
Articles

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COST-EFFECTIVENESS OF SUBSTITUTION OF MINERAL FERTILISERS WITH PLANT PROTECTION PRODUCTS IN THE CROP PRODUCTION PROCESS

Summary

This study assesses, from the economic perspective, cost-effectiveness of substitution of variable factors, i.e. mineral fertilisers (SE295), with plant protection products (SE300) in the process of crop production of commercial farms in Poland.

The analysis was based on the Cobb-Douglas production function model, which was to analyse substitution of the factors. In 2010, the surveyed sample covered 8,583 and in 2011 – 8,378 commercial farms.

From the economic perspective, substitution of mineral fertilisation with plant protection products was beneficial for improvement of crop production efficiency of commercial farms. In 2010, this resulted from three times higher (3.01) rate of transformation of the plant protection product factor into plant bioproduct. In 2011, the ratio amounted to 2.65 to the advantage of plant protection products. The higher the difference between the rates, the higher the economic efficiency of substitution between substitutes.

Key words: Cobb-Douglas production function, sustainable development, substitution, variable factors, mineral fertilisers, plant protection products, commercial farm, crop production, bioproduct

Introduction

Substitution, according to M.E. Porter, manifests itself in all branches of the economy and their constituent enterprises, including commercial farms.

Substitution is used in horizontal and vertical analyses of products, factors of production and production technologies (Porter M.E., 2006). In general, the substitution mechanism helps consumers and entrepreneurs to make rational decisions.

In line with the aforementioned author, substitution is, e.g.: “one of the determinants of the level of profitability of a branch; it enables to set the highest level of prices in the branch; it influences the level of supply of factors and demand for products; substitutes allow for reduction in securities for the market position of an enterprise or production branches” (Porter M.E., 2006).

According to M.E. Porter “substitution is when one product starts to be used by the buyer to perform specific functions instead of another¹ (Porter M.E., 2006). This definition narrows down the scope of substitution to perfect substitutes, eliminating the imperfect ones.

The substitution mechanism fulfils an important role in creating the efficiency of commercial farms (Niezgoda D., 1986, 2011), because a model of industrial agriculture dominates on such farms. This model is very favourable when there is a shortage in supply of bioproducts over demand for them. It attempts to imitate the criteria of the aim of activity of industrial enterprises and their production techniques. When there is a surplus of supply over demand this model presents a drawback consisting in overexploitation of natural resources, generation of external costs and use of technologies applying some variable factors above the needs of plant products (Kopiński J., Tujaka A., 2010), which, in the long run, will deteriorate the efficiency of farms. Production efficiency, for instance, limits the participation of farms in the market structure, termed as perfect competition². The mechanism of the market structure reduces capital accumulation.

Expenditure for conservation of biosphere’s welfare represents another type of efficiency restriction in agriculture. In this case, an individual interest of a farmer gives way to the social interest, which is manifested, e.g., in implementation of the principles of sustainable development (Rogall H., 2010). The theory is based on the equivalence of the three levels:

- sociocultural level, which should be assessed based on the criterion of social equity,
- natural level, which is tasked with biosphere’s welfare,
- economic level, which is defined by the transformation rate of factors into products.

But “the increasingly more intensive process of globalisation and competition on the agri-food markets leads to stronger economic preference for effi-

¹ Own translation [translator’s footnote].

² “In a perfectly competitive industry all producers are price-takers.” (Krugman P., Wells R, 2012) [own translation – translator’s note].

ciency of agriculture over other areas. This is linked to the conflict of economic and social competitiveness.” (Zegar J.S., 2011).

The aim of the paper and economic competitiveness are linked to one of the principles of sustainable development economy – “the principle of strong durability: individual types of capital are complementary and not substitutional towards each other” (Kiełczewski D., 2012). It excludes independent and substitutional relations between different types of capital.

Many authors present a different opinion on the substitutional relations between various types of capital (Krugman P., Wells P., 2012; Toffler A.M., 1996; Samuelson P.A., Nordhaus W.D., 2004; Allen R.G.D., 1961). “All goods can be substitutes but not all can be complements.”³ (Allen R.G.D., 1961).

