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Effect of Long-term Use of Some Agronomy Practices on the Physical and Agro-chemical Properties of the Slightly Leached Chernozem Soils in Dobroudja Region. I. Soil Unit Composition and Water Sustainability of Structural Soil Units

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Abstract: The investigation was carried out during 2003–2007 in the trial field of Dobrudja Agricultural Institute General Toshevo on slightly leached chernozem soil type (Haplic Chernozem). The effect of some agronomy practices on the soil unit composition and on the water sustainability of the structural units was studied in two stationary field trials. The analysis on soil units was done according to the method of Savinov modified by Vershiinin–Revut. The analysis was performed in two stages: dry screening of air-dried soil to determine the amount of the soil units of different sizes in the fractions >5, 5-3, 3-1, 1-0.25 and <0.25 mm; wet screening to determine the distribution of the water sustainable soil units of various size.

The crops from the first trial were included in 6-field crop rotation (grain maize–wheat–sunflower–wheat–bean–wheat) and were grown with five soil tillage systems (ploughing at 24-26 cm–ploughing at 14-16 cm; ploughing at 24-26 cm–disking at 10-12 cm; disking at 10-12 cm–disking at 10-12 cm; nil tillage–nil tillage; cutting at 26-24 cm–cutting at 8-10 cm). The soil tillage system in the second field trial with 2-field crop rotation was ploughing at 24-26 cm–disking at 10-12 cm. The following variants were selected from a wide range of fertilization combinations: $N_0P_0K_0$, $N_{60}P_0K_0$, $N_{120}P_0K_0$, $N_{180}P_0K_0$, $N_{60}P_{180}K_0$, $N_{120}P_{120}K_{120}$ and $N_{180}P_{60}K_{60}$.

The long-term use of disking increased the amount of the <0.25 mm soil units in the surface soil layer (0-10 cm). In comparison to ploughing, the low rate of crumbling after cutting and the elimination of the mechanical impact at depth below 10 cm after the minimal and nil tillage decreased and excluded their destructive effect on the soil units. The long-term usage of minimal, nil and tillage without turning the plow layer decreased the water sustainability of the structural units in the surface soil layer. In the lower layers of the ploughing horizon re-structuring and increasing of the water sustainability of the soil units was observed after these types of soil tillage. The independent long-term nitrogen fertilization increased the amount of the <0.25 mm fraction. At the same time the independent phosphorus fertilization contributed significantly to the increase of the agronomically valuable soil units. The combined mineral fertilization with $N_{60}P_{180}K_0$ and $N_{180}P_{60}K_{60}$ contributed to the structuring of soil in the root-deep layer (0.60 cm), its effect being only slightly lower than the effect of independent phosphorus fertilization.

Key words: soil tillage systems, crop rotation, fertilization, soil structure, soil units, water sustainable soil units

INTRODUCTION and LITERATURE REVIEW

In order to develop conditions suitable for sowing, germination, growth and development of the agricultural crops, it is necessary to use agronomy practices which provide optimal regulation of the water, air, thermal and nutrition regime of soil, regulation of the organic substance in the ploughing layer, ploughing of fertilizers and post-harvest residues, control of weeds, diseases and pests.

The aim of the agronomy practices is to differentiate to a maximum degree and simultaneously to simplify the agronomic technologies for cultivation of the field crops in accordance with the peculiarities of soil and the requirements of the plants (Dilkova et al., 1984).

According to Kuznetsova and Dolgov (1975), soil has a sustainable structure when the water sustainable soil units with size >0.25 mm are no less than 40%. When these soil units are in lower concentration, the soil becomes compact after rainfalls and its water-and-air permeability deteriorates.

Mamedov (1988) has pointed out that the water sustainable soil units with size >0.25 mm must be 60-80 % from the total sum of macro units.

A number of purposeful investigations have been carried out at Dobrudja Agricultural Institute – General Toshevo to follow the effect of different agronomy practices on the structure, the water sustainability of structural units on the slightly leached chernozem soils in Dobrudja region and on the content of the main nutrition elements in them (Klochkov, 1983; Yankov, 1999; Nankova et al., 1997; Yankov et al., 2004, etc.).

The aim of this investigation was to follow the effect of the long-term use of different agronomy practices on some physical and agro-chemical properties of the slightly leached chernozem soils in Dobrudja region.

MATERIALS AND METHODS

Soil characteristics

The region where Dobrudja Agricultural Institute is situated is characterized with mean annual rainfalls of 516.7 mm and mean annual air temperature of 10.5o C.

