www.jard.edu.pl DOI: 10.17306/JARD.2016.71

Journal of Agribusiness and Rural Development

pISSN 1899-5241
eISSN 1899-5772

3(41) 2016, 433–443

SUSTAINABLE DEVELOPMENT OF THE FARMS IN POLAND

Jadwiga Zaród✉

Zachodniopomorski Uniwersytet Technologiczny w Szczecinie

Abstract. Based on statistical data of the Central Statistical Office regarding Polish farms two linear-dynamic multicriteria optimization models have been created. The first model concerned plant production, the other plant and animal production. In both models, objective functions maximized agricultural income and production, and minimized loss of organic soil matter. Balancing these three objectives is the essence of a farm's sustainable development. The models have been solved with goal programming. The optimal solution yielded a production structure allowing for the highest quality of production, under given conditions of agricultural income, with no degradation of the natural environment. The goal of the following article is to confirm whether it is possible to simultaneously realize the production, economic and ecological goals of Polish farms over the course of four years.

Key words: sustainable development, agricultural production, agricultural profit, soil organic matter, multicriteria optimization model

INTRODUCTION

The principles of sustainable development apply to all sectors of economy and therefore agriculture. Sustainable development of farms includes predominantly: assurance of continuous soil fertility, abiding to the rules of proper agricultural technology and animal husbandry, usage of exclusively necessary chemical plant protection products, limiting the use of mineral fertilizers, good vegetation soil coverage, reasonable furnishing of farms in terms of mechanization and income to ensure a decent standard of living for farmers.

The listed rules are aimed at realization of three goals: economic and ecologic production, as well as maintenance of the balance between them. Production task involves manufacture, in appropriate amounts, of agricultural products of quality required by the consumers or the processing industry. Economic actions are focused on the development of agricultural income comparable to salaries in other national economy sectors, and allowing for farm modernization and development. Ecologic goals aim at guaranteeing agroecosystem stability and natural environment's degradation prevention.

The goal of the following article is check whether it is possible to simultaneously realize the production, as well as economic and ecologic goals of Polish farms for four years. Such a research will make it possible to make linear-dynamic multicriteria optimization models.

Many authors from around the world have already dealt with agricultural production optimization. Among others, Wesonga (2007) based on farm optimal models' solution, suggested the structure of production, that should significantly decrease poverty and hunger in African countries. Manos et al. (2013) have studied agricultural production sustainable development in the Tasalii (Greece) region using optimization models. Sha-sha et al. (2013) optimized agricultural production structure in uncertain conditions in Dancheny County (China). Rodríguez et al. (2009) have used optimization models for pig breeding planning.

✉dr Jadwiga Zaród, Katedra Zastosowań Matematyki w Ekonomii, Zachodniopomorski Uniwersytet Technologiczny w Szczecinie, ul. K. Janickiego 31, 71-270 Szczecin, Poland, e-mail: jzarod@zut.edu.pl

As a result of the solutions of the models presented in this work, a production structure will be formed that will not degrade the environment while yielding the highest possible, under given conditions agricultural, income and assure a high standard of production.

RESEARCH METHOD

The main research method of the paper are linear-dynamic optimization models with three goal criteria. The models describe a typical Polish farm, and their goal functions relate to agricultural income, production volume and the amount of organic substances in the soil.

The mathematical model of such a goal adapted to agricultural needs takes the form of (Krawiec, 1991):

$$ax(t) \le b(t) \text{ limiting conditions} \quad (1)$$

$$x(t+1) \le x(t) + f_t[x(t), u(t)] \text{ dynamics equations} \quad (2)$$

$$[g(t+1)]^T u(t) \ge [h(t+1)]^T x_z(t+1)] \text{ feed balance (in livestock production model)} \quad (3)$$

$$F = \max \{F_1, F_2, F_3\} \text{ control criterion} \quad (4)$$

$$x(t) \ge 0,\ u(t) \ge 0 \text{ boundary conditions} \quad (5)$$

where:

t – states (consecutive years of farming), $t = 0, 1, 2,\dots, k$
a – technical and economic parameters' vector
$b(t)$ – subsequent states' limits vector
$x(t)$ – state vector
$u(t)$ – control vector
$g(t + 1)$ – fodder plant unit efficiency (yield) vector
$h(t + 1)$ – annual individual demand for feed and plant materials' vector
$x_z(t + 1)$ – livestock state vector.

