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INFLUENCE OF DIFFERENT SOIL TILLAGE SYSTEMS ON FUEL CONSUMPTION, LABOUR REQUIREMENT AND YIELD IN MAIZE AND WINTER WHEAT PRODUCTION

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SUMMARY

An experiment with five different tillage systems and their influence on fuel consumption, labour requirement and yield of tested crops was carried out on Albic Luvisol in northwest Slavonia in the period of 1996.-2000. The compared tillage systems were: 1. conventional tillage system (CT), 2. reduced tillage system (RT), 3. conservation tillage system I (CP), 4. conservation tillage system II (CM), 5. no-tillage system (NT). The crop rotation was maize (Zea mays L.) - winter wheat (Triticum aestivum L.) – maize – winter wheat. Comparing the fuel consumption to CT system, RT system consumed 6.8% less, CP system 12.1% less, CM system 27.4% less, while NT system consumed even 82.7% less fuel. The labour requirement showed that RT system saved 7.6%, while CP system required 21.8% less, CM system 38.6% less labour, respectively. NT system saved 81.7% of labour in comparison to CT system. The highest yield of maize in the first experimental year was achieved under CT system and the lowest under RT system. In all others experimental years the highest yield of winter wheat and maize was achieved under CM system, while the lowest under RT system.

Key words: soil tillage, fuel consumption, labour requirement, maize, winter wheat, yield

INTRODUCTION

Maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) are the most important crops in Croatian agriculture. The technology of soil tillage in their production is mainly conventional based on ploughing as primary tillage operation and disc harrowing as secondary tillage operation or seedbed preparation.

This tillage technology is, on one hand, the most expensive, complicated, organisationally slow, with high fuel consumption and labour requirement, and, in the other one, ecologically unfavourable (Žugec et al., 2000). In the recent years, some authors from Croatia carried out experiments with different tillage systems in maize and winter wheat production. According to Stipešević et al. (1997), application of reduced or conservation soil tillage for arable crops in Croatia conditions is recommended because of reasons as follow: ecological (soil compaction reduction), economic (cost reduction) and organizational (reducing of field operations). Kanisek et al. (1997) reported that operating costs of implements and labour were 9.2% lower with conservation tillage system without ploughing than the conventional tillage system in East Croatia. Many European authors also pointed out ecological and economical benefits which can be achieved by using conservation tillage systems instead of conventional, for example: Borin and Sartori (1995), Malicki et al. (1997), Moreno et al. (1997), Tebrügge and Düring (1999), Birkas and Gyurica (2000), Bonciarelli and Archetti (2000), Dimitrov et al. (2000.), and many others. Regarding crop yields, many authors reported that lots of crops suffer higher or lower yield reductions while changing from conventional tillage to minimum or no-tillage. The results differ depending on the type of soil, crop and weather conditions. According to Sartori and Peruzzi (1994) maize cultivated by minimum tillage methods produced around 20-25% less than with those based on ploughing; while yield reduction is even more obvious with no-tillage. Winter cereals, among which winter wheat is the most widely studied,

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adapt better to the tillage reduction, losing 5% and 10% on the average with minimum tillage and no-tillage, respectively.
General objectives of this experiment were determining of different tillage systems influence on fuel consumption and labour requirement as well as their influence on crop yield within common crop rotation on a silty loam soil representing a significant area of the north-west Slavonian Croatian region.

MATERIAL AND METHODS

The experiment was conducted during period 1996-2000 at agricultural company "Poljoprivreda Suhopolje" located 150 km northeast from Zagreb (45° 50' N, 17° 26' E). The soil of the experimental field was the Albic Luvisol (according to FAO Classification, 1998) which, by its texture (Table 1), belongs to the silty loam (according to the Soil Survey Staff of the United States Department of Agriculture, 1975). According to the basic chemical properties, this soil is acid with pH 5.6 (measured in water) and pH 4.9 (measured in M KCl), rich in phosphorus and potassium (determined by AL method), as well as in nitrogen (determined by Micro-Kjeldahl method). As for the organic matter level of 2.7% (assessed by bichromath Tjurin method), it belongs to a group of soil with good level of organic matter.

