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THE ROLE OF MINIMUM TILLAGE IN PROTECTING ENVIRONMENTAL RESOURCES OF THE TRANSYLVANIAN PLAIN, ROMANIA

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ABSTRACT

Conservative tillage systems tested in the hilly area of the Transylvanian Plain (Romania), confirms the possibility of improving the biological, physical, chemical and technologizcal properties of the soil. Conservative components include minimum tillage systems and surface incorporation of crop residues. The minimum tillage soil systems with paraplow, chisel or rotary harrow are polyvalent alternatives for basic preparation, germination bed preparation and sowing, for fields and crops with moderate loose requirements being optimized technologies for: soil natural fertility activation and rationalization, reduction of erosion, increasing the accumulation capacity for water and realization of sowing in the optimal period. The minimum tillage systems ensure an adequate aerial-hydrical regime for the biological activity intensity and for the nutrients solubility equilibrium. The vegetal material remaining at the soil surface or superficially incorporated has its contribution to intensifying the biological activity, being an important resource of organic matter. Humus content increases by 0.41%. The minimum tillage systems rebuild the soil structure (hydrostable macroagregate content increases up to 2.2% to 5.2%), improving the global drainage of soil which allows a rapid infiltration of water in soil. Water reserve, accumulated in the 0-50 cm depth is with 1-32 m^3 ha^{-1} higher in the minimum tillage variants. The result is a more productive soil, better protected against wind and water erosion and needing less fuel for preparing the germination bed.

Key words: minimum tillage, soil conservation, crop production.

INTRODUCTION

There is a tendency in extending the soil tillage alternatives, in order to preserve and improve the fertility feature of land that is increasingly manifested in the last 20 years. The technological systems for soil working have greatly developed in the last years, both in Romania as elsewhere, both in concepts and enlargement of conservatives' ways in soil management. Implementation of soil conservatives tillage differs from a country to another, depending on the mechanization possibilities and is developing with the increase of tractors and agriculture machinery capacities and with the diversification of equipments for soil loose, preparation and sowing (Budoi et al., 1997; Ştefanic et al., 1997; Şarpe et al., 1999; Gus et al., 2003; Rusu et al., 2009; Cociu, 2012).

Today, the conservatives tillage's (non-conventional) of soil are constitute from a wide variety of procedures, from direct sowing (no-tillage, direct drill) in a non-prepared soil to deep loosing without furrow tilt. Between those extremes, one can find: reduced tillage (classic, rationalized), minimum tillage (under 30% coverage), minimum tillage with vegetal mulch (over 30% coverage), ridge tillage, strip till or zone till, cover crops (catch crops) tillage etc. These terms indicate the specificity of the applied procedure at a certain time, in a certain area, according to the local specific (Ionescu, 1977; Griffith et al., 1992; Gheorghe et al., 1997; Săndoiu, 1999; Horn and Arvidsson, 2000; Moroizumi and Horino, 2002; Moraru and Rusu, 2013; Sin, 2013).

The sustainable development of agriculture has stated that there is no universally applicable system for soil tillage because of the local differences, especially climate and soil type and also the technical level of endowment (Domuta et al., 2012).

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The soil conservative systems in different areas have to show specific features according to ecological properties and to cultivated plants characteristics; thus, this systems must be applied in different ways (Sin and Ioniță, 1997; Canarache, 1999; Gus et al., 2004; Picu, 2005; Hera and Kleps, 2007; Dumitru et al., 1999; Cociu, 2011; Rusu et al., 2013; Wozniak et al., 2014).

The influence of soil tillage system on soil properties is proved by indices important to conservation of soil fertility and to evaluate the sustainability of agricultural system (Ghinea et al., 1967; Hulpoi, 1969; Gus, 1997; Rusu, 2001; Mark et al., 2004; Feiza et al., 2005; Ulrich et al., 2006, Jitareanu et al., 2006; Romaneckas et al., 2009; Marin et al., 2012; Penescu and Ionescu, 2013; Rusu et al., 2014). The conservation of soil fertility requires a tillage system that optimizes the plant needs in accordance with the soil modifications, that ensures the improvement of soil features and the obtainment of big and constant crops (Lăzureanu et al., 2011; Cociu and Cizmaș, 2013). Thus, the conservation of soil fertility is tied to maintaining and improving the soil fertility indices and to the productivity of tillage system in work.

Our researches follow the effects of the three variants with minimum tillage systems on soil properties and on the crop production obtained on Molic Aluviosol from the Transylvanian Plain from the perspective of environmental protection.

