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EVALUATION OF THE TECHNICAL EFFICIENCY OF DAIRY FARMS USING THE DEA METHOD

OCENA EFEKTYWNOŚCI TECHNICZNEJ GOSPODARSTW MLECZNYCH Z WYKORZYSTANIEM METODY DEA

Agriculture in economic theory

Economic theory was first applied to problems associated with agriculture in the ancient world. Agriculture was the key branch of the economy, and slaves were the main source of labor. The farming sector became stratified in ancient times. The agricultural system comprised large-area farms as well as small estates cultivated by the owners¹.

The early Christian era witnessed economic changes and the rising significance of Christian thought which initiated changes in the approach to agricultural economics. The Christian doctrine was highly critical of the accumulation of excessive wealth. Christian economic thought was strongly rooted in the Bible².

Physiocratism, the ensuing school of thought that dealt with agricultural economics, evolved in response to farming problems in France. The economic model proposed by the Physiocrats was laid out in the form of the Economic Table. The movement's proponents argued that economic development was highly dependent on nature and natural order. The laws of nature affect humans and their behavior, therefore, they should be observed by all men. According to the Physiocrats, the most important factor of production was land, the key source of wealth in farming. Agriculture was the only sector of the economy which produced surplus output relative to the invested cost. Physiocratism was an agrarian philosophy that praised farming and a natural style of living. This school of thought contributed to the reform of France's agrarian structure. The Physiocrats were advocates of economic freedom, and they opposed all trade restrictions. In Poland, a new philosophical movement spoke in favor of releasing peas-

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¹ W. Stankiewicz, *Historia myśli ekonomicznej*, PWE, Warszawa 2007, s. 1–520.

² *Ibid.*, s. 1–520.

ants from the yoke of serfdom. This school of thought contributed to agricultural reform and greater specialization in the Polish farming sector³.

Classical economics was a modern school of economic thought which also dealt with agricultural issues. Its major developers were Adam Smith and David Ricardo. Smith made a vast contribution to the theory of factor income distribution, that is the distribution of income between the main factors of production – land, labor and capital. According to Smith, prices were determined by production costs which, in turn, were affected by wages, profits and rents. Smith argued that the value of rents was strongly correlated with the availability of land, natural conditions, soil fertility and location⁴.

David Ricardo was also one of the most influential classical economists who analyzed the laws governing income distribution. His most important contributions were the value theory and the theory of distribution. Ricardo postulated that the value of a product is determined by the quantity of labor required in its production. Ricardo was also responsible for developing theories of rent, wages and profit. His theories rely on the assumption that the amount of both arable and non-arable land is fixed. Agriculture is an economic sector governed by the law of diminishing returns which states that when the share of one factor of production is increased in the production process, while other factors are held constant, lower per-unit returns can be expected in agriculture at some point.

The issue of rents was also analyzed by Czyżewski and Matuszczak (2010) who claimed that rents did not exist in small farms. Differential rents could arise due to variations in resource use and lower inputs. Absolute rent is a different concept postulating that rents have to be extracted by all landowners, including the owners of small farms. This concept is particularly important in an era of sustainable development⁵.

The theory of agricultural location was built on the concept of rings of agricultural activity. In the proposed model, the centers of effective (intensive?) production lie closest to markets in urban areas, whereas extensive farm units tend to be localized further away from the cities⁶.

Developmental economics is a branch of economics which deals with unequal growth in rural areas, high employment in the agricultural sector, poverty and low educational standards among rural inhabitants. In line with this concept, rural development is closely related to an increase in farming productivity levels and an improvement in rural livelihoods. Agrarian reforms implemented on the basis of this theory were only successful in limiting the extent of farm settlement⁷.

In the neoliberal approach to agricultural development, the expansion of farm area is regarded as the key prerequisite for agricultural effectiveness. The economic situation of Polish farmers improved after Poland had joined the European Union and became subject to the Common Agricultural Policy. The owners of large farms were in favor of Poland's accession to the EU because they recognized the economic opportuni-

³ J. Gudowski, *Rolnictwo w teorii i praktyce rozwoju gospodarczego*, w: R. Piasecki (red.), *Ekonomia rozwoju*, Polskie Wydawnictwo Ekonomiczne, Warszawa 2007, s. 144–162.

⁴ M. Nasiłowski, *Historia myśli ekonomicznej – dlaczego studiujemy?*, Wydawnictwo Key Text, Warszawa 1998, s. 1–134.

