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IMPACT OF DIFFERENT TILLAGE SYSTEMS AND ORGANO-MINERAL FERTILIZATION ON SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS IN THE MOLDAVIAN PLAIN

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ABSTRACT - The investigations conducted during 1998 – 2008 followed the influence of different soil tillage systems on crop yield and soil chemical and physical characteristics. Trials were set up in split–split plots on a typical Cambic Chernozem of clayey-loam texture, mean humus content (3.2 %), weakly acid reaction and mean supply in mineral elements. After 11 years of experiences, ploughing to a depth of 20 cm has resulted in settling the soil layer at depth of 19-25 cm, causing the increase in apparent density to 1.52 g/cm^3, the decrease in total porosity to 43.3 % and the increase in compaction degree until 16.2 % of the volume. In case of the tillage system with chisel and paraplow, the mean yields obtained in the last 10 years were lower by 2-5% (53-145 kg/ha) in wheat, by 4-5% (202-282 kg/ha) in maize and by 4-8% (106-206 kg/ha) in soybean, in comparison with ploughing to a depth of 20 cm. At soil tillage with chisel + disk in maize crop, the percent of hydrostable aggregates from soil, at depth of 0-30 cm was by 15% higher, in comparison with ploughing to a depth of 20 cm. Soil tillage with chisel and paraplow determined the increase by 5.5 mg/kg (12%) and 16.0 mg/kg (7.0%), respectively, in mobile phosphorus and potassium content from soil, in comparison with ploughing to a depth of 20 cm, due to improved soil physical characteristics. At soil tillage with chisel and paraplow, the content of organic carbon from soil was higher by 0.33-0.38 g/kg, in comparison with ploughing to a depth of 20 cm.

Key words: conservation tillage, fertilization, manure, crop residues, organic carbon, wheat, maize

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REZUMAT - Impactul diferitelor sisteme de lucrare a solului si de fertilizare organo-minerală asupra însuşirilor fizice şi chimice ale solului în Câmpia Moldovei. Cercetările efectuate în perioada 1998-2008 au urmărit influența diferitelor metode de lucrare a solului asupra producției şi a însuşirilor fizice şi chimice ale solului. Experiențele au fost amplasate după metoda parcelelor subdivizate pe un sol de tipul cernoziom cambic tipic, cu textură luto-argiloasă, cu un conținut mediu de humus (3.32 %), cu o reacție slab acidă şi cu o asigurare mijlocie în elemente minerale. După 11 ani de experimentare, efectuarea arăturii la adâncimea de 20 cm a determinat tasarea stratului de sol, la adăncimea de 19 -25 cm, determinând creşterea densitătii aparente la 1.52 g/cm^3, scăderea porozității totale la 43.3 % şi creşterea gradului de tasare pană la 16.4 % din volum. La lucrările solului efectuate cu cizelul si paraplowul, producțiile medii obtinute în ultimii 10 ani au fost mai mici, comparativ cu arătura la 20 cm adăncime, doar cu 2-5% (53-145 kg/ha) la grău, 4-5% (202-282 kg/ha) la porumb şi cu 4-8% (106-206 kg/ha) la soia. La lucrarea solului cu cizelul + discul, la cultura porumbului, procentul de agregate hidrostabile din sol, pe adâncimea de 0-30 cm, a fost mai mare, comparativ cu arătura la 20 cm, cu 15% **.** Lucrările solului cu cizelul şi paraplowul au determinat creşterea conținutului de fosfor si potasiu mobil din sol, în comparație cu arătura la 20 cm, cu 5.5 mg/kg (12%) şi, respectiv, cu 16.0 mg/kg (7.0%) datorită îmbunătățirii însuşirilor fizice ale solului. La lucrările executate cu cizelul şi cu paraplowul, conținutul de carbon organic din sol a fost mai mare, comparativ cu sistemul convențional cu arătura la 20 cm, cu 0.33 -0.38 g/kg.