MATERIAL AND METHODS

The data presented in this paper were obtained in the Transylvanian Plain, on Molic Aluviosol (SRTS, 2003), at University of Agricultural Sciences and Veterinary Medicine in Cluj-Napoca, within the Research Center for Minimal Systems and Sustainable Agricultural Technologies. The field is a class II quality type, having 73 points for arable use. The soil profile is of type: Amp-Am-A/C-C_{Ca}. The clay content on 0-40 cm depth varies between 46.6% and 51.1%. On 0-20 cm depth, soil has a reaction at the limit neutral-weak basic, with a value of 7.25. The presence of carbonates in the next horizon, the 20-40 cm depth determines an increase of pH value to 7.35. The base saturation degree of 96% frames this soil type in the eubasic soils, meaning base saturated. As for the humus content, the soil is appreciated as medium, namely 3.01% in the first 20 cm and 2.96% in the 20-40 cm depth. The field is plane, with the ground water level at 2–3 m depth.

The experimental variants chosen were: A – conventional tillage system: V_1 – classic plough + disc-2x; B – minimum tillage system: V_2 – paraplow + rotary harrow, V_3 – chisel + rotary harrow, V_4 – rotary harrow. The experimental variants were studied in a four years crop rotation: maize → soy bean → autumn wheat → potato/rape. Determination of soil properties was done at the end of the rotation, and fuel consumption determinations, respective productions were determined annually. Experience was conducted in 2009-2013. Climatic conditions during this period in the experimental field are presented in Table 1. In these climatic conditions, characterizes by the average annual temperature higher than the area average, and the average annual precipitation below the average area, the results were affected. Yields were higher in the system that has managed to preserve more water in the soil.

Table 1. Multiannual average (years 2009-2013) of temperature and precipitation in the experimental field

Years	Temperature, ºC	Precipitation, mm
2009	10.67	524
2010	11.18	475
2011	11.50	385
2012	11.71	397
2013	10.90	515
Multiannual average (1950-2005)	9.56	554

The analyses and determinations were done according to acting methodology and standards (SRTS, 2003; MESP, vol. I-III, 1987, Guide to Agrotechnics and Experimental Technology). Soil quality bonitation index and class qualities determination was made by the Pedologic

Studies Elaboration Metodology (MESP, 1987). The results of the annual determinations were statistically analysed by ANOVA test. A significance level of $P \leq 0.05$ was established a priori.

RESULTS AND DISCUSSION

The influence of minimum tillage systems on physical properties of soil

The determinations show that applying minimum tillage systems leads to modification of soil bulk density (Table 2). The values were 1.18-1.26 g cm^{-3} in the first 20 cm depth and 1.39 g cm^{-3} in the 20-30 cm depth, for the classic tillage variant, and 1.19-1.35 g cm^{-3} in the first 20 cm depth and 1.32-1.38 g cm^{-3} in the 20-30 cm depth for the minimum tillage systems variants. One can appreciate that the soil settlement, specific to minimum tillage has no influence on penetration strength of roots, but changes can be registered for water use, nitrification and soil temperature.

Table 2. The influence of tillage system on soil physical features

Variant	Depth, cm	Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Bulk density, g cm^{-3}	0-10	1.18	1.21	1.23	1.19
	10-20	1.26	1.28	1.33	1.35
	20-30	1.39	1.32	1.34	1.38
	30-40	1.41	1.34	1.38	1.39
	40-50	1.45	1.45	1.45	1.46
Resistance to penetration, kgf cm^{-2}	0-10	10.97	10.98	10.85	10.02
	10-20	12.14	14.94	15.93	13.27
	20-30	21.33	19.81	22.22	21.25
	30-40	28.71	27.80	29.27	27.93
	40-50	31.65	29.47	30.88	31.72
Total porosity, %	0-10	55	54	54	56
	10-20	52	52	50	49
	20-30	47	48	49	46
	30-40	47	49	52	47
	40-50	45	45	45	45
Compaction degree, %	0-10	-3.8	-1.9	-1.9	-9.4
	10-20	1.9	1.9	5.7	7.5
	20-30	11.3	8.7	9.5	10.9
	30-40	11.3	11.5	11.9	11.3
	40-50	15.1	15.1	15.1	15.1

The soil resistance to penetration is significantly influenced by using rotary harrow on 0-10 cm depth, when, regardless the basic tillage, have been registered values practically equal. Beneath 10 cm depth, the values are 12.14-31.65 kgf cm^{-2} in the conventional system and 13.27-31.72 kgf cm^{-2} in the minimum tillage systems. The conclusion that one make on the data obtained for the soil resistance to penetration is that in all experimental variants (conventional and minimum), the penetration of roots is not disturbed.