⁵ B. Czyżewski, A. Matuszczak, *Rola rent gruntowych w zrównoważonym rozwoju rolnictwa*, *Acta Scientiarum Polonorum seria Oeconomia* 9(3), Warszawa 2010, s. 65–72.

⁶ J. Gudowski, op. cit., s. 144–162.

⁷ Ibid.

ties flowing from EU membership⁸. Nonetheless, the EU enlargement process was also strongly opposed by many rural inhabitants.

The concept of agricultural productivity has many interpretations, but it is generally defined as the ratio of agricultural outputs to agricultural inputs. The foundations of the concept of agricultural efficiency have been laid by Vilfredo Pareto who observed that no-one could be made better off without making someone else worse off⁹. Neoclassical economists postulate that production efficiency is determined by inputs and results, whereas institutional economics focuses on the role of institutions in shaping economic behavior, and it argues that employee motivation increases productivity¹⁰. Efficiency in the agricultural sector can be improved in various ways, including by purchasing means of production at low prices, relying on economies of scale, transfers of technology and selling products at attractive prices¹¹.

Agricultural efficiency is a broad area of research for a number of reasons. First, only efficient farms can survive on the market, and second, farm productivity is affected by EU programs, direct subsidies and other measures¹².

Materials and methods

The objective of this study was to evaluate the economic situation of Polish dairy farms. Our survey was carried out in 2010, and it analyzed 27 dairy (cattle breeding) farms in the Region of Podlasie. Their technical efficiency was analyzed with the use of Data Envelopment Analysis. The foundations of the DEA model were laid down by M. J. Farrell in his work entitled "The Measurement of Productive Efficiency". The DEA methodology was formally developed by A. Charnese, W.W. Cooper and E. Rhodes (1978) who published their findings in the *European Journal of Operational Research*¹³. The model is rarely used in Poland, but some authors have relied on this method in analyses of pig production to observe that productivity is correlated with the efficiency of allocated input resources¹⁴. In the DEA model, efficiency is defined as the maximum ratio of a weighted sum of outputs to a weighted sum of inputs, and the efficiency index is calculated by means of linear programming. In highly productive farms, the value of the efficiency index approximates 1. When the value of the index is <1,

⁸ Ibid.

⁹ S. Figiel, *Cenowa efektywność rynku towarowego na przykładzie zbóż w Polsce*, Wydawnictwo UWM w Olsztynie, Olsztyn 2002.

¹⁰ A. Domagała, *Metoda Data Envelopment Analysis jako narzędzie badania względnej efektywności technicznej*, „Badania Operacyjne i Decyzyjne” 2007, nr 3–4, s. 21–34.

¹¹ J. Ziółkowska, *Produktywność w gospodarstwach wielkotowarowych w latach 2005–2007 – pomiar i determinanty*, „Zagadnienia Ekonomiki Rolnej” 2009, nr 4 (321), s. 111–125.

¹² C. Nauges, Ch.J. Donnel, J. Quiggin, *Uncertainty and technical efficiency in Finnish agriculture: a state-contingent approach*, „European Review of Agricultural Economics” 2011, Vol. 38(4), p. 449–467.

¹³ A. Charnes, W.W. Cooper, E. Rhodes, *Measuring the efficiency of decision making units*, „European Journal of Operational Research” 1978, No. 2, pp. 429–444.

¹⁴ E. Szymańska, *Zastosowanie metody DEA do badania efektywności gospodarstw trzodowych*, „Journal of Agribusiness and Rural Development” 2009, No. 2(12), p. 249–255.

a more effective combination of resources can be achieved through cost minimization¹⁵.

In our study, we analyzed the availability of land resources and the economic performance of farms. The studied subjects' agricultural inputs were examined. Descriptive methods were applied, and the results of our analyses are presented in tabular form.

Economic efficiency of farms

Land resources are used both in agriculture and in non-farm activities. According to Górska and Michna (2010), agricultural acreage in Poland decreased from 20.4 million ha in 1946 to 16.1 million ha in 2009. The above change was accompanied by an increase in average farm size¹⁶.

Large-size farms generate higher rents and higher incomes for their owners. Large-scale agricultural production delivers benefits both for the State and the consumers who are provided with cheaper products of higher quality. Large farms are more technologically advanced, they generate higher incomes and use their resources more efficiently, which is why they are more likely to contribute to agricultural advancement, economic growth and national development than small agricultural estates.

