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Maize and winter wheat production with different soil tillage systems on silty loam

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From 1996 to 1998 five different tillage systems were compared in maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) production on one experimental field (silty loam – Albic Luvisol) located in north-west Slavonia, Croatia. The compared tillage systems were as follows: conventional tillage (CT), reduced conventional tillage (RT), conservation tillage I (CP), conservation tillage II (CM), no-tillage system (NT). The aim of the research was to determine the influence of those tillage systems on the energy and labour requirement, and on the yield of the maize and of the winter wheat. Comparing the energy requirement to CT system, RT system required 16.1% less, CP system 26.9% less, CM system 40.8% less, while NT system required even 85.1% less energy per hectare. The labour requirement showed that RT system saved 16.4%, while CP system required 20.5% less, CM system 39.5% less labour respectively. NT system saved 82.1% of labour in comparison to CT system. The first year greatest maize yield of 7.78 Mg ha^{-1} was achieved with CT system, while other systems in comparison to CT system, except RT, achieved not significantly lower yields. The second year greatest winter wheat yield of 5.89 Mg ha^{-1} achieved CM system, while other systems in comparison to CM, except RT, achieved not significantly lower yields.

Key words: conventional tillage, reduced tillage, conservation tillage, no-till, energy requirement, labour requirement, yield

Introduction

The soil tillage is one of the operations that require the most direct energy in arable production. Pellizzi et al. (1988) reported that 55–65% of the direct field energy consumption should be accounted to the soil tillage. Although it is known that usage of non-conventional tillage systems (reduced, conservation and no-till or direct drilling) in comparison to conventional tillage system can save enormous quantity of energy and labour, currently 85% of the fields in Central Europe are being tilled by the conventional tillage system (Stroppel 1997). The conventional tillage system is method based on a high inten-

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sity of the soil engagement and inversion of the soil with a mouldboard plough as characteristic implement. The conservation tillage systems try to disturb the soil as little as possible to conserve its natural structure, leave the maximum vegetal residue next to the soil surface, and/or try to build a rough surface; typical machines for the conservation tillage are chisels and wingtine cultivators (Weise and Bourarach 1999). Many authors from Central Europe: Poje (1994), Borin and Sartori (1995), Kornmann and Köller (1997), Knakal and Prochazkova (1997), Malicki et al. (1997), Tebrügge and Düring (1999), pointed out of ecological and economical benefits which can be achieved by using conservation tillage systems instead of conventional. Regarding crop yields, many authors reported that many crops suffer greater or lesser yield reductions in changing from conventional tillage to minimum or no-tillage. The results differ depending on the type of crop, soil and weather pattern. According to Sartori and Peruzzi (1994) maize cultivated with minimum tillage methods produced around 20–25% less than with those based on ploughing; while the yield reduction is even more obvious with no-tillage. Winter cereals, among which winter wheat is the most widely studied, adapt better to the reduction in tillage, losing 5% and 10% on average with minimum tillage and no-tillage, respectively.

Some authors from Croatia carried out experiments with different tillage systems. According to Stipesevic et al. (1997), application of reduced or conservation soil tillage for arable crops in East Croatia conditions is recommended because of the following reasons: 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 reduced tillage system without ploughing than the conventional tillage system in East Croatia. Today almost 99% of arable land in Croatia has been tilled by the conventional system (mouldboard ploughing, discharrowing and tineharrowing or seedbed preparation with combined implement), which is aftermath of two essential factors: first, farmers are traditionally conservative and slowly accept the new ideas and technologies, especially when they are connected with some production risks such is lower yields; second factor is very low average farm area (in Croatia only 2.9 ha) and low investment capability of farmers.

Agricultural Engineering Department, Faculty of Agronomy, Zagreb, carried out experiment with different tillage systems in arable production. Five various systems including four systems of reduced or conservation tillage and the conventional tillage as control were tested in the production of the most important crops in Croatian agriculture – maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.). The general objectives of this experiment were determining of different tillage systems influence on energy and labour requirement so as well as their influence on crop yield within common crop rotation on a silty loam soil representing a significant area of the region north-west Slavonia.

Material and methods

The experiment was conducted during 1996–1998 at agricultural company "Poljoprivreda Suhopolje" located 150 km northeast from Zagreb (45°50'N, 17°26'E). The tillage with different systems was performed on the Albic Luvisol, according to FAO Classification (1998) which, by its texture, belongs to the silty loam (Table 1), according to the Soil Survey Staff of the United States Department of Agriculture (1975). According to the basic chemical property data this soil is acid with pH 5.6 (measured in water) and pH 4.9 (measured in M KCl), very rich in physiological nutrients, 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.

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Table 1. Soil particle size distribution.