The virgin land status of the soils in the trial field, expressed through the amount of water sustainable soil units >1mm and >0.25 mm, was 46.9 % and 79.2 %, respectively, being comparatively good (Yolevsky et al., 1959). The content of these fractions in the same layer of cultivated soils (9.7 % and 43.2 %, respectively) gives an idea about the unsatisfactory structural status of the cultivated lands. At the same time slightly leached chernozem soils are highly capable of restructuring. Slightly leached chernozems (Haplic Chernozem, FAO, 2002) typically possess very good structure of the sub-ploughing horizons, which in many cases contain 40-50 % of water sustainable soil units >1 mm. Humus content in A horizon varied from 3.74 to 3.79 % according to Tyurin. Total nitrogen reserve in the surface layers was within 156–166 mg/1000 g soil (Kjeldahl) and characterized soil as medium-rich in nitrogen. The data on mobile phosphorus and potassium characterized the investigated soils as medium-rich in these elements. In fact most of the slightly leached chernozems, including the soils of our trial fields, belong to the group of poor to medium-rich in mobile phosphorus (Gospodinov, 1981). The carbonates are situated under the humus and the transitional horizons. The soil reaction of these horizons is neutral (pH is from 6.5 to 7.4), and changes to alkali in the carbonate horizon (pH 8.6).

The effect of some agronomy practices on the physical and agro-chemical properties of the slightly leached chernozem soils (Haplic Chernozems, FAO, 2002) in Dobrudja region is being investigated in regular stationary field trials. This investigation was conducted during 2003–2007.

First trial

The trial was initiated in 1987. Twenty-four soil tillage systems are being investigated in it based on different soil tillage tools. For this investigation the following tillage systems were selected: ploughing at 24-26 cm–ploughing at 14-16 cm; ploughing at 24-26 cm–disking at 10-12 cm, disking at 10-12 cm–disking at 10-12 cm, nil–nil; cutting at 24-26 cm–cutting at 8-10 cm. The crops involved in the trial were grown in 6-field crop rotation as follows: grain maize–wheat–sunflower–wheat–bean–wheat.

All types of spring crops tillage, with the exception of direct sowing, included additional single disking and spring pre-sowing cultivations with harrowing. A total herbicide was used to destroy the weeds before sowing in the variant with nil tillage.

Second trial

The trial was initiated in 1967 by the method of the grate square using the full design (4 x 4 x 3 = 48) in four replicates, the trial plot being 63 m2, and the harvest plot – 20 m2. Four nitrogen and phosphorus norms were tested: 0, 60, 120 and 180 kg/ha, as well as three potassium norms: 0, 60 and 120 kg/ha. The trial included and additional variant – N180P180K180 kg/ha and thus the total number of tested variants of independent and combined fertilization was 49. The soil tillage system in 2-field crop rotation of wheat and maize was ploughing at 24-26 cm–disking at 10-12 cm.

The analysis of soil units was done by the method of Savinov in the modification of Vershiinin–Revut. It was carried out in two stages:

- Dry screening to determine the amount of soil units with different sizes in air-dry soil in the following fractions: >5, 5-3, 3-1, 1-0.25 and <0.25 mm;
- Wet screening to determine the size distribution of the water sustainable soil units.

Based on the results from the structural analysis, the values of the mean weighted diameters of the dry and water sustainable structural soil units were calculated by the formula:

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

where: a_1, a_2, a_3, a_4 и a_5 are the percent of the fractions with sizes: >5, 5-3, 3-1, 1-0.25 and <0.25 mm

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

RESEARCH RESULTS

First trial

The data from the analysis on dry soil units for the amount distribution by size fractions of the structure soil units showed considerable variations according to the technology of soil tillage. In the 0-10 cm layer the 5-3 mm soil units were predominant in all tillage systems involving ploughing (Table 1). In direct sowing, as well as in minimal and tillage without turning of plow layer, the amount of 1-0.25 mm structural soil units was highest. Highest percent of the <0.25 mm fraction was observed in the systems disking–disking and ploughing–disking.

The results from the 10-20 cm layer showed that in the systems ploughing–ploughing and ploughing–disking, the soil units with size >5mm and 5-3 mm were predominant, similar to the upper layer. In cutting and direct sowing the amount of the >5 mm fraction increased. The rate of soil dispersion in this horizon decreased at constant disking.

In the 20-40 cm layer the percent of the large sized structural soil units increased in all investigated tillage systems.

The amount of the structural soil units with size <0.25 mm at depth 40-60 cm was highest in constant ploughing. In minimal, nil and tillage without turning of plow layer the fraction with size >5 mm was predominant.

The mean weighted diameter of dry structural soil units in the 0-10 cm layer was highest in constant ploughing. Second came annual cutting. In the systems disking–disking and ploughing–disking the mean weighted diameter of structural units was lowest.

In the 10-20 cm layer the mean weighted diameter of dry structural units was highest in the systems nil–nil and cutting–cutting. In the tillage systems involving ploughing the mean weighted diameter of the dry structural soil units increased.

At depth 20-40 cm the value of the mean weighted diameter of the dry structural units was also highest at constant nil tillage.

In the 40-60 cm layer the mean weighted diameter of the dry structural units was lowest in the systems involving ploughing.