It should be assumed that the initial system state in the $t = 0$ moment is known and describes the plant acreage and livestock state in the moment preceding the first year of the research.

Vector of the $x(t)$ takes the form:

$$x(t) = [x_t(t), x_p(t), x_r(t)] = [x_1(t),..., x_n(t)] \quad (6)$$

where:

$x_t(t)$ – commodity operations' state vector (it describes the acreage of forage plants grown in the year t and animal classes and species that yield commodity production in the year t, like milk, meat)
$x_p(t)$ – subsistence operations' state vector (it describes the acreage of forage plants grown in the year t and animal classes and species that do not yield commodity production)
$x_r(t)$ – other operations' state vector, e.g. purchases of production materials, feeds.

Control vector $u(t) = u_{ij}(t)$ presents the flows inside the farm or between the farm and its surroundings. This vector's components describe acreages of subsequent plants, livestock class change, livestock sale or purchase, during the farms transition from state t to $t+l$. The i, j, indices determine the order of succession, e.g. after a plant i, plant j will be grown, or an animal of i class will pass into j class.

Dynamics equations for plant production take the form of:

$$x_i(t+1) = \sum_p u_{pi}(t) \quad (7)$$

where:

$x_i(t + 1)$ – acreage of i-th arable crop in the year $t + 1$
$u_{pi}(t)$ – acreage of various forecrops p after which i-th is grown in the year $t + 1$.

The dynamics equations' form for livestock production is as follows:

$$x_i(t+1) = x_i(t) - u_{is}(t) + u_{iz}(t) + u_{ji}(t) \quad (8)$$

where: $x_i(t + 1)$ – i-th species' livestock state in the year $t + 1$
$x_i(t)$ – i-th species' livestock state in the preceeding year
$u_{is}(t)$ – i-th species' livestock sales in the t year
$u_{iz}(t)$ – i-th species' livestock purchase in the t year
$u_{ji}(t)$ – i-th species' livestock quantity from own livestock, reclassing.

To sum up, it should be said that dynamics and constraints of linear equations transition of the farm from state t to state $t + 1$, meaning from the previous to the next research year. They incorporate: the farm's state in year t, control that could be utilized while transitioning from state t to state t+1, and limits of agricultural production.

The F_1 goal criterion regards gross agricultural income and is expressed with equation:

$$F_1 = \sum_t [m(t)^T u(t) + w(t+1)^T x(t+1)] \to \max \quad (9)$$

where: $m(t)$, $w(t + 1)$ – individual income vector for variables control and state denoting commodity activity or individual outlays incurred by farms involved in non-commodity activity.

F_2 is a control criterion maximizing production volume, it takes the form of:

$$F_2 = \sum_t [g(t)^T u(t) + k(t+1)^T x(t+1)] \rightarrow \max \quad (10)$$

where: $g(t)$, $k(t + 1)$ – individual efficiency vector of variable control and state in subsequent years;

The F_3 function maximizes the soil organic substance's amount:

$$F_3 = \sum_t [o(t)^T u(t) + p(t+1)^T x(t+1)] \rightarrow \max \quad (11)$$

where: $o(t)$, $p(t + 1)$ – vector of individual reproduction rates or soil degradation for state and control variables.

The multicriteria optimization model could be solved with goal programming. Its creators are Charnes and Cooper (Charnes and Cooper, 1961). This approach incorporates solving a constructed model separately due to each criterion. After acquiring optimal results, each goal function is treated as the model's separate limiting condition in the form of:

$$m(t)^T u(t) + w(t + 1)^T x(t + 1) = dr \quad (12)$$

$$g(t)^T u(t) + k(t + 1)^T x(t + 1) = pr \quad (13)$$

$$o(t)^T u(t) + p(t + 1)^T x(t + 1) = so \quad (14)$$

where:

dr – the greatest agricultural income value acquired from a single-criterion model's solution

pr – optimal agricultural production volume acquired from a single-criterion model's solution

so – the amount of organic substance retained in the soil, acquired from a single-criterion model's optimal solution.