In our study, we analyzed the land management practices of dairy farms. In 2010, the average farm size was 42.36 ha which was equivalent to 31.54 conversion hectares. The average soil valuation index was 0.74. The main yield components were maize (27.9%), wheat (22.2%) and triticale (13.8%). The high share of maize and triticale can be attributed to the fact that those cereals are major feedstuffs. In an attempt to minimize costs, the surveyed farmers increased the on-farm production of feed.

Table 1. Area of surveyed farms

Variable	Average per farm
Agricultural acreage (ha)	42.36
Acreage in terms of conversion hectares	31.54
Agricultural acreage, including:	24.77
Wheat	5.51
Rye	0.76
Oats	1.31
Triticale	3.42
Barley	2.30
Rapeseed	3.02

¹⁵ M. Helta, M. Świtlyk, *Efektywność produkcji mleka w gospodarstwach należących do europejskiego stowarzyszenia producentów mleka w 2005 r.*, „Roczniki Nauk Rolniczych” 2007, seria G, t. 93, s. 80–87.

¹⁶ J. Górska, W. Michna, *Ubytek użytków rolnych na cele pozarolnicze w Polsce*, „Więś i Rolnictwo” 2010, nr 4/149, s. 57–74.

Mixed cereals	1.04
Potatoes	0.51
Maize	6.90
Meadows	10.88
Pastures	6.71

Source: own study.

Animal production was investigated at successive stages of the study. The surveyed farms had a high average milk yield of 6100 liters, which can be attributed to high nutritional quality of animal diets and the presence of dairy breeds. Heifers (8 head) and bulls (1.8 head) were also bred. In the analyzed farms, heifers were used for herd replacement.

Dairy profitability is determined mostly by the purchase prices of milk. In retail, one liter of milk fetches an average price of PLN 2.5–3.5, which implies that the producer has an estimated 46% share of the price paid by consumers. Dairy farmers could improve their profitability ratios through integration. Dairy cooperatives and other collaborative undertakings enable farmers to generate higher incomes, and they eliminate intermediaries in the processing and sale of dairy products.

Table 2. Animal production in the surveyed farms

Variable	Per hectare of agricultural acreage	Average per farm
Cattle population density (head)	0.84	35.5
Milk yield (liter)	144.7	6 127.8
Total milk production (liter)	5 520.0	233 827.8
Total milk production (PLN)	6 627.2	280 728.5
Price per liter (PLN)	-	1.18
Bulls (head)	0.04	1.81
Heifers (head)	0.19	8.0
Calves (head)	0.25	10.6

Source: own study.

Out of 2 million farms in Poland, only 243,000 (10.2%) sell their production on the market and meet Community standards. They are large farms which are characterized by extensive resources and high productivity. Their owners participate in training courses to expand their knowledge and improve the farms' efficiency¹⁷.

Competition in the agricultural sector is largely focused on productivity, which prompts farmers to apply the most effective production technologies. Farm effective-

¹⁷ W. Józwiak, *Efektywność i innowacyjność a konkurencyjność polskich gospodarstw rolnych*, „Więś i Rolnictwo” 2010, nr 1/150, s. 75–86.

ness and competitiveness of agricultural products are determined by costs which, in turn, are affected by the choice of production technology¹⁸.

The purchase of feedstuffs was the main item in the surveyed farms' cost structure (36.1%). The owners of dairy farms buy concentrate to maximize milk yield. Other significant cost items included the purchase of diesel oil (17.4%) and nitrogen fertilizers (12.2%). Those cost categories are related to plant production. The analyzed farms' efficiency was also determined by electricity costs (5.8%) and pesticide purchases (4.4%). The cost structure of the surveyed estates was typical of the agricultural sector. The high share of pesticides indicates that the main yield components were maize and wheat, cereals whose production requires high inputs.