The sustainability of soil to leaching by water is an index, which characterizes the effect of the tillage systems on soil structure. In this relation both the sum total of the water sustainable units in soil and their distribution by size fractions are highly significant.

In the surface layer (0-10 cm) the 5-1 mm fraction was predominant in the systems ploughing – ploughing and ploughing–cutting (Table 2). In constant disking the content of structural units with size 1-0.25 and <0.25 mm was highest. The amount of fraction >5 mm was highest in constant direct sowing and annual cutting.

The amount of the >5 mm fraction in the 10-20 cm layer considerably decreased in the systems ploughing–ploughing and ploughing–disking. In comparison to the upper layer, the content of 5-1 mm units in the 10-20 cm layer increased in the tillage The investigated index increased in the 10-20 cm layer in minimal and nil tillage. In constant ploughing comparison to the upper layer.

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	
ploughing 24-26 cm ploughing 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
	40-60	29.56	23.31	21.05	19.11	6.97	3.70
ploughing 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
	40-60	31.01	25.07	17.11^a	20.18	6.63	3.81
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
	40-60	33.64^c	20.44	15.96^b	23.95^c	6.01^a	3.82
nil nil	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
	40-60	31.84^a	23.51	18.90	19.76	5.99^a	3.84
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
	40-60	32.74^a	21.98	17.43^a	21.86^c	6.00^a	3.83
Gd	*5%*	*1.86*	*3.91*	*3.42*	*1.26*	*0.90*	*0.17*
	1%	*2.61*	*5.48*	*4.79*	*1.77*	*1.27*	*0.24*
	0.1%	*3.69*	*7.74*	*6.77*	*2.50*	*1.79*	*0.34*

[a, b, c] – significance of variations at P= 5%, 1% and 0.1%

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	
ploughing 24-26 cm ploughing 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
	40-60	0.29	3.55	23.27	28.33	44.57	0.86
ploughing 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
	40-60	0.09	4.17	28.83	25.43	41.47	0.96
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
	40-60	0.62	4.24	29.63	25.13	40.37^a	1.02^a
nil nil	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
	40-60	1.20^a	4.43	31.83^a	23.00^a	39.53^a	1.10^b
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
	40-60	0.79	4.21	29.97^a	25.37	39.67^a	1.04^a
Gd	*5%*	*0.77*	*2.05*	*6.41*	*3.94*	*3.85*	*0.13*
	1%	*1.09*	*2.88*	*8.99*	*5.53*	*5.40*	*0.18*
	0.1%	*1.53*	*4.07*	*12.71*	*7.82*	*7.64*	*0.26*

[a, b, c] – significance of differences at P= 5%, 1% and 0.1%

Table 3. Statistical groups of the investigated soil tillage systems by amounts of structural units (Duncan, N=8)

Soil tillage systems	Groups			
	a	b	c	d
Structural soil units >5 mm				
ploughing-ploughing	26.13			
ploughing-disking	26.68	26.68		
cutting-cutting	28.02	28.02	28.02	
disking-disking		28.27	28.27	
nil-nil			28.89	
Structural soil units 5-3 mm				
disking-disking	18.97			
nil-nil		23.08		
cutting-cutting			25.12	
ploughing-disking			26.09	26.09
ploughing-ploughing				27.89
Structural soil units 3-1 mm				
ploughing-disking	18.39			
ploughing-ploughing	18.53			
cutting-cutting	18.62			
disking-disking	18.95			
nil-nil	19.97			
Structural soil units 1-0.25 mm				
ploughing-ploughing	21.08			
nil-nil	21.72			
ploughing-disking	21.97			
cutting-cutting	22.00			
disking-disking		26.92		
Structural soil units <0.25 mm				
cutting-cutting	6.25			
nil-nil	6.35			
ploughing-ploughing	6.38			
ploughing-disking	6.88			
disking-disking	6.89			

Table 5. Effect of different mineral fertilization variants on the structural unit composition pf slightly leached chernozem soils (%)