Table 1. Particle size distribution and Texture class
Tablica 1. Mehanički sastav i teksturna oznaka tla

Depth Dubina	Particles size distribution (%) Mehanički sastav tla (%)				
cm	< 0.002 mm	0.002-0.02 mm	0.02-0.2 mm	0.2-2 mm	Texture
0-10	22.6	28.0	42.9	6.5	Silty loam
10-20	22.8	27.8	43.3	6.1	Silty loam
20-30	21.4	24.6	48.6	5.4	Silty loam

The experimental field consisted of 15 plots with 100 m in length and 28 m in width each, and organized as randomized blocks with three replications. The five tillage systems and implements, included in the some system, were as follows:
(CT) - Conventional tillage system (plough, disc harrow, combination harrow)
(RT) - Reduced tillage system (plough, combination harrow)
(CP) - Conservation tillage system I (chisel plough, power harrow)
(CM) - Conservation tillage system II (chisel plough, multitiller)
(NT) - No-tillage system (no-till planter for maize and direct drill for wheat)

The implements had following working width: mouldboard plough - 105 cm, disc harrow - 350 cm, seedbed implement - 600 cm, chiesel plough - 250 cm, power harrow 200 cm, multitiller 400 cm, no-tillage planter - 350 cm and direct drill - 250 cm.
Due to the fact that direct sowing was done in no-tillage system, the energy for sowing was added to all other systems. At all experiment plots, except no-till, mounted pneumatic 6 row planter and 20 row seed drill was used in maize sowing in winter wheat sowing.
In the season 1995-1996 this field was in a resting stage. The preceding crop in the season of 1994-1995 was winter barley, and the tillage was conventional. In the first year of the experiment primary tillage with mouldboard plough and chisel plough was done in November 14, 1996. Secondary tillage with disc harrow, combined implement, power harrow and multitiller was done in April 15, 1997. Field was sawn with the maize (*Zea mays* L.) cultivar "BC-592" in April 18, 1997. Prior to sowing 60 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O was applied in a form of compound NPK fertilizer. Urea was also applied prior to sowing in dose of 80 kg ha^{-1}. The crop protection was first time performed after sowing in April 25, 1997 with 1.5 l ha^{-1} of Dual 960 EC. The second treatment was in May 04, 1997 with 3.0 l ha^{-1} of Basagran. The top dressing was performed in May 15, 1997 with 200 kg ha^{-1} Calcium Ammonium Nitrate (commercial name KAN). The third treatment was conducted in May 26,

1997 with 1.0 l ha^{-1} of Motivell and 0.6 l ha^{-1} of Banvel 480 S. Fertilization and crop protection were uniform for the whole experimental field in both experimental years. Maize was harvested in October 07, 1997.

In the second year of this experiment a primary tillage was done in October 23, 1997., while a secondary tillage was done on October 28, 1997. The field was seeded with winter wheat (*Triticum aestivum* L.) cultivar "Manda" on October 30, 1997. Prior to seeding 60 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O was applied in a form of compound NPK fertilizer. The urea was also applied prior to seeding in dose of 200 kg ha^{-1}. The weed control was first time performed after seeding in October 31, 1997 with 2.0 l ha^{-1} of Dicuran Forte (herbicide). The first top dressing was performed in February 26, 1998 with 200 kg ha^{-1} Calcium Ammonium Nitrate and the second treatment was conducted in May 16, 1998 with the same rate of KAN. The final crop protection was performed on May 09, 1998 with 0.8 l ha^{-1} Starane (herbicide), 0.5 l ha^{-1} Tilt (fungicide), 0.3 l ha^{-1} Bavistin-FL (fungicide) and 0.6 l ha^{-1} Chromorel (insecticide). The winter wheat was harvested in July 07, 1998.

