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NON-CONVENTIONAL SOIL TILLAGE SYSTEMS IN WINTER BARLEY AND SOYBEAN PRODUCTION

UDC

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Abstract. *The paper presents results of the two-year experiment in winter barley (*Hordeum vulgare *L.) and soybean (*Glycine max *L.) production. Short-term study of non-conventional soil tillage systems was conducted at the experimental field near Staro Petrovo Selo (45° 10’ N, 17° 30’ E) on Hypogley-vertic type of soil and semi humid climate conditions. The tillage systems and implements used were: CT – mouldboard plough, disc harrow, seed-bed implement, drill, RT 1 - chisel plough, disc harrow, seed-bed implement, drill, RT 2 - chisel plough, rotary harrow integrated with seed drill, RT 3 - mouldboard plough, rotary harrow integrated with seed drill. The highest average yields were obtained by RT 3 in barley production (4.42 t ha^{-1}) and RT 1 system in soybean (3.78 t ha^{-1}) production. The greatest energy and labour savings in soil tillage, among the lowest total cost of production, were achieved by RT 2 system, but due to the significantly lower yields this system has not proved adequate for soybean production, while it could be recommend in barley production due to the highest productivity accompanied with high yields and economic efficiency. The highest economic efficiency of barley production has shown RT 3 system (coefficient of 1.75), while in soybean production the most profitable system was RT 1 (coefficient of 2.16). Regarding the choice of tillage systems, assuming uniform level of yields, the advantage should be given to systems with lower level of tillage intensity, not only to reduce costs but also because of the possibility of simpler production organization due to less machine and labour requirement.*

Key words: *soil tillage, energy consumption, production costs, economic efficiency.*

1. INTRODUCTION

Soil tillage aims to create favourable conditions for seed germination and plant growth and is considered an indispensable part of arable crop production. The intensification of tillage, along with fertilization, crop protection and selection, has enabled a significant increase in yields, but also caused soil degradation, increased risk of erosion and rise of production costs. Greatest possibility for production rationalization offers tillage reduction, mainly by substitution of mouldboard ploughing as most energy and time-demanding task with conservation tillage systems.

Winter barley (*Hordeum vulgare* L.) and soybean (*Glycine max* L.) are important arable crops largely represented in the crop rotation on arable areas in Croatia. The mainly utilised soil tillage system in barley and soybean production, among other arable crops, is conventional system based on mouldboard ploughing as primary tillage operation, followed with secondary tillage performed by disc harrow and seed-bed implement. The long term application of conventional tillage showed significant economic and environmental drawbacks. From an economic point of view, disadvantages of conventional tillage systems are high energy and labour, large investment and maintenance costs of machinery, and ultimately higher costs of crop production. According to some European researches conventional tillage system requires 434 kWh ha^{-1} of energy and 4.1 h ha^{-1} human-machine work [1], [2]. In contrast, reduced tillage systems can bring about 30% -50% savings of the energy and human-machine work, and direct sowing as much as 70%, compared to conventional tillage. From an ecological point of view, disadvantages of conventional tillage systems are increased soil compaction caused by excessive number of machinery passes, systematic reduction of soil organic matter (humus content) as a result of intensive and frequent tillage and the greater the susceptibility to soil erosion [3]. A significant CO_2 emissions from the combustion of large amounts of fuel consumed in the intensive tillage is also an environmental issue [4]. Stroppel [5] reported that by the end of the last century about 85% of the arable land of central Europe was under conventional tillage systems. The implementation of reduced tillage systems has not significantly increased to date, and it is estimated that there are still less than 10% [6]. The world leading agricultures in substitution of conventional soil tillage systems with different variations of the reduced tillage and direct sowing are United States and Canada in North America and Brazil, Argentina, Uruguay and Paraguay on the South, where conservation tillage and no-tillage systems applied to more than half of total arable crop area [7]. Despite the mentioned trends, it is estimated that over 90 % of the fields in Croatia are still being tilled with the conventional tillage system [8].

Previous studies suggest that reduced tillage is favourable for high density crops such as winter wheat, spring barley and canola, while much worse option for spring row crops such as corn and soybeans [9], [10], [11], [12]. While some authors [13] have noticed a decrease of yield of spring barley with the degree of tillage reduction (14% lower yield at a reduced tillage and 27% lower in direct drilling), others claim that there is no significant difference in realized yields between different tillage systems [14]. Reduction of production costs by applying some of the reduced tillage systems, in conditions where yields were not significantly reduced due to lower tillage intensity, enables a lower profitability threshold [15], [16], [17].

