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ENERGETIC AND ECONOMICS OF TILLAGE SYSTEMS IN WINTER WHEAT PRODUCTION

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Abstract: The paper presents results of one year experiment in winter wheat production with three different soil tillage systems carried out in Slavonia, at fields of agricultural enterprise Hana Našice d.o.o, location Lila. Test crop was winter wheat, variety Renan. Tillage systems were: conventional, conservation and no-till. Energy requirement comparison showed extraordinary expensiveness of conventional tillage with specific consumption of 46.6 L ha^{-1} and 8.19 L Mg^{-1} of diesel fuel. Conservation tillage I system required 29.8 L ha^{-1} and 4.92 L Mg^{-1}, which is 36.1 % less energy per hectare and 40.0 % less energy per ton. Conservation tillage II required 18.9 L ha^{-1} and 2.85 L Mg^{-1}, which is 59.4 % less energy per hectare and 65.2 % less energy per ton. The most energy saving soil tillage system is no-till with fuel consumption of only 6.2 L ha^{-1} 0.92 L Mg^{-1} of diesel fuel or 86.7 % less energy per hectare and 88.8 % less energy per ton than conventional system. Soil tillage systems comparison regarding labour requirement unveiled that conventional tillage required 1.95 h ha^{-1} and 0.34 h Mg^{-1}, while conservation tillage I required 1.29 h ha^{-1} and 0.21 h Mg^{-1} or 33.8 % and 37.9 % less labour requirement than conventional tillage system respectively. Conservation tillage II required 0.74 h ha^{-1} and 0.11 h Mg^{-1} or 62.3 % and 67.6 % less labour requirement. No-till required only 0.32 h ha^{-1} and 0.05 h Mg^{-1} which is 83.8 % and 86.3 % less than conventional tillage system. The lowest yield of 5.69 t ha^{-1} achieved conventional tillage, while the highest yield of 6.73 t ha^{-1} achieved no-till.

Key words: *Soil tillage, energy requirement, production costs, winter wheat.*

1. INTRODUCTION

Winter wheat (*Triticum aestivum* L.) with 200.000 ha in average or almost 1/3 of total cereals area is besides maize (*Zea mays* L.) among the most important arable crops in Croatia (Anonymous 2006a). The mainly utilised soil tillage system in this crop production is conventional system, based on mouldboard ploughing as primary tillage operation, followed with secondary tillage performed by disc harrow and seed-bed implement. This tillage technology is, from one side, the most expensive, complicated, organisationally slow, with high fuel consumption and labour requirement, and, from another side, ecologically unfavourable (Zugec et al., 2000.). Although it is known that non-conventional tillage systems in comparison to conventional tillage system can save enormous quantity of energy and labour, decreasing thus environment pollution and production costs, currently 93.7% of the fields in Croatia are being tilled by the conventional tillage system (Zimmer et al., 2001).

2. MATERIALS AND METHODS

The experiment was performed at agricultural company "Njive"d.o.o. near a village Lila, located 250 km north-east from Zagreb (45° 30’ N, 18° 06’ E). Experimental field was consisted of 9 plots with dimension length 100 m x width 30 m each, organized as randomized blocks with three replications. Implements, which were included in different tillage systems, are as follows:

1. Conventional tillage - plough, disc harrow, seed-bed implement (CT); 2. Conservation tillage I – chisel plough, disc harrow (RT 1); 3. Conservation tillage II – shallow chisel plough, disc harrow (RT 2); 4. No-till - no-till drill (NT).

Depth of tillage for mouldboard plough was in average 29.6 cm, disc harrow 10.4 cm and seed-bed implement 6.0 cm. Chisel ploughing was done to 30.3 cm in average, while shallow chisel worked in average to 15 cm. The tillage with different systems was performed on the Gleyic Podzoluvisol, (Anonymous, 1998). Its texture in ploughed layer according to Anonymous (1975) belongs to the silty loam.