In my opinion, individual types of capital can be joined by both complementary, substitutional and independent relations. The same factors can be substitutes, at the economic level, competing for a share in the budget, which leads to changes in production techniques. At the natural level, the same factors complement each other thus making it possible to get a bioproduct at a similar level of production potential as a given variety. Lack of even one of the factors, makes it impossible to produce the bioproduct, therefore, the possibility to substitute “individual types of capital” is undermined in the natural aspect. This comment, on the natural level, refers to the researched capital factors.

It follows from the above that although three levels form a kind of entirety in the theory of sustainable development, there can be different relations between the same factors of production at each level, which enables to get a bioproduct compliant with their fixed characteristics. Moreover, in the natural environment plant and animal species are bounded by different relations, including also substitutional (competitive) relations.

The above-presented opinions of authority figures from the field of economy and theory of sustainable development justify the purposefulness of economic analysis of competitive relations between the researched factors of production.

Research objective, scope and methodology

The research is to assess the cost-effectiveness of substitution between different types of capital, i.e. mineral fertilisers in PLN and plant protection products in PLN, in the process of crop production carried out by commercial farms in Poland.

The research was held in 2010 and 2012. Considering, in this substitution analysis, the correlation between two variable factors will allow for determination of the level of economic advantage in short periods of time, namely one year. This will help farmers to make rational decision concerning changes in the share of factors in the crop production process.

³ Own translation [translator’s footnote].

The research was based on fully reliable figures determined on the same methodological grounds in each of the analysed years. In 2010, the research covered 8,583 and in 2011 – 8,378 commercial farms conducting crop production process in Poland. The figures provided by the Polish FADN show that it was expedient to use the designations of properties in line with the system, even more so that it is applicable in the European Union. This also fosters comprehensibility of the research results.

Additionally, the compilation covered statistical data on the level of sales of mineral fertilisers and plant protection products in Poland from 1999/2000 to 2010/2011. This was used to set the dynamics of changes in the demand for the analysed factors of production in agriculture as a production branch.

The research on substitution between variable factors of production, directly contributing to crop production growth, uses the following research methods:

- 1) literature studies, mainly regarding microeconomy and theory of sustainable development as well as theory of perfect competition;
- 2) Cobb-Douglas production function⁴ model targeted at analysis of substitution factors.

The Cobb-Douglas function was defined for the following properties according to the FADN nomenclature.

SE135 – crop production in PLN,

SE025 – utilised agricultural area (UAA) in ha,

SE295 – mineral fertilisers in PLN,

SE300 – plant protection products in PLN.

The Cobb-Douglas function parameters were estimated with the use of GRETL statistical programme.

From the list of the aforementioned properties, included in the function model, it follows that some factors were omitted, which had a limiting effect on the assessment of benefits in the crop production process. The criterion of economies of scale is used only for comparative purposes. It is not an important barrier in the analysis of substitution between *SE295* and *SE300* at average UAA in the surveyed years and for set average value of *SE135*.

It was assumed that the substitutional relation between *SE295* and *SE300* was based on competition for the level of share in the budget allocated to the needs of crop production process at farms.

It is important, from the methodological perspective, that factors *SE295* and *SE300* wholly transform into a product over one year.

The Cobb-Douglas function method allows rational selection of the direction of substitution between factors of production, especially a substitution of the factor

⁴ “Theory of an enterprise is presented – with the use of production function and marginal productivity equations – as a consequence of profit maximisation. Profit, output and input are measurable elements of the theory and it is possible to estimate correlations between them, which are an empirical counterpart of equations created by the economic theory.” (Klein L.R., 1965) [own translation – translator’s note].

showing a lower transformation rate with the one that has higher transformation rate⁵. Most often it makes sense to substitute more expensive factors with their less expensive close substitutes, which fosters reductions in production costs⁶.

The analysis of substitutional relations between factors of production uses also the method of qualitative analysis as well as horizontal and vertical analysis, which enabled assessment of the obtained results based on a comparative method.

Changes in production techniques are founded on innovations implemented by farmers based on the substitution mechanism. The research covered innovative variable factors, which are aggregates composed in case of *SE295* of different mineral fertilisers, and in case of *SE300* of highly differentiated plant protection products.

The cost-effectiveness of various proportions of substitutes was assessed using profitability index of their combination in *ceteris paribus* conditions.

The selected farms are in the group of the most efficient and effective ones; thus, possibilities of improvement of cost-effectiveness of crop production defined on their basis will be useful in a longer time perspective, above all, for less competitive farms.