Cuvinte cheie: lucrări de conservare a solului, fertilizare, gunoi de grajd, resturi vegetale, carbon organic, grâu, porumb

INTRODUCTION

The conventional system with annual ploughing, carried out at the same depth and with repeated treatments for seedbed preparation with disk- harrows, has negative consequences on some soil physical characteristics: mechanical and water stability of aggregates, porosity, infiltration capacity, hydraulic conductivity, water holding capacity, stratification of organic matter and nutrients, activity and diversity of edaphic flora and fauna, carbon biomass, soil water and temperature regime (Angers, 1997, Oswaldo E., 2006, Ulrich, S.A., 2006, Jităreanu, G. 2007, 2008, Rosner, J., 2008).

Because the farming conventional systems have caused soil degradation in many countries, the technologies concerning the mechanization of agricultural practices must be adapted to the requirements concerning soil and water protection, and soil conservation practices are necessary in the areas with more sensitive soils to degradation, (Guş, 1998; Sandoiu, 1996; Sin, 2000; Lal, 2006). Soils tilled at time, differentiated according to the requirements of crop rotations, to climatic conditions, contribute to the improvement of soil physicochemical characteristics, to the diminution of weed infestation degree, allow manure and crop residue incorporation.

In the last period, the goal of many studies carried out in different countries was to improve the technological elements concerning soil fertilization, tillage and rotations with perennial grasses and legumes, which determine the increase in the content of organic carbon from soil and the diminution in the effect of greenhouse gases.

For protecting soils across the EU, the European Commission, by the Framework Directive for the protection of soil (SFD) (COM 232, 2006), considers that the organic matter decline is one of the main threats affecting soil degradation.

The adoption of good agricultural practices, e.g. improving rotation with forage crops, returning crop residues to soil, minimum tillage, growing of green manure crops and supplying soil with organic matter (compost, manure, etc.), determines the increase in the content of organic matter from soil and maintains the ecological and socio-economic functions of soil and yield sustainability.

The investigations carried out on a Gray Luvisol in north-western Alberta, Canada, which has a sandy loam texture (distribution of the average particle size in the 0-15 cm layer is 650 g kg^{-1} sand, 220 g kg^{-1} silt and 130 g kg^{-1} clay) have shown that after 12 years, the content of organic carbon was influenced by the quantity of crop residues, which remained in soil from red clover, peas and wheat crops, and by the quality of crop residues, as concerns the C:N ratio and lignin content (Soon and Arshad, 2006).

The content of organic carbon in the shallow layer (0-10 cm) on Gleyc Luvisol with sandy loam texture from Halle, Germany, after 37 years of applying different soil tillage systems, was differentiated from 10.0 g/kg, under the conventional system with ploughing to a depth of 25 cm to 14.9 g/kg at chisel tillage to a depth of 25 cm and, respectively, to 13.2 g/kg under no-tillage (Ulrich, S., 2006). At depth of 0-20 cm, the content of organic carbon was of 10.2 g/kg at ploughing to a depth of 25 cm, 12.7 g/kg at chisel tillage and 11.6 g/kg, under no-tillage.

In Austria, between 1994 and 2007, the mean soil losses in the three locations decreased from 6.1 t/ha/year to 1.8 t/ha/year with conservation tillage in cover crops, and to 1.0 t/ha/year with direct drilling. Nitrogen (9.2, 3.7, 2.5 kg/ha/year) and phosphorus (4.7, 1.3, 0.7 kg/ha/year) losses showed similar tendencies (Rosner et al. 2008).

Soon and Arshad (2006) show that after applying no-till system for 12 years on sandy-clayey fields from north-western Alberta, Canada, the content of organic carbon and total nitrogen from soil increased by 1.9 g C kg^{-1} soil and 0.20 g N kg^{-1} soil, respectively, in comparison with the conventional tillage.

Other authors show that in the cold and humid areas, the content of organic carbon and nitrogen from soils with sandy-loam texture is less influenced by the tillage system, because of a lower decomposition of the organic matter. Thus, Franzluebbers and Arshad (1996) assess that in the cold areas with subhumid climate from north-western Canada, the content of organic carbon has recorded only after 16 years higher values at no-till, in comparison with the conventional system. Angers et al. (1997) found that in the sandy loam soils from cold and humid regions from Canada, at depth of 60 cm, the carbon content from soil was not significantly differentiated at no-till, chisel and mouldboard practices.

