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ENERGY AND ECONOMIC EFFECTS OF REDUCED TILLAGE IN CROP ROTATION

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Abstract. The present research covers the time of the second rotation: sugar beet-spring wheat-pea-winter triticale (1999-2002). The investigations were conducted on a very good rye complex soil. A reduced tillage for sugar beet and no-tillage for the other crops in crop rotation result in labor, fuel and energy consumption reduction, as compared with conventional tillage by an average of 50% and expenditure by 42%. The highest energy effectiveness in crop rotation was observed in the system in which sugar beet was cultivated in reduced tillage, and other crops in no-tillage. The effectiveness increases by 135% for conventional tillage for all the crops in rotation. The lowest effectiveness is obtained for conventional tillage with intercrop for sugar beet and pea, and conventional tillage for spring wheat and winter triticale.

Key words: reduced tillage in crop rotation, energy consumption and effectiveness of tillage systems

INTRODUCTION

Over the past few years there has been a growing interest in reduced tillage potential by Polish researchers. Conventional tillage can be gradually replaced by various new methods which involve machines development and a decreased time-consumption in tillage operations. The reduction in field production is an objective necessity, especially on large-acreage farms due to necessary cost-cutting accompanied by an increased plantation area of some crops on the farm. Tillage is an element of growing practices, showing considerable time and energy-consumption, which has become of special importance with new generations of tillage-sowing aggregates and a wide range of herbicides Kuś [1999]. A substantial importance assumed for reduced tillage is due to a potential labor reduction without neither a clear yield reduction nor a deteriorated yield quality Caravalho and Basch [1994], Höppner et al. [1995], Kordas [1997a]. In some cases there was even recorded a slight increase in cereal yield [Kordas 1997b]. Most of

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those reports involved research into reduced tillage for one crop in rotation. Multiple reductions in case of crop rotation can give quite different results.

A decreased demand for labor and a decreased tillage operations time is possible by limiting the number and the intensity of tillage operations in soil preparation for sowing Śmierzchalski et al. [1979].

The evaluation of crop production is often limited to production and economic criteria. The economic analysis of plant production is well supplemented by energy calculation Kuś et al. [1990], offering a possibility to compare the results over time and space irrespective of the price relation and to make comprehensive evaluations [Maciejko 1984, Nowacki 1985].

Besides the energy calculation, an economic calculation is also of special importance. Low profitability and limited possibilities of selling crops make the farmers lower plant production costs Dzienia and Boligłowa [1988].

The aim of the present research was to compare labor and fuel consumption and energy inputs for tillage of 4 year-rotation crops: sugar beet-spring wheat-pea-winter triticale, and relations of those inputs, depending on the tillage system, to the yield value.

MATERIAL AND METHODS

The research was conducted at the Swojec Experiment Station of the Agricultural University of Wrocław, on alluvial soil, formed from loamy sand on medium loam, of very good rye complex. Four tillage methods for crops in 4-year rotation were analyzed. Conventional tillage was a typical tillage used for particular crops (post-harvest tillage: skimming 10 cm + harrowing, pre-sowing tillage: pre-sowing ploughing – 20-22 cm, conventional sowing), while no-tillage used cultivator (15 cm deep), instead of plough (Table 1). Sowing was carried out using single disc coulter. In no-tillage, all the tillage was given up and drilling involved the use of direct seeder offered by Great Plant, type: Stand 7. Labor time and fuel consumption was measured for particular tillage operations, which are part of particular tillage systems, and index values of energy effectiveness were calculated.

