loam soil in New York. *Soil Till. Res.* **67**, 135–146.

Koposov, G. F., Shinkarev, A. A. & Perepelkina, Ye. B. 1994. Impact of Land Use on the Grey Forest Soils Structural-Aggregate Composition. *Soil Science* **5**, 37–41 (in Russian).

Laffan, M., Grant, J. & Hill, R. 1996. A method for assessing the erodibility of Tasmanian forest soils. *Aust. J. of Soil and Water Conservation* **9**, 16–22.

Lal, R. 1991. Soil structure and sustainability. *J. of Sustainable Agriculture* **14**, 67–92.

Lal, R. 1993. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. *Soil Till. Res.* **27**, 1–8.

Lal, R. & Kimble, J. M. 1997. Conservation tillage for carbon sequestration. *Nutr. Cycl. Agroecosyst.* **49**, 243–253.

Magdoff, F., R. & van Es, H. M. 2000. *Building Soils for Beter Crops*. Second edition. Handbook Series Book 4. Sustainable Agric. Network, Beltsville, MD, 240 pp.
Mapa, R., B. & Ariyapala, D. 1998. Effect of pioneer species on improving soil aggregate stability in a degraded forest land in Sri Lanka. CD Proceeding, Symposium no. 2, Scientific registration no. 755.16th WCSS, Montpellier, France.
Martens, D. A. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. *Soil Biol. and Biochem*. **32**, 361–369.
Martens, D. A., Reedy, T. & Lewis, D. T. 2003. Soil organic carbon content and composition of 130-year crop, pasture and forest land-use managements. *Global Change Biology* **10**, 65–78.
Oades, J. M. 1984. Soil organic matter and structural stability: mechanisms and implications for management. *Plant Soil* **76**, 319–337.
Pulleman, M. M., Six, J., van Breemen, N. & Jongmans, A. G. 2005. Soil organic matter distribution and microaggregate characteristics as affected by agricultural management and earthworm activity. *Eur. J. Soil Sci.* **56**, 453–467.
Reeves, D. W. 1997. The role of organic matter in maintaing soil quality in continuous croping systems. *Soil Till. Res.* **43**, 131–167.
Rowell, D. L. 1997. *Bodenkunde. Untersuchungsmethoden und ihre Anwendungen*. Springer, Berlin, 614 pp.
Saroa G. S. & Lal, R. 2003. Mulching effects on aggregation and carbon sequestration in Miamian soil in central Ohio. *Land. Degrad. Dev*. **14**, 481–493.
Shein, Ye. V., Arhangel'skaya, T. A., Goncharov, V. M., Guber, A. K., Pochatkova, T. N., Sidorova, M. A., Smagin, A. V., & Umarova, A. B. 2001. *Field and laboratory methods of physical properties and soil status investigation*. Publisher: The University of Moscow, 199 pp. (in Russian).
Shepherd, T. G., Saggar, S., Newman, R. H., Ross, C. W. & Dando, J. L. 2001. Tillage-induced changes to soil structure and organic carbon fraction in New Zealand soils. *Aust. J. Soil Res.* **39**, 465–489.
Six, J., Paustian, K., Elliott, E. T. & Combrink, C. 2000a. Soil structure and soil organic matter. I. Distribution of aggregate size classes and aggregate associated carbon. *Soil Sci. Soc. Am. J.* **64**, 681–689.
Six, J., Elliott, E. T. & Paustian, K. 2000b. Soil macroaggregate turnover and microaggregate formation: a mechanisam for C sequestration under no-tillage agriculture. *Soil Biol. Biochem.* **32**, 2099–2103.
Skoric, A., Filipovski, G. & Ciric, M. 1985. *Classification of Yugoslav Soils*. Academy of sciences and arts of Bosnia and Hercegovina, Special Publications, Tome LXXXVIII, Department of natural and mathematical sciences, Issue 13, Interacademic committee for soil research, Sarajevo, 72 pp. (in Serbian).
Skøien, S. 1993. Long-term effects of crop rotation, manure and straw on soil aggregation. *Norw. J. Agric. Sci.* **7**, 231–247.
Tisdall, J. M. & Oades, J. M. 1982. Organic matter and water-stable aggregates in soils. *J. Soil Sci.* **33**, 141–163
Tisdal, J. M. 1996. Formation of soil aggregates and accumulaton of soil organic matter. In Carter, M.R. & Stewart B.A. (eds): *Structure and organic matter storage in agricultural soils*, pp. 57–97. C RC Press, Boca Raton, FL.