All of these conditions include a restrictive limitation of equality type that should be weakened. A complete equality's weakening is called transformation which includes variables of deficiency (u^-) or excess (u^+) expressing the achieved values' non-fulfillment volume in single-criterion models. After transformation, the added limiting conditions will take on the form of:

$$m(t)^T u(t) + w(t + 1)^T x(t + 1) - u_1^+ + u_2^- = dr \quad (15)$$

$$g(t)^T u(t) + k(t + 1)^T x(t + 1) - u_3^+ + u_4^- = pr \quad (16)$$

$$o(t)^T u(t) + p(t + 1)^T x(t + 1) - u_5^+ + u_6^- = so \quad (17)$$

Next, many criteria are replaced with a single distance function describing the costs (penalties) of deviations from the target values. This functions includes both variables regarding agricultural income and agricultural production deficiency or excess, as there are no specific recommendations on how to achieve them. However, the soil organic substance deficiency must be minimized so as not to degrade the natural environment. The distance function will take on the form of:

$$F = u_1^+ + u_2^- + u_3^+ + u_4^- + u_6^- \rightarrow min \quad (18)$$

FORMATION OF FARM MULTICRITERIA MODELS

For two types of farms: field crops and mixed (plant and animal production) in 2009–2012, linear dynamic multicriteria optimization models have been created. In 2012 the type of field crops covered 10% of farms in Poland, and the type of mixed crops up 61%. They focused the largest area of arable land in the country (respectively 20.8% and 52.1%).

The first model dealing with the crop production consisted of 44 decisive variables and 47 constraints. Whereas, the second model constructed for an average farm dealing with the crop and livestock production comprised 104 variables and 122 balance constraints.

To build these models, data from Central Statistical Office (GUS) and Farm Accountancy Data Network (FADN) were used. The collected information concerning area of agricultural land, area and structure of crops and grants came from the publication FADN (Polski FADN 2011–2014). While, the data about yields, prices of agricultural products and means of production came from CSO (GUS 2009–2012).

Tables 1 and 2 include selected information about farm.

Average values from the acquired information were or allowed for calculation of technical and economic parameters, free terms and objective function coefficients. Limiting factors of models in each studied year formed a linear programming model. Merging of these models occurred via crop and livestock herd rotation, that is through dynamics equations also known as binding conditions. Table 3 depicts the accepted crop rotation's scheme. In order to assure constant field area in rotation, crop acreage was assumed to be average for the studied years.

After rye and oats harvest in a farm dedicated solely to crop production, sowing of winter aftercrop was planned. It consisted of mulch for sugar beet growing and was a source of natural fertilizers.

Table 1. Basic characteristics of a farm – type of field crops
Tabela 1. Podstawowe charakterystyki gospodarstwa rolnego – typ uprawy polowej

Specification – Wyszczególnienie	2009	2010	2011	2012
Agricultural land area (ha) Powierzchnia użytków rolnych (ha)	53.0	66.5	64.5	64.4
Sown area (ha) Powierzchnia zasiewów (ha)	52.07	65.49	63.69	63.55
Structure of sown area, of which (%): Struktura zasiewów, w tym (%):	100	100	100	100
Cereals – Zbóż	66.89	63.16	66.12	67.6
Industrial crops – Roślin przemysłowych	21.0	25.03	23.06	21.4
Potatoes – Ziemniaków	4.98	5.2	4.13	4.53
Feed crops – Roślin pastewnych	4.75	4.23	4.49	4.44
Other crops – Innych upraw	2.38	2.38	2.2	2.03
Yields ($dt \cdot ha^{-1}$): – Plony ($dt \cdot ha^{-1}$):				
Cereals – Zbóż	34.8	35.6	34.3	34.6
Rape – Rzepaku	30.8	23.6	22.4	26.4
Potatoes – Ziemniaków	191	211	232	242
Sugar beets – Buraków cukrowych	543	483	574	582
Procurement prices ($PLN \cdot dt^{-1}$): Ceny skupu ($zł \cdot dt^{-1}$):	48.26	59.84	81.99	88.68
Wheat – Pszenicy Rye – Żyta	32.74	41.12	74.24	74.40
Barley – Jęczmienia	40.8	48.98	75.38	81.49
Oats – Owsa	30.82	34.30	64.34	65.07
Triticale – Pszenżyta	37.05	46.65	72.01	79.56
Potatoes – Ziemniaków	31.73	36.53	37.0	37.76
Sugar beets – Buraków cukrowych	11.57	11.31	14.40	13.72
Rape – Rzepaku	108.24	127.76	183.91	183.91