Table 1. Scheme of the experiment
Tabela 1. Schemat doświadczenia

Tillage system System uprawy roli	Sugar beet Burak cukrowy	Spring wheat Pszenica jara	Pea Groch siewny	Winter triticale Pszenżyto ozime
A. Conventional Tradycyjny	conventional tillage uprawa tradycyjna	conventional tillage uprawa tradycyjna	conventional tillage uprawa tradycyjna	conventional tillage uprawa tradycyjna
B. Conventional + intercrop Tradycyjny + międzyplon	conventional tillage + intercrop tradycyjna + międzyplon	conventional tillage uprawa tradycyjna	conventional tillage + intercrop tradycyjna + międzyplon	conventional tillage uprawa tradycyjna
C. Reduced tillage Uprawa uproszczona	reduced tillage uprawa uproszczona	reduced tillage uprawa uproszczona	reduced tillage uprawa uproszczona	reduced tillage uprawa uproszczona
D. Direct drilling Siew bezpośredni	direct drilling siew bezpośredni	direct drilling siew bezpośredni	direct drilling siew bezpośredni	direct drilling siew bezpośredni

This research coincided with the second rotation (1999-2002). All the fuel consumption and labor time measurements were made with an electronic meter MP-01, installed in 5314 Ursus tractor, used for all tillage operations. The research was conducted in optimum tillage conditions for particular tillage type. The measurements of particular tillage operations were made executed on an area of 0.3 ha, which secured high measurement accuracy, and then the results were converted per 1 ha. The costs and energy input per 1ha of particular crop tillage, depending on the tillage system, were calculated. The labor costs were calculated applying the current market prices for particular tillage operations for the Dolnośląskie Province [Dolnośląski informator rolniczy 2002]. The cost of fuel was estimated based on the market price of diesel oil (2.60 PLN·1 dm^{-3}). The energy consumption was calculated following energy-consumption tables developed by Gonet and Zaorski [1988], assuming that 1 dm^3 of diesel oil equals 36 MJ, while 1 man-hour – 7 MJ. The grain yield was converted into energy units following the farm animals feeding standards [1985]. Energy effectiveness index values were based on the ratio of the energy obtained for crop yield (MJ) to soil tillage inputs, and based on agricultural produce evaluation method, MET, following Anuszewski [1987].

RESULTS

The conventional tillage (A) for all the crops in crop rotation resulted in the fuel consumption of 251.2 l (Table 2). In conventional system with intercrops (B) the fuel consumption increased by 4%, as compared with conventional tillage (A), while for all the tillage operations for all the crops in crop rotation fuel consumption decreased, as compared with conventional tillage, by 50% (C) and by 54% in the system which involved direct drilling (D), as a result of reduced system.

Table 2. Fuel consumption for particular crops in crop rotation, $dm^{-3} \cdot ha^{-1}$ (means of 1999-2002)
Tabela 2. Zużycie paliwa pod poszczególne rośliny zmianowania, $dm^{-3} \cdot ha^{-1}$ (średnie z lat 1999-2002)

Tillage system System uprawy roli	Sugar beet Burak cukrowy	Spring wheat Pszenica jara	Pea Groch siewny	Winter triticale Pszenżyto ozime	Total Razem
A. Conventional Tradycyjny	74.6	45.3	73.2	58.1	251.2
B. Conventional + intercrop Tradycyjny + międzyplon	89.4	45.3	78.4	48.5	261.6
C. Reduced tillage Uprawa uproszczona	49.2	14.8	29.6	32	125.6
D. Direct drilling Siew bezpośredni	56	14.8	29.6	14.8	115.2

In conventional tillage for all the crops in crop rotation labor consumption accounted for 23.8 hours (Table 3). In conventional system with intercrops, labor consumption for tillage in crop rotation was only 1% higher than in the conventional system. Labor consumption was on average 51% lower, as compared with conventional tillage with cultivator, instead of plough, and also in direct drilling.