Many studies carried out in different areas with different soil and climatic conditions followed the establishment of some soil tillage and fertilization systems, which contribute to the diminution of soil erosion and of mineral element losses in the agricultural environment (McGregor, 1975; Sharpley, 1992; Franzluebbers, 2006). The studies carried out by Sharpley (1992), in El Reno, Oklahoma, with mean annual rainfalls of 740 mm, have shown that the use of no-till practice resulted in the diminution of the eroded soil from 12.8 Mg ha^{-1} to 0.4 Mg ha^{-1} and of phosphorus losses from 5.9 to 1.7 kg ha^{-1} yr^{-1}. In Woodward Oklahoma, of the total of 600 mm recorded rainfalls, the mean volume of runoff water due to erosion was of 17% at soil tilled with disk and 23% at no-till practice, while soil and phosphorus losses were of 39.6 Mg ha^{-1} and 14.9 kg ha^{-1} yr^{-1}, respectively, at disk tillage and 1.9 Mg ha^{-1} and 2.9 kg ha^{-1} yr^{-1} at no-till practice. In Mississippi, the soil losses by erosion were of 18 Mg ha-1 yr^{-1} at ploughing system and of 3.0 Mg ha-1 yr^{-1} at conservation tillage (McGregor et al., 1975, quoted by Alan J. Franzluebbers, 2006).

From the experiences carried out on two experimental fields from south-western Finland, they found that the use of no-till (direct drilling) determined, after 5 years, the pH diminution, at depth of 0-5 cm, from 6.3 to 6.0 on 59% clay soils, in the plough layer from Jokioinen and from 5.9 to 5.6 on 30% clay soils from Aurajoki, in comparison with the conventional tillage (Muukkonen, 2006). The content of organic carbon at depth of 0-5 cm in the plough layer has increased at no-tillage practice from 2.5% to 2.8% on fields from Jokioinen and from 1.8 to 3.1 in Aurajoki, in comparison with the conventional tillage. Other researchers show that in Finland, after 14 years of using conservation tillage, the content of organic carbon, at depth of 0-5 cm was by 8% higher than the one recorded at conventional tillage (Pitkänen, 1989). Similar results were obtained in other northern areas from Norway, where, after 13 years, the content of organic carbon, at depth of 0-5 cm has increased by 18% at reduced tillage, compared with the conventional system (Børresen and Njøs, 1993).

The investigations conducted by Lazarov showed that the mean annual rate of erosion on the arable lands from Bulgaria was of 4.76 t/ha and of 2.69 t/ha on improved arable lands. Soil losses by erosion on the fields ploughed on the upstream-downstream direction, which are cultivated with maize, are of 7.48 t/ha. In sunflower, cultivated with the conventional tillage system, the annual eroded soil was of 3.044 t/ha, and due to wheat straw and green fertilizer incorporation into soil, erosion decreased at 2.327 t/ha and 0.937 t/ha, respectively (Mitova, 2006).

MATERIALS AND METHODS

Investigations conducted during 1998-2008 on a Cambic Chernozem at the Agricultural Research and Development Station of Podu-Iloaiei, Iaşi County, have followed the influence of different soil tillage systems and fertilizers on yield, in soybean, wheat and maize crops, and of soil agrochemical characteristics.

The typical Cambic Chernozem from Podu-Iloaiei was formed on a loessy loam, has a mean humus content (3.1-3.4%), is well supplied with mobile potassium (215-235 ppm) and moderately supplied with phosphorus (28-35 ppm) and nitrogen (0.160-0.165%). Experiments were set up in split-split plots with four replicates. Soil has a high clay content (39-41%) being difficult to treat when soil moisture is close to the wilting coefficient (12.2 %). In wheat, we have used the Gabriela variety, and in maize, the Oana hybrid.

Physical and chemical analyses of soil samples were carried out according to the methods established by the Research Institute of Bucureşti, which are applied by all the agrochemistry laboratories from Romania. The soil on which physical and chemical analyses were done was sampled at the end of plant growth period.

Soil response was determined in water suspension by potentiometrical means with glass electrode.

The content of organic carbon was determined by the Walkley-Black method, to convert SOM into SOC it was multiplied by 0.58 (Nelson and Sommers, 1982), the content in mobile phosphorus from soil was determined by Egner-Riechm Domingo method, in solution of ammonium acetate-lactate (AL) and potassium was measured in the same extract of acetate-lactate (AL) at flame photometer.