Table 1. Soil particle size distribution and soil type

Sample	0.2-2 μm (%)	0.05-0.2 μm (%)	0.002-0.05 μm (%)	<0.002 μm (%)	Soil type
A	0.80	28.80	44.60	25.80	Loam
B	2.20	8.60	69.40	19.80	Silty loam
C	1.00	10.20	58.00	30.80	Silty clay loam

Schedule of the field operations (tillage, fertilizing, sowing, crop protection, harvesting) and soil moisture content at the moment of tillage are shown in Table 2. On the experimental field previous crop was onion (*Allium cepa* L.). Working conditions regarding soil moisture content, soil compaction and post-harvest residues at the beginning of experiment were equal for all tillage treatments. The energy requirement of each tillage system was determined by tractor’s fuel consumption measurement for each implement in each tillage system applying volumetric method. Energy equivalent of 38.7 MJ L^{-1} (Cervinka, 1980) was presumed. In this experiment 4WD tractor with engine power of 141 kW was used. The working width of the tillage implements was chosen according to the pulling capacity of the tractor. The labour requirement was determined by measuring the time for finishing single tillage operation at each plot of the known area (3000 m^2). The yields were determined by weighing grain mass of each harvested plot. For economic analysis data on labour inputs for various operations under each tillage system, cost of soil preparation and other operations were collected. Production costs for each tillage system were based on actual sequence of operations conducted in the experiment. Costs of all field operations during the growing season, wage price of labour and prices of soybean and winter wheat were obtained according to Anonymous (2006a) and Anonymous (2006b). All costs and income figures are presented as per hectare.

Table 2. Date of field operations, soil moistures and application rates

Description	*Cropping period* 2005/2006
Tillage & Sowing	
Primary tillage	October 10th 2005
Soil moisture, % at 0;15;30 cm depth	30.6; 34.7; 34.5
Secondary tillage	October 12th 2005
Soil moisture, % at 0;15;30 cm depth	26.4; 30.8; 32.2
Sowing date	October 13th 2005
Crop; Cultivar	Winter Wheat; "Renan"
Fertilising	
Application date	October 09th 2005
Fertiliser; rate, kg ha^{-1}	KCl (60%); 210 / Urea; 150 / *MAP (12:52:0); 320
Application date	February 11th 2006
Fertiliser; rate, kg ha^{-1}	**CAN (27%); 120 and *MAP (12:52:0); 50
Application date	March 26th 2006
Fertiliser; rate, kg ha^{-1}	Urea (46%); 150
Crop protection	
Application date	October 29th 2005
Chemical; rate, l ha^{-1}	Tornado; 1.7
Application date	May 25th 2006
Chemical; rate, l ha^{-1}	Direkt; 0.17
Application date	May 16th and May 25th 2006
Chemical; rate, l ha^{-1}	Artea; 0.52, Duet Ultra; 1.0
Harvest	
Harvesting date	July 12th 2006

**monoammonium phosphates*
***calcium ammonium nitrate*

3. RESULTS AND DISCUSSION

3.1 Yield

In winter wheat production, NT system achieved the greatest average yield of 6.73 Mg ha^{-1} or 18.3% more than CT system, while RT 2 and RT 1 achieved 16.5% and 6.5% more than CT, respectively. CT system achieved the lowest yield of 5.69 Mg ha^{-1}. Although yield differences were recorded, analysis of experimental data by ANOVA showed that differences weren't significant. The similar results obtained Dawelbeit and Babiker (1997). Juric et al. (2004) obtained not statistically significant difference of winter wheat yields with conventional tillage and single disc harrowing tillage system. Lyon et al. (1998) determined 8.0% greater winter wheat yield with conventional tillage than with no till. Lawrence et al. (1994) showed in a four years study that no-till had a higher wheat yield than reduced or conventional tillage did. Arshad and Gill (1997) comparing conventional, reduced and zero tillage systems found that during three years experiment the greatest average wheat yield had reduced tillage, while conventional tillage had the lowest. Moreno et al. (1997) reported of higher winter wheat yield under conservation than traditional tillage but differences weren't significant.