Table 3. Expenditure for tillage of particular crops in crop rotation, PLN·ha^{-1} (means of 1999-2002)
Tabela 3. Zestawienie nakładów pieniężnych poniesionych na uprawę roli w zmianowaniu, PLN·ha^{-1} (średnie z lat 1999-2002)

Tillage system System uprawy roli	Sugar beet Burak cukrowy	Spring wheat Pszenica jara	Pea Groch siewny	Winter triticale Pszenżyto ozime	Total Razem
A. Conventional Tradycyjny	7.3	3.9	6.8	5.8	23.8
B. Conventional + intercrop Tradycyjny + międzyplon	8.5	3.9	6.9	4.6	24.0
C. Reduced tillage Uprawa uproszczona	4.8	1.7	2.9	2.3	11.8
D. Direct drilling Siew bezpośredni	4.9	1.7	2.9	1.7	11.4

The expenditure for tillage operations in conventional tillage was PLN 1.531 (Table 4). Applying reduced tillage, a 41% decrease in expenditure was recorded and even a greater decrease – for no-tillage system.

Table 4. Labour consumption for particular crops in crop rotation, h·ha^{-1} (means of 1999-2002)
Tabela 4. Zużycie czasu pracy na poszczególne rośliny zmianowania, h·ha^{-1} (średnie z lat 1999-2002)

Tillage system System uprawy roli	Sugar beet Burak cukrowy	Spring wheat Pszenica jara	Pea Groch siewny	Winter triticale Pszenżyto ozime	Total Razem
A. Conventional Tradycyjny	449	261	444	377	1531
B. Conventional + intercrop Tradycyjny + międzyplon	571	261	437	260	1529
C. Reduced tillage Uprawa uproszczona	348	166	238	154	906
D. Direct drilling Siew bezpośredni	347	166	238	105	856

For conventional tillage for all the crops in crop rotation, the energy input was 9208 MJ (Table 5), while when accompanied by an intercrop, a 4%increase in energy input was observed. Replacing the plough with the cultivator in no-tillage decreased energy input, as compared with conventional tillage, by 50%. The lowest value of the energy input was recorded in direct drilling; a 54% decrease. The highest yield expressed in energy units (MJ) in crop rotation was noticed in conventional tillage (294925 MJ) (Table 6). The reduced tillage system resulted in a 1.6% yield decrease, and the direct drilling – a 6% yield decrease. The highest yield decrease (11%) was recorded when stubble intercrop was applied in conventional tillage.

Table 5. Energy consumption in crop rotation as affected by the tillage method (means of 1999-2002)
Tabela 5. Energochłonność uprawy roli w zmianowaniu w zależności od systemu uprawy (średnie z lat 1999-2002)

Tillage system System uprawy roli	Sugar beet Burak cukrowy	Spring wheat Pszenica jara	Pea Groch siewny	Winter triticale Pszenżyto ozime	Total Razem
A. Conventional Tradycyjny	2736	1657	2683	2132	9208
B. Conventional + intercrop Tradycyjny + międzyplon	3278	1657	2871	1779	9585
C. Reduced tillage Uprawa uproszczona	1805	544	1085	1170	4604
D. Direct drilling Siew bezpośredni	2050	544	1085	544	4223

Table 6. Comparison of energy values of particular crops in crop rotation, $MJ \cdot ha^{-1}$ (means of 1999-2002)
Tabela 6. Zestawienie energetycznej wartości plonów poszczególnych roślin w zmianowaniu, $MJ \cdot ha^{-1}$ (średnie z lat 1999-2002)

Tillage system System uprawy roli	Sugar beet Burak cukrowy	Spring wheat Pszenica jara	Pea Groch siewny	Winter triticale Pszenżyto ozime	Total Razem
A. Conventional Tradycyjny	169257	53000	16668	56000	294925
B. Conventional + intercrop Tradycyjny + międzyplon	137126	52000	20279	53000	262405
C. Reduced tillage Uprawa uproszczona	157113	48000	37040	48000	290153
D. Direct drilling Siew bezpośredni	134343	48000	42596	53000	277939

As a result of conventional tillage for all the crops in crop rotation, the value of the energy effectiveness index (Ec) was 32.0 (Table 7). In conventional system modified by the application of the intercrop, the energy effectiveness decreased by 14%, as compared with the conventional tillage. While applying reduced system a 97% increase in energy effectiveness was recorded, as compared with conventional tillage, and in case of direct drilling – 135% increase. The energy consumption index value for conventional system was 3.1 and in conventional tillage with intercrop – a 19% increase was observed. As a result of reduced system, the tillage energy consumption decreased, as compared with conventional tillage, by 48 and by 58% in direct drilling.