Research results

The researched factors of production directly contribute to a growth in crop production in a given production cycle. The land factor ensures conditions for growth in crop production, but these are not sufficient to ensure high level of crop yields. Therefore, the soil is improved with mineral fertilisers and better crop growth conditions are created with the use of plant protection products. The scale of farmers' demand for mineral fertilisers (*SE295*) in Poland is illustrated by figures compiled in Table 1.

Data in Table 1 show that in 2010/2011, against 1999/2000, there was a growth in demand for mineral fertilisers by 13.41%. The growth rate was relatively low, which gives witness to some stabilisation in their use in the crop production process of commercial farms.

The use of nitrogen fertilisers differs considerably from the general trend. Increased demand for this type of fertiliser in 2010/2011, against the reference level (1999/2000), amounted to 46.07%. This caused a change in the proportion of nitrogen, phosphate and potassium, and negatively affected the level of efficiency of mineral fertilisers against other growth-enhancing factors.

⁵ "It might seem that better efficiency of action through an increase in outputs or reduction in inputs is equally important. In reality, the drive at better efficiency through a reduction in inputs can result and usually results in lower share of the seller in the market." (Allen R.G.D., 1961) [own translation – translator's note].

⁶ "Substitutes are pairs of goods for which a rise in the price of one of the goods leads to an increase in the demand for the other." (Krugman P., Wells R, 2012) [own translation – translator's note].

Table 1

**Consumption of mineral or chemical fertilisers and lime per pure component
per 1 ha of UAA in kg in Poland**

Years	Specification				
	Total	including:			agricultural lime
		nitrogen fertilisers	phosphate fertilisers	potassium fertilisers	
1999/2000	85.8	48.4	16.7	20.7	95.1
2001/2002	83.2	51.0	18.9	23.3	94.1
2004/2005	102.4	56.3	20.4	25.7	91.5
2008/2009	117.9	68.0	23.3	26.6	32.9
2009/2010	114.6	66.3	22.7	25.6	38.2
2010/2011	126.6	70.7	26.4	29.5	36.8
Growth rate in %	13.41	13.27	14.37	12.96	3.56

Source: Rocznik statystyczny rolnictwa 2012. GUS, Warszawa, 2012.

Because Poland is rich in soils of poor quality absorbing complex, fertilisers are washed out, which is the main reason for lowering their rate of transformation into plant bioproducts. Another reason for lower efficiency of fertilisation is, for example, the binding of phosphorus with aluminium and iron oxides. These chemical reactions result in poor water solubility of the created chemical compounds and their poor availability for plants (Ilnicki P., 2004). Excess of nitrogen is very harmful for the entire biosphere. Farmers seeking to maximise profit contribute to the degradation of the natural environment through “1) acid rains, 2) eutrophication, 3) propagation, i.e., spread of dangerous compounds in the environment, and 4) parching caused by lack of water” (Heijman W. et al., 1997).

Plant protection products (*SE300*) are another variable factor. Data compiled in Table 2 illustrate demand for the factor in Poland.

The data included in the Table show that sales of plant protection products in Poland was characterised by high growth rate as compared to mineral fertilisers. In 2011, demand for *SE300*, against the reference year (2000), increased by 37.73%. One of the reasons for this growth rate is high differentiation of the factor of production (Table 2) and boosting demand for new types of plant protection products. For example, a growth in nitrogen fertilisation increases the susceptibility to lodging of cereals and to counteract it the so-called growth regulators have to be used. This illustrates complementarity of different types of plant protection products captured at a natural level.

Table 2

Sales of plant protection products in Poland in tonnes of commodity weight

Specification	2000	2002	2005	2009	2011	2012
Total	22,164	26,578	41,135	49,761	51,613	58,736
Insecticides	2,533	1,439	1,917	3,390	2,945	3,320
Fungicides and seed treatments	4,686	7,525	9,915	13,531	12,867	13,557
Herbicides	13,233	14,970	24,455	28,035	30,228	35,948
Growth regulators	*	2,296	2,483	3,058	3,014	3,227
Rodenticides	53	109	249	146	147	95
Other	1,659	239	2,116	1,601	2,412	2,589

* No data.

Source: Rocznik statystyczny rolnictwa 2012. GUS, Warszawa, 2012.