Table 3. Production costs (PLN)

Variable	Per hectare of agricultural acreage	Average per farm	%
Purchase of seeds	69.62	2 949.3	2.4
Purchase of calves	47.21	2 000	1.7
Purchase of concentrate	1 026.39	43 477.8	36.1
Purchase of hay and straw	37.42	1 585.2	1.3
Calcium fertilizers	39.00	1 651.9	1.4
Nitrogen fertilizers	347.25	14 709.3	12.2
Phosphorus fertilizers	89.70	3 977.8	3.3
Potassium fertilizers	62.43	2 644.4	2.2
Pesticides	124.70	5 282.2	4.4
Veterinary drugs	109.29	4 629.6	3.8
Diesel oil	494.62	20 951.9	17.4
Water	69.15	2 505.6	2.1
Electricity	164.09	6 950.8	5.8
Harvester services	62.03	2 627.8	2.2
Agricultural tax	29.39	1 244.8	1.0
Insurance	40.37	1 710.1	1.4
Farmers' social insurance	37.77	1 600	1.3
Total	2 844.63	123 1298.5	100.0
Short-term loans	66.32	2 809.3	-
Long-term loans	433.67	18 370.4	-

Source: own study.

Costs are determined not only by the production process, but also by risk factors in agriculture. They key risks are natural hazards resulting from varied climate condi-

¹⁸ D. Niezgoda, *Zróżnicowanie dochodu w gospodarstwach rolnych oraz jego przyczyny*, „Zagadnienia Ekonomiki Rolnej” 2009, nr 1/318, s. 24–37.

tions that cannot be controlled by human activity (drought, precipitation, hail, flood, plant and animal diseases). Farming effectiveness is also determined by technological risk where the use of advanced technologies contributes to the uncertainty of future income streams. Environmental factors, including resource prices, food demand and price relations, determine the magnitude of economic risk. According to Jerzak (2009), the price risk is an equally significant factor, in particular sudden changes in the prices of agricultural products. Due to a long production cycle in agriculture (usually one year), farmers are often unable to generate the anticipated income upon the sale of their products¹⁹. In dairy production, the production cycle is effectively longer because the productive life of a cow is several years (lactations).

European Union policies have transformed agricultural markets in Poland and other Member States. Those markets are regulated by the Common Agricultural Policy which aims to enhance the competitiveness of the farming sector and improve the livelihoods of rural residents with the involvement of instruments such as direct subsidies. In a sense, the financial streams generated by direct payments are a source of rent for farmers. In the analyzed farms, the average value of direct subsidies was relatively high at PLN 33,754 per farm and PLN 797 per hectare of agricultural acreage. Farmers can significantly enhance their productivity by making the most of the opportunities created by EU funds. EU subsidies and programs targeting the agricultural sector enable less productive countries to catch up with the more economically developed Member States.

Poczta et al. (2009) observed that the process of European integration has stimulated Poland's agricultural production and increased farm incomes in terms of fixed prices. In comparison with pre-accession data (2000–2003), farm incomes doubled after Poland had joined the EU (2004–2008)²⁰. The observed growth in productivity was influenced in 70% by an increase in the value of direct subsidies, whereas factors such as technological effectiveness were responsible for improved performance in 30%.

In our study, the respondents were asked to estimate the value of farm investments carried out in the previous year. Most farmers had purchased machines, land and buildings. The value of those investments was not very high, in particular when calculated per hectare of agricultural acreage. The reported purchases indicate that farmers make extensive use of the opportunities created by the Rural Development Program for 2007–2013. The program enables farmers to buy machines and embark on other investment projects that improve their competitiveness.

The European model of sustainable and multifunctional development in agriculture is implemented in rural areas. The two pillars of the Common Agricultural Policy are production support and rural development. Legislative proposals have been made to maintain the basic two pillar structure of the CAP for the Financial Perspective 2014–2020²¹.

¹⁹ M. Jerzak, *Zarządzanie ryzykiem cenowym jako czynnik poprawy konkurencyjności gospodarstw rolnych w warunkach liberalizacji wspólnej polityki rolnej*, „Zagadnienia Ekonomiki Rolnej” 2009, nr 1/318, s. 13–23.

²⁰ W. Poczta, W. Czubak, K. Pawlak, *Zmiany w wolumenie produkcji i dochodach rolnych w warunkach akcesji Polski do UE*, „Zagadnienia Ekonomiki Rolnej” 2009, nr 4/321, s. 40–52.

²¹ J. Wilkin, *Przyszłość wspólnej polityki rolnej Unii Europejskiej – próba podsumowania dyskusji*, „Wieś i Rolnictwo” 2010, nr 1/150, s. 28–36.

Table 4. Investments in surveyed farms (PLN)

Variable	Average	Per hectare of agricultural acreage
Purchase of land	7 963.0	188.0
Purchase of machines	22 555.6	532.5
Construction materials	3 000	70.8
Construction services	444.4	10.5

Source: own study.