Source: own elaboration based on data from GUS and FADN.
Źródło: opracowanie własne na podstawie danych GUS i FADN.

The numbers of cows and sows was determined based on the average value in 2009–2012. However, the numbers of the remaining animal species were derived from the changeable composition of the livestock.

In order to reflect processes occurring in a farm as accurately as possible, the models encompass a series of balances ensuring inner consistency (balances of crop rotation, livestock herd rotation, mineral and natural fertilizing, animal nutrition, working hours).

In the crop production-only mode, the parameters of first goal function individual agricultural income were calculated as a difference between production value (price × crop) and production cost (Augustyńska-Grzymek, 2012) without pricing the farmer's work.

Table 2. Basic characteristics of a farm – type mixed*
Tabela 2. Podstawowe charakterystyki gospodarstwa rolnego – typ mieszany*

Specification – Wyszczególnienie	2009	2010	2011	2012
Agricultural land area (ha) – Powierzchnia użytków rolnych (ha)	29.9	29.1	28.7	29.8
Sown area (ha) – Powierzchnia zasiewów (ha)	29.55	28.52	28.16	29.17
Structure of sown area, of which (%): – Struktura zasiewów (%), w tym:	100	100	100	100
Cereals – Zbóż	65.04	63.85	63.88	64.9
Industrial crops – Roślin przemysłowych	22.1	23.0	23.06	23.4
Potatoes – Ziemniaków	6.03	7.0	6.5	5.53
Feed crops – Roślin pastewnych	6.19	5.1	5.42	5.11
Other crops – Innych upraw	0.64	1.05	1.14	1.06
Procurement prices: – Ceny skupu:				
Beef for slaughter ($PLN \cdot kg^{-1}$) – Żywca wołowego ($zł \cdot kg^{-1}$)	4.52	4.56	5.58	6.40
Pork for slaughter ($PLN \cdot kg^{-1}$) – Żywca wieprzowego ($zł \cdot kg^{-1}$)	4.56	3.89	4.52	5.45
Milk ($PLN \cdot l^{-1}$) – Mleka ($zł \cdot l^{-1}$)	0.9	1.07	1.21	1.20
Cattle (heads), of which (%): – Pogłowie bydła, w tym (%):	23	23	23	23
Cows – Krów	8	8	8	8
Pigs (heads), of which (%): – Pogłowie trzody chlewnej, w tym (%):	97	97	97	97
Sows – Loch	3	3	3	3

Yields and prices like in Table 1.
Source: own study based on data from GUS and FADN.
Plony i ceny upraw jak w tabeli 1.
Źródło: opracowanie własne na podstawie danych GUS i FADN.

Table 3. Crop succession covered by the models
Tabela 3. Następstwo roślin uwzględnione w modelach

Year – Rok	Field I – Pole I	Field II – Pole II	Field III – Pole III	Field IV – Pole IV
2008	Potatoes – Ziemniaki Beats – Buraki Oats – Owies	Wheat – Pszenica Barley – Jęczmień	Rape – Rzepak Triticale – Pszenżyto	Rye – Żyto Other crops – Inne uprawy
2009	Wheat – Pszenica Barley – Jęczmień	Rape – Rzepak Triticale – Pszenżyto	Rye – Żyto Other crops – Inne uprawy	Potatoes – Ziemniaki Beats – Buraki Oats – Owies
2010	Rape – Rzepak Triticale – Pszenżyto	Rye – Żyto Other crops – Inne uprawy	Potatoes –Ziemniaki Beats – Buraki Oats – Owies	Wheat – Pszenica Barley – Jęczmień
2011	Rye – Żyto Other crops – Inne uprawy	Potatoes – Ziemniaki Beats – Buraki Oats – Owies	Wheat – Pszenica Barley – Jęczmień	Rape – Rzepak Triticale – Pszenżyto

Source: own elaboration.
Źródło: opracowanie własne.

