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Energy Efficiency of Conservative Tillage Systems in the Hilly Areas of Romania

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Abstract: Conservative tillage systems, specific to sustainable agriculture, require productivity at least equal to that of conventional technology, optimized energy efficiency and, at the same time, diminished environmental impact. An energy saving way is that of implementing optimal technology specific to each culture and pedoclimatic area. The minimum tillage and no-tillage systems represent alternatives to the conventional system of soil tillage, due to their conservation effects on soil features and to the assured productions, maize: 96-98.1% at minimum tillage and 99.8% at no-tillage, soybean: 102.9-111.9% at minimum tillage and 117.2% at no-tillage, wheat: 93.4-96.8% at minimum tillage and 106.9% at no-tillage, as compared to the conventional system. Correct choice of the right soil tillage system for the crops in rotation help reduce energy consumption, thus maize: 97.3-97.9% at minimum tillage and 91.3% at no-tillage, soybean: 98.6-98.2% at minimum tillage and 92.8% at no-tillage, wheat: 97.4-98% at minimum tillage and 91.6% at no-tillage. Energy efficiency is in relation to reductions in energy savings, but also with efficiency and impact on the tillage system on the cultivated plant. For all crops in rotation, energy efficiency (energy produced from 1 MJ consumed) was the best in no-tillage and 10.44 MJ ha^{-1} at maize, 6.49 MJ ha^{-1} at soybean, 5.66 MJ ha^{-1} at wheat. Energy-efficient agricultural system: the energy consumed-energy produced-energy yield, necessarily have to be supplemented by soil energy efficiency, with the conservative effect of the agricultural system. Only then the agricultural system will be sustainable, durable in agronomic, economic and ecological terms. The implementation of minimum and no-tillage soil systems have increased the organic matter content from 2 to 7.6% and water stabile aggregate content from 5.6 to 9.6%, at 0-30 cm depth, as compared to the conventional system. While the soil fertility and the wet aggregate stability have initially been low, the effect of conservation practices on the soil characteristics led to a positive impact on the water permeability in the soil. Availability of soil moisture during the crop growth led to a better plant watering condition. Subsequent release of conserved soil water regulated proper plant water condition and soil structure.

Key words: No-tillage · Minimum tillage · Yield · Energy efficiency · Soil conservation

INTRODUCTION

Sustainable agricultural activity must be organized in a system, scheduled in a sequence and always analysed as part of the relationship: soil-plant-climate area-socio-economic conditions-crop-efficiency [1-4]. Recommendation of flexible and multifunctional technologies consequently equally aims at reducing the consumption of energy, particularly in the field of aggressive soil tillage, as well as obtaining high yields, soil conservation and environmental protection [5-8].

The essence of the living system consists in the unique capacity of plants to convert, through photosynthesis, the solar energy, carbon dioxide and water into biochemical alimentary energy. Therefore, a successful measure in agriculture is the quantity of energy gathered under the form of biomass, as a result of efficient human and fossil energy use [9-13].

The soil tillage has as main purpose a series of immediate effects (with a positive side), resulting from the objectives of the soil tillage themselves: basic tillage, germinal layer preparation, field maintenance. Still, the

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effects of the soil tillage can often have an immediate negative part or long lasting effects, positive or negative [14-20].

The influence of soil tillage system on soil properties and energy efficiency is proved by important factors of soil fertility conservation and evaluation of the sustainability of agricultural system [21-24]. Long-term field experiments provide excellent opportunities to quantify the long-term effects of soil tillage systems on accumulated soil water [25-27]. The hydrological function of the soil (especially the capacity to retain optimum water quantity and then gradually make this available for plant consumption) is one of the most important functions determining soil fertility, productivity and soil evolution. Intrinsic soil properties such as organic matter and texture, along with applied tillage practices combine to modify the soil structure, porosity, permeability and water capacity. This, in turn, is a critical factor in the water cycle and affects water accumulation in the soil. 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 obtaining large and constant crops. Thus, the conservation of soil fertility is tied to maintaining and improving the soil fertility indices and to the productivity of the tillage system.

MATERIAL AND METHOD

The experiments have been conducted at the University of Agricultural Sciences and Veterinary Medicine in Cluj Napoca, Romania (46°46'N, 26°36'E), on a moderately fertile Fluvisoil [28]. The humus content was 3.01%, pH was 7.2 and soil texture was clay (42% clay in the arable stratum). The experimental field has an annual temperature of 8.2^{0}C and annual rainfall of 613 mm.