The total porosity and compaction degree are in accordance with the soil settlement (determined by bulk density). The total porosity values vary between 45 and 55% in the plough tillage and between 45 and 56% in the minimum tillage variants. Between the two technologies, conventional and minimum, the differences are significant only in the superior side of the soil layer.

From the compaction degree determinations it can be observed very clearly the effect of interventions made by the tillage system; the effect is the physical state of the soil and the extremes that might be registered (compacted or loose), as well as the necessity and the urgency for future interventions. These determinations confirm the moderate loose state of conventional tillage variant (values from 1.9 to 3.8% in the 0-20 cm depth). Also, in all variants with minimum tillage, until the 30 cm depth, the values for compaction degree are below 11%, meaning specific average values for Molic Aluviosol.

The influence of minimum tillage systems on ecological determinants: structure and texture

Soil fertility is very tight related to its structural state. The structure crushing and the physical properties are the first changes directly induced by the tillage system. The solid phase/porous space ratio regulates the thermal, chemical and biological regime of the soil. The minimum tillage systems, through a reduced number of interventions on soil and a bigger amount of organic material remaining on the soil surface, has an essential contribution to rebuilding its structure. The mulch on the soil surface has a protection function and a structure amelioration function (by transforming under the micro and macro-organisms in soil). The content of hydro stable macro-aggregates increases in all minimum tillage variants – with 0.1-2.2% in 0-10 cm depth and with 4.9-5.2% in the 10-30 cm depth, compared to the classic system (Table 3). The soil texture has not changed by applying the minimum tillage system (Table 4).

Table 3. The influence of tillage system on hydrostability degree of soil structure

Variant	Depth, cm	Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Hydrostability degree, %	0-10	69.2	69.6	69.3	71.4
	10-20	71.3	79.0	79.5	79.2
	20-30	73.6	79.4	79.6	78.5

Table 4. The influence of tillage system on soil texture

Variant	Initial	Final			
		Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Clay (< 0.002 mm), %	51.1	50.1	51.0	51.1	50.9
Dust (0.02-0.002 mm), %	16.0	15.0	16.4	16.5	16.1
Sand (2-0.02 mm), %	32.9	34.9	32.6	32.4	33.0

The influence of minimum tillage systems on water reserve in soil

The soil infiltration determinations – done at soil surface, with a field permeameter – show the value of 5.7 l m^{-2} $minute^{-1}$ of water in soil in the plough tillage variant and of 6.5-7.9 l m^{-2} $minute^{-1}$ in the minimum tillage variants (Table 5). Related to this soil feature, the water reserve, accumulated in the 0-50 cm depth is with 1-32 m^3 ha^{-1} higher in the minimum tillage variants.

Table 5. The influence of tillage system on of physical properties of soil

Variant	Depth, cm	Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Infiltration, l m^{-2} $minute^{-1}$	0-5	5.7	7.9	6.5	6.8
Water reserve, m^3 ha^{-1}	0-50	936	968	954	937

The influence of minimum tillage on agrochemical properties of soil

The soil reaction and base saturation degree remain practically unchanged, no matter the way the soil was tilt (Table 6). Still, a tendency in pH decreasing is observed (leading to soil acidifying), as a result of increasing the hydrolytic acidity and decrease of bases sum. The pH changing tendency is justified by phosphorous stratification at soil surface and by the intensification of biological activity (including of fungi's).

Table 6. The influence of soil tillage on agrochemical properties of soil (0-20 cm)

Variant	Initial	Final			
		Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
$CaCO_3$, %	1.60	2.00	1.50	1.55	1.60
SB, me 100 g^{-1} sol	26.22	27.00	26.90	27.31	26.83
SH, me 100 g^{-1} sol	1.10	1.07	1.10	1.05	1.20
T, me (SB+SH)	27.30	28.07	28.00	28.36	28.03
V, %	95.94	96.18	96.07	96.29	95.72

Note: SB – sum of bases; SH – sum of hydrogen; T – cation exchange capacity; V – base saturation degree.