In the third year a primary tillage was performed in October 29, 1998 and a secondary tillage in April 15, 1999. The maize cultivar "BC-408 B" was sown in May 04, 1999. Prior to sowing 50 kg ha^{-1} N, 140 kg ha^{-1} P_2O_5 and 210 kg ha^{-1} K_2O was applied in a form of compound NPK fertilizer. Urea was also applied prior to sowing in dose of 80 kg ha^{-1}. The weed control was performed in May 10, 1999 with 8.0 l ha^{-1} of Ciatral-SCZ (herbicide). The top dressing was performed in May 18, 1999 with 200 kg ha^{-1} Calcium Ammonium Nitrate. The maize was harvested in October 21, 1999.

In the fourth year the winter wheat primary tillage was done in October 23, 1999 and a secondary one in October 25, 1999. The winter wheat cultivar "Manda" was seeded in October 26, 1999. The weed control was the first time performed after seeding in October 26, 1999 with 2.0 l ha^{-1} of Dicuran Forte (herbicide). Prior to seeding 50 kg ha^{-1} N, 140 kg ha^{-1} P_2O_5 and 210 kg ha^{-1} K_2O was applied in a form of compound NPK fertilizer. The urea was also applied prior to seeding in dose of 200 kg ha^{-1}. The first top dressing was performed on March 30, 2000 with 200 kg ha^{-1} Calcium Ammonium Nitrate and the second treatment in May 17, 2000 with 120 kg ha^{-1}. The final crop protection was performed in May 23, 2000 with 1.0 l ha^{-1} Duett (fungicide) and 0.2 l ha^{-1} Fastac (insecticide). Winter wheat was harvested in July 03, 2000.

The climate is characterized by semihumid with average annual precipitation of 817 mm and average annual temperature of 11.1 °C. Weather conditions in Suhopolje, during the maize and the winter wheat growing seasons and their comparison with 30-year averages (1965-1994), are shown in Table 2.

Table 2. Weather conditions in Suhopolje during growing season of maize (1997.and 1999), winter wheat (1997/98 and 1999/2000) and 30-year averages (1965-1994)

Tablica 2. Vremenski uvjeti u Suhopolju tijekom sezone rasta kukuruza (1997. i 1999.) i pšenice (1997./98. i 1999./2000.) te 30-godišnji prosjeci (1965.-1994.)

Month *Mjesec*	Precipitation (mm) *Oborine (mm)*					Air temperature (ºC) *Temperatura zraka (ºC)*				
	1997	1998	1999	2000	1965-1994	1997	1998	1999	2000	1965-1994
January		89.9	32.0	5.0	47.5		3.3	0.9	-0.7	0.1
February		2.5	85.1	20.3	45.9		6.0	2.0	5.0	1.6
March		57.6	26.6	43.8	65.0		5.4	8.6	7.6	6.4
April	53.4	77.8	92.8	52.4	61.3	7.5	12.7	12.5	14.5	11.2
May	81.5	90.0	86.4	55.9	82.1	17.5	15.9	17.1	17.8	16.2
June	101.1	62.8	157.9	40.8	102.9	20.4	21.5	19.8	18.8	19.0
July	144.7	163.8	135.9		61.6	20.1	21.3	21.8		21.8
August	77.6	143.0	83.1		75.0	20.3	21.0	20.9		21.2
September	2.3	115.7	48.8		69.9	16.4	15.4	18.7		17.2
October	79.2	131.3	44.4		68.6	9.1	12.8	11.5		11.2
November	89.7	93.5	132.3		62.3	5.8	4.1	3.7		5.0
December	97.7	40.2	56.9		75.2	2.9	-2.3	1.7		1.9

The fuel consumption for each tillage system, implement and crop was determined by measuring the tractor fuel consumption applying volumetric system. The specific density of diesel fuel was 0.835 kg dm^{-3} and the energy requirement was calculated with net heating value of 42 MJ kg^{-1} (35.07 MJ L^{-1}) of diesel fuel. A Four Wheel Drive tractor powered with engine of 92.0 kW was used in this experiment. 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 (2800 m^2). The yields were determined by weighing grain mass of each harvested plot. The obtained data for each experimental year were analysed applying the analysis of variance (ANOVA). The Duncan's test was used to compare the mean results, after a significant variation had been highlighted by ANOVA.