Treatments used in the study were as follows: A. Conventional tillage (CT): V_1-classic plough (20-25 cm) + disc harrow-2x (8 cm) (witness treatment). B. Minimum tillage (MT): V_2-paraplow (18-22 cm) + rotary harrow (8 cm); V_3-chisel plough (18-22 cm) + rotary harrow (8 cm); V_4-rotary harrow (10-12 cm). C. No-tillage (NT): V_5-direct drill with Accord Optima HD for hoeing and SUP adapted for wheat.

All soil tillage was accomplished during the autumn period for wheat; for corn and soybeans we used the plough, paraplow, chisel plough in the autumn and finally, for the germinal layer preparation, we used the disc harrow and rotary harrow in the spring. Crop rotation was: maize-*Zea mays* L., soy-bean-*Glycine hispida* L. Merr and wheat-*Triticum aestivum* L.

The experimental design was a randomized complete block design with three replications. The area of a parcel was 300 m^2. Except for the soil tillage system, all other variables were held constant, including the herbicide used: wheat-post emergent dicamba 120 g/l + 2.4D 300 g/l, 0.9 l ha^{-1}; corn-pre emergent acetochlor 820-860 g/l + antidote, 2.5 l ha^{-1} and post emergent dicamba 120 g/l + 2.4D 300 g/l, 0.9 l ha^{-1}; soybeans-pre emergent acetochlor 820-860 g/l + antidote, 2.5 l ha^{-1} and post emergent bentazon 480 g/l + Wettol 150 g/l, 2.5 l ha^{-1}.

To quantify the change in soil properties under different tillage practices, determinations were made for each culture in four vegetative stages (spring, 5-6 leaves, bean forming and harvest). Soil parameters monitored included soil water content (gravimetric method, Aquaterr probe-Frequency domain reflectometry), soil bulk density (determined by volumetric ring method using the volume of a ring 100 cm^3), water stable aggregates (Czeratzki method), soil permeability (using the Infiltrometer method) and organic matter content (Walkley-Black method). The average values obtained during the vegetal phases were statistically analysed. The results were analysed using ANOVA and Duncan's test [29]. A significance level of $P \leq 0.05$ was established a priori.

Regarding energetic assessment, the most realistic means of comparison of various agricultural technologies remains energy efficiency, using the following indicators: Energy Efficiency Factor: e = (Er-Ec)/Er [MJ]; Energy Yield: γ = Er/Ec [MJ]; Energy Report r = Ec/Er [MJ]. Where: Er-energy as gathered biomass [MJ]; Ec-technologically consumed energy to produce this biomass [MJ].

Consumed and produced energy represent in fact a sum of inputs and outputs in the technological process. Consequently: Er = Erp+Ers [MJ]. Where: Erp-energy corresponding to primary harvest; Ers-energy corresponding to secondary harvest.

Technologically consumed energy has several components: Ec=Ect+Ecm+Ecs+Ecf+Ecp+Ecu+Eo [MJ]. Where: Ect-energy consumption related with the tractor [MJ]; Ecm-energy consumption related with agricultural machinery [MJ]; Ecs-energy consumption related with seeds [MJ]; Ecf-energy consumption related with fertilization [MJ]; Ecp-energy consumption related with pesticides [MJ]; Ecu-energy consumption related to human work resources [MJ]; Eo-energy consumed in other ways [MJ]. Each component is the sum of elementary energies specific to each technological operation. Quantification of consumed energy and of the produced energy has been achieved on the basis of equivalents mentioned in specialty literature [30-32].

The Equivalence Indicators Are: Energy consumed: basic tillage-classic plow: 1,102.98 MJ ha^{-1}; paraplow: 853.92 MJ ha^{-1}; chisel: 782.76 MJ ha^{-1}; rotary grape: 711.6 MJ ha^{-1}; direct sowing: 978.24 MJ ha^{-1}. Preparation of the germinative layer-disc: 426.96 MJ ha^{-1}; rotary grape: 640.44 MJ ha^{-1}. Fertilization-135.97 MJ ha^{-1}. Materials-1 kg N: 92.51 MJ; 1 kg P_2O_5: 20.34 MJ; 1 kg K_2O: 14.84 MJ; 1 l diesel oil: 35.58 MJ; 1 kg bentazone: 252.5 MJ; 1 kg acetochlorine: 101.3 MJ; 1 kg dicamba: 294 MJ; 1 kg insecticide, fungicide: 205.2 MJ. Sowing-corn: 160.11 MJ ha^{-1}; soy bean: 160.11 MJ ha^{-1}; wheat: 192.13 MJ/ha. Herbicides: 46.25 MJ/ha. Harvest: 511.99 MJ ha^{-1}. Human work force: 1.318 MJ/person/hour. Other energetic inputs: 426.96 MJ ha^{-1}.