Fertilization variant	Depth, cm	Structural soil units, mm					D_d
		>5	5-3	3-1	1-0.25	<0.25	
$N_0P_0K_0$	0-10	22.60	11.09	29.31	30.20	6.80	2.92
	10-20	23.25	14.94	29.54	25.59	6.68	3.10
	20-40	23.58	16.55	29.81	24.24	5.82	3.19
	40-60	24.82	16.73	30.65	22.07	5.73	3.29
$N_{60}P_0K_0$	0-10	22.56	12.02	25.91^b	31.73	7.78^c	2.90
	10-20	24.40	13.98	25.47^b	28.49^a	7.67^c	3.09
	20-40	23.59	14.74	29.29	25.11	7.27^c	3.11
	40-60	22.67^a	16.70	33.45^a	19.91	7.27^c	3.17
$N_{120}P_0K_0$	0-10	19.47^b	12.05	26.22^b	34.36^b	7.90^c	2.69^c
	10-20	23.35	14.37	28.39	26.08	7.81^c	3.07
	20-40	23.09	15.70	28.89	25.01	7.31^c	3.10
	40-60	21.95^b	17.67	30.38	22.70	7.30^c	3.11
$N_{180}P_0K_0$	0-10	17.60^c	12.91	25.78^b	36.25^c	7.46^c	2.59^c
	10-20	23.64	14.28	26.18^b	28.37^a	7.53^c	3.05
	20-40	21.80	16.93	30.84	22.93	7.50^c	3.08
	40-60	21.03^c	18.23	32.32	20.96	7.46^c	3.09
$N_0P_{180}K_0$	0-10	25.46^b	14.66^b	29.01	24.72^c	6.16^c	3.24^c
	10-20	28.15^c	15.35	27.72	22.71^a	6.07^c	3.43
	20-40	29.88^c	15.38	27.83	21.09^a	5.82	3.55
	40-60	29.51^c	17.65	32.01	15.19^c	5.64	3.66
$N_{60}P_{180}K_0$	0-10	25.74^b	11.20	28.85	27.97	6.24^c	3.14^c
	10-20	26.36^b	12.45^a	27.62	27.42	6.15^c	3.21
	20-40	26.98^b	14.66	27.04^a	25.20	6.12^a	3.32
	40-60	28.57^c	14.78	28.56	22.21	5.88	3.45
$N_{120}P_{120}K_{120}$	0-10	24.18	12.12	26.68^a	30.72	6.30^c	3.03^a
	10-20	23.87	14.20	27.82	27.82	6.29^b	3.10
	20-40	23.70	15.20	28.16	26.74	6.20^b	3.12
	40-60	24.19	17.09	30.66	21.94	6.12^b	3.26
$N_{180}P_{60}K_{60}$	0-10	25.40^b	12.21	24.81^b	31.28	6.30^c	3.09^b
	10-20	26.46^b	12.42^a	25.54^c	29.19^a	6.25^b	3.18
	20-40	22.91	21.23^c	25.68^c	23.17	6.18^a	3.23
	40-60	24.24	21.73^c	26.51^c	22.55	5.94	3.37
Gd	*5%*	*1.95*	*2.13*	*2.17*	*2.72*	*0.26*	*0.10*
	1%	*2.66*	*2.90*	*2.96*	*3.71*	*0.36*	*0.14*
	0.1%	*3.58*	*3.91*	*3.99*	*5.00*	*0.48*	*0.19*

$^{a, b, c}$ – significance of variations at P= 5%, 1% and 0.1%

In the 20-40 cm layer an increase of the percent of large-sized structural units was observed in all investigated fertilization variants. In the variants with independent phosphorus fertilization and its combining with various nitrogen and potassium norms there was a tendency towards decrease of the soil dispersion rate.

The amount of the <0.25 mm structural units at depth 40-60 cm was highest in the variants with independent nitrogen fertilization. In the rest of the variants the >5 mm fraction was predominant.

The mean weighted diameter of dry structural units in the 0-10 cm layer had highest value in the variant with N0P180K0. In the fertilization variants with independent nitrogen fertilization the investigated index was lowest.

In the 10-20 cm layer the mean weighted diameter of dry structural units was again highest in the variant with N0P180K0. The different nitrogen, phosphorus and potassium combinations follow it. At independent nitrogen fertilization the mean weighted diameter of dry structural units also increased.

At depth 20-40 cm the value of the mean weighted diameter of dry structural units was highest in annual independent phosphorus fertilization. In the variants with N60P0K0, N120P0K0, and N180P0K0 the mean weighted diameter of the dry structural units increased in comparison to the upper layer.

In the 40-60 cm layer the investigated index had the highest value in the variant with N180P0K0.

Table 6. Effect of different mineral fertilization variants on the water sustainability of structural units in slightly leached chernozem soils (%)