2. MATERIAL AND METHODS

The experiment was performed at agricultural company ”PK Nova Gradiška” near village Stivica, located 150 km south-east from Zagreb (45° 09’ N, 17° 31’ E). Experimental field was consisted of 12 plots with dimension length 250 m x width 56 m each, organized as randomized blocks with three replications. The tillage with different systems was performed on the Hypogley-vertic type of soil [18] and its texture in ploughed layer belongs to the silty clay loam (Table 1).

Table 1. Soil particle size distribution

Depth (cm)	Particle size				Texture[1]
	0.2-2 µm (%)	0.05-0.2 µm (%)	0.002-0.05 µm (%)	<0.002 µm (%)	
0-30	16.0	28.0	22.0	34. 0	SiCL
30-60	13.0	32.0	26.0	29.0	SiCL-SiL
60-90	13.0	31.0	28.0	28.0	SiCL

1) SiCL = Silty clay loam, SiL = Silty loam

Implements, which were included in different tillage systems, are as follows:

1. Conventional tillage – mouldboard plough, disc harrow, multitiller, drill (CT);
2. Conservation tillage 1 - chisel plough, disc harrow, multitiller, drill (RT1);
3. Conservation tillage 2 - chisel plough, rotary harrow + drill (RT2);
4. Conservation tillage 3 - mouldboard plough, rotary harrow + drill (RT3).

Mouldboard plough used in tillage systems CT and RT3 was Kuhn Multimaster 151 with four bodies, disc harrow was Kuhn Discover XM 44/660, multitiller Lemken Korund 750L, and seed drill Tive 2000. Chisel plough used in RT1 and RT2 was Agram GeoDec SVD6. In conservation tillage systems RT2 and RT3 an integrated implement Kuhn Integra 3000 was used, consisted of rotary harrow and seed drill.

Energy requirement of each tillage system was determined based on the tractor’s fuel consumption. The amount of fuel consumed was measured for each implement (tillage and sowing) on every single plot. Specific energy consumption is calculated based on the energy equivalent of 38.7 MJ L^{-1} for diesel fuel used. In this experiment 4WD tractor with engine power of 136 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 (14,000.00 m^2). The yields were determined by weighing grain mass of each harvested plot, and recalculated according to grain moisture content in storage conditions afterwards. Fertilization and crop protection was uniform in all tillage, determined by crop specific requirements.

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 winter wheat. Working conditions regarding soil moisture content, soil compaction and post-harvest residues at the beginning of experiment were equal for all tillage treatments.

Table 2. Date of field operations and application rates

Description	Winter barley	Soybean
	Tillage & Sowing	
Primary tillage	1st November 2009	August 26th 2010
Soil moisture (%) at 5; 15; 30 cm depth	18.8; 28.7; 33.2	16.2; 44.2; 44.4
Secondary tillage	15th October 2009	April 21st 2011
Soil moisture (%) at 5; 15; 30 cm depth	30.1; 29.7; 31.0	23.9; 45.9; 43.7
Sowing date	15th October 2009	April 21st 2011
Crop-cultivar (kg ha^{-1})	Mombasa (210)	Podravka (120)
	Fertilizing	
Application date	14th October 2009	March 29th 2011
Fertilizer-rate (kg ha^{-1})	Urea 46% (100)	NPK 0:20:30 (400)
Application date	2nd March 2010	April 20th 20011
Fertilizer-rate (kg ha^{-1})	CAN 27% (150)	Urea 46% (100)
Application date		June 7th 2011
Fertilizer-rate (kg ha^{-1})		CAN 27% (100)
	Crop protection	
Application date	27th November 2009	April 22nd 2011
Chemical-rate (l ha^{-1})	cyhalothrin (0.15) triasulfuron (45 g ha^{-1})	metribuzin (0.70) dimetenamid (1.30)
Application date	15th April 2010	May 10th 2011
Chemical-rate (l ha^{-1})	azoxistrobin (0.033)	fomesafen (0.75) tifensulfuron-metil (0.008)
Application date	21th April 2010	June 4th 2011
Chemical-rate (l ha^{-1})	epoxichonazol + crezoxim-metil (0.8)	propakizafop (1.00) bentazon (2.5)
Application date	12th May 2010	April 22nd 2011
Chemical-rate (l ha^{-1})	prothioconazole (0.9)	metribuzin (0.70) dimetenamid (1.30)
	Harvest	
Harvesting date	12th July 2010	September 16th 2011

