

CHANGES IN THE COMPOSITION AND WATER SUSTAINABILITY OF SOIL UNITS UNDER THE EFFECT OF SOME SOIL TILLAGE SYSTEMS

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Abstract

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The investigation was carried out during 2003-2008 in the trial field of Dobrudzha Agricultural Institute on slightly leached chernozem soil type. A stationary field trial investigated the effect of some soil tillage systems (plowing at 24-26 cm – plowing at 14-16 cm; plowing at 24-26 cm – disking at 10-12 cm; disking at 10-12 cm – disking at 10-12 cm; no tillage – no tillage; cutting at 26-24 cm – cutting at 8-10 cm) on the composition and water sustainability of the structural soil units. Soil samples were taken after harvesting of wheat from the 0-10, 10-20 and 20-40 cm layers. Soil structure was determined through dry and wet screening of soil to find out the percent of the structural soil units of different size (>5, 5-3, 3-1, 1-0.25 and <0.25 mm). The systems involving annual tillage with plowshare destabilized the soil units and decreased the percent of water sustainable soil units along the entire depth of the cultivated profile. The constant shallow tillage done with disk clod-breaker at the same depth deteriorated soil structure in the surface layer. The low degree of crumbing at cutting and the elimination of the mechanical impact at minimal (below 10 cm) and no tillage in combination with decreased mineralization processes as a result from reduced air circulation lead to the decrease or the lack of destructive effect of these soil tillage systems on the soil units. In the lower plow layer, restructuring and increasing of the water sustainable soil units was observed at these types of soil tillage.

Key words: soil tillage systems, soil units, water sustainable soil units

Introduction

Formation and destruction of soil structure is determined by the impact of three factors: biogenic, climatogenic and anthropogenic, soil tillage and fertilization being most important with the third factor (Revut, 1972). The percent of 10-1 mm soil units is determining for the quality of the used tillage (Stoynev, 2004).

Plowing causes strong dispersion and destruction

of the cultivated soil layer (Hristov, 1995). Similar researches have been carried out also by Dimitrov and Mitova (1997) who pointed out that the percent of the slimy fraction in the 20-40 cm layer increased at annual ploughing as a result from the turning of the plough layer. Liebhard et al. (1995) also reported reduced stability of soil units in the 0-40 cm layer.

During the recent decades considerable attention is being paid to the plowless types of tillage. Due to economic and ecological effects of these types of till-

age, they are adopted in the agricultural systems all over the world (Fowler and Rockstorm, 2001; La Scala et al., 2006). They reduce the degradation of arable lands and preserve the available soil moisture (Amezketta, 1999).

Many authors have reported improvement of soil structure when using minimal and no tillage (Mirchev and Dilkova, 1985; Shishlyannikov, 1997; Oyedele et al., 1999). Other authors found tendencies towards increasing of the amount of water sustainable soil units when using minimal and plowless tillage (Klochkov, 1983; Dimitrov and Mitova, 1997; Fedorov and Vorontsov, 1995; Madari et al., 2005).

The positive effect from the use of minimal tillage can not be considered absolute because it is affected by the local soil type and climatic conditions (Rasmussen, 1999).

The aim of this investigation was to follow the effect of long-term use of different soil tillage systems on the composition and water sustainability of soil units in the slightly leached chernozem of Dobrudzha region.

Material and Methods

Dobrudzha Agricultural Institute is situated at 43° 40' northern latitude and 28° 10' eastern longitude. The mean annual precipitation sum in the region is 520 mm, and the mean annual air temperature is 10.5°C. January is the coldest month (−1.0°C), and July is the hottest (21.0°C). The maximum of rainfalls is in May-June, and the minimum – in August-September.

The soil type in the trial field is slightly leached chernozem (Haplic Chernozem, FAO, 2002). The structural status of this soil type in the virgin lands is comparatively good (Yolevsky et al., 1959). The arable soil layer is characterized with an unsatisfactory structure. At the same time the slightly leached chernozem soil type has high capacity of restructuring. The very good structure of the sub-plough layers is typical for this soil; in many cases they contain 40-50 % of the water sustainable soil units >1 mm. The slightly leached chernozem soils have a comparatively powerful humus horizon (60-80 cm) and moderate humic content

in the plough layer (3.47-3.79 %). Total nitrogen content characterizes these soils as having medium reserves. P₂O₅ reserves are low to medium, and K₂O reserves – from medium to good. Soil reaction is neutral.