Energy produced-1 kg corn: 16.41 MJ; 1 kg corn cob: 15.29 MJ; 1 kg soy bean: 20.79 MJ; 1 kg soy stems: 15.42 MJ; 1 kg wheat: 16.06 MJ; 1 kg wheat straws: 15.26 MJ.

RESULT AND DISCUSSION

The soil tillage system influences the yields obtained in a differentiated way, depending on the culture type (table 1). Corn crop assures the highest yield with plough and no-tillage systems. Paraplow and chisel give smaller yields (6,710-6,730 kg ha^{-1}), with statistically ensured differences (significantly negative) and confirmed by the test of multiple comparisons, Duncan's test (ab). The smallest corn productions were obtained with rotary harrow, the differences being distinctly negative, statistically ensured (b). Soybean culture had the best reaction within the rotation, both with the no-tillage (very significant positive differences as compared to the plough), as well as with minimum soil tillage system, with paraplow and rotary harrows (ab). For wheat culture no-tillage ensure highest yield, 3,986 kg ha^{-1} and the lowest production has been achieved with chisel (93.4%).

The quantity of energy produced depending on soil tillage system, is related to main and secondary yield, being higher in the plough variant. Energy efficiency is influenced by the soil tillage system, being higher in no-tillage (e=0.9042, 101%), followed by the variants with chisel and paraplow (100.1%). Energetic efficiency is influenced by the energy consumed within every technologic system, the smaller the consumed energy within the system, the higher the efficiency. The high power efficiency in no-tillage (γ=10.44 MJ ha^{-1}), chisel (γ =9.66 MJ ha^{-1}) and paraplow (γ =9.65 MJ ha^{-1}), as compared to the plough system (γ =9.54 MJ ha^{-1}), shows that the energy invested in these variants has had a higher efficiency. The proportional expression between the produced and consumed energy, through energetic report, as certains the lower value of this indicator of 0.096 in no-tillage and the highest value, of 0.108 for the rotary harrow variant.

Considering the amount of produced energy, in maize culture, we can emphasize the advantages of the plough variant. The intense soil mobilization, in conjunction with the effects produced in the soil linked to the release of adequate nutrients and providing necessary conditions for maize development ensures the highest productions. Intense impact on soil does not, however, always have positive effects. Eventually, the energy efficiency demonstrates the superiority of the no-tillage and minimum tillage systems, in terms of energy consumption reductions and optimization of agricultural technologic system.

Table 1: The influence of different soil tillage systems upon the plants yield in the case of maize, soybean and wheat crops.

Soil tillage systems	Classic plough + disc-2x	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow	No Tillage
Maize, kg ha^{-1}	6,860 a	6,730 ab	6,710 ab	6,583 b	6,849 a
Significance (%)	$^{wt.}$(100)	^{0}(98.1)	^{0}(97.8)	^{00}(96)	^{ns}(99.8)
Soybean, kg ha^{-1}	3,025 b	3,385 ab	3,113 b	3,313 ab	3,546 a
Significance (%)	$^{wt.}$(100)	**(111.9)	^{ns}(102.9)	**(109.5)	***(117.2)
Wheat, kg ha^{-1}	3,730 ab	3,615 ab	3,486 b	3,612 ab	3,986 a
Significance (%)	$^{wt.}$(100)	^{ns}(96.9)	^{0}(93.4)	^{ns}(96.8)	*(106.9)

Note: wt-witness, ns-not significant, *positive significance, ^{0}negative significance, a, ab, b, c-Duncan's classification (the same letter within a row indicates that the means are not significantly different)

Maize: DL5% = 100.01 kg ha^{-1}, DL1% = 151.45 kg ha^{-1}, DL0.1%= 243.30 kg ha^{-1}

Soybean: DL5% = 190.75 kg ha^{-1}, DL1% = 271.16 kg ha^{-1}, DL0.1%= 392.62 kg ha^{-1}

Wheat: DL5% = 241.21 kg ha^{-1}, DL1% = 338.57 kg ha^{-1}, DL0.1%=477.99 kg ha^{-1}

Table 2: The influence of the soil tillage system on energy efficiency in maize culture.