Fertilization variant	Depth, cm	Water sustainable soil units, mm					D_w
		>5	5-3	3-1	1-0.25	<0.25	
$N_0P_0K_0$	0-10	0.20	2.04	28.40	22.68	46.68	0.86
	10-20	0.34	2.30	30.70	24.44	42.22	0.94
	20-40	0.52	2.50	31.38	24.44	41.16	0.97
	40-60	0.78	2.84	32.40	27.46	36.52	1.04
$N_{60}P_0K_0$	0-10	0.26	0.30^{c}	24.18^{c}	21.00	54.26^{c}	0.71^{c}
	10-20	0.54	1.12^{c}	24.22^{c}	25.36	48.76^{c}	0.79^{c}
	20-40	1.00^{a}	1.16^{c}	30.42	26.60^{a}	40.82	0.95
	40-60	1.20	1.28^{c}	30.94	30.16^{b}	36.42	0.99^{a}
$N_{120}P_0K_0$	0-10	0.34	0.46^{c}	24.68^{c}	20.26^{a}	54.26^{c}	0.73^{c}
	10-20	0.50	0.88^{c}	25.06^{c}	20.74^{c}	52.82^{c}	0.77^{c}
	20-40	1.12^{b}	1.26^{c}	31.54	26.66^{a}	39.42	0.98
	40-60	1.80^{c}	1.38^{c}	32.44	28.60	35.78	1.06
$N_{180}P_0K_0$	0-10	0.04	0.54^{c}	26.80	22.02	50.60^{a}	0.76^{c}
	10-20	0.56	1.46^{c}	29.44	22.64	45.90^{a}	0.89^{a}
	20-40	1.30^{c}	1.46^{c}	30.01	23.22	44.01	0.96
	40-60	2.14^{c}	1.54^{c}	31.12	27.12	38.08	1.06
$N_0P_{180}K_0$	0-10	1.12^{c}	1.28^{c}	28.20	25.94^{b}	43.46^{a}	0.92^{a}
	10-20	1.36^{c}	1.38^{c}	29.94	27.18^{b}	40.14	0.98
	20-40	2.40^{c}	1.44^{c}	30.16	31.08^{c}	34.92^{c}	1.08^{c}
	40-60	2.40^{c}	1.86^{c}	32.24	32.12^{c}	31.38^{b}	1.14^{c}
$N_{60}P_{180}K_0$	0-10	1.06^{c}	2.00	26.58^{a}	22.36	48.00	0.89
	10-20	1.20^{c}	2.32	27.60^{b}	23.06	45.82^{a}	0.94
	20-40	1.40^{c}	2.36	30.92	27.38^{b}	37.94^{a}	1.04^{b}
	40-60	1.50^{b}	2.44^{a}	32.28	28.62	35.16	1.08
$N_{120}P_{120}K_{120}$	0-10	0.10	1.22	26.68	22.76	49.24	0.79^{b}
	10-20	0.63	1.32^{c}	29.83	24.36	43.86	0.90
	20-40	0.98^{a}	1.33^{c}	32.66	25.86	39.17	0.99
	40-60	1.04	1.94^{c}	33.38	32.34^{c}	31.30^{b}	1.06
$N_{180}P_{60}K_{60}$	0-10	1.10^{c}	0.78^{c}	27.10	24.20	46.82	0.87
	10-20	1.10^{b}	1.27^{c}	28.56^{a}	25.68	43.39	0.92
	20-40	1.25^{b}	2.34	30.44	27.82^{c}	38.15	1.02^{a}
	40-60	1.48^{b}	2.42^{a}	31.08	30.88^{b}	34.14	1.07
Gd	*5%*	*0.42*	*0.37*	*1.80*	*1.82*	*3.08*	*0.04*
	1%	*0.57*	*0.50*	*2.45*	*2.48*	*4.19*	*0.06*
	0.1%	*0.77*	*0.68*	*3.31*	*3.35*	*5.65*	*0.08*

$^{a, b, c}$ – significance of variations at P= 5%, 1% and 0.1%

Table 7. Statistical groups of the investigated fertilization variants by amount of structural units (Duncan, N=8)

Fertilization variant	Groups			
	a	b	c	d
Structural soil units >5 mm				
$N_{180}P_0K_0$	21.02			
$N_{120}P_0K_0$	21.97	21.97		
$N_{60}P_0K_0$		23.30	23.30	
$N_0P_0K_0$		23.56	23.56	
$N_{120}P_{120}K_{120}$		23.98	23.98	
$N_{180}P_{60}K_{60}$			24.75	
$N_{60}P_{180}K_0$				26.91
$N_0P_{180}K_0$				28.25
Structural soil units 5-3 mm				
$N_{60}P_{180}K_0$	13.27			
$N_{60}P_0K_0$	14.36	14.36		
$N_{120}P_{120}K_{120}$	14.65	14.65		
$N_0P_0K_0$	14.83	14.83	14.83	
$N_{120}P_0K_0$	14.95	14.95	14.95	
$N_{180}P_0K_0$		15.59	15.59	
$N_0P_{180}K_0$		15.76	15.76	
$N_{180}P_{60}K_{60}$			16.89	
Structural soil units 3-1 mm				
$N_{180}P_{60}K_{60}$	25.64			
$N_{60}P_{180}K_0$		28.02		
$N_{120}P_{120}K_{120}$		28.33		
$N_{120}P_0K_0$		28.47		
$N_{60}P_0K_0$		28.53		
$N_{180}P_0K_0$		28.78		
$N_0P_{180}K_0$		29.14		
$N_0P_0K_0$		29.83		
Structural soil units 1-0.25 mm				
$N_0P_{180}K_0$	20.93			
$N_0P_0K_0$		25.53		
$N_{60}P_{180}K_0$		25.70		
$N_{60}P_0K_0$		26.31		
$N_{180}P_{60}K_{60}$		26.55		
$N_{120}P_{120}K_{120}$		26.81		
$N_{120}P_0K_0$		27.04		
$N_{180}P_0K_0$		27.13		
Structural soil units <0.25 mm				
$N_0P_{180}K_0$	5.92			
$N_{60}P_{180}K_0$	6.10			
$N_{180}P_{60}K_{60}$	6.17			
$N_{120}P_{120}K_{120}$	6.23			
$N_0P_0K_0$	6.26			
$N_{180}P_0K_0$	7.49			
$N_{60}P_0K_0$	7.50			
$N_{120}P_0K_0$	7.58			