RESULTS AND DISCUSSION

The results obtained under different soil and climate conditions showed that the conservation tillage and, especially, the no-tillage system contributed to the improvement of physical, chemical and biological characteristics of soil (Jităreanu et al., 2006; Rusu et al., 2008).

On moderately fertile Fluvisol from Cluj-Napoca, Romania, with a content of 46.6-51.1% clay in the layer of 0-40 cm, the resistance to penetration recorded values comprised between 12.14 and 31.65 kgf/cm^2 at conventional tillage and between 13.27 and 31.72 kgf/cm^2 at minimum tillage (Rusu et al., 2008). At the classic tillage and at depth of 0-20 cm, the values of the compaction degree show a moderate loosening (1.9-3.8%), while in all the variants with minimum tillage, the compaction degree had values below 11%.

The content of hydrostable macro-aggregates has increased by 0.1-2.2%, at depth of 0-10 cm and by 4.9-5.2% at the soil layer of 0-30 cm, in case of minimum tillage, compared to classic tillage system. The humus content from soil, recorded after 4 years of applying no-till system (3.12-3.52%), in 4-year crop rotation (maize-soybean-winter wheat-potato/rape), has increased by 0.41%, compared with the ploughed variant (3.11%) (Rusu et al., 2008). On the Fluvisol from the Transylvanian Plain, replacing the classic tillage system with paraplow or chisel or rotary hoe determined the diminution in the fuel consumption by 64.1-91.4% in wheat, 52.7-91.6% in maize and 58.6-97.0% in soybean. The obtained yields at minimum tillage were close to the ones obtained at plough tilled variant, in wheat (95.1-98.2%), soybean (96.4-101.6%) and rape (94.8-97.8%) and lower in maize (92.1-97.9%) and potato (82.4-93.4%).

In the Moldavian Plain, rainfall registered during January-June (1999-2008) assured normal conditions for wheat growing in 5 years. Rainfall amounts were lower, compared to the multiannual mean on 81 years (248 mm) in 5 years, when the rainfall deficit was between 53.3 and 119.0 mm. The climatic conditions during 1999-2008 were favourable to maize growth and development in 5 years and unfavourable, due to low rainfall amounts, in the other 5 years. In the last 10 years, the deficit of rainfall recorded during January-August, compared to the multiannual mean of the area, was between 31.4 and 136.9 mm in 5 years. The drought recorded in autumn and during January-August required the adjustment of soil preparation practices to the requirements of soil and water conservation.

Table 1 - Influence of soil tillage system and fertilization on wheat yield (kg/ha)

Soil tillage	N_0P_0	$N_{80}P_{80}$+ 6 t/ha wheat straw	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$+ 30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	1920	3060	3437	3693	3770	**3176**	100	0
30 cm ploughing + disk	1997	3388	3827	4050	4081	**3469**	109	293
Chisel + disk	1950	2919	3388	3653	3705	**3123**	98	-53
Paraplow + disk	1790	2853	3233	3627	3650	**3031**	95	-145
One year ploughing, one year disking	1727	2873	3202	3359	3500	**2932**	92	-244
Mean	**1877**	**3019**	**3417**	**3676**	**3741**	**3146**		
%	100	161	182	196	199			
Difference kg/ha	0	1142	1541	1800	1865			

	Soil tillage (A)	Fertilizer (B)	Interaction AxB
LSD 5%	184	118	300
LSD 1%	268	157	413
LSD 0.1%	402	207	568

The mean wheat yields obtained during 1999-2008 in the variant ploughed to a depth of 20 cm were of 3176 kg/ha and in case of seedbed preparation by paraplow + disk and by repeated disking, the yields obtained were lower by 5.0% (145 kg/ha) and by 8.0 % (224 kg/ha), respectively, as compared to ploughing to a depth of 20 cm (*Table 1*). At the same period, the mean wheat yields obtained under unfertilized were of 1877 kg/ha and the rates of N_{120} + 80 kg/ha P_2O_5 or

N_{160} + 80 kg/ha P_2O_5 resulted in getting yield increases of 82 % (1541 kg/ha) and 96% (1800 kg/ha), respectively. The application in wheat of a rate of N_{80} + 80 kg/ha P_2O_5 + 30 t/ha manure has resulted in getting yield increases of 99 % (1865 kg/ha).

