Original Research

Effects of Different Tillage Systems on Fuel Savings and Reduction of CO_2 Emissions in Production of Silage Corn in Eastern Slovenia

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Abstract

Soil tillage is one of the greatest energy consumers in agriculture and also a significant contributor to CO_2 emissions. For this reason, field experiments with different tillage systems and their influence on fuel consumption and CO_2 emissions were carried out at two locations in Eastern Slovenia. Three tillage methods were researched: direct seeding after gliphosat spraying (DS-G), reduced tillage with chisel plough and seeding (RT), and conventional tillage with mouldboard plough, rotary harrow and seeding (CT). The testing crop was corn silage (*Zea mays* L.) in rotation after ryegrass. The highest fuel consumption was under the CT system; the CO_2 emission was 225.03 kg ha^{-1} on silty clay loam and 188.06 kg ha^{-1} on silty loam. The use of the DS-G system saved on average 164.41 kg ha^{-1} of diesel oil and the use of the RT system, 104.77 kg ha^{-1}. At both locations, the highest yield of dry matter was produced with CT, followed by DS-G and RT; however, on silty clay loam the difference was significant. The alternative soil tillage reduced the CO_2 emission on average by 79.45% (DS-G) and 61.07% (RT). Presuming the use of the CT system in the growing of corn silage on arable land of Eastern Slovenia would decrease from its current 93.7% by 30% as forecasted under the EU soil tillage trend, the total annual emissions of CO_2 could be reduced by 1.08 Gg, or 24.0%.

Keywords: soil tillage, corn silage, fuel consumption, CO_2 emission, Slovenia

Introduction

Soil tillage is one of the most energy-intensive processes in agricultural production. It is the most expensive and complicated operation, being organizationally slow, fuel-demanding, labor-difficult and ecologically unfavorable in arable crop production [1].

The high cost of energy has forced farmers to find alternative economic tillage systems. It is clearly recognized that the application of an energy-saving method can make an effective contribution to the economy [2].

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The conventional tillage (CT) system is based on a high intensity of soil engagement and inversion of the soil with mouldboard plough. Conversely, 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 build a rough surface. Typical machines are hereby chisels and wing-tine cultivators [3].

When producing crops in arable land, conventionally measured CO_2 emissions can reach 110 g m^{-2}, which is largely the result of burning fossil fuels. Besides the harvest, soil tillage is one of the operations that requires the most direct energy in arable production [4], wherein even

Table 1. Locations of experiment, soil types and textures[a].

Location	Position	Soil type	Soil texture
Sestrže	46°21'N, 15°38'E	calcaric gleysol	silty loam
Pohorski dvor	46°30'N, 15°37'E	dystric cambisol	silty clay loam

[a] Classification according to FAO [19]

55-65% of the direct field energy consumption should be accorded to tillage of heavy clay soils [5].

The Japanese have reported that they experienced about 15.0-29.0% CO_2 rate reduction due to fuel savings after the introduction of a reduced tillage cropping system that had been adopted instead of the CT system [6].

In Slovenian agriculture, for each hectare 5.9 GJ energy (184.83 l ha^{-1}) of diesel fuel is used on average: 38% (70.23 l ha^{-1}) for basic soil preparation with mouldboard plough and harrow, 32% (59.14 l ha^{-1}) for harvesting, 20% (36.97 l ha^{-1}) for application of fertilizer and spraying and 10% (18.48 l ha^{-1}) for transport and irrigation [7].

Average fuel consumption depends on soil texture, tillage system and differences within stubble crops (winter wheat, barley) and row crops (maize, soybean) [8]. For this reason, significant differences in fuel consumption were reported whenever maize was produced under conventional tillage (60.99 l ha^{-1}), reduced tillage (34.81 l ha^{-1}) and no-tillage (7.35 l ha^{-1}) on silty loam soil in Eastern Slavonia. It has reported that the largest release of 167.72 kg ha^{-1} CO_2 emissions in conventional tillage can be reduced to 95.73 kg ha^{-1} in reduced tillage and to only 20.21 kg ha^{-1} in no-tillage, respectively [9].

Moreover, direct drilling can also reduce significantly the water losses and NO_3-N and NH_4-N leaking from the upper 0-30 cm soil layer into the 30-60 cm subsoil layer during the winter period [10].

Although it is known that the use of conservation and direct drilling can save an enormous quantity of energy and labor in comparison to conventional tillage, currently 93.7% of Slovenian fields are being tilled conventionally [11]. The main reason for this situation lies with the farmers, who are traditionally conservative and unwilling to accept new technologies.

In Slovenia, silage corn is growing in an area of 26.900 ha [11], which represents the third most important arable crop after wheat and grain corn The conventional method of preparing the seedbed is based on mouldplough and rotary harrow in rotation after perennial ryegrass (*Lolium perenne* L.). However, the main disadvantage of this method is represented by excessive field traffic, high energy cost, time limits during soil preparation, and bad weather in the spring.

