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ECONOMIC EFFICIENCY OF SOYBEAN PRODUCTION DEPENDING ON SOIL TILLAGE SYSTEM

Key words: soybean, cultivars, seeds yield, fertilization, gross margin, profitability

ABSTRACT. The aim of the study was to evaluate the economic efficiency of soybean cultivars at different soil tillage system (ploughing method, reduced tillage, strip tillage). The study was based on the results of a five-year (2016-2020) field study, conducted at the Agricultural Experimental Station in Kępa Puławy (farm in Osiny), belonging to the Institute of Soil Science and Plant Cultivation in Puławy. In the scheme of trial two cultivars of soybean: Aldana (000 – early) and Merlin (00-mid-early) were used. The strip-till system brought the highest value of harvested soybean seeds of Merlin cultivar – 6,262 PLN/ha (mean in 2016-2020). The high value was also obtained under full ploughing system (6,251 PLN/ha). The highest profitability of soybean cultivation determined based relation production value of seeds to direct cost was obtained under strip-tillage system (mean for two cultivars – 1.68). In direct cost structure the highest percentage had seeds material cost. The gross margin was determined as an indicator of economic efficiency. The economic effectiveness of cultivation of two soybean cultivars was evaluated from the perspective of utilizing the basic factors of production – land. Analysis showed that the highest level of gross margin determined on based the difference of production seeds value, direct cost and indirect cost was obtained in soybean cultivation under strip-tillage system. The profitability index was also determined as the relation of production value of soybean seeds to direct costs. The level of the gross margin was more impacted by the level of the obtained yield and the cost of agrotechnical treatments than by the level of other direct costs.

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INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is one of the most important legume crop cultivated worldwide. World production increased from approximately 160 million tons cultivated on 70 million hectares in 1998 to 350 million tons on 130 million hectares in 2021. The European Union imported an annual average of 14 million tons of soybeans [FAOSTAT 2022]. Soybeans have become widespread in the world crop production as a valuable oilseed and high-protein crop with a favorable biochemical composition.

The agricultural production efficiency, as an economic category, is the ratio of the results of production activities and its costs [Kordas 2005]. Tillage systems cover a wide range of possible solutions, from traditional ploughing to no-till through the combinations at various levels of minimization. Mechanical tillage is one of the important factors regulating soil fertility. Proper tillage is supposed to provide optimal conditions for sowing and seed germination and ensure proper plant growth and development. Nowadays, the cultivation of many species, including soybeans, uses full plough tillage with deep plowing, supported by other tools to prepare the soil for sowing [Małecka et al. 2012]. This tillage is gradually being replaced by new methods that reduce the time of tillage work. The main reason for this is economic considerations reducing primarily energy inputs, as well as labor costs [Kordas 2005]. The introduction of simplified systems of tillage methods makes sense when it leads to a reduction in production costs without a decrease in productivity [Faligowska, Szukała 2015]. This is because the proposed solutions are characterized by a number of advantages. Reducing the intensity of tillage slows down the decomposition of organic matter and reduces the release of carbon dioxide into the atmosphere. Reducing the amount, depth and intensity of tillage operations results in a significant reduction in unit production costs (lower fuel consumption and labor inputs), and can also lead to the elimination of soil degradation processes, improve biological activity and promote humus accumulation [Smagacz 2015].

Reduced tillage contributes to the accumulation of nutrients in the top of soil, which is important for plant growth [Smagacz 2012]. Johan Arvidsson [2013] in his study found that reduced tillage compared to full plough tillage results in a yield reduction of winter wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oilseed rape (*Brassica napus* L.), oats (*Avena sativa* L.), peas (*Pisum vulgare* L.), sugar beet (*Beta vulgaris* L.) and potatoes (*Solanum tuberosum* L.) of several percent.