	Energy, MJ		Energy Efficiency			
Variant	Consumption (%)	Produced	e	%	Energy yield (γ)	Energy report (r)
Classic plough + disc-2x (wt)	22,364.09 (100)	213,417.78	0.8952	100	9.54	0.104
Paraplow + rotary harrow	21,901.55 (97.9)	211,284.48	0.8963	100.1	9.65	0.103
Chisel plow + rotary harrow	21,830.39 (97.6)	210,956.28	0.8965	100.1	9.66	0.103
Rotary harrow	21,759.23 (97.3)	200,646.19	0.8915	99.6	9.22	0.108
No-Tillage	20,425.41 (91.3)	213,237.27	0.9042	101.0	10.44	0.096

Table 3: Influence of soil tillage system on energy efficiency in soybean culture.

	Energy, MJ		Energy Efficiency			
Variant	Consumption (%)	Produced	e	%	Energy Yield (γ)	Energy report (r)
Classic plough + disc-2x (wt)	25,364.09 (100)	132,858.00	0.8091	100	5.23	0.191
Paraplow + rotary harrow	24,901.55 (98.2)	148,669.20	0.8325	102.9	5.97	0.167
Chisel plow + rotary harrow	24,830.39 (97.9)	136,722.98	0.8184	101.1	5.51	0.182
Rotary harrow	24,759.23 (97.6)	145,506.96	0.8298	102.5	5.88	0.170
No-Tillage	23,545.75 (92.8)	152,740.32	0.8458	104.5	6.49	0.154

Table 4: Influence of soil tillage system on energy efficiency in wheat culture.

	Energy, MJ		Energy efficiency			
Variant	Consumption (%)	Produced	e	%	Energy yield (γ)	Energy report (r)
Classic plough + disc-2x (wt)	23,272.38 (100)	129,458.88	0.8202	100	5.56	0.179
Paraplow + rotary harrow	22,809.84 (98.0)	125,475.58	0.8182	99.7	5.50	0.182
Chisel plow + rotary harrow	22,738.68 (97.7)	120,992.76	0.8121	99.0	5.32	0.188
Rotary harrow	22,667.52 (97.4)	125,366.36	0.8192	99.9	5.53	0.181
No-Tillage	21,315.48 (91.6)	120,586.40	0.8232	100.4	5.66	0.177

Table 5: The influence of soil tillage system upon soil properties (0-30 cm).

Soil tillage systems	Classic plough + disc -2x (wt)	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow	No-tillage
OM, %	3.03 a	3.12 ab	3.09 ab	3.23 b	3.26 b
Significance (%)	^{wt}(100)	^{ns}(103.1)	^{ns}(102.0)	^{ns}(106.5)	^{ns}(107.6)
WSA, %	71.33 a	76.00 b	75.33 b	76.33 b	78.21 b
Signification (%)	$^{wt.}$ (100)	* (106.5)	*(105.6)	*(107.0)	*(109.6)
BD, g/cm^3	1.34 a	1.34 a	1.35 a	1.34 a	1.38 a
Signification (%)	$^{wt.}$(100)	^{ns}(100.0)	^{ns}(100.6)	^{ns}(100.0)	^{ns}(102.9)
W, m^3/ha	878 a	1.010 c	998 b	987 b	995 b
Signification (%)	$^{wt.}$(100)	*(115.0)	*(113.7)	*(112.4)	*(113.3)

Note: wt-witness, ns-not significant, *positive significance, ^{0}negative significance, a, ab, b, c-Duncan's classification (the same letter within a row indicates that the means are not significantly different). OM-organic matter. WSA-water stability of structural macro-aggregates. BD-bulk density. W-water supply accumulated in soil.

The energy required for setting up and maintaining the soybean culture after conventional system represents 25,364.09 MJ/ha and goes down to 97.6-98.2% at MT and at 92.8% at NT. Energy efficiency is superior in all variants as compared to the witness, soy reacting very well with MT and NT systems. Energy yield confirms this positive reaction, the results being 6.49 MJ ha^{-1} at NT and 5.51-5.97 MJ ha^{-1} at MT, for 1 MJ ha^{-1} consumed.

