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IMPACT OF SOIL TILLAGE REDUCTION ON CULTIVATION PRODUCTIVITY OF WHEAT, BARLEY AND SOYBEAN

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Abstract

Field experiments were done to evaluate the impact of soil tillage reduction on energy efficiency and labour productivity in cultivation of winter wheat, spring barley and soybean. Besides the conventional tillage (CT), in non-conventional tillage methods the following implements were used: RT1 - chisel plough, disc harrow, multi-tiller, seed-drill; RT2 - shallow chisel, seed-drill; NT - no-till seed-drill. As the efficiency indicators of different tillage methods, the following parameters were measured: work rate, energy requirement and yield. It was observed that tillage systems greatly differed regarding energy and labour requirements. Substitution of mouldboard plough with chisel in primary tillage provided a substantial specific energy efficiency improvement. Grain yields varied depending on soil tillage method and growing season. The differences in yield were not significant in winter wheat and soybean cultivation, while the yield of spring barley was significantly higher in RT2 and NT variants then in CT. Cereals such as winter wheat and spring barley responded well to the reduction of tillage, and no-till system might be the best option for these crops cultivation.

Key words: *conservation tillage, energy efficiency, work rate, grain yield.*

INTRODUCTION

Reduced soil tillage is a broad concept that requires elaborate methods and machines suitable for specific crop cultivation, as well as soil and climate conditions. Direct sowing or no-tillage represents the highest level of reduction in soil preparation. Between no-tillage and traditional tillage using the plough for primary tillage, there are various other possibilities of combining operations and tools aiming an optimum soil preparation for planting. Energy consumption, working time and costs of mechanization are different for each of these systems.

More than half of direct energy (or fuel consumption) utilised from soil preparation to harvest was accounted to the soil tillage when conventional tillage method is practised, in which case the primary tillage requires up to 65% of total energy utilised before seeding (Pellizzi et al., 1988).

The long-term application of conventional tillage showed significant environmental and economic drawbacks. According to Tebrüge and Düring (1999), conventional tillage requires 434 kWh ha^{-1} of energy and 4.1 h ha^{-1} of human-machine work. In contrast, reduced tillage systems can save up to 30-40% of fuel/energy and human-machine work, and direct sowing as much as 90%, compared with conventional tillage (Kosutic et al., 2006).

Main disadvantages of conventional tillage 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 (Birkás et al., 2014).

The world leading agricultures in substitution of conventional soil tillage 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 are applied to more than half of total arable crop area (Derpsch, Friedrich, 2009).

According to FAO statistics, in the period 1960-2015, there were approximately 157 million of hectares worldwide under conservation soil tillage (FAO, 2018). The share of agricultural land in Europe under some system of reduced tillage has not been increased significantly until recent, and it is estimated that is still less than 5% in EU-28 (ECAF 2017).

Numerous studies on reduced tillage and no-tillage have been presented in the literature, but most studies were based on biological factors such as grain yield, yield components, soil structure, weeds, and pests, but few are directed towards soil tillage methods from the standpoint of energy consumption and human labour.

Previous studies suggest that reduced tillage is favourable for high density crops such as wheat, barley and canola, while much worse option for row crops such as corn and soybean (Kisic et al., 2010; Spoljar et al., 2009). Reduced tillage systems, specific to sustainable agriculture, require productivity at least equal to that of conventional technology, optimized energy efficiency and, at the same time, diminished environmental impact (Rusu and Moraru, 2013).

Considering these requirements, the main objective of this study was to determine the impact of soil tillage reduction on energy and labour requirements and to evaluate the opportunities productivity improvements in cultivation of winter wheat, spring barley and soybean.

MATERIALS AND METHODS

Field experiments were done at agricultural company “Njive” (45°30' N, 18°06' E) in Slavonia region. Soil type on the location was Gleyic Podzoluvisol (Škorić, 1986) and its texture in ploughed layer belongs to silty clay loam (Table 1). The climate in this area is semi-humid with a total annual precipitation of 806 mm and an average annual temperature of 11.0°C (Meteorological and hydrological institute of Croatia).

Table 1. Soil particle size distribution

Depth (cm)	Particle size (mm), percentage				Texture[1]
	0.2-2	0.05-0.2	0.002-0.05	<0.002	
0-10	0.80	28.80	44.60	25.80	L
10-20	2.20	8.60	69.40	19.80	SiL
20-30	1.00	10.20	58.00	30.80	SiCL

[1] L = Loam, SiL = Silty loam, SiCL = Silty clay loam

Experimental field consisted of 12 plots with dimension 100 m x 30 m each, organized as randomized blocks with three replications. Test crops were winter wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.) and soybean (*Glycine max* L.). Cultivars and sowing rates are given in table 2.