Depth cm	Particles size distribution (g kg^{-1})				
	< 2 µm	2–20 µm	20–200 µm	200–2000 µm	Texture[1)]
0–10	226	280	429	65	Silty loam
10–20	228	278	433	61	Silty loam
20–30	214	246	486	54	Silty loam

[1)] According to the Soil Survey Staff of the United States Department of Agriculture

The experimental field consisted of 15 plots with dimensions of 100 m in length and 28 m in width each, and organized as randomized blocks with three replications. The five tillage systems and implements, which were included in the some system, were as follows:

CT – Conventional tillage (plough, discharrow, combination harrow)
RT – Reduced conventional tillage (plough, combination harrow)
CP – Conservation tillage I (chisel plough, power harrow)
CM – Conservation tillage II (chisel plough, multitiller)
NT – No-tillage system (no-till planter for maize and direct drill for wheat)

Due to the fact that in the no-tillage system the direct sowing was done, the energy for sowing was added to all other systems. At all experiment plots except no-till, in first year (test crop maize) we used mounted pneumatic 6 row planter and in second year (test crop winter wheat) 20 row drawn seed drill.

In the season of 1995–1996 this field was in a resting stage. The previous crop in the season of 1994–1995 was winter barley, and the tillage was conventional. Schedule of the tillage operations and soil moistures at the moment of tillage are showed in the Table 2. Sampling for soil moisture determination was done at all experimental plots in three layers 0–10 cm, 10–20 cm and 20–30 cm in three replicates before tillage and soil moisture was determined by the gravimetric method. The soil moisture content at field capacity was determined by measuring of water retention at 0.03 MPa on pressure plate apparatus.

In the first season of this experiment the maize (*Zea mays* L.) cultivar 'BC-592' was sown on 18 April 1997. Prior to sowing 60 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O in a form of compound NPK fertilizer was applied. Urea was also applied prior to sowing in dose of 80 kg ha^{-1}. The crop protection was first time performed after sowing on 25 April 1997 with 1.5 l ha^{-1} of Dual 960 EC. The second treatment was on 4 May 1997 with 3.0 l ha^{-1} of Basagran. The third treatment was on 26 May 1997 with 1.0 l ha^{-1} of Motivell and 0.6 l ha^{-1} of Banvel 480 S. Fertilizing and crop protection were uni-

Table 2. Date of tillage operations and soil moistures at the moment of tillage and at field capacity (FC).

Operation	Soil moisture (%, w/w)		
	Depth (cm)		
	0–10	10–20	20–30
Primary tillage 14 Nov 1996	22.1	19.8	19.1
Secon. Tillage 15 Apr 1997	18.4	19.6	20.3
Primary tillage 23 Oct 1997	21.6	20.1	19.8
Secon. Tillage 28 Oct 1997	19.9	19.6	19.4
FC	33.8	34.2	35.0

Table 3. A weather conditions in Suhopolje during the growing period of maize in 1997 (April–October) and during the growing period of winter wheat (October 1997 – July 1998) and 25-year averages (1972–1996).

Month	Mean air temperature (ºC)			Precipitation (mm)		
	1997	1998	1972–1996	1997	1998	1972–1996
Jan	–	3.3	0.1	–	89.9	53.2
Feb	–	6.0	1.8	–	2.5	46.2
Mar	–	5.4	6.6	–	57.6	52.6
Apr	7.5	12.7	10.7	53.4	77.8	66.8
May	17.5	15.9	16.0	81.5	90.0	76.5
Jun	20.4	21.5	19.1	101.1	62.8	86.0
Jul	20.1	21.3	20.9	144.7	163.8	72.9
Aug	20.3	–	20.2	77.6	–	80.8
Sep	16.4	–	16.1	2.3	–	69.2
Oct	9.1	–	11.0	79.2	–	71.9
Nov	5.8	–	5.0	89.7	–	81.5
Dec	2.9	–	1.6	97.7	–	68.4

form for whole experimental field in both experimental years. Maize was harvested on 7 October 1997. In the second season, postharvest residues of maize were chopped and distributed over soil surface with tractor's drawn chopper on 20 October 1997. The field was sown with the winter wheat (*Triticum aestivum* L.) cultivar 'Manda' on 30 October 1997. Prior to sowing 60 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O in a form of compound NPK fertilizer was applied. Urea was also applied prior to sowing in dose of 200 kg ha^{-1}. Weed control was first time performed after sowing on 30 October 1997 with 2.0 kg ha^{-1} of Dicuran Forte. The first top dressing was performed on 26 February 1998 with 200 kg ha^{-1} Calcium Ammonium Nitrate (commercial name KAN) and the second treatment on 16 May 1998 with the same rate of KAN. The final crop protection was performed on 9 May 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). Winter wheat was harvested on 7 July 1998.