This investigation was carried out during 2003-2008. The effect of the different soil tillage systems on the physical and agro-chemical characteristics of the slightly leached chernozem soils in the region of Dobrudzha are being studied in a field trial initiated in 1987. The crops typical for this region are involved in a 6-field crop rotation: wheat, grain maize, bean and sunflower. The following soil tillage systems were chosen for this investigation: 1) ploughing at 24-26 cm – ploughing at 14-16 cm; 2) ploughing at 24-26 cm – disking at 10-12 cm; 3) disking at 10-12 cm – disking at 10-12 cm; 4) no tillage – no tillage; 5) cutting at 26-24 cm – cutting at 8-10 cm. All types of tillage for spring crops included additional single disking in autumn and spring pre-sowing cultivation with harrowing, with the exception of direct sowing. A total herbicide was applied for control of weeds before sowing in the variant with no tillage.

Soil samples were taken after harvesting of wheat from the 0-10, 10-20 and 20-40 cm layers. Soil structure was determined through dry and wet screening of soil to find out the percent ratio of the soil units of different size (>5, 5-3, 3-1, 1-0.25 and <0.25 mm). On the basis of the results from the structural analysis, the values of the mean weighted diameters of the dry and water sustainable soil units were calculated:

$$D = (7.5a_1 + 4a_2 + 2a_3 + 0.625a_4 + 0.125a_5)/100$$

Where: a₁, a₂, a₃, a₄ and a₅ are the percents of the fractions with size: >5, 5-3, 3-1, 1-0.25 and <0.25 mm

The mathematical analysis of the obtained results was done with the help of software SPSS 13.0.

Results and Discussion

The effect of the tillage systems on the structural composition of soil is determined by the tools used and the number of operations in the respective element or technological process (Table 1).

Table 1
Effect of different soil tillage systems on the soil unit composition of slightly leached chernozem, %

Soil tillage systems	Depth, cm	Structural soil units, mm					D _d
		>5	5-3	3-1	1-0.25	<0.25	
plowing 24-26 cm plowing 14-16 cm	0-10	20.71	34.34	15.09	23.83	6.03	3.39
	10-20	25.36	29.12	17.73	21.57	6.22	3.56
	20-40	28.88	24.78	20.26	19.79	6.29	3.69
plowing 24-26 cm disking	0-10	20.95	27.06 ^b	20.38 ^b	24.45	7.16 ^a	3.22
	10-20	26.02	26.47	18.12	22.39	7.00	3.52
	20-40	28.75	25.75	17.93	20.86	6.71	3.68
disking disking	0-10	19.83	17.61 ^c	22.95 ^c	30.91 ^c	8.70 ^c	2.85 ^c
	10-20	27.14	18.19 ^c	19.98	27.95 ^c	6.74	3.35 ^b
	20-40	32.47 ^b	19.65 ^a	16.89	24.87 ^c	6.12	3.72
no tillage no tillage	0-10	24.34 ^b	22.36 ^c	21.51 ^b	24.91	6.88	3.31
	10-20	28.78 ^b	22.97 ^b	20.37	21.54	6.34	3.63
	20-40	30.58	23.43	19.11	20.68	6.20	3.75
cutting 24-26 cm cutting 8-10 cm	0-10	22.53	28.35 ^c	18.30	24.37	6.46	3.35
	10-20	27.07	26.05	19.05	21.56	6.28	3.60
	20-40	29.73	24.11	19.69	20.24	6.25	3.72
Gd	0.05	1.86	3.91	3.42	1.26	0.90	0.17
	0.01	2.61	5.48	4.79	1.77	1.27	0.24
	0.001	3.69	7.74	6.77	2.50	1.79	0.34

^{a, b, c} – significance of variations at P=0.05, 0.01 and 0.001

The larger amount of structural units with size 1-0.25 and <0.25 mm in the 0-10 cm layer in the systems including disking was due to the constant soil tillage operations carried out at the same depth which, though fewer in number, strongly destroyed the soil structure in comparison to annual plowing. The worsened soil structure after direct sowing and plowless tillage in this horizon was due to the processes of physical and chemical volatilization of the surface layer exposed to the constant destructive influence of temperature variations, rainfall kinetic energy and chemical erosion by rainfall waters.

The comparatively low rate of crumbling after plowless tillage and the elimination of the mechanical impact under minimal and no tillage in the 10-20 cm layer decreased or excluded the destructive effect of tillage on soil structure. As a result the percent of the

agronomical valuable soil units increased. The same tendency, though expressed to a lower degree, was observed in the systems involving plowing.