3.2 Energy requirement

The conventional tillage system (CT) was expectantly the greatest fuel consumer with 46.6 L ha^{-1}. RT 1 system enabled saving of 36.1% of energy per hectare and RT 2 system enabled saving of even 59.4%, while NT achieved enormous saving of 86.7% in comparison to CT soil tillage system. Bowers (1992) showed a composite of average fuel consumption and energy expended, based on data from different countries around the world and reported that average fuel consumption for mouldboard ploughing is 17.49±2.06 L ha^{-1}, chisel ploughing 10.20±1.50 L ha^{-1}, while no-till planter required 4.02±1.03 L ha^{-1}. In comparing these data to other sources, wide variations can be expected due to soil types, field conditions, working depth, etc. On the other hand, Köller (1996) reported that the fuel consumption was 49.40 L ha^{-1} for mouldboard ploughing, 31.30 L ha^{-1} for chisel ploughing and 13.40 L ha^{-1} for no-till. Hernanz and Ortiz-Cañavate (1999) presented data that coincide between previously mentioned results.

Table 3. Energy and labour requirement of different soil tillage systems

Tillage system	Fuel L ha^{-1}	Energy MJ Mg^{-1}	Work rate ha h^{-1}	Productivity h Mg^{-1}
CT	Average Yield = 5.69 Mg ha^{-1}			
Plough	33.5	227.8	0.73	0.24
Disc harrow	7.2	49.0	3.47	0.05
Drill	5.9	40.1	3.38	0.05
Total	46.6	316.9		0.35
RT 1	Average Yield = 6.06 Mg ha^{-1}			
Chisel	16.7	106.6	1.41	0.12
Disc harrow	7.2	46.0	3.47	0.05
Drill	5.9	37.7	3.38	0.05
Total	29.8	190.3		0.22
RT 2	Average Yield = 6.63 Mg ha^{-1}			
Shallow Chisel	5.8	33.9	6.55	0.02
Disc harrow	7.2	42.0	3.47	0.04
Drill	5.9	34.4	3.38	0.04
Total	18.9	110.3		0.10
NT	Average Yield = 6.73 Mg ha^{-1}			
No till drill	6.2	35.7	3.15	0.05

Further comparison of tillage systems was done with respect to energy requirement to obtained yield (Table 3). The CT system showed to be the greatest energy consumer requiring 316.9 MJ Mg^{-1}. RT 1 and RT 2 systems required 190.3 MJ Mg^{-1} and 110.3 MJ Mg^{-1}, enabled thus saving of 39.9% and 65.2%, respectively. NT system proved to be even more efficient requiring only 35.7 MJ Mg^{-1} enabling saving of 88.8% in comparison to CT system.

3.3 Economic analysis

Total costs include all the inputs (labour, machine costs, seed, fertiliser and plant protection chemicals) from soil tillage to harvest, including grain transport within field. Storage and handling costs weren't taken into account since its great variability.

CT system resulted in the highest costs with 1002.00 \$ ha^{-1}. The costs of RT 1 system with 967 \$ ha^{-1} were only 3.5% lower, while RT 2 with 941 \$ ha^{-1} achieved 6.1% lower costs. NT system with 866 \$ ha^{-1} achieved 13.6% lower costs (Table 4). Although both RT systems and NT realised only slightly lower costs than CT system, comparison of gross margins could better express benefits of non-conventional soil tillage systems versus conventional tillage system. So, RT 1 realised 32.2% greater gross margin, while RT 2 realised even 72.3% greater gross margin. NT system achieved respectably 103.8% greater gross margin than CT system. According to Zentner et al. (1996) net economic return in reduced tillage was higher than in mouldboard plough tillage on the heavy clay soil. On the contrary Hoffman et al. (1999) found that net economic returns in the mouldboard plough tillage system increased more than in reduced and no-tillage systems.