The tillage depth of implements had been similar for both experimental years. The average tillage depth for the mouldboard plough was at 34 cm, for the discharrow at 9 cm and for the seedbed implement at 6 cm. The chiesel ploughing was done to 33 cm and the power harrowing to 10 cm. The multitiller's depth of the tillage was 8 cm. The no-tillage drill was set to 5 cm for the maize and to 8 cm for the winter wheat. Seed bed preparation in CT system was performed by 2 passes of a discharrow and 2 passes of a combination harrow, while at RT system was done with 2 passes of a combination harrow. At conservation tillage systems seed bed preparation was done by single pass of a power harrow (CP) and single pass of a multitiller (CM).

The weather conditions during the maize and the winter wheat growing seasons and their comparison with 25-year averages (1972–1996) are shown in the Table 3. The average air temperature during growing season of maize 1997 (April-October) was 15.9°C, which was 2.5% less in comparison to twenty-fifth year average. The greatest temperature deviation of 3.2°C less than 25-year average was recorded in April 1997. The total precipitation during growing season of maize 1997 was 539.8 mm, which was 3.0% more in comparison to twenty-fifth year average. The greatest precipitation deviation of 98.5% more than 25-year average, was recorded

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in July, while in September was 96.7% less precipitation in comparison to 25-year average. Although there were deviation of the air temperature and precipitation, growing period of the maize could be characterized as more or less as common growing season.

The average air temperature during winter wheat growing season 1997–1998 (November-June) was 9.2°C, 21.1% higher than twenty-fifth year average. The greatest air temperature deviation of 4.2°C more than twenty-fifth years average was recorded in February 1998. The total precipitation of 568 mm during growing season of winter wheat 1997–1998 was 6.9% more than twenty-fifth year average. Distribution of precipitation during mentioned period regarding monthly distribution was relatively even, except February with recorded precipitation of 2.5 mm that was 94.6% less than twenty-fifth year average. In comparison to the 25-year average metheorological data, the growing season of winter wheat could be described as a bit warmer growing season.

The energy requirement for each tillage system, implement and crop was determined by measuring of 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 with the engine power of 92 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. The differences had been considered as significant if $P < 0.05$.

Results and discussion

Energy requirement

Measurements of fuel consumption were carried out every experimental year and average results are shown in Table 4. Working conditions regarding soil moisture content, soil compaction and post-harvest residues at the beginning of experiment were equal for all tillage treatments. The conventional tillage system that includes treatment and inversion of whole soil profile by mouldboard plough and afterwards two passes of discharrow and combination harrow efficiently buried harvesting residues and created fine seedbed. But this system due to mentioned characteristics was expectantly the greatest energy consumer. Having reduced the conventional tillage system (sustaining plough and combination harrow and avoiding discharrow), energy saving of 23.9% was achieved but created seedbed was much coarser than at conventional system. The introduction of the chisel plough instead of the mouldboard plough contributed to 8.9% of energy saving because chisel plough doesn't inverse soil profile. The conservation tillage system I where after chisel plough seedbed preparation was done by single pass of a power harrow required 26.9% less energy in comparison to the conventional tillage system. The conservation tillage system II with a chisel plough and single pass of a multitiller saved 40.8% energy in comparison to conventional tillage system. With respect to the energy requirement, the best results were achieved with no-till system. In comparison to the conventional tillage system, the amount of the energy saved increased to 82.6%. Although it was expected that the reducing of tillage intensity would increase the weed infestation, no such experience were noticed, what could be perhaps accounted to the proper plant protection and the shorter duration of experiment.

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

Table 4. The average energy and labour requirement of different soil tillage systems: CT – conventional tillage, RT – reduced conventional tillage, CP – conservation tillage I, CM – conservation tillage II, NT – no-tillage system.

Tillage system	Fuel consumption (L ha^{-1})	Energy requirement (MJ ha^{-1})	Work rate (ha h^{-1})	Labour requirement (h ha^{-1})
Plough	20.38	714.73	0.82	1.22
Discharrow	10.07	353.15	2.84	0.35
Com. harrow	6.88	241.28	7.02	0.14
Planter	3.82	133.97	4.13	0.24
CT Total	41.15	1443.13	–	1.95
Plough	20.38	714.73	0.82	1.22
Com. harrow	7.10	249.00	5.85	0.17
Planter	3.82	133.97	4.13	0.24
RT Total	31.30	1097.10	–	1.63
Chisel pl.	18.16	636.87	1.58	0.63
Pow. harrow	15.39	539.73	1.46	0.68
Planter	3.82	133.97	4.13	0.24
CP Total	37.37	1310.57	–	1.55
Chisel pl.	18.16	636.87	1.58	0.63
Multitiller	7.79	273.19	3.24	0.31
Planter	3.82	133.97	4.13	0.24
CM Total	29.77	1044.03	–	1.18
NT Total	7.14	250.40	2.84	0.35
LSD[1] ($P < 0.05$)	3.01	105.56	–	0.16

[1)] LSD = Least significant difference

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 USA. 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}, discharrowing 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 discharrow) 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.

