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Soybean and barley production with conservation soil tillage systems

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Abstract

Short term experiment with different soil tillage systems in soybean (*Glycine max* L.) and spring barley (*Hordeum vulgare* L.) production was conducted at the experimental field near Našice on gleyic soil type and semi humid climate conditions. The tillage systems and implements used were: CT – mouldboard plough, disc harrow, seed-bed implement, RT 1 - chisel plough, disc harrow, seed-bed implement, RT 2 – shallow chisel, NT – no-till. Soybean production was economically efficient only with the substantial reduction or complete omission of tillage. While the production of spring barley has proven to be economically efficient at all variants of soil tillage, better economic results were achieved with the reduced tillage and no-till systems. The highest productivity regarding labour requirement per hectare and ton of grain yield was achieved with NT system in both winter barley and soybean production. 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

Introduction

Soybean (*Glycine max* L.) and barley (*Hordeum vulgare* L.) are important crops largely represented in the crop rotation on arable areas in Croatia. The mainly utilised soil tillage system in soybean and barley production is conventional system based on mouldboard ploughing as primary tillage operation, followed by secondary tillage carried out with 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 *(*Košutić et al., 2006). According to some European researches (Tebrügge et al., 1998, Tebrügge and Düring, 1999) conventional tillage system requires 434 kWh ha^{-1} of energy and 4.1 h/ha human-machine work. 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 with 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 (Birkas, 2008). A significant CO_2 emissions from the combustion of large amounts of fuel consumed in the intensive tillage is also an environmental issue (Filipović et al., 2006).

Stroppel (1997) 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% (ECAF, 2013). 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 (Derpsch and Friedrich, 2009). Despite the mentioned trends, it is estimated that over 90 percent of the fields in Croatia are still being tilled with the conventional tillage system (Zimmer et al., 2002).

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 (Vratarić and Sudarić, 2000; Pospišil et al., 2002; Špoljar et al., 2009; Kisić et al., 2010). While some authors (Chatskikh and Olesen, 2007), 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 (Moret and Arrué, 2007). 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 (Stipešević et al., 2007; Košutić et al., 2008; Jug et al., 2010).

Material and methods

The experiment with four different tillage systems was established on the surface of 4 ha, and applied tillage systems and implements were as follows: 1. CT (conventional tillage) – mouldboard plough, disc harrow, seed-bed implement, 2. RT1 (conservation tillage 1) - chisel plough, disc harrow, seed-bed implement, 3. RT2 (conservation tillage 2) - shallow chisel, 4. NT (direct sowing) - no-till drill. The experiment was carried out at the experimental field near Našice (45° 30' N, 18° 06' E) on the gleyic soil type (Škorić, 1986) and semi-humid climate with 11.0°C of mean air temperature and 806 mm of total precipitation. Soil texture in ploughed layer varies from loam to 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 (%)	
0-10	0.80	28.80	44.60	25.80	L
10-20	2.20	8.60	69.40	19.80	SL
20-30	1.00	10.20	58.00	30.80	SCL

[1)] L = Loam, SL = Silty loam, SCL = 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 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.

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 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.

Table 2. Date of field operations and application rates

Description	Soybean	Barley
	Tillage & Sowing	
Primary tillage	November 28th	November 8th
Soil moisture (%) at 5; 15; 30 cm depth	21.8; 29.6; 32.5	19.8; 28.3; 30.4
Secondary tillage	May 2nd	February 5th
Soil moisture (%) at 5; 15; 30 cm depth	24.1; 41.6; 38.2	25.3; 38.6; 39.2
Sowing date	May 2nd	February 6th
Crop-cultivar (kg ha^{-1})	Anica (135)	Prestige (200)
	Fertilizing	
Application date	March 29th	October 20th
Fertilizer-rate (kg ha^{-1})	NPK 0:20:30 (400)	NPK 8:26:26 (350)
Application date	April 4th	March 30th
Fertilizer-rate (kg ha^{-1})	Urea 46% (100)	CAN 27% (130)
Application date	June 7th	May 6th
Fertilizer-rate (kg ha^{-1})	CAN 27% (100)	CAN 27% (90)
	Crop protection	
Application date	May 3rd	March 28th
Chemical-rate (l ha^{-1})	metribuzin (0.70) dimetenamid (1.30)	izoproturon+diflufenikan (1.7)
Application date	May 16th	April 15th
Chemical-rate (l ha^{-1})	fomesafen (0.75) tifensulfuron-metil (0.008)	aminopiralid+florasulam (0.033)
Application date	June 4th	May 7th
Chemical-rate (l ha^{-1})	propakizafop (1.00) bentazon (2.5)	metaconazole+azoxystrobin (0.8)
	Harvest	
Harvesting date	October 4th	June 25th

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.

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 (SAS Institute, 1990) 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.

Results and discussion

Yield

In soybeans production the highest average yield of 2.97 t ha^{-1} was obtained with reduced tillage RT2, which was almost 20% higher than the yield recorded on a conventional tillage system (2.40 t ha^{-1}). The lowest average yield of soybeans 2.14 t ha^{-1}, or 9% less than conventional system was recorded in RT1. No-till system achieved the same average yield as the conventional tillage. Analysis of variance revealed there were no significant differences in average yields between tillage systems. Although the soil tillage had no significant effect on grain yield, below-average yields were recorded in all tillage variants, presumably due to unfavourable climate conditions.