The influence of minimum tillage systems on humus and mineral nutrients content

The soil content in phosphorous (P) and mobile potassium (K) changes significantly under the influence of tillage system because of the applied fertilizers which are located in different depths in soil (Table 7). Thus, the rotary harrow tillage fixed large amounts of mobile phosphorous in the first 10 cm of tilt soil; the paraplow and chisel tillage do the same thing, bringing the phosphorous in the same amount as the plough tillage in the 10–20 cm depth. The intensity of aeration and the large density of plants are justifications for the smaller amounts of mobile phosphorous in the classic plough tillage. Stratification tendency is more reduced to nitrogen (N). The humus content of soil has a tendency to grow by applying the minimum tillage systems. This is first because of the bigger quantities of remaining vegetal material (minimum 30%), in different decomposition stages, at the soil surface and in the first 10-20 cm; secondly, because of the trimming in the mineralization/humification ratio, done in a specific physical, thermal and biological regime. By determining the humus content after 4 years, it can be observed an increasing tendency when applying the minimum tillage systems (the increase is up to 0.41%). The registered values were 3.11% in the plough variant and 3.12-3.52% in the minimum tillage variants.

Table 7. The influence of tillage system on humus and mineral nutrients content (0-20 cm)

Variant	Initial	Final			
		Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Humus, %	3.02	2.84	2.93	3.12	3.15
Mobile P, ppm 100 g^{-1} soil	130	108	125	135	142
Mobile K, ppm 100 g^{-1} soil	165	170	165	182	183
Total N, % 0-10 cm	0.210	0.214	0.236	0.246	0.236
10-20 cm	0.230	0.254	0.214	0.236	0.256
20-30 cm	0.252	0.263	0.211	0.214	0.196

The influence of minimum tillage systems on enzymatic activity in soil

The enzymatic activity in soil – represented by dehydrogenase activity (AD), enzymatic catalytic activity (AC) and biological index of soil fertility (IBFS = AD×AC/100) – shows the superiority of biological features of soil by applying the minimum tillage systems.

The influence of minimum tillage systems on fuel consumption

The tilt furrow ploughing is one of the most expensive operations (meaning big fuel consumer). More, when soils have an average-fine to fine texture and the tillage is done in the depth.

Replacing this operation, at least partially, and working the soil after two or three years, especially if the yield is the same, is a solution to reduce the fuel consumption.

Replacing the classic tillage system with a minimum one, with paraplow, chisel and rotary harrow, leads to a reduction in fuel consumption to 64.1-91.4% in the wheat cultivation (Table 8), to 52.7-91.6% in the maize cultivation (Table 9) and to 58.6-97.0% in the soybean cultivation (Table 10).

Table 8. The fuel consumption (l ha^{-1}), by technology variants, in wheat cultivation

Specific consumption		l ha^{-1}	%	Difference	Difference significance
Variant	Ploughing	61.60	100	control	control
	Paraplow	56.33	91.4	- 5.27	***
	Chisel	51.32	83.8	- 10.28	***
	Rotary harrow	39.50	64.1	- 22.10	***
LSD 5% = 1.46 l ha^{-1}; LSD 1% = 2.21 l ha^{-1}; LSD 0.1% = 3.54 l ha^{-1}.					

Table 9. The fuel consumption (l ha^{-1}), by technology variants, in maize cultivation

Specific consumption		l ha^{-1}	%	Difference	Difference significance
Variant	Ploughing	95.62	100	control	control
	Paraplow	87.58	91.6	- 8.04	***
	Chisel	71.69	75.0	- 23.93	***
	Rotary harrow	50.36	52.7	- 45.26	***
LSD 5% = 1.22 l ha^{-1}; LSD 1% = 1.84 l ha^{-1}; LSD 0.1% = 2.96 l ha^{-1}.					

Table 10. The fuel consumption (l ha^{-1}), by technology variants, in soybean cultivation

Specific consumption		l ha^{-1}	%	Difference	Difference significance
Variant	Ploughing	67.63	100	control	control
	Paraplow	65.59	97.0	-2.04	*
	Chisel	51.74	76.5	-15.89	***
	Rotary harrow	39.63	58.6	-28.00	***
LSD 5% = 1.79 l ha^{-1}; LSD 1% = 2.71 l ha^{-1}; LSD 0.1% = 4.35 l ha^{-1}.					

The influence of minimum tillage systems on yield

The tillage system has an influence on the cultivated species productivity and finally on the obtained yield. The crops within the crop rotation have a different reaction to the minimum tillage systems application (Table 11). Thus, in the wheat, soy-bean and rape crops, the yields obtained by applying the minimum tillage systems were very close to those obtained in the conventional tillage system, the differences being not statistically assured (except for the rotary harrow variant in the wheat crop).