Consumption of individual types of *SE300* was more differentiated than of *SE295*. In the researched period demand was the highest for fungicides, seed treatments and herbicides.

Varied rage of plant protection products confirms a high intensity of introducing product innovations at farms and process innovations adjusted thereto.

The growth in demand for insecticides is surprisingly low, which partially shows a decrease in the population of insects. It is especially dangerous for crop production; protection of insects starts to be a necessity.

In general, excessive mineral fertilisation and much more plant protection products than needed contributes to degradation of UAA and dynamic growth in external costs, which deteriorates social efficiency of crop production and limits growth in this branch of the economy.

Conditions of running commercial farms in the system of market economy are reflected in their revenues and costs. This is influenced by competitive relations between factors of production and products. The level of used factors of production and their total productivity in the crop production process of researched farms is compiled in Table 3.

Table 3 shows that, in the researched years, the UAA (*SE025*) did not change considerably, consequently, the growth factor of the land concentration level failed to exert impact on better production results captured in value terms on the researched farms (*SE135*). This confirms the minimally differentiated level of the coefficient of variation of *SE025* in the researched years.

Table 3

**Statistical characteristics of properties researched on commercial farms
in 2010 and 2011**

Property symbol as per the Polish FADN	Measurement unit	2010		2011	
		Arithmetic mean	Coefficient of variation	Arithmetic mean	Coefficient of variation
SE135	PLN	100,278.0	1.61	115,559.0	1.57
SE025	ha	36.3	1.18	36.4	1.17
SE295	PLN	17,904.3	1.64	20,784.6	1.59
SE300	PLN	7,762.0	2.07	8,261.4	1.95

Source: figures: the Polish FADN. Own calculations.

In the analysed period the expenditures on the components of variable costs, i.e. SE295 and SE300, grow, thus proving rationality of farmers' actions from their perspective. At the same time, variation of the properties between the researched years was relatively minor, which indirectly points to stability of applied technologies and production structure at commercial farms.

The production potential is important but productivity of the analysed factors, which reflects the skills regarding their management, decides on its efficiency. Analysis of the Cobb-Douglas function, estimated in the given years, will be helpful in this respect.

The Cobb-Douglas function models, showing the correlation between the level of crop production (SE135) and UAA (SE025), mineral fertilisers (SE295) and plant protection products (SE300), took on the following forms in individual years:

2010:

$$SE135 = 5.0176 \cdot SE025^{0.2056} \cdot SE295^{0.1501} \cdot SE300^{0.4704}$$

$$P \quad 0.0000 \quad 0.0000 \quad 0.0000$$

$$R^2 = 0.7060$$

2011:

$$SE135 = 5.4539 \cdot SE025^{0.3102} \cdot SE295^{0.1505} \cdot SE300^{0.3986}$$

$$P \quad 0.0000 \quad 0.0000 \quad 0.0000$$

$$R^2 = 0.7534$$

The coefficient of determination shows that the degree of explanation of the reasons for variation of the dependent variable was rather high, given the fact that the equation omits other important factors affecting the level of crop production for the researched farms, which has already been mentioned. High level of probability of the coefficient of regression confirms matching of the production function to the set of figures characterising the researched farms. In the Cobb-Douglas function, the coefficients of regression are, at the same time, measures of production elasticity (*SE135*) against individual independent variables (*SE025*, *SE0295* and *SE300*).

From the estimated equations it also follows that in a short-term there was a change in the transformation rates of researched factors into products (*SE135*). The lowest transformation rate of a factor into a product was noted for mineral fertilisation (*SE295*). Then, it should be assumed that the use of this factor is close to saturation and, from the economic perspective, its further intensification is not advisable. But again, the coefficient of production elasticity (*SE135*), against plant protection products (*SE300*), was high. This means that it was purposeful to increase their use because they were characterised by high rate of transformation into a product (*SE135*). Its level dropped in 2011, against 2010, which was caused by an increase in the intensity of use of the plant protection products and negative effects of excessive use of mineral fertilisation.

The analysis shows that limited resources of the researched factors of production were used by farmers, who deemed them the most valuable, because they contributed to production growth (*SE135*).