Table 2. Cultivars and sowing rates of test crops

Crop	Cultivar	Sowing rate (kg ha^{-1})
Winter Wheat	Renan	220
Soybean	Anica	135
Spring Barley	Prestige	200

Soil tillage methods and implements used were:

1. Conventional tillage (CT): mouldboard plough, disc harrow, seedbed implement, seed-drill;
2. Reduced tillage 1 (RT1): chisel plough, disc harrow, multi-tiller, seed-drill;
3. Reduced tillage 2 (RT2): shallow chisel, seed-drill;
4. No-tillage (NT): no-till seed-drill.

Ploughing depth in CT was 30 cm in average and chisel plough in RT1 was adjusted at the same working depth. Tillage with shallow chisel in RT2 was done at 12.5 cm depth in average. There were two passes with disc harrow in CT and one pass in RT1.

A 4WD tractor with engine power of 140 kW was used for all tillage operations. The working width of the tillage implements (Table 3) was chosen according to the pulling capacity of the tractor.

Table 3. Tractor-implement aggregates in soil tillage

Field operation	Implement	Working width (m)
Ploughing	Rabewerk Supertaube 180 MX	1.58
Deep chiselling	Pegoraro Mega Drag	3.50
Shallow chiselling	Horsch Terrano 5 FX	4.00
Disc-harrowing	OLT Neretva-68	4.00
Seedbed preparation	Lemken System Korund 750L	7.00

Energy requirement of each tillage method was determined based on the tractor’s fuel consumption. Energy equivalent of 38.7 MJ L^{-1} was presumed (Cervinka, 1980). The amount of fuel consumed was measured for each implement during tillage and sowing on each plot. Specific energy requirement was calculated as the ratio of input energy from fuel in relation to crop yield. Labour requirement was determined by measuring the time for finishing single tillage operation at each plot of the known area. Yields were determined by weighing grain mass of each harvested plot and recalculated according to storage grain moisture content. Fertilization and crop protection were uniform in all variants, determined by crop specific nutrient requirements and pest occurrence. In the first vegetation year of this research has been previous crop was onions after which the soil surface remained free of weeds and with very little residue.

Statistical data analysis was done with the SAS software (SAS Institute, 2002). The signify-cance of differences between the mean values of measured parameters was assessed by analysis of variance (ANOVA).

The Fisher's least significant difference test (LSD) was used to compare the means and those differences were considered as significant at the level of probability $p < 0.05$.

RESULTS AND DISCUSSIONS

Conventional soil tillage (CT) was expectedly most fuel/energy consuming tillage system. Average fuel consumption in CT was 65.57 L ha^{-1} in which the primary tillage with mouldboard plough stands out with 34.08 L ha^{-1} or 52% of total fuel consumption for tillage and sowing. This is in accordance with experiences of Zimmer et al. (2014), who stated that ploughing required 25-35 L ha^{-1}, depending on soil types, field conditions and machinery and equipment used.

Substitution of mouldboard plough with chisel plough in RT1 and omission of one pass with disc harrow, enabled 42.5% fuel savings compared to CT.

Average fuel consumption in RT1 was 37.71 L ha^{-1} out of which 16.29 L ha^{-1} or 43.2% was utilised in primary tillage with chisel plough. Reduction of tillage depth only to the shallow seeding layer in RT2, resulted in further decrease in fuel consumption, 16.22 L ha^{-1} in average or 75.3% less than in CT. In No-tillage (NT), only 10.3% of fuel required in CT was consumed.

Values of fuel consumption in individual tillage methods for each crop cultivation are presented in Table 4. A significant decrease in fuel consumption is observed with reduction of soil tillage intensity.

Table 4. Yields, energy requirement and productivity of different soil tillage methods

Crop	Tillage	Yield (Mg ha^{-1})	Fuel (L ha^{-1})	Specific energy (MJ Mg^{-1})	Productivity (ha h^{-1})	Productivity (Mg h^{-1})
Winter wheat	CT	5.689	76.79 a	522.4 a	0.354 c	2.017 c
	RT1	6.059	35.10 b	224.2 b	0.636 c	3.853 c
	RT2	6.629	15.46 c	90.3 c	1.516 b	10.047 b
	NT	6.726	6.33 d	36.4 d	3.413 a	22.956 a
Soybean	CT	2.398	62.50 a	1008.7 a	0.417 c	1.001 c
	RT1	2.136	40.56 a	734.9 a	0.677 c	1.447 c
	RT2	2.973	14.15 b	184.2 b	1.335 b	3.970 b
	NT	2.402	5.92 c	95.4 b	2.987 a	7.175 a
Spring barley	CT	3.391 c	57.42 a	655.3 a	0.436 c	1.478 d
	RT1	4.227 b	37.46 ab	343.0 b	0.648 bc	2.741 c
	RT2	5.101 a	19.05 bc	144.5 bc	1.094 b	5.581 b
	NT	5.122 a	8.10 c	61.2 c	3.327 a	17.041 a

[1] Different letters within a crop growing season indicate significant differences at p < 0,05 level.