The acquired income was increased by direct grants (Single Area Payments and compensatory payments) and by sugar payment in case of sugar beet. In the livestock breeding model for variables related to commodity production, the way of individual income calculation was not changed. However, crops intended for feeds and livestock for raising in objective function were burdened with costs decreased by additional payments.

Individual crop yields are second goal criterion factors in a crop production-only model. In livestock production model, crop production is expressed in one kind of units (dt·ha^{-1}) and livestock production in another (kg, l), that is why it was presented in terms of value in the goal function.

For the purpose of determining the parameters of the third objective function, the soil organic matter reproduction and degradation coefficients according to Eich and Kindler (Fotyma and Mercik, 1992) were used.

Reproduction and degradation factors describe the degree of soil depletion or enrichment in organic matter (in t·ha^{-1}) for cultivation of a given crop kind or utilization of organic fertilizers' specific dose.

RESEARCH RESULTS

The model solution was two-staged. Table 4 presents the production structure acquired through solving

Table 4. Linear-dynamic optimization models' solutions with field crops
Tabela 4. Rozwiązania liniowo-dynamicznych modeli optymalizacyjnych z produkcją roślinną

Variables – Zmienne	Single-criterion models – Modele jednokryterialne			Multicriteria model Model wielokryterialny
	model I*	model II*	model III*	
1	2	3	4	5
2009				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	61.20	61.20	61.20	61.20
Wheat – Pszenicy	8.57	8.57	8.57	8.57
Barley – Jęczmienia	0.61	0.61	0.61	0.61
Rye – Żyta	6.12	6.12	29.38	6.12
Oats – Owsa	23.26	0.00	0.00	23.26
Triticale – Pszenżyta	2.45	25.70	2.45	2.45
Rape – Rzepaku	6.73	6.73	6.73	6.73
Potatoes – Ziemniaków	3.06	3.06	9.18	3.06
Sugar beets – Buraków	6.12	6.12	0.00	6.12
Other crops – Innych upraw	4.28	4.28	4.28	4.28
Aftercrop – Poplonu	6.12	6.12	29.38	19.38
2010				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	61.20	61.20	61.20	61.20
Wheat – Pszenicy	7.34	7.34	7.34	7.34
Barley – Jęczmienia	25.10	1.84	1.84	25.10
Rye – Żyta	4.90	28.15	4.90	4.90
Oats – Owsa	0.00	0.00	23.26	0.00
Triticale – Pszenżyta	1.22	1.22	1.22	1.22
Rape – Rzepaku	7.96	7.96	7.96	7.96

Table 4 cont. – Tabela 4 cd.