The main objective of this experiment was to determine the different CO_2 emissions based on the measurements of fuel consumption of three different soil tillage systems, which were applied in the production of silage corn in Eastern Slovenia. The second goal was to estimate possible fuel savings and the reduction of the CO_2 emission by introducing non-conventional tillage systems.

Methods

The experiment was conducted in 2007 at two locations, Sestrže and Pohorski dvor, with different but the most common soil type in the region of Eastern Slovenia (Table 1).

The sowing of corn (*Zea mays* L.) was performed with a four-row Monosem NX pneumatic planter (Fig. 1.) for direct and conventional seeding with precise seed and fertilizer metering units. In both experiments, the corn used was Unixx Duo hybrid for silage, which was resistant to focus ultra herbicide. A randomized block design with four blocks was used for statistical analysis. Each treatment

Fig. 1. The pneumatic planter while seeding the DS-G plot.

Table 2. Diesel oil consumption and CO_2 emissions for field operations in conventional tillage, DS-G and RT system.

Tillage system	Operation	Implement	Fuel consumption (l ha^{-1})				CO_2 emissions (kg ha^{-1})			
			Sestrže		Pohorski dvor		Sestrže		Pohorski dvor	
			$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
CT	Ploughing	Mouldboard plough	28.15	3.73	34.68	4.93	77.41	10.25	95.37	13.56
	Soil preparation	Rotary harrow	28.06	1.37	34.09	2.77	77.16	3.76	93.74	7.34
	Sowing and fertilization	Pneumatic planter	12.18	0.39	13.06	0.42	33.49	1.07	35.92	1.16
	Total		68.38	5.49	81.83	8.12	188.06	15.08	225.03	22.06
DS-G	Herbicide spraying	Boom sprayer	2.58	0.07	2.69	0.08	7.09	0.19	7.4	0.21
	Sowing and fertilization	Pneumatic planter	12.18	0.39	13.42	0.43	33.49	1.08	36.9	1.18
	Total		14.76	0.46	16.11	0.51	40.58	1.27	44.3	1.39
RT	Soil preparation	Chisel plough	22.84	2.67	25.81	3.27	62.81	7.35	70.98	8.98
	Sowing and fertilization	Pneumatic planter	12.25	0.39	13.12	0.43	33.68	1.08	36.08	1.19
	Total		35.09	3.06	38.93	3.7	96.49	8.43	107.05	10.17

represents the 2.80 m wide and 30 m long parcel. The seeding rate was 100,000 seeds ha^{-1}, with 70 cm row width and 6 cm planting depth.

After mowing grass from the field, three different tillage methods of preparing the soil were compared:
- conventional tillage with plough and rotary harrow (CT),
- direct seeding after gliphosat (Boom effect 5 l ha^{-1}) one week before seeding (DS-G),
- reduced tillage with chisel plough (RT)

Table 2 outlines a series of field operations through every tillage method for which diesel oil consumption was calculated. In the CT system, the trail plots were tilled with mouldboard plough and then harrowed with rotary harrow in one pass before seeding of corn silage.

The no-tillage under the DS-G system included only one application of a non-selective herbicide gliphosat with boom sprayer one week before seeding, while the RT system included one pass with chisel plough before seeding. For all operations, a four-wheel tractor with engine power of 80.00 kW was used.

Fuel consumption was measured by applying the volumetric system and calculated on mean fuel efficiency (l h^{-1}). The calculation of CO_2 emissions was based on tractor fuel consumption and the fact that the combustion of 1.0 l of diesel oil results in the emission of 2.75 kg CO_2 [12]. To calculate total CO_2 emissions associated with the arable crop production in Eastern Slovenia the cropping area data from Statistical Yearbook 2007 [11] was used. The calculation of the possible fuel savings and the reduction of the CO_2 emission were made for each tillage system separately. These estimates are based on the assumption of the EU-15 soil trend in 2015 [13], which supposes the reduction of conventional tillage on 70% of all arable land.

Statistical analyses of results were performed using the SPSS Package Program 11.0 (SPSS Inc.).

Results and Discussion

Fuel Consumption

The measurements of fuel consumption at both locations are shown in Table 2. The highest fuel consumption was recorded for conventional tillage (81.83 l ha^{-1}) on Pohorski dvor, with the silty clay loam soil folowed by conventional tillage on silty loam in Sestrže (68.38 l ha^{-1}). Fuel consumption was significantly lower (68.38 l ha^{-1}) on Sestrže than on Pohorski dvor (81.83 l ha^{-1}), due to the different soil texture.

With the RT system diesel consumption decreased to 35.09 l ha^{-1} (Sestrže) and 38.93 l ha^{-1} (Pohorski dvor), whereby on the silty clay loam significantly higher values were again measured.