Labour requirement

From the results in the Table 4 it is seen that conventional tillage system is also the greatest labour consumer, and the greatest part of labour

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requirement, 62.6% was consumed by ploughing. A reduced conventional tillage system, without discharrowing, saved 16.4% of labour. The conservation tillage system with a chisel plough and a power harrow required 20.5% less labour and the conservation system with a chisel plough and a multitiller required 39.5% less labour respectively. The best results with respect to labour requirement were again achieved with no-till system and labour saving was 82.1% in comparison to conventional tillage system. 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 the great possibility of labour requirement savings (up to 80%) owing to the use of the 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) in comparison to conventional tillage system.

Yield

Although the weather conditions during maize growing season were within 25-years average, experimental yields were above average yield level in Croatia. According to Statistical Yearbook of Central Bureau of Statistics of the Republic of Croatia (1995), 10-years (1985–1994) average maize yield at agricultural companies was 5.90 t ha^{-1}.

The greatest yield of maize was achieved with the conventional tillage system, even though the conservation system with a chisel plough and a multitiller gained almost the same yield (Table 5). There was a slightly lower yield

Table 5. Mean grain yields, thousand-kernels weights (14% moisture content for maize) and grain moistures at harvest of maize and winter wheat at different tillage systems.

Tillage system	Yield (Mg ha^{-1})	1000 kernels weight (g)	Grain moisture (g $100g^{-1}$)
Maize 1997			
Conventional tillage	7.78	339.14	39.1
Reduced conv. tillage	7.17	339.24	37.6
Conservation tillage I	7.54	338.96	37.8
Conservation tillage II	7.77	340.93	38.7
No – tillage	7.56	340.64	37.5
LSD[1] ($P < 0.05$)	0.59	NS[2]	NS
Winter wheat 1998			
Conventional tillage	5.75	37.9	12.81
Reduced conv. tillage	5.27	38.3	12.56
Conservation tillage I	5.51	37.3	13.07
Conservation tillage II	5.89	38.8	13.02
No – tillage	5.73	39.2	13.25
LSD ($P < 0.05$)	0.48	NS	NS

1) LSD = Least significant difference
2) NS = Not significant

with a no-till system (2.8% lower) and the conservation system with a power harrow (3.1% lower) but differences weren't significant. Compared to the conventional system, a significantly lower yield, 7.8% was recorded only at the reduced tillage system. The yield reduction could be accounted to coarser seedbed of this tillage treatment that affected to worse seed placement and later lower plant density. Among a thousand kernels weights at five different tillage system there were no significant differences.

In comparison to the 25-year average metheorological data, the growing season of winter wheat 1997–1998 could be described as a bit warmer growing season. Yields of winter wheat achieved in the experiment were within 10-years (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). In the second season of this experiment, the greatest yield was achieved with the conservation tillage system II, 2.4% more than the conventional tillage system. Although no-till system achieved 0.3% less yield and the conservation tillage system I achieved 4.2% less yield than the conventional tillage system, differences weren't significant. The lowest yield was again achieved with the reduced tillage system and it was significantly lower (8.3%) than the yield accomplished with the conventional tillage system.

This short term experiment showed that both conservation tillage systems and no-till system achieved not significantly different yields than the conventional tillage system, but their significantly lower energy and labour requirements could be of economical importance due to production costs reduction.

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 others 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 1995–1996 in eastern Slavonia (Croatia) conditions. Kapusta et al. (1996) had studied the effects of tillage systems for twenty years and found 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 then 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 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.

Conclusion

The two years experiment with five different tillage systems were performed on one experimental field (silty loam – Albic Luvisol) located in north-west Slavonia, Croatia. The tested crops were the most important crops in Croatian agriculture – maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.). With respect to the energy requirement, the best results were achieved with no-till system. In comparison to the conventional tillage system, no-till system saved even 82.6% of energy. The best results with respect to the labour requirement were also achieved with no-till system and the labour saving was 82.1% in comparison to the conventional tillage system. The first year the greatest maize

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yield of 7.78 Mg ha^{-1} was achieved with conventional tillage system, and the second year the greatest winter wheat yield of 5.89 Mg ha^{-1} achieved with conservation tillage system II. The results, although achieved in the short term experiment, indicate of the energy and labour saving possibilities that could be achieved by the utilization of non-conventional tillage systems without the significant yield reduction. So, using of 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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