1	2	3	4	5
Potatoes – Ziemniaków	3.06	3.06	10.40	3.06
Sugar beets – Buraków	7.34	7.34	0.00	7.34
Other crops – Innych upraw	4.28	4.28	4.28	4.28
Aftercrop – Poplonu	4.90	28.15	28.15	4.90
2011				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	61.20	61.20	61.20	61.20
Wheat – Pszenicy	7.96	7.96	0.00	7.96
Barley – Jęczmienia	2.44	2.44	33.66	2.44
Rye – Żyta	4.90	4.90	4.90	4.90
Oats – Owsa	0.00	23.26	0.00	0.00
Triticale – Pszenżyta	25.09	1.84	1.84	25.09
Rape – Rzepaku	7.34	7.34	7.34	7.34
Potatoes – Ziemniaków	2.45	2.45	9.18	2.45
Sugar beets – Buraków	6.73	6.73	0.00	6.73
Other crops – Innych upraw	4.28	4.28	4.28	4.28
Aftercrop – Poplonu	4.90	4.90	4.90	4.90
2012				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	61.20	61.20	61.20	61.20
Wheat – Pszenicy	8.57	8.57	0.00	8.57
Barley – Jęczmienia	0.61	23.87	9.18	0.61
Rye – Żyta	28.76	5.51	5.51	28.76
Oats – Owsa	0.00	0.00	0.00	0.00
Triticale – Pszenżyta	3.67	3.67	26.93	3.67
Rape – Rzepaku	6.73	6.73	6.73	6.73
Potatoes – Ziemniaków	3.06	3.06	3.06	3.06
Sugar beets – Buraków	6.12	6.12	6.12	6.12
Other crops – Innych upraw	3.67	3.67	3.67	3.67
Aftercrop – Poplonu	6.12	6.12	5.51	28.76
Agricultural income (PLN) Dochód rolniczy (zł)	617 059.46			596 715.18
Agricultural production (PLN) Produkcja rolnicza (zł)		26 287.57 703 189.87		26 266.64 703 161.49
Organic substance amount (t) Substancja organiczna gleby (t)			2.39	1.77

* Optimization criteria (I – agricultural income, II – agricultural production, III – organic substance amount).
Source: own calculations on Matlab program.
* Kryteria optymalizacji (I – dochód z rolnictwa, II – produkcja rolnicza, III – wielkość substancji organicznej).
Źródło: obliczenia własne w programie Matlab.

single-criterion models (first stage) and a multicriteria model with profile plant.

Acquired optimal solutions are in line with the rules of sustainable agriculture at the farm level. They include the accepted crop rotation (Table 3), acceptance good soil coverage with crops and timely performance of agricultural treatments.

Agricultural income and production were slightly decreased in multicriteria model solution, and the organic substance amount in soil decreased by 25.94%, however its positive value is evidence of non-degradation of natural environment.

The optimal solution for a model of a crop and livestock production farm also allows for a positive balance of organic substance amount in soil. Table 5 presents crop production structure acquired through solving single-criterion models (first stage) and a multicriteria model.

The state of individual livestock species in optimal solutions was conditioned by their profitability, cow and sow quantity and livestock herd closed rotation. This amount was unchanging in each analysed year and amounted to: 8 cows, 7.84 calves, 6.27 young beef cattle, 1 replacement heifers and 1 culled cows, 3 sows, 48 piglets, 46.56 pigs for fattening, 0.75 replacement sows and 0.75 culled sows. The model retained fractional livestock numbers which demonstrate a given specimen not having been on the farm the entire year or incomplete utilization of stations.

Table 5. Linear-dynamic optimal models' solutions with livestock production
Tabela 5. Rozwiązania liniowo-dynamicznych modeli optymalizacyjnych z produkcją zwierzęcą

Variables – Zmienne	Single-criterion models – Modele jednokryterialne			Multicriteria model Model wielokryterialny
	model I*	model II*	model III*	
1	2	3	4	5
2009				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	28.85	28.85	28.85	28.85
Wheat – Pszenicy	0.00	3.17	0.00	3.17
Barley – Jęczmienia	5.34	2.17	12.98	2.17
Rye – Żyta	4.33	4.33	4.33	4.33
Oats – Owsa	0.00	0.00	0.00	0.00
Triticale – Pszenżyta	9.09	9.09	1.44	9.09
Rape – Rzepaku	4.04	4.04	4.04	4.04
Potatoes – Ziemniaków	1.73	1.73	1.73	1.73
Sugar beets – Buraków	3.17	3.17	3.17	3.17
Other crops – Innych upraw	1.15	1.15	1.15	1.15
Grasslands – Łąk	3.90	3.90	5.00	5.00
Pastures – Pastwisk	2.41	2.41	3.00	3.00
2010				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	28.85	28.85	28.85	28.85
Wheat – Pszenicy	0.00	3.46	0.00	3.46
Barley – Jęczmienia	4.90	1.44	4.90	1.44
Rye – Żyta	11.97	11.97	4.33	11.97
Oats – Owsa	0.00	0.00	0.00	0.00
Triticale – Pszenżyta	1.59	1.59	9.23	1.59
Rape – Rzepaku	3.75	3.75	3.75	3.75

Table 5 cont. – Tabela 5 cd.