Economic efficiency of different soil tillage systems was calculated based on the natural indicators of barley and soybean production (energy consumptions, labour requirement, raw materials, yields). Statistical analysis of data for all research indicators was done with computer program SAS [19] using analysis of variance (ANOVA). The significance of differences between the observed parameters were indicated by F-test at the level of probability $p = 0.05$.

3. RESULTS AND DISCUSSION

3.1. Yield

In winter barley production the greatest average yield of 4.42 t ha^{-1} was achieved by RT3 tillage system followed by CT with average yield of 4.14 t ha^{-1} and RT2 with 4.04 t ha^{-1}. The lowest average yield was obtained with RT1 system 3.71 t ha^{-1}. According to ANOVA, differences of average winter barley yields obtained by different soil tillage systems were statistically significant between RT3 and RT1, at probability level of $p<0.05$. CT and RT2 yields were not significantly different to other tillage systems.

In the cultivation of soybeans the highest average yield of 3.78 t ha^{-1} was obtained with reduced tillage RT1, which is 15% higher than the yield recorded on a conventional tillage system (3.28 t ha^{-1}). The lowest average yield of soybeans 2.76 t ha^{-1}, or 19% less than conventional system was recorded in RT2. Analysis of variance revealed significant differences in average yields between RT1 and RT2 on the $p <0.05$ level. At variant RT3 average yield was slightly lower than in the variant with conventional tillage and that difference was not statistically significant.

Along with noticed occurrence of yield instability with a reduction of soil tillage [20], yields may also be susceptible to seasonal climate deviations [21], [22].

3.2. Energy and labour requirement

The conventional tillage system (CT) was expectedly the greatest fuel consumer (Table 3). In winter barley production the greatest fuel consumption of 50.93 L ha^{-1} was recorded in conventional tillage system. RT3 system enabled 10.3% saving and RT2 20.1% saving of fuel compared to conventional tillage. The greatest energy saving per hectare (35.1%) in winter barley was obtained by RT1 system.

A total of 48.23 L ha^{-1} diesel fuel was spent in tillage and planting soybeans with conventional system wherein the mouldboard ploughing stands out as the most significant consumer with about 64% of total energy consumption. At variants with reduced soil tillage RT1 and RT2 were spent a third less fuel/energy in which the system RT1 points to 42.2% lower specific energy consumption (328.7 MJ t^{-1}) due to significantly higher yield compared to the conventional system.

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

	Winter barley				**Soybean**			
Tillage system	Fuel L ha^{-1}	Energy MJ t^{-1}	Productivity h ha^{-1}	h t^{-1}	Fuel L ha^{-1}	Energy MJ t^{-1}	Productivity h ha^{-1}	h t^{-1}
CT	**Average yield = 4.14 t ha^{-1} ab (1)**				**Average yield = 3.28 t ha^{-1} b**			
Mouldboard plough	33.4	312.3	1.21	0.29	31.12	367.0	1.35	0.41
Disc harrow	9.95	93.0	0.28	0.07	9.67	114.0	0.34	0.10
Multitiller	4.95	46.3	0.24	0.06	4.31	50.8	0.17	0.05
Seed drill	2.63	24.6	0.41	0.10	3.13	36.9	0.56	0.17
Total	**50.93**	**476.2**	**2.14**	**0.52**	**48.23**	**568.7**	**2.42**	**0.74**
RT 1	**Average yield = 3.71 t ha^{-1} b**				**Average yield = 3.78 t ha^{-1} a**			
Chisel plough	18.42	192.4	0.58	0.16	15.00	153.6	0.57	0.15
Disc harrow	7.03	73.4	0.26	0.07	9.67	99.0	0.34	0.09
Multitiller	4.95	51.7	0.24	0.06	4.31	44.1	0.17	0.04
Seed drill	2.63	27.5	0.41	0.11	3.13	32.0	0.56	0.15
Total	**33.03**	**344.9**	**1.49**	**0.40**	**32.11**	**328.7**	**1.64**	**0.43**
RT 2	**Average yield = 4.04 t ha^{-1} ab**				**Average yield = 2.76 t ha^{-1} c**			
Chisel plough	18.42	176.4	0.58	0.14	15.00	209.2	0.57	0.20
Rotary harrow + drill	22.26	213.2	0.78	0.19	17.04	237.6	0.61	0.22
Total	**40.68**	**389.6**	**1.36**	**0.34**	**32.04**	**446.8**	**1.18**	**0.42**
RT 3	**Average yield = 4.42 t ha^{-1} a**				**Average yield = 3.27 t ha^{-1} b**			
Mouldboard plough	28.86	252.9	1.23	0.28	31.12	368.6	1.35	0.41
Rotary harrow + drill	16.83	147.5	0.76	0.17	16.44	194.7	0.59	0.18
Total	**45.69**	**400.4**	**1.99**	**0.45**	**47.56**	**563.4**	**1.94**	**0.59**