Table 8. Statistical groups of the investigated fertilization variants by amount of water sustainable soil units (Duncan, N=8)

Fertilization variant	Groups				
	a	b	c	d	e
Water sustainable soil units >5 mm					
$N_0P_0K_0$	.46				
$N_{120}P_{120}K_{120}$	.69	.69			
$N_{60}P_0K_0$	.75	.75	.75		
$N_{120}P_0K_0$	.94	.94	.94		
$N_{180}P_0K_0$	1.01	1.01	1.01		
$N_{180}P_{60}K_{60}$		1.23	1.23		
$N_{60}P_{180}K_0$			1.29		
$N_0P_{180}K_0$				1.82	
Water sustainable soil units 5-3 mm					
$N_{60}P_0K_0$	.97				
$N_{120}P_0K_0$	.99				
$N_{180}P_0K_0$	1.25				
$N_{120}P_{120}K_{120}$	1.45				
$N_0P_{180}K_0$	1.49				
$N_{180}P_{60}K_{60}$	1.70				
$N_{60}P_{180}K_0$	2.28				
$N_0P_0K_0$	2.42				
Water sustainable soil units 3-1 mm					
$N_{60}P_0K_0$	27.44				
$N_{120}P_0K_0$	28.43	28.43			
$N_{180}P_{60}K_{60}$	29.30	29.30	29.30		
$N_{180}P_0K_0$	29.34	29.34	29.34		
$N_{60}P_{180}K_0$	29.35	29.35	29.35		
$N_0P_{180}K_0$		30.14	30.14		
$N_{120}P_{120}K_{120}$			30.64		
$N_0P_0K_0$			30.72		
Water sustainable soil units 1-0.25 mm					
$N_{180}P_0K_0$	23.75				
$N_{120}P_0K_0$	24.07	24.07			
$N_0P_0K_0$	24.76	24.76	24.76		
$N_{60}P_{180}K_0$	25.36	25.36	25.36	25.36	
$N_{60}P_0K_0$		25.78	25.78	25.78	
$N_{120}P_{120}K_{120}$			26.33	26.33	
$N_{180}P_{60}K_{60}$				27.15	
$N_0P_{180}K_0$					29.08
Water sustainable soil units <0.25 mm					
$N_0P_{180}K_0$	37.48				
$N_{180}P_{60}K_{60}$		40.63			
$N_{120}P_{120}K_{120}$		40.89			
$N_0P_0K_0$		41.65			
$N_{60}P_{180}K_0$		41.73			
$N_{180}P_0K_0$			44.65		
$N_{60}P_0K_0$			45.07		
$N_{120}P_0K_0$			45.57		

In the surface layer the amount of water sustainable soil units with size <0.25 cm was again highest in the variant with independent nitrogen fertilization (Table 6). In the other fertilization variants the amount of fractions >5 and 5-1 mm was higher.

In the 10-20 cm layer the amount of structural units with size less than 1 mm decreased and the amount of the >5 mm and 5-1 mm fractions increased in all fertilization variants.

The water sustainable structural units with size >5 mm increased their percent in the 20-40 cm layer in all investigated fertilization variants. The water sustainable structural units with size <0.25 mm were most numerous in the variants with independent nitrogen fertilization.

In the 40-60 cm layer the fractions with size >5 mm and 5-0.25 mm increased their percent of fractions, and the percent of the <0.25 fractions decreased in all investigated fertilization variants.

The mean weighted diameter of the water sustainable structural units in the 0-10 cm layer had highest values after independent phosphorus fertilization. The variants with various combinations of nitrogen, phosphorus and potassium followed it.

The investigated index increased in the 10-20 cm layer in all fertilization variants. It had lowest values in this horizon in the variants with independent nitrogen fertilization.

At depth 20-40 cm the highest value of the mean weighted diameter of water sustainable structural units was in the N0P180K0 variant, followed by the combinations N60P180K0 and N180P60K60.

The investigated index in the 40-60 cm layer had highest values again in the variant with independent phosphorus fertilization.

Depending on the structural unit composition and the water sustainability of the soil units, the investigated fertilization variants were divided into 4 and 5 respective statistical groups (Tables 7 and 8). With regard to fractions <0.25 mm (in the structural units) and 5-3 mm (in the water sustainable soil units), the investigated variants did not differ between themselves. Fractions 3-1 and 1-0.25 mm (in the structural soil units) were divided into two groups, which confirmed the unfavorable effect of long-term usage of higher nitrogen doses on the soil structure. Fractions 5-3 mm (in the structural units), 3-1 mm and <0.25 mm (in the water sustainable units) were divided into three groups. A clear tendency of the effect of the investigated fertilization variants on the soil structure and the water sustainability of the soil structural units was not observed in them.