Energy inputs per cereal unit are similar to those of energy consumption for soil tillage. As a result of conventional tillage for all the crops in crop rotation, the energy inputs per cereal unit were 12.4 MJ and decreased, as compared with the conventional tillage, due to reduced tillage, by 48% and, due to no-tillage – by 54%.

Table 7. Energy effectiveness of tillage systems (means of 1999-2002)
Tabela 7. Efektywność energetyczna systemów uprawy roli (średnie z lat 1999-2002)

Tillage system System uprawy roli	Nakłady energii Energy input Ne $MJ \cdot ha^{-1}$	Całkowita wartość energetyczna plonu Total yield energy value Pc $MJ \cdot ha^{-1}$	Wskaźnik efektywności energetycznej Energy effectiveness index $Ee = Pc \cdot Ne$	Energochłonność uprawy Tillage energy consumption $We = Ne \cdot Pc \cdot 100$	Na jednostkę zbożową Per cereal unit MJ
A. Conventional Tradycyjny	9208	294925	32.0	3.1	12.4
B. Conventional + intercrop Tradycyjny + międzyplon	9585	262405	27.4	3.7	15.2
C. Reduced tillage Uprawa uproszczona	4604	290153	63.0	1.6	6.4
D. Direct drilling Siew bezpośredni	3690	277939	75.3	1.3	5.6

DISCUSSION

Reduced tillage affected the labor and fuel consumption, as well as energy inputs expenditure for tillage, and the total yield energy value.

As for sugar beet, the lowest energy, fuel and labor consumption was recorded when applying reduced tillage, which included medium ploughing, harrowing with heavy harrowing and intercrop sowing, no pre-sowing tillage and the application of direct drilling.

As compared with conventional tillage, fuel consumption and energy inputs recorded a 34% decrease and labor consumption – a 35% decrease, which is confirmed by the results reported by Kordas [1999a]. The expenditure for sugar beet tillage decreased in no-tillage by 34%, as compared with conventional tillage, due to a decreased number of tillage operations. Similar results were reported by Gutmański et al. [1999]. After applying no-tillage for spring wheat, labor consumption was 55% lower, and fuel and energy consumption – 67% lower, as a result of a single tillage operation only (direct drilling) in no-tillage system. Similar results were also observed by Kordas [1999b]. Expenditure for tillage in no-tillage system was 41% lower, as compared with conventional tillage. No-tillage system with intercrop for pea resulted in a 56% decreased labor consumption, and 60% decreased fuel and energy consumption. Similar results were also obtained by Dzienia and Dojss [1999]. Such considerable decreases in direct drilling system were possible thanks to giving up post-harvest and pre-sowing tillage and applying intercrop and indirect drilling only. The costs of no-tillage decreased by 50%, as compared with conventional tillage, due to a limited number of tillage operations.

In case of winter tirticale, no-tillage system, with neither post-harvest nor pre-sowing tillage, yet applying only indirect drilling, resulted in a 70% decrease in labor consumption and in 74% fuel and energy consumption decreases, as compared with conventional tillage. The costs of no-tillage system decreased by 72%, as compared with conventional tillage. Similar results were reported by Gonet and Zaorski [1988].

The present research into reduced tillage in crop rotation, including no-tillage, showed that the tillage systems compared affected the value of energy effectiveness index. The highest effectiveness was achieved when using reduced tillage for sugar beet and no-tillage for the other crops in crop rotation. On average the effectiveness of no-tillage was more than two-fold higher than the conventional tillage. Similar results were recorded for energy consumption, depending on the tillage system. As for reduced tillage for sugar beet and no-tillage system for the other crops in crop rotation, labor and fuel consumption was more than a half lower. Such considerable labor and fuel consumption decrease was due to limited number of tillage operations. Similar results were recorded by Dzienia and Sosnowski [1990], as well as Włodek et al. [1999].