(1) Different letters indicate significant ($p \leq 0.05$) differences

The highest productivity regarding labour requirement per hectare and ton of grain yield was achieved with RT2 tillage system in both winter barley and soybean production. Comparing the results with allegations by other authors [23], [24] larger deviations due to soil types, current conditions in the field, depth of tillage and implements used could be expected, but an increase in labour productivity with the degree of reduction of tillage is noticeable.

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 were not taken into account since its great variability.

In both seasons CT system resulted in the highest costs with 546.00 € ha^{-1} (winter barley) and 790 € ha^{-1} (soybean) mainly due to great number of field operations and large amount of labour requirement (Table 4). In winter barley production the highest income was obtained with RT3 system and that variant also showed the best economic efficiency (coefficient 1.75). In soybean production the highest economic efficiency was achieved in RT1 system (coefficient 2.16) together with the highest income due to significantly higher yield compared to other tillage systems.

Similar to findings of other authors [25] [26] better economic effects were achieved principally with reduced tillage systems.

Table 4. Economic efficiency indicators of soybean and barley production

Tillage	**Winter Barley**				**Soybean**			
	Gross income € ha^{-1}	Total costs € ha^{-1}	Gross margin € ha^{-1}	Income/ Costs ratio	Gross income € ha^{-1}	Total costs € ha^{-1}	Gross margin € ha^{-1}	Income/ Costs ratio
CT	875.00	564.00	311.00	1.55	1,394.00	790.00	604.00	1.76
RT 1	816.00	537.00	279.00	1.52	1,560.00	721.00	839.00	2.16
RT 2	862.00	496.00	366.00	1.74	1,225.00	703.00	522.00	1.74
RT 3	913.00	523.00	390.00	1.75	1,389.00	731.00	658.00	1.90

4. CONCLUSIONS

Summarizing the results together with previously acquired experience it could be concluded that the production of winter barley and soybean, as important arable crops largely represented in the crop rotation on arable areas in Croatia, has proven to be economically efficient at all variants of soil tillage.

Better economic results were achieved mainly with the reduced tillage systems as a result of higher yields and reduced production costs compared to conventional system. Thus, the best improvement of economic efficiency in the production of winter barley was 13% obtained with RT3 tillage system and 23% with RT1 system in soybean production. Although the reduction of soil tillage has shown a positive impact on the production costs, it was justified only if there has not led to significant yield reduction as was the case with RT1 tillage system in winter barley and RT2 in soybean production.

Conventional tillage system was expectedly the greatest energy and labour consumer. The greatest energy saving per hectare in winter barley production was obtained by RT1 system (35.1% less than CT) and in soybean 33.5% by RT 1 and RT2. The highest productivity regarding labour requirement per hectare and ton of grain yield was achieved with RT2 system in both winter barley and soybean production, but due to the significantly lower yields this system has not proved adequate for soybean production, while it could be recommend in barley production due to the highest productivity accompanied with high yields and economic efficiency.

As this short-term experiment showed that non-conventional tillage systems could be economically important tool to decrease production costs, in the preferred choice of soil tillage system, assuming uniform levels of yield, the advantage should be given to a system with lower level of tillage intensity, not only to reduce costs, but also because of the simpler production organization due to less machine and human labour requirement.

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