Substantive aspects and statistical analysis of approximated Cobb-Douglas function models justify the substitution analysis between factors *SE295* and *SE300*. The assessment of differentiation of the share of independent variables in the shaping of the level of dependent variable is a first step to the analysis (Table 4).

Table 4

The level and structure of crop production elasticity (*SE135*) against factors *SE025*, *SE295* and *SE300* for the researched farms in Poland between 2010 and 2011

Total level of coefficients of production elasticity of researched factors	Share of factors of production in the total value of the coefficient of production elasticity in %		
	<i>SE025</i>	<i>SE295</i>	<i>SE300</i>
2010			
0.8593	36.10	17.51	46.39
2011			
0.8321	24.71	18.76	56.53

Source: own calculations. Figures: the Polish FADN.

Table 4 shows that the researched correlations between *SE135* and *SE025*, and between *SE295* and *SE300* were characterised by diseconomies of scale, which is linked, mainly, to the omission of a part of factors engaged in the production process and short period of time considered. What was possible in the researched period, was only a change in the level of variable factors, i.e. *SE295* and *SE300*, and production result (*SE135*) because of their higher productivity. Changes in economies of scale can also be caused by a growth in product prices or a drop in the prices of variable factors used by commercial farms or introduction of innovations.

Table 4 shows also that the level of production elasticity, as regards a given factor, does not automatically mean its high share in the obtained production level (*SE135*). For instance, a minor decrease in the coefficient of production elasticity against factor *SE295* caused an increase in its share in shaping the production level. Consequently, it should be noted that the structure of production technique was still not rational. One of the reasons for the varied share of factors in the formation of the level of *SE135* was a lower value of the coefficient of total production elasticity in 2011 than in 2010.

The above observations justify the purposefulness of the calculation of the average and marginal productivity of the researched factors of production (Table 5).

The average productivity of land (*SE025*) and plant protection products increased in the analysed period (Table 5), while marginal productivity of land (*SE025*) increased and that of variable factors decreased.

The decrease in marginal productivity of mineral fertilisers (*SE295*) was especially unfavourable, i.e. below one, which deteriorates the crop production efficiency for the researched farms.

Table 5

**Average and marginal productivity of the researched factors of production
(*SE025*, *SE295* and *SE300*) in the group of commercial farms in Poland
between 2010 and 2011**

Factor type	Measurement unit	Average productivity of researched factors in:		Marginal productivity of researched factors in:	
		2010	2011	2010	2011
<i>SE025</i>	PLN/ha	2,760.20	3,176.44	567.50	985.02
<i>SE295</i>	PLN/ha	5.60	5.56	0.87	0.84
<i>SE300</i>	PLN/ha	12.92	13.99	6.08	5.58

Source: own calculations. Figures: the Polish FADN.

Substitutional relations between factors of production serve to implement different types of innovations to the production processes conducted at farms. In general, substitution of one factor for the other to meet the same demand leads to changes in the production techniques. For example, the use of multi-component fertilisers reduces labour-intensity and energy-intensity of bioproduct production processes. Substitution of factors and technological processes is, in general, done when it contributes to reduction in explicit costs of production or decrease in arduousness of human labour.

Changes in the structure of the factors of production made with the use of substitution show an entrepreneurial attitude of agricultural producers, which speeds up technological progress at farms that is a fundament of economic progress. As a result of entrepreneurial behaviours of farmers in the area of production and exchange, it is possible to achieve short-term competitive advantage and extraordinary profits. Substitution in the field of supply is, then, an important development mechanism for commercial farms (Niezgoda D., 2011). This thesis is proved by isoquant equations for 2010 and 2011:

2010:

$$SE300 = \left(\frac{SE135}{5.0176 \cdot SE025^{0.2056} \cdot SE295^{0.1561}} \right)$$

2011:

$$SE300 = \left(\frac{SE135}{5.4539 \cdot SE025^{0.3102} \cdot SE295^{0.1551}} \right)$$

The regression equations allow for calculation of coordinates for isoquants, which were set based on factors *SE295* and *SE300* at average value of *SE025* in the researched years and crop production (*SE135*). The value of dependent variable was set on the basis of a regression equation at average level of independent variables. In 2010, it amounted to PLN 98,545.53, and in 2011 – PLN 115,860.70. Table 6 presents the results of analysis of substitution of factor *SE295* with *SE300*.