Annual plowing followed by multiple additional tillage and constant disturbance in the vertical position of the cultivated layer, together with the mechanical destruction of soil by tillage tools, destabilizes the soil units down the depth profile by accelerating the organic substance mineralization. The biological factors which cause the loss of the soil structure are due to the aerobic microorganisms destroying the thin layer of gel formed from organic colloids, which clots together the micro soil units (Shleymovich, 1973).

The greater amount of 5-3 mm soil units caused higher values of the mean weighted diameter of the structural units after using the systems plowing-plowing and cutting-cutting in the 0-10 cm layer. The lower

Table 2
Effect of different soil tillage systems on the water sustainability of the structural units in slightly leached chernozems, %

Soil tillage systems	Depth, cm	Water sustainable soil units, mm					D _w
		>5	5-3	3-1	1-0.25	<0.25	
plowing 24-26 cm plowing 14-16 cm	0-10	0.29	3.71	23.30	27.90	44.80	0.87
	10-20	0.11	3.49	23.10	28.90	44.40	0.85
	20-40	0.46	3.44	23.40	28.20	44.50	0.87
plowing 24-26 cm disking	0-10	0.15	3.55	27.90	26.30	42.10	0.93
	10-20	0.04	4.06	29.00	25.40	41.50	0.96
	20-40	0.09	4.91	29.60	24.60	40.80	1.00
disking disking	0-10	1.59 ^b	0.61 ^b	16.80 ^a	32.30 ^a	48.70 ^a	0.74
	10-20	0.21	5.69 ^a	32.60 ^b	24.50 ^a	37.00 ^b	1.09 ^b
	20-40	0.07	6.43 ^b	39.50 ^c	18.60 ^c	35.40 ^c	1.21
no tillage no tillage	0-10	2.88 ^c	0.42 ^b	22.20	29.00	45.50	0.91
	10-20	0.40	6.30 ^a	33.90 ^b	21.80 ^b	37.60 ^b	1.14 ^c
	20-40	0.33	6.57 ^b	39.40 ^c	18.20 ^c	35.50 ^c	1.23
cutting 24-26 cm cutting 8-10 cm	0-10	1.72 ^b	1.28 ^a	22.00	30.40	44.60	0.87
	10-20	0.26	5.15	31.00 ^a	25.60	38.00 ^b	1.05 ^b
	20-40	0.40	6.21 ^a	36.90 ^c	20.10 ^c	36.40 ^c	1.19
Gd	0.05	0.77	2.05	6.41	3.94	3.85	0.13
	0.01	1.09	2.88	8.99	5.53	5.40	0.18
	0.001	1.53	4.07	12.71	7.82	7.64	0.26

^{a, b, c} – significance of variations at P=0.05, 0.01 and 0.001

level of this index after using the systems with disking was due to the higher percent of 1-0.25 mm and <0.25 mm soil units.

The increased mean weighted diameter of the dry structural units in the 10-20 cm layer in all investigated soil tillage systems resulted from the higher percent of the large-sized fraction (>5 mm).

At depth 20-40 cm the higher value of the mean weighted dry structural unit diameter after constant no tillage and annual disking was due to the percent increase of the >5 mm and 5-3 mm fractions. In the systems cutting-cutting, plowing-plowing and plowing-disking the levels of the above index also increased in comparison to the upper layer because the percent of the large fraction (>5 mm) increased.

The percent of water sustainable structural soil units characterizes not so much the variations in the de-

composed soil units but highlights the rate of weakening of the forces which hold together the separate particles in the structural elements under the effect of the used soil tillage and their respective strengthening when soil is left undisturbed (Table 2).