Under these conditions, the yields obtained were: 2,747-2,867 kg ha^{-1} for soybean, 3,282-3,451 kg ha^{-1} for wheat and 1,505-1,588 kg ha^{-1} for spring rape.

The maize crop and especially the potato crop gave smaller productions by applying the minimum tillage systems. In the maize cultivation there are significant differences between the variant applied also; thus in the classic plough variant were obtained 5,857 kg ha^{-1}, in the chisel and paraplow variant were obtained 5,704-5,737 kg ha^{-1} (97.3-97.9% of the control yield). The yield was smaller, very significantly negative in the rotary harrow variant (92.1% of the control yield).

In the potato crop, the yields obtained by applying the minimum tillage systems were 82.4-93.4% of the control yield (plough variant).

Table 11. The influence of Molic Aluviosol soil tillage system on yields obtained in maize, soybean, wheat, potato and rape crops

Technological variant	Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Maize, kg ha^{-1}	5,857	5,737	5,704	5,395
%	100	97.9	97.3	92.1
Diff.±	control	- 120	- 153	- 462
Significance	control	-	-	000
	LSD 5%= 180.04 kg ha^{-1}, LSD 1%= 261.88 kg ha^{-1}, LSD 0.1%= 392.82 kg ha^{-1}			
Soybean, kg ha^{-1}	2,848	2,867	2,860	2,747
%	100	101.6	100.4	96.4
Diff.±	control	+ 19	+ 12	- 101
Significance	control	-	-	-
	LSD 5% = 136.74 kg ha^{-1}, LSD 1% = 198.89 kg ha^{-1}, LSD 0.1% = 298.34 kg ha^{-1}			
Wheat, kg ha^{-1}	3,451	3,387	3,391	3,282
%	100	98.1	98.2	95.1
Diff.±	control	- 64	- 60	- 169
Significance	control	-	-	0
	LSD 5% = 140.11 kg ha^{-1}, LSD 1% = 203.80 kg ha^{-1}, LSD 0.1% = 305.70 kg ha^{-1}			
Potato, kg ha^{-1}	39,428	36,853	36,317	32,521
%	100	93.4	92.1	82.4
Diff.±	control	- 2,575	- 3,111	- 6,907
Significance	control	0	00	000
	LSD 5% = 1,827.94 kg ha^{-1}, LSD 1% = 2,658.83 kg ha^{-1}, LSD 0.1% = 3,988.24 kg ha^{-1}			
Rape, kg ha^{-1}	1,588	1,532	1,552	1,505
%	100	96.5	97.8	94.8
Diff.±	control	- 56	- 36	- 83
Significance	control	-	-	-
	LSD 5% = 166.94 kg ha^{-1}, LSD 1% = 252.80 kg ha^{-1}, LSD 0.1% = 406.11 kg ha^{-1}			

The influence of minimum tillage systems on bonitation index

The soil quality is expressed by bonitation indices (Table 12) for the arable use in crop rotation: maize → soy-bean → wheat → potato / rape. Soil tillage system did not affect its quality, but increases the points of bonitation in the paraplow variants (75) and chisel (74). The classic soil tillage caused a reduction of bonitation points (70), in particular by reducing the content of humus that the permeability and porosity lower.

Table 12. The influence of tillage system on global quality of soil (Bonitation index)

Variant	Initial	Final			
		Classic plough + disc 2x	Paraplow + rotary harrow	Chisel + rotary harrow	Rotary harrow
Bonitation index	73	70	75	74	73
Quality class	II	II	II	II	II

Quality class: I (100-80); II (80-60); III (60-40); IV (40-20); V (20-0).

CONCLUSIONS

The minimum tillage systems represent alternatives to the conventional system of soil tillage, due to their conservation effects on soil features and to the assured yields.

By continuously applying for four years the same tillage system in a crop rotation: maize → soybean → wheat → potato/rape, an improvement in physical, hydro-physical and biological properties of soil was observed, together with the rebuilt of structure and increase of water permeability of soil.

The yields obtained by applying the minimum tillage systems show very differentiated results, choosing the working variant being related to the cultivated plant thus, compared to the conventional tillage variant, the yields obtained in the minimum tillage variants represented: 92.1-97.9% in maize, 96.4-101.6% in soybean, 95.1-98.2% in wheat, 82.4-93.4% in potato and 94.8-97.8% in the rape crop.

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