Amit Kumar Jha et al. [2011] found that the total time and cost of tillage and seeding treatments with strip-till machine was 5.1 h/ha, which was 72% less than time required by plough tillage of wheat, but 28% more than no-till. In addition to performing simultaneous strip till and seeding, there is the possibility of simultaneous localized fertilization, which further reduces the costs associated with fuel consumption and labor [Talarczyk, Łowiński

2018]. The use of strip till technology saves more than 20 liters of fuel per hectare compared to reduced tillage and 30 fuel per hectare compared to conventional plow tillage [Jaskulska, Jaskulski 2020]. Marek Różniak [2016] comparing fuel use in winter wheat, found that replace in tillage with strip-till reduced fuel use by 25 liters per hectare.

The aim of the study was to evaluate the economic efficiency of soybean varieties at different soil tillage system (ploughing method, reduced tillage, strip tillage).

RESEARCH MATERIAL AND METHODS

A five-year experiment was conducted in the years 2016-2020 at the Agricultural Experimental Station in Kępa-Puławy, Osiny farm [51°27′53″N 22°03′52″E] (Lubelskie Voivodeship, Poland) belonging to the Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy. The two-factor experiment was carried out in split-plot design on a soil belonging to a good wheat complex, class IIIa, in four replications.

The first experimental factor was the soil tillage system: A – ploughing method, B – reduced tillage, C – strip tillage. The second factor was soybean cultivar: Aldana and Merlin.

The experimental site is located in a moderate continental climatic zone. The long-term mean annual total precipitation is 446 mm, with an average air temperature of 12.9°C.

In plough tillage, after harvesting the forecrop, straw was crushed, and a disc aggregate was used. Then, the soil was harrowed with a heavy harrow, and sown to a depth of 3-4 cm. In the reduced tillage system, after chopping the straw, the disc aggregate was used twice, followed by active cultivation and sowing 80 seeds per m^2 to a depth of 3-4 cm. In strip-till system, soybean was seeds directly to the soil by seeder of C MZURI Valtra.

Phosphorus (P) and potassium (K) fertilization was applied in doses of 50 and 90 kg/ha, respectively. Directly after sowing, Stomp 330 EC (3.5 l/ha) was applied into soil, and after emergence, Corum 502.4 SL (1.25 l/ha) + Dash – 1.0 l/ha and Targa Super 05 EC (1.0 l/ha) by KFMR Krukowiak sprayer to control annual weeds. Due to weed infestation control in strip-tillage system, Klinik 360 SL (5.0 l/ha), while in spring Vival 360 SL (4.0 l/ha).

The number of inputs of production means was determined based on actual consumption in the experience of fertilizers, seeds material and plant protection products, cost of agrotechnical treatments. The costs of production means were determined based on purchase prices, and the value of soybean production was determined according to the average seeds purchase price in 2021, which amount in this period mean 2,620 PLN per 1 ton. Value direct payment was used according to the purchase in 2021.

The economic assessment was carried out in a simplified way. The average seeds yield for the years 2016-2020 were used as the main criteria for assessing production efficiency. All analysis were made in terms of 1 hectare.

The analysis considered the effect of differentiated tillage methods on the productive and economic efficiency of tillage system by calculating fuel consumption costs according to the formula proposed by Adam Harasim [2006]. Fuel costs were calculated as the product of tractor power expressed in kW, the coefficient defining fuel consumption per unit of power (0.110 g/kW), and the fuel price expressed in PLN/liter. For the conversion of fuel quantity from kilograms to liters, the density of diesel was used (0.83 g/cm).

Taken as a measure of economic efficiency, the gross margin was calculated as the difference between the harvested value of seeds and direct and indirect costs.

The economic effectiveness of cultivation of both cultivars of soybean was evaluated from the perspective of utilizing one of the basic production factors: land (the gross margin in PLN/ha). The gross profitability index for particular variants of the experiment was also calculated as the relation of the production value (W) to direct costs (K) (including the value of consumed fuel).

In addition, the unit direct cost was calculated, as the ratio of total direct costs to the yield of the plant in question, the cost competitiveness of the crop, recognized as the ratio of total direct costs to the gross margin, the economic efficiency of the crop (profitability of cultivation), calculated as a percentage of the ratio of the value of production to the direct costs. Moreover, the unit direct cost production of one kg of protein were determinated. The protein yield was calculated as a ratio of seeds yield and protein content in seeds soybean. The price of 1 kg of protein was determined as a relation of direct cost and protein yield. Seeds yield offsetting direct costs (t/ha) as calculated as the relation of total cost and price of soybean seeds.