In maize, ploughing to a depth of 30 cm has determined yield increases of 10 % (512 kg/ha), compared to ploughing to a depth of 20 cm, and in case of paraplow + disk, the obtained yields were by 5.0 % lower (282 kg/ha). Soil treatment by disk alone has resulted in yield diminution by 9.0 % (468 kg/ha) (*Table 2*). In maize, the fertilizers applied at rates of N_{80} + 80 kg/ha P_2O_5 + 6 t/ha wheat straw or N_{80} + 80 kg/ha P_2O_5 + 30 t/ha manure have determined yield increases between 78% (2377 kg/ha) and 98 % (2974 kg/ha). In maize, the fertilizers were better valorised under conditions of soil tillage at greater depths (ploughing to a depth of 30 cm; chisel + disk), where yield increases have varied between 83 and 122 % (2520-3703 kg/ha), according to rates.

Table 2 - Influence of soil tillage system and fertilization on maize yield (kg/ha)

Soil tillage	N_0P_0	$N_{80}P_{80}$+ 6 t/ha wheat straw	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$+ 30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	3145	5560	5620	6070	6103	**5300**	100	0
30 cm ploughing + disk	3178	5843	6293	6890	6855	**5812**	110	512
Chisel + disk	3037	5367	5480	5787	5820	**5098**	96	-202
Paraplow + disk	2933	5217	5413	5717	5810	**5018**	95	-282
One year ploughing, one year disking	2900	5090	5260	5433	5477	**4832**	91	-468
Mean	**3039**	**5415**	**5613**	**5979**	**6013**	**5212**		
%	100	178	185	197	198			
Difference kg/ha	0.0	2377	2575	2941	2974			

	Soil tillage (A)	Fertilizer (B)	Interaction AxB
LSD 5%	167	145	278
LSD 1%	243	229	383
LSD 0.1%	364	332	528

In soybean, ploughing to a depth of 30 cm has determined yield increases of 10 % (251 kg/ha), compared to ploughing to a depth of 20 cm, and in case of paraplow + disk, the yields obtained were lower by 8.0 % (206 kg/ha) (*Table 3*). In soybean, the mean yields obtained at paraplow and chisel + disk tillage were very close and in case of soil tillage with disk, the obtained yields diminished by 10.0 % (239 kg/ha). In soybean, the obtained yield increases were between 43 % (654 kg/ha) at a rate of N_{60} + 60 kg/ha P_2O_5 and 96 % (1454 kg/ha) at a rate of N_{60} + 60 kg/ha P_2O_5+ 30 t/ha manure, compared to the unfertilized variant.

Table 3 - Influence of soil tillage system and fertilization on soybean yield (kg/ha)

Soil tillage	N_0P_0	$N_{60}P_{60}$	$N_{60}P_{60}$+ 6 t/ha wheat straw	$N_{90}P_{60}$	$N_{60}P_{60}$+ 30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	1663	2037	2570	2848	3123	**2448**	100	0
30 cm ploughing + disk	1750	2517	2730	3177	3325	**2700**	110	251
Chisel + disk	1472	2117	2497	2599	3027	**2342**	96	-106
Paraplow + disk	1371	2087	2437	2610	2709	**2243**	92	-206
One year ploughing, one year disking	1320	2092	2423	2552	2660	**2210**	90	-239
Mean	**1515**	**2170**	**2531**	**2757**	**2969**	**2389**		
%	100	143	167	182	196			
Difference kg/ha	0.0	654	1016	1242	1454			
	Soil tillage (A)	**Fertilizer (B)**	**Interaction AxB**					
LSD 5%	133	142	302					
LSD 1%	194	206	416					
LSD 0.1%	291	297	573					

Table 4 - Soil bulk density in maize, placed under different variants of soil tillage and fertilization (0-30 cm)