Soil tillage did not have a significant impact on grain yield in winter wheat nor in soybean cultivation. The highest average yield of winter wheat was achieved in NT (7.726 Mg ha^{-1}) and soybean in RT2 (2.973 Mg ha^{-1}).

In spring barley cultivation, however, yields were significantly different across tillage methods.

The highest average yield was again recorded in NT (5.122 Mg ha^{-1}), which was 51% more than in CT. RT1 also provided significantly lower yield than RT2 and NT, but higher than CT. That may be a consequence of cumulative soil degradation caused by consecutively applied conventional tillage (Birkas, 2008).

Specific energy requirement (MJ Mg^{-1}) for different soil tillage methods varied due to wide range of crop yields, but a decrease of energy demands with reduction of soil tillage is clearly noticeable and those differences were in most cases statistically significant.

In conventional tillage system the specific energy requirement was 728.8 MJ Mg^{-1} in average for all crops. The lowest specific energy requirement was in NT with 64.3 MJ Mg^{-1} or 91.2% less than in CT. RT1 with 434.0 MJ Mg^{-1} and RT2 with 139.7 MJ Mg^{-1} were 40.5% and 80.8% less demanding than CT, respectively.

Productivity of soil tillage methods have been calculated both considering the machine work rate (ha h^{-1}) and in respect to obtained yields (Mg h^{-1}). Conventional tillage showed the lowest overall productivity with average work rate 0.402 ha h^{-1}.

Primary tillage with mouldboard plough accounted for 58% of total time spent for soil tillage and sowing in CT.

Replacing a mouldboard plough with chisel plough for primary tillage had positive impact on work rate in RT1 which was 0.654 ha h^{-1} or 62.7% higher than in CT.

It should be noticed that in RT1 only one pass with disc harrow was done in secondary tillage, but chisel plough itself had twice the work rate of mouldboard plough.

Further reduction of tillage depth and aggregate passes in RT2 resulted with 3.27 times higher work rate (1.315 ha h^{-1}) than in CT.

The highest work rate was achieved in no-tillage system, 3.242 ha h^{-1} or 8.1 times higher than CT. Similar relations are noticeable in productivity per ton of grain yield.

Average productivity of conventional tillage for all three test crops was 1.499 Mg h^{-1}. In RT1 productivity has increased to 2.680 Mg h^{-1}, or 78.8% higher than CT.

In RT2 and NT productivity was to 6.533 Mg h^{-1} and 15.724 Mg h^{-1} or 4.36 and 10.5 times higher than in CT respectively.

Greater variations in results between test crops were present here (Table 4) due to wide range of different crops yields, but there was a statistically significant increase in productivity with decrease of specific energy requirement as a result of soil tillage reduction (Figure 1). Coicu (2010) and Jug et al. (2007) also highlighted a significant increase in labour productivity with degree of soil tillage reduction, realised through adequate tillage systems where yields were not impaired.

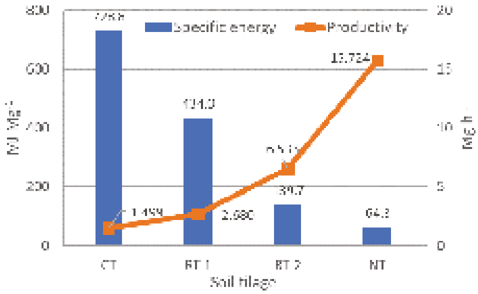

Figure 1. Average values of specific energy requirement and productivity of different soil tillage methods

CONCLUSIONS

The results of this research revealed some important advantages of non-conventional tillage methods over the conventional tillage in wheat, barley and soybean production. Utilization of reduced soil tillage methods has enabled significant fuel/energy saving in field operations prior to sowing. Reduction of soil tillage did not cause a significant decrease of grain yield of test crops. On the contrary, in most tillage methods obtained yields were higher than with conventional tillage. Therefore, the reduced tillage or no-tillage method could be an important tool to improve energy efficiency and labour productivity in arable crop production. In the selection of preferred soil tillage method, assuming uniform levels of yield, the advantage should be given to a method with lower level of tillage intensity, not only to reduce energy requirements and soil degradation, but also because of the simpler production organization due to less machine and human labour.

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