Table 4. Total cost, gross income and gross margin for different tillage systems

Tillage	Gross income US\$ ha^{-1}	Total costs US\$ ha^{-1}	Gross margin US\$ ha^{-1}	Income : Costs ratio
CT	1290	1002	289	1.29
RT 1	1349	967	382	1.39
RT 2	1440	941	498	1.53
NT	1455	866	589	1.68

4. CONCLUSIONS

Summarizing results of annual experiment results together with previously acquired experience following could be concluded:

1. Conservation tillage system I (RT 1) enabled 36.1% energy saving per hectare, while conservation tillage system II (RT 2) achieved saving of 59.4% energy per hectare in comparison to conventional tillage system (CT) energy requirement.
2. No-till (NT) system achieved saving of 86.7% energy per hectare in comparison to conventional tillage system (CT) energy requirement.
3. Conservation tillage system I (RT 1) achieved 37.1% higher productivity, conservation tillage system II (RT 2) achieved 71.4% higher and no-till (NT) even 85.7% higher productivity in comparison to conventional tillage system (CT).
4. No-till (NT) achieved the greatest yield of 6.73 Mg ha^{-1}, the next is conservation tillage system II (RT 2) with yield of 6.63 Mg ha^{-1} then follows conservation tillage system I (RT 1) with 6.06 Mg ha^{-1} and finally conventional tillage system (CT) with 5.69 Mg ha^{-1}. Differences weren't statistically significant.

5. No-till (NT) realised 103.8% higher gross margin, while conservation tillage system II (RT 2) and conservation tillage system I (RT 1) had 72.3% and 32.2% higher gross margins than conventional tillage system. This short-term experiment showed that non-conventional tillage systems due to their lower energy and labour requirement could be economically important tool to decrease production costs.

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ENERGETIKA I EKONOMIKA OBRADE TLA U PROIZVODNJI OZIME PŠENICE

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Sadržaj: U radu su prikazani rezultati jednogodišnjeg eksperimenta proizvodnje ozime pšenice različitim sustavima obrade tla, provedenim na površinama imanja Njive d.o.o. u mjestu Lila, pokraj Našica. Test usjev je bila ozima pšenica, varijetet Renan. Primjenjeni sustavi obrade tla bili su kako slijedi: konvencionalni, konzervacijski i direktna sjetva bez obrade. Usporedba sustava obrade prema utrošku energije pokazuje svu rastrošnost konvencionalne obrade tla sa specifičnom potrošnjom goriva od 46.6 L ha^{-1} i 8.19 L Mg^{-1}. Konzervacijska obrada I je iziskivala 29.8 L ha^{-1} i 4.92 L Mg^{-1}, odnosno 36.1% i 40.0 % manje energije respektivno. Konzervacijska obrada II je trebala 18.9 L ha^{-1} i 2.85 L Mg^{-1}, što je 59.4 % i 65.2 % respektivno manje energije od konvencionalne obrade. Najveće uštede energije postignute su direktnom sjetvom bez obrade ili no-till sustavom koji je trošio svega 6.2 L ha^{-1} i 0.92 L Mg^{-1} diesel goriva, odnosno 86.7% i 88.8% respektivno manje od konvencionalne obrade. Usporedba različitih sustava obrade tla prema utrošku ljudskog rada pokazuje da konvencionalna obrada troši 1.95 h ha^{-1} i 0.34 h Mg^{-1}, konzervacijska obrada I troši 1.29 h ha^{-1} i 0.21 h Mg^{-1} ili 33.8% i 37.9% respektivno manje od konvencionalne obrade. Konzeravacijska obrada II iziskivala je 0.74 h ha^{-1} i 0.11 h Mg^{-1}, odnosno 62.3% i 67.6% respektivno manje. Direktna sjetva trebala je svega 0.32 h ha^{-1} i 0.05 h Mg^{-1}, što je 83.8% i 86.3% respektivno manje od konvencionalne obrade. Najmanji urod od 5.69 t ha^{-1} postignut je konvencionalnom obradom, dok je najveći urod od 6.73 t ha^{-1} postignut direktnom sjetvom bez obrade.

Ključne riječi: *Obrada tla, utrošak energije, proizvodni troškovi, ozima pšenica.*