The Table shows that the proportions between the researched factors changed, which simultaneously means differentiation of the rates of substitution between them. In case of using a low level of fertilisation it was advisable to ensure the best possible conditions for growth of crops with the use of plant protection products and contrariwise. Each point on an isoquant signifies a different value of the marginal rate of substitution and, at the same time, a wide range of alter-

native production techniques and their adaptation to the conditions of a specific farm. This proves the differentiated level of the profitability index included in the Table.

Table 6

Coordinates of isoquants determined by the following factors: mineral fertilisers (SE295) in PLN, plant protection products (SE300) in PLN and their marginal rates of substitution at fixed level of crop production (SE135) in PLN and UAA (SE025) in ha, between 2010 and 2011, for the researched farms in Poland

2010				2011			
Coordinates of isoquants in PLN		KSS ^a PLN/ PLN	Cost-effectiveness of production techniques in PLN/PLN	Coordinates of isoquants in PLN		KSS ^a PLN/ PLN	Cost-effectiveness of production techniques in PLN/PLN
SE295	SE300			SE295	SE300		
2,000	16,670.8	2.76	5.28	2,000	19,864.8	3.75	5.30
5,000	12,299.9	0.82	5.70	5,000	14,055.1	1.06	6.08
8,000	10,523.6	0.44	5.31	8,000	11,769.7	0.56	5.86
11,000	9,468.3	0.28	4.81	11,000	10,436.3	0.36	5.40
14,000	8,740.1	0.21	4.33	14,000	9,528.0	0.26	4.92
17,000	8,194.7	0.16	3.91	17,000	8,854.5	0.20	4.48
20,000	7,764.4	0.13	3.55	20,000	8,327.5	0.16	4.09
23,000	7,412.6	0.11	3.24	23,000	7,899.4	0.13	3.75
26,000	7,117.0	0.09	2.98	26,000	7,542.1	0.11	3.45
17,984.3	8,055.0	0.33	3.80	20,784.6	8,207.4	0.38	4.00

$$^a \text{KSS} = \frac{-\Delta SE300}{\Delta SE295}$$

Source: own calculations. Figures: the Polish FADN.

Cost-effectiveness of production techniques, defined by the relation of SE135 to the sum of costs of SE295 and SE300, was the higher the larger was the advantage of factor SE300 in their structure. At the same time, it justifies the correct direction of substitution between the researched independent variables.

Along with a growth in the level of productivity of a given factor, its share in plant bioproduct production should also grow, and limits of this participation are set by natural conditions. For plant bioproduct production, not necessarily what is right from the economic perspective is beneficial at the level of nature and society, i.e. human and animal welfare. Lack of such coherence is evidenced by the degree of environmental degradation, especially including drinking water,

which was demonstrated by research of P. Ilnicki (Ilnicki P., 2004). Then, from the research of J. Kopiński and A. Tujak it stems that “Countrywide, the gross nitrogen balance has a positive balance at the level of 57 kg of N per ha of UAA with 56% use efficiency” (Kopiński J., Tujaka A., 2010). This means a high level of environmental degradation, nitrogen waste and nitrogen contamination of drinking water.

The average cost-effectiveness of the dominant production technique, as regards *SE295* and *SE300*, amounted in 2010 to 3.80 PLN/PLN and in 2011 – 4.00 PLN/PLN. Changes in the level of the rates of transformation of the researched factors of production were the main reason for changes in cost-effectiveness of crop production in *ceteris paribus* conditions.

Isoquant coordinates included in Table 6 allowed for economic assessment of substitution of *SE295* with *SE300*. To this end, marginal rates of substitution were calculated. It turned out that the marginal rate of substitution decreases along with a growth in the input of plant protection products. Changes in the marginal rate of substitution were influenced by about three times higher input of factor *SE300* in the level of *SE135* in 2010, and 2.65 times higher in 2011.

Using the formula of J. Jaworski (Jaworski J., 1972), optimum production technique was used considering only factors *SE295* and *SE300*:

2010:

$$\frac{SE300}{SE295} = \frac{0.4704}{6.08} : \frac{0.1561}{0.87} = 0.43 : 1$$

2011:

$$\frac{SE300}{SE295} = \frac{0.3986}{5.58} : \frac{0.1505}{0.84} = 0.40 : 1$$

The presented correlations between coefficients of production elasticity, regarding *SE295* and *SE300*, and their prices show that the most beneficial relation between them in 2010 should amount to PLN 0.43 of *SE300* per PLN 1 of *SE295*, and in 2011, respectively, 0.40 PLN/PLN. The data concerns average size of a farm from the researched sample. It is clear that some part of farms failed to reach such a relation between the researched substitutes, which caused that the level of financial surplus was, in their case, lower than it should be.