The fuel and labor consumption was similar to energy inputs for tillage in crop rotation. As a result of conventional tillage for all the crops in crop rotation, the value of energy inputs was 9208 MJ; and as a result of reduced tillage for sugar beet and direct drilling for the other crops in crop rotation, a decrease in energy inputs was recorded, which was also confirmed by similar results reported by Kordas [1999a].

The highest yield value in crop rotation, expressed in energy units, of 294925 MJ, was noticed as a result of conventional tillage for all the crops in crop rotation. As a result of reduced tillage for sugar beet and no-tillage for the other crops in crop rotation, a 6% decrease in the total yield energy value was recorded, which is partially confirmed by the results reported by Śmierzchalski et al. [1979].

CONCLUSIONS

A reduced tillage for sugar beet and no-tillage for the other crops in crop rotation result in labor, fuel and energy consumption reduction, as compared with conventional tillage by an average of 50%, while implementing intercrop to conventional tillage increased the energy inputs by an average of 8%.

The expenditure for tillage decreases by an average of 42%, as compared with conventional tillage, as a result if reduced tillage for sugar beet and no-tillage system for the other crops in crop rotation, and reduced tillage for sugar beet and winter triticale, and no-tillage – for spring wheat and pea.

The highest yield value expressed in energy units is obtained in conventional tillage system for all the crops in crop rotation. The highest yield decrease, by an average of 11%, as compared with the conventional tillage, was recorded while applying stubble intercrop in conventional tillage.

The highest energy effectiveness in crop rotation was shown for the system of reduced tillage for sugar beet and no-tillage system for the other crops in crop rotation. As compared with conventional tillage, the effectiveness increased by 135%. The lowest effectiveness was obtained for conventional tillage with intercrop for sugar beet and pea, conventional tillage – for spring wheat and winter triticale.

No-tillage recorded the lowest energy consumption; it was 58% lower than conventional tillage.

The lowest energy input per cereal unit was noted for reduced tillage for sugar beet, and no-tillage for the other crops in crop rotation; it decreases by 55%, as compared with conventional tillage.

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ENERGETYCZNE I EKONOMICZNE SKUTKI STOSOWANIA UPROSZCZEŃ W UPRAWIE ROLI W ZMIANOWANIU

Streszczenie. Badania obejmują okres drugiej rotacji zmianowania: burak cukrowy – pszenica jara – groch siewny – pszenżyto ozime (lata 1999-2002). Doświadczenia przeprowadzono na obiektach o powierzchni 0,3 hektara, przy optymalnych warunkach uprawowych. Zastosowanie uprawy uproszczonej pod burak cukrowy, a systemu uprawy zerowej pod pozostałe gatunki uprawiane w zmianowaniu powoduje zmniejszenie pracochłonności, ilości zużytego paliwa, a także nakładów energetycznych średnio o 50% w stosunku do uprawy tradycyjnej, a kosztów o 42%. Najwyższą efektywnością energetyczną w zmianowaniu charakteryzuje się system, w którym pod burak cukrowy stosowano uprawę uproszczoną, a pod pozostałe rośliny uprawę zerową. Wzrasta ona o 135% w stosunku do uprawy tradycyjnej stosowanej pod wszystkie rośliny zmianowania. Najmniejszą efektywność uzyskuje się stosując uprawę tradycyjną z międzyplonem pod burak cukrowy i groch siewny oraz uprawę tradycyjną pod pszenicę jarą i pszenżyto ozime.

Słowa kluczowe: uproszczenia uprawy roli w zmianowaniu, energochłonność, efektywność systemów uprawy roli