RESULTS AND DISCUSSION

Measurements of fuel consumption were carried out every experimental year and average results are shown in Table 3. Working conditions regarding soil moisture content, soil compaction and post-harvest residues at the beginning of experiment were equal for all tillage treatments. The CT system that includes treatment and inversion of the whole soil profile by mouldboard plough and seedbed preparation by disc harrow and combination harrow efficiently buried harvesting residues and created fine seedbed. But this system due to mentioned characteristics was the greatest fuel consumer. Having reduced the conventional tillage system (RT system) with sustaining plough and combination harrow, and avoiding disc harrow, fuel saving of 6.8% was achieved but created seedbed was coarser than at the CT system. The introduction of the chisel plough instead of the mouldboard plough contributed to fuel saving because chisel plough doesn't inverse soil profile. So, the CP system where after chisel plough a power harrow did seedbed preparation required 12.1% less fuel compared to the CT system.

Table 3. The average energy and labour requirement of different soil tillage systems
Tablica 3. Prosječni utrošak energije i rada kod različitih sustava obrade tla

Tillage system ***Sustav obrade***	Fuel consumption ***Potrošnja goriva*** (L ha^{-1})	Energy requirement ***Utrošak energije*** (MJ ha^{-1})	Work rate ***Radni učinak*** (ha h^{-1})	Labour requirement ***Utrošak rada*** (h ha^{-1})
Plough	20.79	729.10	0.81	1.23
Disc harrow	10.48	367.53	2.78	0.36
Com. harrow	6.93	243.04	7.14	0.14
Planter	3.86	135.37	4.17	0.24
CT Total	42.06	1475.04	-	1.97
Plough	20.79	729.10	0.81	1.23
Com. harrow 2x	14.53	509.57	2.86	0.35
Planter	3.86	135.37	4.17	0.24
RT Total	39.18	1374.04	-	1.82
Chisel pl.	18.02	631.96	1.59	0.63
Pow. harrow	15.10	529.56	1.49	0.67
Planter	3.86	135.37	4.17	0.24
CP Total	36.98[a]	1296.89[a]	-	1.54[a]
Chisel pl.	18.02	631.96	1.59	0.63
Multitiller	8.65	303.36	2.94	0.34
Planter	3.86	135.37	4.17	0.24
CM Total	30.53[b]	1070.69[b]	-	1.21[b]
NT Total	7.29[c]	255.66[c]	2.78	0.36[c]

[a] Significantly different at $P<0.05$; [b] Significantly different at $P<0.01$; [c] Significantly different at $P<0.001$

The CM system with a chisel plough and a multitiller saved 27.4% fuel compared to the CT system. With respect to the fuel consumption, the best results were achieved with NT system. In comparison to the CT system, the amount of the fuel saved increased to 82.7%. Although it was expected that the reducing of tillage intensity would increase the weed infestation, no such experience was noticed, that could be perhaps accounted to the proper plant protection and relatively shorter duration of the experiment. From the results in the Table 3 can be seen that CT system is also the greatest labour consumer, and the greatest part of labour requirement, 62.4% was consumed by ploughing. The RT system, without disc harrowing, saved 7.6% of labour. The CP system required 21.8% less labour whereas the CM system required 38.6% less labour respectively. The best results with respect to labour requirement were again achieved with the NT system and labour saving was 81.7% compared to the CT system.
In the first season of this experiment the greatest yield of maize, 7.78 t ha^{-1} was achieved with the CT system, even though the CM system gained almost the same yield (Table 4). There was a slightly lower yield with the NT system (2.8%) and the CP system (3.1%) but differences weren't significant. Compared to the CT system, a significantly lower yield (7.8%) was recorded at the RT system. The yield reduction could be accounted to coarser seedbed of this tillage treatment that affected worse seed placement and later lower plant density. In the third season of the experiment the greatest yield of maize (7.65 t ha^{-1}) was achieved with the CM system. This season was known for slightly lower (0.7%) yield achieved with the CT system. The NT system achieved 1.8% and the CP system 2.5% lower yield. The lowest yield was achieved with RT system, but difference wasn't significant. For comparison, 10-year (1985-1994) average maize yield at Croatian agricultural companies was 5.90 t ha^{-1}, according to Statistical Yearbook of Central Bureau of Statistics of the Republic of Croatia (1995).