The lowest diesel oil consumption of all tillage systems were recorded with the DS-G system on both location i.e. 16.11 l ha^{-1} (Pohorski dvor) and 14.76 l ha^{-1} (Sestrže), respectively. Again the differences between both locations were mainly influenced by moisture content at the time of tillage. However, it was shown that a greater difference in fuel consumption occurred as a result of different soil texture.

Different soil texture has also influenced the fuel consumption of particular tillage operations within tillage systems. From this reason the most fuel was spent for mouldboard ploughing on Pohorski dvor (34.68 l ha^{-1}) and Sestrže (28.15 l ha^{-1}), followed by rotary harrowing on Pohorski dvor (34.09 l ha^{-1}) and Sestrže (28.06 l ha^{-1}) and chisel ploughing on Pohorski dvor (25.81 l ha^{-1}) and Sestrže (22.15 l ha^{-1}). As seen in all those passes, the soil was tilled deeper than in boom spraying and pneumatic planting, which agreed well with the findings from northern Italy, where almost 60% of fuel consumption was accounted by the primary tillage [5].

Table 3. Corn silage yield produced with different tillage systems.

Tillage system	Sestrže					Pohorski dvor				
	Fresh silage yield			Dry matter yield		Fresh silage yield			Dry matter yield	
	$\bar{x}$	SD	DM	$\bar{x}$	SD	$\bar{x}$	SD	DM	$\bar{x}$	SD
	(kg ha^{-1})	(kg ha^{-1})	(%)	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(%)	(kg ha^{-1})	(kg ha^{-1})
CT	45,661[a]	4,929	44.3	20,228[a]	2,183	42,268[a]	3,711	45.1	19,063[a]	1,673
DS-G	45,304[a]	4,669	43.6	19,752[a]	2,036	38,143[b]	3,147	41.7	15,906 [b]	1,312
RT	40,304[b]	2,884	40.4	16,283[b]	1,165	29,250[b]	3,783	42.8	12,519 [b]	1,619
Average	43,756	4,160	42.8	18,754	1,794	36,553	3,547	43.2	15,829	1,534

[a, b] significant at $p<0.05$ Duncan test

Table 4. Tillage-related CO_2 emissions according to the annual cropping area in Eastern Slovenia in 2007 and the forecast scenarios[a]

	CT system				DS-G system				RT system			
	Area (ha)	%	CO_2 (kg/ha)	CO_2 (Mg)	Area (ha)	%	CO_2 (kg/ha)	CO_2 (Mg)	Area (ha)	%	CO_2 (kg/ha)	CO_2 (Mg)
2007	25,205	93.7	206.54	5,205.97	692	2.57	42.43	29.36	1,002	3.73	101.77	101.97
[b]								-113.57				-101.99
2015	18,830	70.00	206.54	3,887.45	4,035	15.00	42.43	171.24	4,035	15.00	101.77	410.64
[b]								-662.15				-422.57
[1 sce]	0.00	0.00	0.00	0.00	26,900	100.00	42.43	1,141.16	0.00	0.00	0.00	0.00
[b]								-4,414.7				
[2 sce]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.900	100.00	101.77	2,737.61
[b]												-2,818.1

[a] All calculations based on assumption that the cropping area under the corn silage does not change,
[b] reduce versus CT,
[1 sce] scenario 1,
[2 sce] scenario 2

The lowest fuel consumption was measured with the DS-G system varying from 14.76 l ha^{-1} (Sestrže) to 16.11 l ha^{-1} (Pohorski dvor), thus 78.43% of the fuel can be saved on Sestrže and 80.55% on Pohorski dvor in comparison to the CT system. The RT also decreased diesel consumption significantly; for 33.29 l ha^{-1} (48.68%) on silty loam in Sestrže and for 42.90 l ha^{-1} (52.42%) on silty clay loam in Pohorski dvor, whereby there was no significant difference between each system in both locations. Comparing these data to other research, wide variations also were reported due to different soil types, field conditions, working depths and operating widths. For example, according to [14], average fuel consumption under the mouldboard ploughing was 2.06-17.49 l ha^{-1}, chisel ploughing 1.50-10.20 l ha^{-1}, while the no-till planter requires 1.03-4.02 l ha^{-1}, which means that our consumption in primary tillage was much higher.

However, on the other side, in the direct seeding with the seeder planter higher differences were recorded due to very low soil preparation. But when compared to the report of [9] who measured 49.40 l ha^{-1} at the mouldboard ploughing and 13.40 l ha^{-1} in no-till, our findings fit quite well also for the DS-G system.

On the other hand, [15] reported that fuel consumption under mouldboard ploughing was 49.40 l ha^{-1}, under the chisel ploughing 31.30 l ha^{-1}, and 13.40 l ha^{-1} under the no-till, which means that our results are indeed much closer to the research on clay loam than silty on loam soils.