Soil tillage	N_0P_0	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$ +6 t/ha wheat straw	$N_{80}P_{80}$+ 30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	1.36	1.34	1.33	1.32	1.31	**1.33**	100	0.000
30 cm ploughing + disk	1.34	1.33	1.32	1.31	1.30	**1.32**	99	-0.012^{0}
Chisel + disk	1.32	1.33	1.32	1.31	1.30	**1.32**	99	-0.015^{00}
Paraplow + disk	1.33	1.32	1.32	1.31	1.30	**1.32**	99	-0.017^{00}
One year ploughing, one year disking	1.37	1.36	1.35	1.33	1.32	**1.35**	101	0.015^{xx}
Mean	**1.34**	**1.34**	**1.33**	**1.32**	**1.31**	**1.33**		
%	100	99	99	98	97			
Difference	0.000	-0.007	-0.014	-0.027	-0.037			
	Soil tillage (A)	**Fertilizer (B)**	**Interaction AxB**					
LSD 5%	0.006	0.003	0.008					
LSD 1%	0.009	0.004	0.012					
LSD 0.1%	0.013	0.005	0.016					

The determinations of soil bulk density have shown that in maize crop, its values varied according to tillage system and applied fertilizers, between 1.31 and 1.37 g/cm^3 (*Table 4*). The highest values were recorded at ploughing to a depth of 20 cm, while at the 20-30 cm layer it was found a sudden increase in soil bulk density (1.40 g/cm^3). In maize, the greatest values of soil bulk density were recorded at ploughing to a depth of 20 cm, under unfertilized (1.36-1.37 g/cm^3), where the compaction degree has increased at 9.0-10 % of the volume, indicating a moderate compaction degree. The obtained results made us assess that the main limiting factors were weak compaction of horizon at depths of 18-28 cm (forming hardpan) and structure degradation at soil surface after repeated disking.

In maize, found in a 3-year crop rotation (soybean-wheat-maize), the percentage of hydrostable aggregates was less influenced by soil tillage (52.0-59.9%) and more by the applied fertilizers (51.7 – 59.8 %) (*Table 5*). In maize crop, the percentage of hydrostable aggregates has varied, according to applied fertilizer rates, between 49.5 and 57.8 % at ploughing to a depth of 20 cm, between 50.5 and 59.4 % at ploughing to a depth of 30 cm and between 57.8 and 64.9 % at chisel treatment. The highest percentage of hydrostable aggregates was recorded at the rate of N_{80} + 80 kg P_2O_5 +6 t/ha wheat straw (57.0%) and at organo-mineral fertilization ($N_{80}P_{80}$+30 t/ha manure, 59.8%).

Table 5 - The influence of soil tillage and fertilization on the hydrostability of soil aggregates (%) >0.25 mm

Soil tillage	N_0P_0	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$ +6 t/ha wheat straw	$N_{80}P_{80}$ +30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	44.2	49.5	53.6	54.9	57.8	**52.0**	100	0.0
30 cm ploughing + disk	52.6	50.5	53.9	56.9	59.4	**54.7**	105	2.8
Chisel + disk	55.3	57.8	60.2	61.5	64.9	**59.9**	115	8.1
Paraplow + disk	52.3	53.0	57.2	58.6	61.3	**56.5**	109	4.1
One year ploughing, one year disking	42.4	47.6	50.2	53.0	55.7	**49.8**	96	-5.1
Mean	**49.4**	**51.7**	**55.0**	**57.0**	**59.8**	**54.6**		
%	100	105	111	115	121			
Difference	0	2	6	8	10			
	Soil tillage (A)		**Fertilizer (B)**	**Interaction AxB**				
LSD 5%		3.5	1.7	4.8				
LSD 1%		5.1	2.2	6.6				
LSD 0.1%		7.6	3.0	9.0				

In case of chisel and paraplow tillage, the soil pH has shown a diminution tendency, which might be explained by lower decay of crop residues (*Table 6*). Applying high ammonium nitrate rates ($N_{120}P_{80}$- $N_{160}P_{80}$) has determined the pH decrease by 0.69 -1.07 units, compared to the unfertilized variant.