Table 4. Average yields of maize and winter wheat (t ha^{-1})
Tablica 4. Prosječni urodi kukuruza i ozime pšenice (t ha^{-1})

Tillage system *Sustav obrade*	Maize *Kukuruz* 1997	Winter wheat *Ozima pšenica* 1997/98	Maize *Kukuruz* 1999	Winter wheat *Ozima pšenica* 1999/2000
CT	7.78	5.75	7.60	5.42
RT	7.17[a]	5.27[a]	7.39	5.22[a]
CP	7.54	5.51	7.46	5.49
CM	7.77	5.89	7.65	5.73
NT	7.56	5.73	7.51	5.62

[a] Significantly different at $P<0.05$

In the second season of this experiment, the greatest yield of winter wheat was achieved with the CM system, 2.4% more than the CT system. The NT system achieved 2.7% less yield and the CP system 6.5% less yield than the CM system. The lowest yield was again achieved with the RT system and it was significantly lower than the yield at CM system. In the fourth season of the experiment, the greatest yield of winter wheat, 5.73 t ha^{-1} was achieved again with the CM system. This season a second ranking was the NT system with 1.9% lower yield than the CP system with 4.2% lower yield and the CT system with 5.4% lower yield. The lowest yield was again achieved with the RT system. Yields of winter wheat achieved in the both experimental years were within 10-year (1985-1994) average yield at agricultural companies in Croatia (5.57 t ha^{-1}, according to Statistical Yearbook of Central Bureau of Statistics of the Republic of Croatia, 1995).
The greatest number of doubts concerning the application of the conventional tillage system is connected with the energy requirement. This problem can be investigated with respect to the fuel consumption and human work, and more generally as the so-called continuous reckoning of the expenditure with the realisation of tillage technologies for particular species (Malicki et al., 1997). In the literature on the subject, we can find a lot of information concerning significant reduction of the expenditure just with the application of simplifications, sometimes reaching even 70% (Dzienia and Sosnowski, 1990). Bowers (1992) showed a composite of average fuel consumption and energy

expended, based on data from eleven states in the U.S.A. and different countries around the world. In comparing these data to other sources, wide variations can be expected due to soil types, field conditions, working depth, etc. For example, according to Bowers (1992) average fuel consumption for mouldboard ploughing is 17.49±2.06 L ha^{-1}, for chisel ploughing 10.20±1.50 L ha^{-1}, disc harrowing 9.07±3.37 L ha^{-1}, no-till planter in average required 4.02±1.03 L ha^{-1}. On the other hand, Chancellor (1982) showed 24.21 L of diesel fuel per ha for mouldboard ploughing. Bowers (1992) also compared conventional (ploughing and two passes of disc harrow) and minimum tillage (only chisel ploughing) in the production of maize. In that case, the minimum tillage required about two-thirds as much fuel as the conventional tillage did.

According to Patterson et al. (1980), the conventional tillage system also required the greatest amount of labour 4.17 h ha^{-1}, while plough with combined cultivator required 3.70 h ha^{-1} and chisel plough with cultivator 3.33 h ha^{-1}. Comparing the conventional and no-tillage systems in the production of maize in Croatia, (Zimmer et al., 1997) indicated great possibility of labour requirement savings (up to 80%) owing to the use of no-till system. Kanisek et al. (1997) reported on the significant possibility of the labour savings (69.6%) and the financial benefits in the winter wheat production with the use of reduced soil tillage system (rotary cultivator with integrated seed drill) compared to conventional tillage system. Bonciarelli and Archetti (2000) carried out a three year experiment with conventional and minimum tillage and concluded that reducing soil tillage always resulted in notable savings of fuel consumption and working time, while concerning the crop yield, only very slight differences between tillage systems were observed on winter wheat.