Concerning the fraction with size >5 mm (in both structural and water sustainable soil units), the investigated fertilization variants were divided into 4 statistical groups. In both groups there was a clear tendency of a favorable effect of the independent phosphorus fertilization and its combinations with nitrogen and potassium on the investigated factors. The highest differentiation was observed in the 1-0.25 mm fraction (in the water sustainable units), where the used fertilization variants were statistically divided into 5 groups. The fertilization variants based on different nitrogen, phosphorus and potassium ratios as well as the independent phosphorus fertilization contributed to the increase of this fraction. According to Alov (1960), the structural units with size 0.5–1 mm are also capable of making the ploughing layer structure favorable for plant nutrition and development.

DISCUSSION AND CONCLUSIONS

First trial

The effect of the tillage systems on the structure unit composition of soil is determined by they way they are performed, by the tools used and the number of operations in the respective element or technological process.

The reason for the greater amount of the 1-0.25 mm and <0.25 mm structural units in the 0-10 cm layer in the systems with dusking, were the constant soil tillage operations done at the same depth. These operations, though few in number within the same year, lead to increasing destruction of the soil structure in comparison to annual ploughing, a tendency determined by other researchers as well (Klochkov, 1983; Hristov, 1995). The deteriorated soil structure at direct sowing and tillage without turning of plow layer in this horizon is determined by the processes of physical and chemical erosion of the surface layer exposed to the constant destructive effects of temperature variations, the kinetic energy of rainfalls and their chemical influence.

The comparatively low rate of crumbling in безобръщателни обработки and the elimination of the mechanical impact in nil and minimal tillage in the 10-20 cm layer led to decrease and exclusion of the destructive effect of tillage on the soil structure. As a result the percent of agronomically valuable structural units increased. The same tendency was observed in the systems with ploughing, although expressed to a lower degree.

Annual ploughing, accompanied by multiple additional tillage and constant vertical disturbance of the cultivated horizon, together with the mechanical destruction of soil by the soil tillage tools led to destabilization of the structural soil units along the depth profile through acceleration of the organic substance mineralization.

The higher amount of 5-3 mm structural units in the systems ploughing–ploughing and cutting–cutting was the reason for the higher value of the mean weighted diameter of the dry structural units in the 0-10 cm. The lower level of this index in the systems with disking was due to the higher percent of structural units with size 1-0.25 mm and <0.25 mm.

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

At depth 20-40 cm the higher value of the mean weighted diameter of the dry structural units in constant nil tillage and annual disking was a result from the percent increase of the >5 mm and 5-3 mm fractions. In the systems cutting–cutting, ploughing–ploughing and ploughing–disking the levels of the investigated index also increased in comparison to the upper horizon since the percent of the large-sized fraction (>5mm) also increased.

The lower value of the mean weighted diameter of the dry structural units in the systems with ploughing in the 40-60 cm layer was due to the decrease of the 5-3 mm fraction in comparison to the other soil tillage systems. The values of the investigated index in direct sowing, annual disking and constant cutting resulted from the increased percent of the >5 mm fraction.

The percent of water sustainable soil units did not characterize so much the differences in the amount of the crumbled soil units as it highlighted the degree of weakening of the forces which held together the particles into structural elements under the influence of the used soil tillage, and the strengthening of their connection when the soil layer was not disturbed.

In the 0-10 cm layer the greater amount of the <1 mm fractions and the simultaneous decrease of the large-sized structural units in constant disking showed that this type of tillage caused soil dispersion in the surface layer. The comparatively low rate of crumbling in the system cutting–cutting and the elimination of the mechanical impact in nil tillage decreased the harmful effect of soil tillage on the water sustainability of the structural units.

At depth 10-20 cm the amount of large-sized structural units in constant disking increased probably as a result from the fact that at this depth the soil formed a subsoil horizon not disturbed by the soil tillage tools. The elimination of the mechanical impact of the tillage tools on soil along the depth profile in all investigated tillage systems and the decreased mineralization processes as a result from the reduced air circulation led to conditions which allowed preserving of the soil structure and restructuring of the soil particles in these horizons.

The higher values of the mean weighted diameter of the water sustainable units in the 0-10 cm layer at annual ploughing alternated with disking of autumn crops resulted from the greater amount of the 3-1 mm structural units. The low percent of the units with size 3-1 mm in the system disking–disking was the reason for the lowest value of the mean weighted diameter of the water sustainable structural units in this horizon.

The value of the mean weighted diameter of water sustainable units in the 10-20 cm layer in annual direct sowing, constant disking and cutting increased due to the higher percent of the 5-3 mm and 3-1 mm fractions in the upper layer. This index decreased in ploughing due to the lower percent of the >5 mm fractions.