The technical effectiveness of the surveyed farms was evaluated with the use of the DEA method, a useful tool for analyzing production efficiency in agriculture. In this approach, the dependent variable was the value of milk production, and independent variables were: meadow area, pasture area, number of cows, concentrate, nitrogen fertilizers and veterinary drugs. The average index of technical effectiveness was 0.83 in the studied farms. Our results suggest that the surveyed farms do not fully utilize their resources which, at the noted levels of productivity, could be reduced by 17%. The agricultural performance index reached the maximum value of 1 in 41% of the analyzed farms. These results are similar to the findings of Stokes, Et al. in their analysis of Pennsylvania dairy farms. They found that 29% of the farms studied were DEA efficient²². Similarly, the 0.83 technical effectiveness found here is comparable to the average of 88% in the studies reviewed by Silva et al.²³ The efficiency measures could indicate that not all resources are deployed effectively, and that farmers should improve their skills and implement new technologies to maximize resource utilization and increase productivity. The fact that the results are consistent with studies from economies with a longer tradition of independent farmers is a positive indication that the transition of the Polish dairy industry is progressing rapidly, especially with the combination of a switch with the end of communism and with membership in the European Union. More effective utilization of EU funds would also substantially contribute to the technical efficiency of the surveyed subjects.

Table 5. Technical efficiency calculated by the DEA method

Variable	Total
Average TE	0.83
Number of farms where TE = 1	11
Minimal TE	0.65

Source: own study.

²² J.R. Stokes, P.R. Tozer, J. Hyde, *Identifying efficient dairy producers using data envelopment analysis*, „Journal of Dairy Science” 2007, vol. 90(5), p. 2555–62.

²³ E. Silva, A. Arzubi, J. Berbel, *An application of data envelopment analysis (DEA) in Azores dairy farms*, „New Medit Issue” 2004, No. (3)3, p. 39–43.

The use of the DEA model to evaluate the technical efficiency of farms does not produce ideal results, nevertheless it contributes to a reliable assessment of resource management practices. The results of our study indicate that farmers should make rational decisions based on the knowledge acquired during resource management courses.

Conclusions

The analyzed farms were characterized by relatively high productivity. The average value of the technical efficiency index was 0.83, indicating that some farms do not make full use of the existing resources. In the era of European integration, agricultural productivity is determined by the level of subsidies.

Agricultural productivity is influenced by farm area and the available options of expanding agricultural acreage. In Poland, farmland continues to be scarce, and land prices are very high in some regions. Vast land resources are held by the Agricultural Property Agency, which shapes the demand for and the supply of farmland in the country.

The emergence of large farms has resulted in farmland consolidation. The average farm area is on the rise, and the number of small farms is declining. Polish farms maximize their effectiveness by using their products as inputs in the production process, reducing unit costs and maximizing performance per unit area of land. The least fertile soils are used for non-agricultural purposes, such as forestry. In the contemporary world, advanced technology and innovative solutions are the key drivers behind agricultural development.

The key element of the surveyed farms' cost structure was the purchase of feedstuffs and diesel oil. To minimize costs, farmers should increase the on-farm production of feed.

The productivity of a dairy farm is determined by the agricultural pricing system. Individual farmers have little control over the prices at which they sell their products. Higher retail prices of milk might motivate farmers to integrate with other producers and start dairy processing cooperatives.

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STRESZCZENIE

Celem badań było poznanie efektywności technicznej gospodarstw zajmujących się chowem bydła mlecznego. Badania przeprowadzono na terenie województwa podlaskiego w 2010 r. wśród 27 gospodarstw. Badania wykazały, że efektywność techniczna gospodarstw była dość wysoka. Mimo wysokiej efektywności badane gospodarstwa realizowały inwestycje w małym zakresie. Badane gospodarstwa ponosiły dość wysokie koszty zakupu koncentratów, nawozów azotowych i oleju napędowego. Głównym źródłem dochodów była sprzedaż mleka.

SŁOWA KLUCZOWE: efektywność techniczna, gospodarstwa rolne, inwestycje

SUMMARY

The objective of the survey was to recognize technical efficiency of dairy farms. The survey was carried out in Po9dlsie province in 2010 among 27 farms. The survey proved that technical efficiency was quite high. In spite of high efficiency surveyed farms invested in small scale. Surveyed farms had quite high costs of purchase of concentrates, nitrogen fertilizers and diesel oil. The main source of income was milk sale.

KEYWORDS: technical efficiency, farms, investment