Yields are often compared through different tillage systems and authors often report that a greater yield can be achieved with a conventional tillage in comparison to other tillage systems (reduced, conservation and no-till or zero-till). Borin and Sartori (1995) reported that among conventional tillage, minimum tillage and no-tillage in maize production the highest yield had been obtained with the conventional tillage. Maurya (1988) also reported that the maize grain yield was lower with no-till than with conventional tillage. Lyon et al. (1998) determined 8.0% greater winter wheat yield with conventional tillage than with no till. Zimmer et al. (1997) reported that no-till achieved 4% less yield of maize in comparison to the conventional tillage in the experiment during 1995-96 in eastern Slavonia conditions. Kapusta et al. (1996) had studied the effects of tillage systems for twenty years and found out an equal maize yield with no-till, reduced and conventional tillage. But, on the other hand, according to Lal (1997), in long term experiment no-till treatments produced higher maize yield than plough-based treatments. 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 year experiment the greatest average wheat yield had reduced tillage, while conventional tillage had the lowest. Moreno et al. (1997) reported higher winter wheat yield under conservation than traditional tillage but differences weren't significant.

This experiment with different soil tillage systems showed great possibilities of fuel and labour saving in north-west Slavonia region. The conservation tillage systems (CM system and CP system), and specially the NT system achieved not significantly different yields than the CT system, but their significantly lower fuel consumption and labour requirement could be of economical importance due to production costs reduction.

CONCLUSION

The results of this experiment indicate fuel and labour saving possibilities that could be achieved by the utilization of non-conventional tillage systems without significant yield reduction. With respect to the fuel consumption, the best results were achieved with the NT system. In comparison to CT system, NT system saved even 82.7% of fuel. The best results with respect to the labour requirement were also achieved with NT system and the labour saving was 81.7% in comparison to CT system. The highest yield of maize in the first experimental year was achieved under the CM system and the lowest under reduced tillage system. In all other experimental years the highest yield of winter wheat and maize was achieved under conservation tillage system, while the lowest under reduced tillage system. So, using these non-conventional tillage systems could help farmers in this region to decrease production costs in the maize and winter wheat production.

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UTJECAJ RAZLIČITIH SUSTAVA OBRADE TLA NA POTROŠNJU GORIVA, UTROŠAK RADA I UROD U PROIZVODNJI KUKURUZA I OZIME PŠENICE

SAŽETAK

Pokus s pet različitih sustava obrade proveden je na praškasto-ilovastom tlu na području sjeverozapadne Slavonije u razdoblju 1996.-2000., pri čemu je istraživan utjecaj na potrošnju goriva, utrošak rada i urod testiranih usjeva. Istraživani su sljedeći sustavi obrade tla: 1. konvencionalni sustav (CT), 2. reducirani sustav (RT), 3. konzervacijski sustav I (CP), 4. konzervacijski sustav II (CM), 5. sustav nulte obrade (NT). Plodored je bio sljedeći: kukuruz (Zea mays L.) – ozima pšenica (Triticum aestivum L.) – kukuruz – ozima pšenica. U usporedbi s konvencionalnim sustavom, reduciranim sustavom potrošeno je 6,8% manje goriva, konzervacijskim sustavom I 12,1% manje, konzervacijskim sustavom II 27,4% manje, dok je sustavom nulte obrade ostvarena manja potrošnja goriva za čak 82,7%. Istraživanje utroška rada pokazalo je da je reduciranim sustavom utrošeno 7,6% manje rada, konzervacijskim sustavom I 21,8% manje, konzervacijskim sustavom II 38,6% manje, a sustavom nulte obrade 81,7% manje rada, u usporedbi s konvencionalnim sustavom. Najveći urod kukuruza u prvoj pokusnoj godini ostvaren je konvencionalnim sustavom, a najmanji reduciranim sustavom obrade. U svim ostalim pokusnim godinama najveći urod ozime pšenice i kukuruza ostvaren je konzervacijskim sustavom II, a najmanji reduciranim sustavom obrade tla.

Ključne riječi: obrada tla, potrošnja goriva, utrošak rada, kukuruz, ozima pšenica, urod

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