Corn Silage Yield

The highest yields of fresh silage corn were produced at both locations using the CT system (Table 3). In Sestrže (45.661kg ha^{-1}) significant lower yield was measured only with the RT system (40.304 kg ha^{-1}), while there was no difference between CT and DS-G. In contrast, in Pohorski dvor, the alternative soil tillage systems decreased significantly the fresh matter yield of corn silage in DS-D (38.143 kg ha^{-1}) as well as in RT (29.250 kg ha^{-1}) due to the heavy silty clay loam soil, which was rather dry at the time of sowing.

The main reason for higher yields in Sestrže lies in the difference between soil types, soil preparation for the previous crops in rotation and the moisture content of the soil at the tillage. Our results are very close to some earlier experiments with a two- and four-year rotation [8], in which the higher yield of corn was also produced with the CT than the RT system. However, a newer, alternative DS-G tillage system showed important advantages, because it is faster, cheaper and lowered CO_2 emissions.

CO_2 Emissions

The production of silage corn under the CT system released considerable quantities of CO_2, varying from 225.03 kg CO_2 ha^{-1} on Pohorski dvor to 188.06 kg CO_2 ha^{-1} on Sestrže, due to the heavier texture on the second location. On average, in the DS-G system, the CO_2 emissions could be reduced significantly by 147.52 kg CO_2 ha^{-1} on Sestrže and by 181.28 kg CO_2 ha^{-1} on Pohorski dvor, respectively, which equates to an average decrease of 79.45%. On the other hand, the RT system reduced the CO_2 emissions substantially for 91.57 kg CO_2 ha^{-1} (Sestrže) and 117.98 kg CO_2 ha^{-1} on Pohorski dvor, again due to the heavier soil texture.

Table 4 shows an estimate of the total annual amount of CO_2 emissions produced from diesel oil consumption for the corn silage grown under CT, DS-G and RT systems for the whole eastern Slovenia region. As seen, currently the most of the silage maize is under the CT system (25.205 ha) that released 5.20 Gg CO_2, 692 ha soil under DS-G, which produced 29.36 Mg of CO_2 and 1,002 ha is under RT, which released 101.97 Mg of CO_2.

When the conventional soil tillage system is reduced by 70% of the whole area in 2015, as assumed by the EU-15 strategy, only 3.887 Gg CO_2 would be produced from CT, 0.17 Gg CO_2 from DS-G, and 0.41 Gg CO_2 from RT. This means that in this way 1.084 Gg of CO_2 less could be emitted in the atmosphere.

Furthermore, when all the farmers would convert the CT soil preparation into DS-G (scenario 1) only 1.14 Gg CO_2 would be emitted annually and total CO_2 is reduced by 4.414 Gg. On the other hand, when basic soil preparation is changed into the RT system (scenario 2), 2.74 Gg CO_2 would be emitted. Thus, annual emissions of CO_2 could be reduced by 4.41 Gg (78.07%) for DS-G and 2.81 Gg (47.41%) for RT, when adopting the proposed drilling systems. Therefore, to reduce CO_2 emissions in agricultural production, it will be necessary to apply new technologies which reduce fuel consumption significantly.

Our estimation for reducing CO_2 emissions are very close to the application of the direct drilling of silage corn in eastern Croatia due to similar ecological and economic reasons [16]. The same findings were reported from northern Italy, since the conversion of the conventional tillage (based on mouldboard ploughing) to the reduced tillage (disking or chisel tillage) or no-till can lead to drastic reductions in CO_2 emissions [17]. Moreover, the increase of the DS-G and RT systems at the level of 30% as predicted for the EU-15 arable land scenario could reduce CO_2 emissions for 1.085 Gg annually [18].

Conclusions

High fuel consumption for basic soil tillage shows that the CT system in eastern Slovenia was the main reason for large quantities of CO_2 emissions into the atmosphere, which varied from 225.03 kg ha^{-1} on the silty clay loam texture soil to 188.06 kg ha^{-1} on the silty loam texture soil for growing of corn silage.

The DS-G system significantly decreased CO_2 emissions ranging from 40.58 kg ha^{-1} to 44.30 kg ha^{-1} and the RT system reduced emissions on 96.49 kg ha^{-1} and 107.05 kg ha^{-1}, respectively. Given that the use of the CT system on arable land in eastern Slovenia would decrease from the current 93.7% to 70% as assumed by the EU-15 trend for 2015, the total annual emission of CO_2 could be reduced for 1.08 Gg or 24.0%. Furthermore, the benefits of non-conventional tillage systems application could significantly contribute not only to environmental protection due to a decrease of CO_2 emissions and soil water conservation, but also improve the economic result for farmers.

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