In the 0-10 cm layer the higher amount of the <1 mm fractions and the simultaneous decrease of the large-sized structural units after constant disking showed that this type of tillage causes soil dispersion in the surface layer. The comparatively low rate of crumbling in the system cutting-cutting and the elimination of the mechanical impact after direct sowing decreased the detrimental effect of soil tillage on the water sustainability of the soil units. The positive effect of no tillage on the recovery and formation of the soil structure was expressed also in the increased content of organic carbon in the 0-20 cm layer (Castro

Table 3
Statistical groups of the investigated soil tillage systems according to the amount of structural and water sustainable soil units (Duncan, N=8)

Soil tillage systems	Groups				Soil tillage systems	Groups			
	a	b	c	d		a	b	c	d
Structural soil units >5 mm					Water sustainable soil units >5 mm				
A	26.13				B	.09			
B	26.68	26.68			A	.29	.29		
E	28.02	28.02	28.02		C		.62	.62	
C		28.27	28.27		E			.79	.79
D			28.89		D				1.20
Structural soil units 5-3 mm					Water sustainable soil units 5-3 mm				
C	18.97				A	3.55			
D		23.08			B	4.17			
E			25.12		E	4.21			
B			26.09	26.09	C	4.24			
A				27.89	D	4.43			
Structural soil units 3-1 mm					Water sustainable soil units 3-1 mm				
B	18.39				A	23.27			
A	18.53				B		28.83		
E	18.62				C		29.63		
C	18.95				E		29.97		
D	19.97				D			31.83	
Structural soil units 1-0.25 mm					Water sustainable soil units 1-0.25 mm				
A	21.08				D	23.00			
D	21.72				C		25.13		
B	21.97				E		25.37		
E	22.00				B		25.43		
C		26.92			A			28.33	
Structural soil units <0.25 mm					Water sustainable soil units <0.25 mm				
E	6.25				D	39.53			
D	6.35				E	39.67			
A	6.38				C	40.37			
B	6.88				B	41.47			
C	6.89				A		44.57		

Note: A plowing-plowing; B plowing-disking; C disking-disking; D no tillage-no tillage; E cutting-cutting

Filho et al., 2002).

At depth 10-20 cm the content of large-sized soil units after constant disking increased probably as a

result from the circumstance that a sub-plowing layer in soil was formed at this depth, which was not disturbed by the soil tillage tools.

The reduced or eliminated impact of the mechanical soil tillage tools down the depth profile contributed to the preservation of the soil structure and restructuring of the soil units in these horizons in all investigated soil tillage systems.

The higher values of the mean weighted diameter of water soluble structural units in the 0-10 cm layer after using annual plowing alternated with disking was a result from the higher amount of 3-1 mm soil units. Due to the low percent of 3-1 mm soil units, the mean weighted diameter of the water sustainable soil units had lowest values in this horizon after using the system disking-disking. The mean weighted diameter of the water sustainable soil units in the 10-20 cm layer increased after annual direct sowing, constant disking and cutting due to the higher percent of the 5-3 and 3-1 mm fractions in comparison to the upper horizon. After plowing, this index dropped down due to the decreased amount of the >5 mm fraction.

The higher values of the mean weighted diameter of water sustainable soil units after using the system no tillage – no tillage in the 20-40 cm layer was a result from the higher percent of the 3-1 mm fraction in comparison to the other soil tillage systems.

Based on Duncan's test, the investigated soil tillage systems were divided into 4 statistical groups according to the soil unit composition and the water sustainability of the structural units (Table 3). Concerning the fractions 3-1, <0.25 (in the structural soil units) and 5-3 mm (in the water sustainable soil units), the investigated soil tillage systems did not differ. Highest differentiation was observed in the fractions >5 mm (in both structural and water sustainable soil units), 5-3 (in the structural soil units) and 3-1, 1-0.25 mm (in the water-sustainable soil units), where the used soil tillage systems were divided into 3 and 4 respective statistical groups. They clearly showed the effect of the different tillage systems on the soil structure through the number and depth of the performed soil tillage operations. The fractions 1-0.25 (in the structural soil units) and <0.25 (in the water sustainable soil units) were divided into two groups thus confirming the detrimental effect of both constant plowing and disking.

Conclusions

In the systems involving annual harrowing followed by multiple additional tillage and constant disturbance of the vertical order of the cultivated soil horizon, the mechanical destruction of the soil with tillage tools combined with increased mineralization of the organic substance destabilized the soil units and decreased the percent of water sustainable soil units along the entire cultivated profile.

The constant shallow tillage with disk harrow at the same depth deteriorated the soil structure in the surface layer. The worsened soil structure after direct sowing and plowless tillage was determined by the processes of physical and chemical volatilization to which this horizon was subjected.

The low rate of crumbling after cutting and the elimination of the mechanical impact after minimal (at depth less than 10 cm) and no tillage combined with decrease of the mineralization processes as a result from the reduced air circulation caused decrease or absence of the detrimental effect of these tillage systems on the soil units. In the lower plow horizons restructuring and increased water sustainability of the soil units was observed.

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