Conclusions

1. A change in coefficients of production elasticity, as regards factors *SE295* and *SE300*, in the surveyed years influenced, for instance, other level of relations between marginal rates of substitution. In 2010, marginal rate of sub-

stitution of the discussed factors used in the crop production process at an average-sized farm amounted to 0.33 PLN/PLN and in 2011 – 0.38 PLN/PLN. The lower the marginal rate of substitution of *SE295* with *SE300*, the lower the level of production cost-effectiveness for the researched farms. This indirectly confirms purposefulness of setting the direction of substitution between the researched variable factors, based on a difference in the rate of transformation into a product and the level of their prices.

2. Factor innovations underlie the improvement of production techniques determined, in the case, by mineral fertilisers (*SE295*) and plant protection products (*SE300*). Whereas entrepreneurship of farmers determines their implementation into crop production. Together these factors influence better competitiveness of bioproducts, which is important because farmers are the “price-takers”. An example of such an innovation in 2010 was an over three times higher rate of transformation of plant protection products into bioproduct than the estimated one for mineral fertilisers. In 2011, it was 2.64 times more efficient. This allowed for a growth in cost-effectiveness of this production technique, at an average farm under the *ceteris paribus* conditions, from PLN 3.80 of revenue per PLN 1 of total costs of factors *SE295* and *SE300* in 2010 to 4 PLN/PLN in 2011. This resulted from better complementary relations between *SE295* and *SE300* in the crop production process.
3. Debatable is the opinion in the theory of sustainable development on rejection of substitution between factors of production, included in individual types of capital. The research analysed substitution of two types of capital, i.e. mineral fertilisers (*SE295* in PLN) and plant protection products (*SE300* in PLN). Each of them has a specific impact because mineral fertilisers provide nutrients necessary for plant development and plant protection products are tasked with plant protection against attacks of other plant species and elimination of fungi and bacteria. From the economic perspective, substitutes give different level of production costs. A farmer is to ensure such proportions between them which enable to obtain a rational level of yield. It is possible to a different degree because of the complementary relations, since it is necessary to adjust them to the natural environment. Thus, each of the pillars of sustainable development can affect, in a given production process, the complementary, substitutional or independent relations between factors.

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DIONIZY NIEZGODA

Państwowa Szkoła Wyższa im. Papieża JP II
Biała Podlaska

OPLACALNOŚĆ SUBSTYTUCJI NAWOZÓW MINERALNYCH ŚRODKAMI OCHRONY ROŚLIN W PROCESIE PRODUKCJI ROŚLINNEJ

Abstrakt

W opracowaniu dokonano ekonomicznej oceny opłacalności substytucji czynników zmiennych, tj. nawozów mineralnych (SE295) środkami ochrony roślin (SE300) w procesie produkcji roślinnej towarowych gospodarstw rolnych w Polsce.

Podstawą analizy był model funkcji produkcji Cobba-Douglasa ukierunkowany na analizę substytucji czynników. W roku 2010 badana próba liczyła 8 583, a w 2011 – 8 378 towarowych gospodarstw rolnych.

Z ekonomicznego punktu widzenia korzystne dla poprawy efektywności produkcji roślinnej w towarowych gospodarstwach rolnych było zastępowanie nawożenia mineralnego środkami ochrony roślin. W roku 2010 było to

wynikiem trzykrotnie wyższej (3,01) stopy transformacji czynnika środków ochrony roślin w bioprodukt roślinny. W roku 2011 ten stosunek wynosił 2,65 na korzyść środków ochrony roślin. Im większa różnica między tymi stopami, tym wyższa jest ekonomiczna efektywność substytucji między substytutami.

Słowa kluczowe: funkcja produkcji Cobba-Douglasa, zrównoważony rozwój, substytucja, czynniki zmienne, nawozy mineralne, środki ochrony roślin, gospodarstwa towarowe, produkcja roślinna, bioprodukt

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