Table 6 - Evolution of soil response, 11 years after applying different fertilizer rates and soil tillage systems

Soil tillage	N_0P_0	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$+ 6 t/ha wheat straw	$N_{80}P_{80}$+ 30 t/ha manure	Mean	%
20 cm ploughing + disk	6.80	6.00	5.67	6.37	6.53	**6.3**	0.00
30 cm ploughing + disk	6.83	6.20	5.70	6.50	6.67	**6.4**	0.11
Chisel + disk	6.67	5.87	5.60	6.20	6.43	**6.2**	-0.12
Paraplow + disk	6.53	5.83	5.57	6.17	6.50	**6.1**	-0.15
One year ploughing, one year disking	6.77	6.27	5.70	5.57	6.70	**6.2**	-0.07
Mean	**6.72**	**6.03**	**5.65**	**6.16**	**6.57**	**6.2**	
%	100	90	84	92	98		
Difference	0.00	-0.69	-1.07	-0.56	-0.15		

	Soil tillage (A)	Fertilizer (B)	Interaction AxB
LSD 5%	0.12	0.11	0.26
LSD 1%	0.18	0.15	0.36
LSD 0.1%	**0.27**	0.19	0.49

After 11 years of experiencing, the mean content of mobile phosphorus from soil has recorded values comprised between 14.1 and 67.4 ppm, according to the fertilization system (*Table 7*). At chisel and paraplow tillage, the content of mobile phosphorus from soil was higher by 2.3 and, respectively, 5.5 ppm, compared to soil conventional system. A good plant supply with mobile phosphorus was recorded when applying rates of $N_{80}P_{80}$+6 t/ha straw or $N_{80}P_{80}$+30 t/ha manure, which improved soil hydro-physical characteristics.

The content of mobile potassium from soil has diminished once with the increase in applied nitrogen and phosphorus rates (*Table 8*). Chisel and paraplow tillage has determined the increase in mobile potassium content from soil by 9.0-16.0 mg/kg, as compared to ploughing to a depth of 20 cm, due to the improvement in soil physical characteristics. A good and a very good supply with mobile phosphorus from soil were achieved at the organo-mineral fertilization.

Table 7 - Mobile phosphorus content from soil (0-20 cm) at different soil tillage and fertilization systems (parts per million)

Soil tillage	N_0P_0	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$+ 6 t/ha wheat straw	$N_{80}P_{80}$ +30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	12.0	51.3	50.0	51.3	69.0	**46.7**	100	0.0
30 cm ploughing + disk	11.3	49.3	50.0	47.3	65.3	**44.7**	96	-2.1
Chisel + disk	18.3	60.0	56.7	57.3	69.0	**52.3**	112	5.5
Paraplow + disk	17.0	53.3	51.3	56.0	67.7	**49.1**	105	2.3
One year ploughing, one year disking	12.0	47.3	48.0	51.3	66.0	**44.9**	96	-1.8
Mean	**14.1**	**52.3**	**51.2**	**52.7**	**67.4**	**47.5**		
Difference	0.00	38.13	37.07	38.53	53.27			
	Soil tillage (A)	**Fertilizer (B)**	**Interaction AxB**					
LSD 5%	2.2	2.2	5.1					
LSD 1%	3.2	3.0	7.0					
LSD 0.1%	4.8	3.9	9.6					

Table 8 - Mobile potassium content from soil (0-20 cm) at different soil tillage and fertilization systems (parts per million)

Soil tillage	N_0P_0	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$+ 6 t/ha wheat straw	$N_{80}P_{80}$+ 30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	229	219	220	236	250	**231**	100	0
30 cm ploughing + disk	232	222	222	241	249	**233**	101	3
Chisel + disk	252	236	228	252	263	**246**	107	16
Paraplow + disk	244	231	223	247	255	**240**	104	9
One year ploughing, one year disking	225	217	217	231	246	**227**	98	-4
Mean	**237**	**225**	**222**	**241**	**252**	**235**		
%	100	95	94	102	107			
Difference	0.00	-11.73	-14.80	4.73	15.80			
	Soil tillage (A)	**Fertilizer (B)**	**Interaction AxB**					
LSD 5%	5	4	10					
LSD 1%	8	6	14					
LSD 0.1%	**11**	8	19					

The content of organic carbon in the shallow layer (0-20 cm) had values comprised between 18.09 and 19.73 g/kg at the fertilization with N_{120} + 80 kg/ha P_2O_5 and, respectively, $N_{80}P_{80}$+30 t/ha manure (*Table 9*). At chisel and paraplow tillage, the content of organic carbon from soil was higher by 0.33 -0.38 g/kg, compared with ploughing to a depth of 20 cm. Applying for 11 years moderate mineral fertilizer rates ($N_{80}P_{80}$), together with 6 t/ha wheat straw, has resulted in increasing the organic carbon from soil by 1.82 g/kg, compared to the unfertilized variant. The highest content of organic carbon was found at the rate $N_{80}P_{80}$+30 t/ha manure, where it increased by 2.69 g/kg, compared to the unfertilized control.