In the case of autumn wheat culture, technology is energetically equivalent to 23,272.38 MJ ha^{-1} through the CT system (table 4). Application of MT reduces energy consumption to 97.4-98% and NT to 91.6%, compared with the plough system. The influence of the soil tillage system on the amount of gathered energy reflects on the energy efficiency factor, where, in comparison with the witness, a higher efficiency at NT has been calculated (101%). Energy efficiency has been reduced in the other variants, but it does not fall below 99%. Energy yield shows that in 1 MJ ha^{-1} consumed a larger amount of energy is obtained with no-tillage (γ=5.66 MJ ha^{-1}) and the lowest yield was recorded with the chisel plough variant, 5.32 MJ ha^{-1}. The energy report has the best value in no-tillage (0.177), followed by the plough variant (0.179).

Statistical analysis of the results demonstrated that the differences in accumulated soil water depended on the variants of soil tillage (table 5). Soil texture and structure have a strong effect on the available water capacity. The results clearly demonstrate that MT and NT systems promote increased humus content (2-7.6%) and increased water constant aggregate content (5.6-9.6%) at 0-30 cm depth as compared to conventional tillage. Multiple analysis of soil classification and tillage system on the hydric stability of soil structure and water supply accumulated in soil have shown that all variants with minimum tillage are superior (b, c), having a positive influence on soil structure stability. The increase in organic matter content is due to the vegetal remnants at the soil surface (NT) or partially incorporated (MT) and adequate biological activity in this system. In the case of humus content and also in the hydro stability structure, the statistical interpretation of the data shows an increasing positive significance of the MT and NT systems application. The soil fertility and wet aggregate stability were initially low, the effect being the conservation of the soil features and also their reconstruction, with a positive influence on the permeability of the soil for water. More aggregated soils permit more water to reach the root zone. This does not only increase productivity, but it also reduces runoff and thus the erodibility potential.

The bulk density values at 0-30 cm increased by 0.01-0.03% under minimum and no-tillage systems. This raise was not significant in any of the experimental variants. Multiple comparing and classification of experimental variants align all values on the same level of significance (a). On molic Fluvisoils, soils with good permeability, high fertility and low susceptibility to compaction, accumulated water supply was higher (representing 12.4-15%) for all minimum and no-tillage soil systems.

CONCLUSION

The minimum tillage and no-tillage systems represent alternatives to the conventional system of soil tillage, due to their conservation effects on soil features and to the assured productions, maize: 96-98.1% at MT and 99.8% at NT, soybean: 102.9-111.9% at MT and 117.2% at NT, wheat: 93.4-96.8% at MT and 106.9% at NT, as compared to the conventional system.

Correct choice of the right soil tillage system for the crops in rotation help reduce energy consumption, thus maize: 97.3-97.9% at MT and 91.3% at NT, soybean: 98.6-98.2% at MT and 92.8% at NT, wheat: 97.4-98% at MT and 91.6% at NT. Energy efficiency is in relation to reductions in energy savings, but also with efficiency and impact on the tillage system on the cultivated plant, maize: 99.6-100.1% at MT and 101% at NT, soybean: 101.1-102.9% at MT and 104.5% at NT, wheat: 99-99.9% at MT and 100.4% at NT. For all crops in rotation, energy efficiency (energy produced from 1 MJ consumed) was the best in no-tillage and 10.44 MJ ha^{-1} at maize, 6.49 MJ ha^{-1} at soybean, 5.66 MJ ha^{-1} at wheat.

Energy-efficient agricultural system: the energy consumed-energy produced-energy yield, necessarily have to be supplemented by soil energy efficiency, with the conservative effect of the agricultural system. Only then the agricultural system will be sustainable, durable in agronomic, economic and ecological terms.

This study demonstrated that increased organic matter content in soil, aggregation and permeability are all promoted by minimum and no-tillage systems. The implementation of such practices ensures a greater water supply. The practice of reduced tillage is ideal for enhancing soil fertility, water accumulation capacity and reducing erosion. The advantages of minimum and no-tillage soil systems for Romanian pedoclimatic conditions can be used to improve methods in low producing soils with reduced structural stability on sloped fields, as well as measures of water and soil conservation on the whole ecosystem.

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