The results of the study are presented in tabular term. The paper was mainly based on vertical comparative analysis of research results.

RESEARCH RESULTS AND DISCUSSION

The different tillage system affected the yielding of tested soybean cultivar and economic indexes. The average highest yield of soybean seeds Merlin cultivar was obtained in ploughing tillage (average 2.53 t/ha). The high yield of Merlin cultivar was obtained also in in strip-tillage system (2.40 t/ha). In the study Dorota Gawęda et al. [2020] under the plough tillage treatment, the seed yield was higher by 10.3% compared to that obtained under no-tillage. It achieved the highest value of soybean seeds (respectively: 6,251 – Aldana cultivar and 6,262 PLN/ha – Merlin cultivar). It is the effect of the obtained yield of soybean seeds (Table 1).

Direct costs and their structure are an important element of the economic analysis of agricultural crop cultivation. This is because they largely determine the size and value of the production [Abramczuk et al. 2018]. In ploughing tillage system the highest direct cost were generated. The study showed that the seeds material costs stand the largest

percentage in the direct cost structure of soybean cultivation, followed by seeds material and mineral fertilizers. This results are confirmed by Irena Augustyńska and Arkadiusz Bębenista [2019], Józef Śliwa et al. [2015] and Hanna Adamska et al. [2016], the seeds material cost were the highest ration in total direct cost.

Comparison of data presented in Table 1 shows that higher direct costs were incurred when ploughing and reduced tillage system were used in both cultivars. The difference in direct costs was mainly due to a reduction in cost of agrotechnical treatments in reduced and strip-tillage system. Cost of plant protection treatments in strip-tillage system compared to those applied in full ploughing system were less by 29%.

The gross margin, as the difference between the value of seeds yield and direct and indirect costs calculated for each soil tillage system and soybean cultivars, showed definite

Table 1. The value of seeds, direct cost and gross margin of soybean production under different tillage system (mean 2016-2020)

Specification	Tillage system					
	A – ploughing method		B – reduced tillage		C – strip tillage	
	Aldana	Merlin	Aldana	Merlin	Aldana	Merlin
Seeds yield [t/ha]	2.22	2.39	2.14	2.33	2.31	2.41
Protein yield [kg/ha]	716	786	687	769	751	781
The value of harvested seeds [PLN]	5,827	6,251	5,612	6,099	6,063	6,262
Direct costs [PLN], including:	2,183	2,183	2,183	2,183	2,081	2,081
– seeds material	928	900	928	900	928	900
– mineral fertilization	805	805	805	805	805	805
– plant protection cost*	450	450	450	450	348	348
Indirect cost* [PLN], including:						
– tillage and sowing	2,061	2,061	1,600	1,600	1,470	1,470
Total cost	4,244	4,244	3,783	3,783	3,551	3,551
Gross margin	1,583	2,007	1,829	2,316	2,512	2,711
Share in direct costs [%]:						
– seeds material	42.5	42.5	42.5	42.5	44.6	44.6
– nitrogen fertilization*	36.9	36.9	36.9	36.9	38.7	38.7
– plant protection cost*	20.6	20.6	20.6	20.6	16.7	16.7
Direct costs of production unit [PLN/t]	982	915	1,019	938	899	863

* Including application costs in terms of the fuel used
Source: own analysis

differences (Table 1). The gross margin was determined as an indicator of economic efficiency. The economic effectiveness of cultivation of two soybean cultivars was evaluated from the perspective of utilizing the basic factors of production – land.

Analysis showed that the highest level of gross margin was obtained in cultivation of both cultivars under strip-tillage system. The rate of direct profitability (without subsidies) was also determined as the relation of production value of soybean seeds to direct costs (Table 2). The level of the gross margin was more impacted by the level of the obtained yield and the cost of agrotechnical treatments than by the level of other direct costs. In the study of Dorota Gawęda et al. [2020] the average income of soybean cultivated under plough tillage system was higher by EUR 64.6 than that under no-tillage.