1	2	3	4	5
Potatoes – Ziemniaków	2.02	2.02	2.02	2.02
Sugar beets – Buraków	3.46	3.46	3.46	3.46
Other crops – Innych upraw	1.15	1.15	1.15	1.15
Grasslands – Łąk	4.00	4.00	5.00	5.00
Pastures – Pastwisk	2.64	2.64	3.00	3.00
2011				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	28.85	28.85	28.85	28.85
Wheat – Pszenicy	3.75	3.75	0.00	3.75
Barley – Jęczmienia	1.73	1.73	5.48	1.73
Rye – Żyta	4.04	4.04	11.68	4.04
Oats – Owsa	7.65	7.65	0.00	7.65
Triticale – Pszenżyta	1.30	1.30	1.30	1.30
Rape – Rzepaku	3.61	3.61	3.61	3.61
Potatoes – Ziemniaków	1.88	1.88	1.88	1.88
Sugar beets – Buraków	3.61	3.61	3.61	3.61
Other crops – Innych upraw	1.30	1.30	1.30	1.30
Grasslands – Łąk	3.88	3.88	5.00	5.00
Pastures – Pastwisk	1.96	1.96	3.00	2.49
2012				
Sown area (ha), of which: Powierzchnia zasiewów (ha), w tym:	28.85	28.85	28.85	28.85
Wheat – Pszenicy	0.00	3.17	0.00	3.17
Barley – Jęczmienia	13.13	9.96	5.48	9.96
Rye – Żyta	3.61	3.61	3.61	3.61
Oats – Owsa	0.00	0.00	7.65	0.00
Triticale – Pszenżyta	2.02	2.02	2.02	2.02
Rape – Rzepaku	3.46	3.46	3.46	3.46
Potatoes – Ziemniaków	1.59	1.59	1.59	1.59
Sugar beets – Buraków	3.75	3.75	3.75	3.75
Other crops – Innych upraw	1.30	1.30	1.30	1.30
Grasslands – Łąk	3.78	3.78	5.00	5.00
Pastures – Pastwisk	1.40	1.40	3.00	1.40
Agricultural income (PLN) Dochód rolniczy (zł)	436 516.58			415 826.92
Agricultural production (PLN) Produkcja rolnicza (zł)		597 766.43		587 766.43
Organic substance amount (t) Substancja organiczna gleby (t)			4.50	2.51

* Optimization criteria (I – agricultural income, II – agricultural production, III – organic substance amount).
Source: own calculations on Matlab program.
* Kryteria optymalizacji (I – dochód z rolnictwa, II – produkcja rolnicza, III – wielkość substancji organicznej).
Źródło: obliczenia własne w programie Matlab.

The optimal solutions also included information on crops sale (exceeding nutritional needs of livestock), production materials' purchase (mineral fertilizers and concentrated mixtures) and the need for manpower.

Soil was enriched with organic substances with an average of 0.091 t per one hectare in a crop and livestock production farm, and with 0.03 t in a crop-only production farm.

The optimal solution of a crop and livestock production farm model yielded in the studied years (per one hectare): agricultural income higher by 47.83%, production value higher by 77.32% and nearly three times as much organic substances in soil than in a crop production-only farm.

CONCLUSIONS

The analysis subject was two types of Polish farms (field crops and mixed) in 2009–2012. For these types of farms, two linear-dynamic multicriteria optimization models were created. The first model referred only to crop production, the second one to livestock breeding (cattle and pigs) and crop cultivation. Crop rotation has significant influence on the production structure acquired in optimal solutions. The same crop succession was used in both models, which allowed for a comparison of results. The accepted crop rotation allowed for timely performance of agricultural treatments and good soil coverage with crops. Crop cultivation was performed in line with the rules of integrated pest management (Dz. U. L 309 of 24.11.2009, p. 71–86, Art. 14 and annex III). In a farm with livestock production, crops gained their nutrients necessary for development mainly from manure which was allocated for cultivation of potatoes sugar beet and oilseed rape (in respective doses of: 300, 350 and 200 $dt \cdot ha^{-1}$). In a farm with no livestock, organic fertilization included straw and stubble aftercrop plowing. The crops acquired in this manner are characterized by high quality.