Table 9 - Evolution of the organic carbon content from soil, 11 years after applying different fertilizer rates and soil tillage systems (g/kg)

Soil tillage	N_0P_0	$N_{120}P_{80}$	$N_{160}P_{80}$	$N_{80}P_{80}$ +6 t/ha wheat straw	$N_{80}P_{80}$ +30 t/ha manure	Mean	%	Differ. kg/ha
20 cm ploughing + disk	16.87	18.13	18.40	18.87	19.87	**18.43**	100	0.000
30 cm ploughing + disk	16.70	17.90	18.07	18.63	19.63	**18.19**	99	0.013
Chisel + disk	17.57	18.47	18.43	19.13	20.00	**18.72**	102	0.380
Paraplow + disk	17.33	18.07	18.37	19.03	19.73	**18.51**	100	0.327
One year ploughing, one year disking	16.73	17.87	18.17	18.63	19.43	**18.17**	99	-0.327
Mean	**17.04**	**18.09**	**18.29**	**18.86**	**19.73**	**18.40**		
%	100	106	107	111	116			
Difference	0.00	1.05	1.25	1.82	2.69			
	Soil tillage (A)		**Fertilizer (B)**	**Interaction AxB**				
LSD 5%		0.164	0.156	0.361				
LSD 1%		0.239	0.209	0.497				
LSD 0.1%		0.359	0.275	0.685				

CONCLUSIONS

Soil preparation without furrow inverting has resulted in improving soil physical and hydro-physical characteristics and allowed a better valorisation of technological factors and, especially, of fertilizers (N_{160} +80 kg/ha P_2O_5 in wheat and maize, and N_{60}+60 kg/ha P_2O_5 in soybean), which determined greater yield increases by 87 % (1703 kg/ha) in wheat, by 91% (2750 kg/ha) in maize and by 77% (1127 kg/ha) in soybean, compared to the unfertilized control.

In case of the tillage system with chisel and paraplow, the mean yields obtained in the last 10 years were lower only by 2-5% (53-145 kg/ha) in wheat, by 4-5% (202-282 kg/ha) in maize and by 4-8% (106-206 kg/ha) in soybean, in comparison with ploughing to a depth of 20 cm.

At soil tillage with chisel + disk in maize crop, the percent of hydrostable aggregates from soil, at depth of 0-30 cm was by 15% higher, in comparison with ploughing to a depth of 20 cm.

Soil tillage with chisel and paraplow determined the increase by 5.5 mg/kg (12%) and 16.0 mg/kg (7.0%), respectively, in mobile phosphorus and potassium content from soil, in comparison with ploughing to a depth of 20 cm, due to improved soil physical characteristics.

At chisel and paraplow tillage, the content of organic carbon from soil was higher by 0.33-0.38 g/kg, in comparison with ploughing to a depth of 20 cm.

Applying moderate rates of mineral fertilizers ($N_{80}P_{80}$), together with 6 t/ha wheat straw or 30 t/ha manure, has determined, 11 years after using chisel, the increase in organic carbon content from soil by 1.56 and, respectively, 2.43 g/kg.

In soybean- wheat – maize rotation, the content of organic carbon from soil has increased after 11 years by 1.82 g/kg at rates of $N_{80}P_{80}$+6 t/ha wheat straw and by 2.69 g/kg at rates of $N_{80}P_{80}$+30 t/ha manure, compared to the unfertilized control.

Soil tillage by chisel and disk allowed soil treatment under better conditions for wheat growing in dry autumns, which are very frequent in the area.

The obtained results made us assess that soil tillage system must be adjusted to plant requirements from crop rotation and to soil and climatic conditions of the area. Establishing the systems of soil tillage for the whole crop rotation (disking or chisel + disk in wheat, ploughing to a depth of 20 cm in soybean and ploughing to a depth of 25-28 cm in maize) resulted in a better valorisation of the other technological factors, water conservation, maintaining soil physical condition and reduction, on the entire rotation cycle, of the fuel consumption.

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