In the spring barley production there was a statistically significant influence ($p < 0.01$) of tillage systems on grain yields ranging from 3.39 kg ha^{-1} in the variant with conventional tillage, up to 5.12 kg ha^{-1} in the no-till system (51% higher). Conservation tillage RT2 achieved 5.10 t ha^{-1} or 50% more than CT. RT1 system with 4.23 t ha^{-1} was also significantly better (25%) than conventional tillage.

Energy and labour requirement

The conventional tillage system (CT) was expectedly the greatest fuel consumer (Table 3). In soybean production the greatest fuel consumption of 62.50 L ha^{-1} was recorded in conventional tillage system. RT1 system enabled 35% saving and RT2 77% saving of fuel compared to conventional tillage.

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

	Soybean				Barley			
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 = 2.398 t ha^{-1}				Average yield = 3.391 t ha^{-1} c[(1)]			
Plough	33.33	537.9	1.39	0.58	25.10	286.5	1.24	0.36
Disc harrow	17.36	280.2	0.48	0.20	16.63	189.8	0.43	0.13
Seed-bed implement	5.89	95.1	0.19	0.08	7.59	86.6	0.32	0.10
Drill	5.92	95.5	0.33	0.14	8.1	92.4	0.30	0.09
Total	62.50	1008.7	2.40	1.00	57.42	655.3	2.29	0.68
RT 1	Average yield = 2.136 t ha^{-1}				Average yield = 4.227 t ha^{-1} b			
Chisel plough	20.07	363.6	0.71	0.33	13.81	126.4	0.68	0.16
Disc harrow	8.68	157.3	0.24	0.11	7.96	72.9	0.23	0.06
Seed-bed implement	5.89	106.7	0.19	0.09	7.59	69.5	0.32	0.08
Drill	5.92	107.3	0.33	0.16	8.1	74.2	0.30	0.07
Total	40.56	734.9	1.48	0.69	37.46	343.0	1.54	0.36
RT 2	Average yield = 2.973 t ha^{-1}				Average yield = 5.101 t ha^{-1} a			
Shallow chisel	8.23	107.1	0.41	0.14	10.95	83.1	0.61	0.12
Drill	5.92	77.1	0.33	0.11	8.1	61.5	0.30	0.06
Total	14.15	184.2	0.74	0.25	19.05	144.6	0.91	0.18
NT	Average yield = 2.402 t ha^{-1}				Average yield = 5.122 t ha^{-1} a			
No-till drill	5.92	95.4	0.33	0.14	8.1	61.5	0.30	0.06

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

The greatest energy saving per hectare (90%) in winter barley was obtained by NT system. Due to relatively uniform yields of soybean over variants of tillage systems the same trend reflects to specific energy consumption. A total of 57.42 L ha^{-1} diesel fuel was spent in tillage and sowing barley with conventional system wherein the mouldboard ploughing stands out as the most significant consumer with about 44% of total energy consumption. At variant with reduced soil tillage RT1 a third less fuel/energy was spent and in RT2 two thirds less compared to the conventional system. Also, RT1 system points to 47% lower specific energy consumption and RT2 78% lower, due to significantly higher yields than CT. The lowest energy consumption was expectedly recorded in NT system.

The highest productivity regarding labour requirement per hectare and ton of grain yield was achieved with NT system in both winter barley and soybean production.

Comparing the results with allegations by other authors (Pelizzi et al. 1988, Hernanz and Ortiz-Cañavate 1999) larger deviations due to soil types, current conditions in the field, depth of tillage and implements used could be expected, but an increase in labor productivity with the degree of reduction of tillage is noticeable.

Economic analysis

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

In both seasons CT system resulted in the highest costs with 769.70 € ha^{-1} (soybean) and 679.84 € ha^{-1} (spring barley) mainly due to great number of field operations and large amount of labour requirement (Table 4). Soybean production has proven to be economically efficient only with the substantial reduction or complete omission of tillage. The highest income was obtained with RT2 system and that variant also showed the best economic efficiency (coefficient 1.19). Production of spring barley was economically justified in all investigated variants with the highest economic efficiency achieved in NT system (coefficient 2.34) together with the highest income due to significantly higher yield.

Table 4. Economic efficiency indicators of soybean and barley production

Tillage	Soybean				Barley			
	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	731,57	769,70	-38,13	0,95	912,69	679,84	232,84	1,34
RT 1	675,68	707,41	-31,73	0,96	1096,61	625,47	471,14	1,75
RT 2	854,24	717,22	137,02	1,19	1288,89	583,77	705,11	2,21
NT	732,43	699,37	33,06	1,05	1293,51	553,65	739,86	2,34

Conclusions

Summarizing the results together with previously acquired experience it could be concluded that soybean production was economically efficient only with the substantial reduction or complete omission of tillage. Given that the reduction of tillage was a significant factor in reducing the soybean production costs, such tillage systems could be recommended as an alternative to conventional soil tillage. While the production of spring barley has proven to be economically efficient at all variants of soil tillage, better economic results were achieved with the reduced tillage and no-till systems.

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. Although the reduction of soil tillage has generally shown a positive impact on the production costs reduction, it was justified only if there hasn't led to yield reduction as was the case in RT1 system at soybean production.

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