In order to deepen the analysis, same indicators were calculated to determine the economic efficiency of the soybean. The analysis showed that the cultivation of soybeans was economically justified – the economic efficiency index was above 100%. The highest profitability of soybean cultivation determined based relation production value of seeds to direct cost was obtained under strip-tillage system (mean for two cultivars – 1.68). In direct cost structure the highest percentage had seeds material cost.

Table 2. Selected productive and economic indicators of cultivation of soybean under different tillage system (mean 2016-2020)

Specification	Tillage system					
	A – ploughing method		B – reduced tillage		C – strip tillage	
	Aldana	Merlin	Aldana	Merlin	Aldana	Merlin
Seeds yield offsetting direct costs [t/ha]	1.69	1.69	1.50	1.50	1.40	1.40
Direct cost per 1 ton of soybean seeds [PLN]	1,989	1,854	1,841	1,694	1,586	1,536
Cost competitiveness of soybean cultivation [PLN]	3.15	2.42	2.36	1.83	1.53	1.42
The rate of direct profitability (without subsidies) [%]	1.32	1.41	1.42	1.55	1.65	1.71
Direct payment [PLN], in which:	1,609	1,609	1,609	1,609	1,609	1,609
– payment for high-protein crop	686	686	686	686	686	686
The gross margin with direct payment [PLN]	3,012	3,437	3,278	2,156	4,001	2,591
Direct cost production of 1 kg of protein [PLN/kg]	3.05	2.78	3.18	2.84	2.77	2.66

Source: own analysis

SUMMARY

The analysis of production and economic indices (the yield. the gross margin. direct costs and the rate of direct profitability (without subsidies) the most favorable variant of soybean cultivation was the cultivation in strip-tillage system. The strip-till system brought the highest value of harvested seeds of Merlin cultivar – 6,262 PLN/ha (mean in 2016-2020). The high value was also obtained under full ploughing system (6,251 PLN/ha). The highest profitability of soybean cultivation determined based relation production value of seeds to direct cost was obtained under strip-tillage system (mean for two cultivars – 1.68). In direct cost structure the highest percentage had seeds material cost.

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EFEKTYWNOŚĆ EKONOMICZNA UPRAWY SOI W ZALEŻNOŚCI OD SPOSOBU UPRAWY

Słowa kluczowe: soja, odmiany, plon, nawożenie, nadwyżka bezpośrednia, opłacalność

ABSTRAKT. Celem badań była ocena efektywności ekonomicznej uprawy dwóch odmian soi o różnej klasie wczesności, w zależności o sposobu uprawy roli. Analizę przeprowadzono w doświadczeniu polowym, zrealizowanym w latach 2016-2020 w Rolniczym Zakładzie Doświadczalnym Kępa-Puławy, w gospodarstwie w Osinach (51°27′53″N 22°03′52″E) położonym w województwie lubelskim, powiecie puławskim, należącym do IUNG-PIB w Puławach. W schemacie doświadczenia uwzględniono dwie odmiany soi: Aldana (000-wczesna) i Merlin – (000-średniowczesna). Największą wartość produkcji średnio w latach 2016-2020, w odniesieniu do jednostki powierzchni, osiągano z uprawy soi odmiany Merlin w uprawie *strip-rill* (6262 zł/ha). Wysoką wartość wskaźnika uzyskano również z uprawy tej odmiany w pełnej uprawie płużnej (6251 zł/ha). Opłacalność produkcji określona na podstawie relacji wartości produkcji do kosztów bezpośrednich była najwyższa dla uprawy soi w systemie *strip-till* (średnio dla obu odmian 1,68). W strukturze kosztów bezpośrednich największy udział stanowiły koszty kwalifikowanego materiału siewnego. Analiza wykazała. że najwyższy poziom nadwyżki bezpośredniej określonej na podstawie różnicy wartości produkcji i kosztów bezpośrednich zapewniła uprawa w systemie *strip-till*.

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