The higher value of the mean weighted diameter of water sustainable structural units in the system nil tillage–nil tillage and disking–disking 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.

In the 40-60 cm layer the mean weighted diameter of water sustainable units in all investigated systems decreased in comparison to the upper layer because the percent of the 5-1 mm soil units decreased.

Second trial

The effects of fertilization on the structural unit composition and the water sustainability of the structural units are determined by the type of fertilizers, and the amounts and combinations used.

The greater amount of structural units with size 1-0.25 mm and <0.25 mm in the 0-10 cm layer in the variants with independent nitrogen fertilization was probably due to the more intensive processes of mineralization of the organic substance.

The lower mineralization rate in the variant with N0P180K0 in the 10-20 cm layer decreased and eliminated the destructive effect of fertilization on the soil structure. The percent of agronomically valuable structural units increased as a result.

The independent annual fertilization with nitrogen destabilized the structural units along the depth profile due to the more intensive mineralization of the organic substance.

The greater amount of >5 mm structural units in independent phosphorus fertilization was the reason for the high value of the mean weighted diameter of dry structural units in this variant in the 0-10 cm layer. The lower level of the index in the variants with independent nitrogen fertilization was due to the higher percent of structural units with size 1-0.25 mm and <0.25 mm.

The value of the mean weighted diameter of dry structural units in independent nitrogen fertilization in the 10-20 cm layer increased due to the greater amount of the large-sized fraction (>5 mm).

At depth 20-40 cm, as a result from the percent increase of the >5 mm fraction, the value of the mean weighted diameter of dry structural units at annual independent phosphorus fertilization was highest. In the variants with N60P0K0, N120P0K0 and N180P0K0, the investigated index increased because the percent of the 5-1 mm structural units also increased.

The decrease of the structural units with size > 5 mm in the 40-60 cm layer was the reason for the lowest value of the mean weighted diameter of dry structural units in the variant with N180P0K0. The values of the investigated index were higher in comparison to the upper horizon because the percent of the 5-1 mm fraction increased.

The decreased amount of large-sized water sustainable structural units and the increased amount of the <1 mm fraction in the variants with N60P0K0, N120P0K0 and N180P0K0 showed that long-term independent nitrogen fertilization caused soil dispersion in the surface layer.

In the lower layers the probable weaker mineralization processes as a result from the reduced air circulation created conditions favorable for the preservation of the soil structure and restructuring of the soil units.

The high values of the mean weighted diameter of water sustainable units in the 0-10 cm layer at independent phosphorus fertilization were due to the greater amount of structural units with size >5 mm. The lower content of structural units with size 5-1 mm in the variants with constant independent nitrogen fertilization led to lower values of the investigated index.

The mean weighted diameter of the water sustainable units increased in the 10-20 cm layer in all investigated fertilization variants because of the increased percent of the >5 mm and 5-3 mm fractions.

At depth 20-40 cm, as a result from the higher percent of the >5 mm and 5-3 mm fractions in comparison to the other fertilization variants the values of the mean weighted diameter of water sustainable structural units in the variants with N0P180K0, N60P180K0 and N180P60K60 was highest.

In the 40-60 cm layer the mean weighted diameter of water sustainable units in all investigated fertilization variants increased in comparison to the upper layers because the percent of the <0.25 mm structural units increased.

In the systems including annual tillage with plowshare accompanied with multiple additional plough tillage and constant disturbance of the vertical order of the cultivated horizon, the mechanical destruction of soil by the soil tillage tools combined with accelerated mineralization of the organic substance destabilized the soil structural units and decreased the percent of water sustainable units along the depth of the cultivated profile.

The constant shallow tillage with disking harrow at the same depth deteriorated the structure of soil in the surface layer (0-10 cm). The worsened soil structure at direct sowing and tillage without turning of plow layer was determined by the processes of physical and chemical erosion to which this horizon was subjected.

The low crumbling rate at cutting and the elimination of the mechanical effect at depth below 10 cm in minimal and nil tillage combined with lower mineralization processes as a result from reduced air circulation decreased or eliminated the destructive effect of these tillage systems on the soil structural units. In the lower levels of the ploughing horizon these types of soil tillage caused restructuring and increased water sustainability of the soil units.

The effects of fertilization on the structural unit composition and the water sustainability of the structural units of soil were determined by the norm and ratio of the macro elements in the fertilization combination.

The decreased amount of the larger-sized structural and water sustainable units and the increased amount of the <1 mm fractions in the variants with independent nitrogen fertilization showed that their long-term usage with increasing norms destabilized the soil structural units along the depth profile. At the same time the independent phosphorus fertilization contributed significantly to the increase of the economically valuable structural units.

The combined mineral fertilization with N60P180K0 and N180P60K60 contributed to the restructuring of soil in the root-deep layer (0-60 cm) and only slightly conceded to the positive effect of independent phosphorus fertilization with 180 kg/ha.

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