In both models, abiding to the rules of sustainable production allowed for acquiring a positive balance of organic substance in soil (1,77 t and 2,51 t).

The agricultural income in a crop production-only farm, acquired in a multicriteria model's optimal solution amounted to an annual average of 149 178.40 PLN (70 257.61/4) which is 12 431.57 PLN per month for 3 persons. In livestock production farms, agricultural income acquired in an optimal solution amounted (587 766,43/(4×12) = 12 245.13 PLN).

Average monthly net salary (measure comparable to agricultural income) in Polish enterprise sector, according to GUS (Zgierska, 2012) in 2012 was 2563.35 PLN. Thanks to a large area of agricultural land and livestock in the surveyed farms, the agricultural income was obtained higher than net wages in the corporate sector.

Nonetheless, the number of Polish farmers dealing with livestock production is getting lower year by year. The main reasons for this abandonment of livestock production are the high quality standards and no funds for farm modernization.

The linear-dynamic multicriteria optimization models allow for checking the realization of economic, production and ecologic goals for a period of a few years in a farm upholding the sustainable development principles.

REFERENCES

Augustyńska-Grzymek, I. (Ed.) (2012). Produkcja, koszty i dochody z wybranych produktów rolniczych. Warszawa: Wyd. IERiGŻ-PIB.

Charnes, A., Cooper, W. (1961). Management Models and Industrial Applications of Lineal Programming. Nowy Jork: Wiley.

Dyrektywa Parlamentu Europejskiego i Rady 2009/128/WE z dnia 21 października 2009 r. (2009). Dz.U. L 309 z 24.11.2009, str. 71–86; art. 14 oraz załącznik III.

Fotyma, M., Mercik, S. (1992). Chemia rolna. Warszawa: Wyd. Nauk. PWN.

GUS (2009–2012). Retrieved June 10th 2015 from: http://www.stat.gov.pl/bdl/app/dane_cechter.display?p_id=515610&p_token=0.2053507342456372.

Krawiec, B. (1991). Metody optymalizacji w rolnictwie. Warszawa: PWN.

Manos, B., Chatzinikolaou, P., Kiomourtzi, F. (2013). Sustainable Optimization of Agricultural Production. APCBEE Procedia, 5, 410–415.

Polski FADN (2011–2014). Wyniki standardowe uzyskane przez indywidualne gospodarstwa rolne uczestniczące w Polskim FADN. Retrieved July 25th 2016 from: http://fadn.pl/wp-content/uploads/2013/06/SRprob_2009_SN18_-1.pdf; http://fadn.pl/wp-content/uploads/2013/06/wyniki_indywid_czesc1_opt.pdf; http://fadn.pl/wp-content/uploads/2013/06/wyniki_indywidualne_2011_czesc1.pdf; http://fadn.pl/wp-content/uploads/2014/03/Wyniki_indywidualne_2012_czesc1.pdf.

Rodríguez, S., Albornoz, V., Plà, L. (2009). A two-stage stochastic programming model for scheduling replacements in sow farms. TOP, 17/1, 171–189.

Sha-sha, L., Yan-sui, L., Hua-lou, L., Xing-liang, G. (2013). Agricultural Production Structure Optimization: A Case Study of Major Grain Producing Areas, China. J. Integr. Agric. Sci. Direct, 12(1), 184–197.

Wesonga, R. (2007). Stochastic Optimization Model Using Remote Sensing Technologies for Agricultural Management in Africa. Retrieved June 5th 2015 from: http://www.stats.gov.cn/english/icas/papers/p020071113380904847616.pdf.

Zgierska, A. (Ed.). (2012). Przeciętne zatrudnienie i wynagrodzenie w sektorze przedsiębiorstw. Retrieved June 17th 2015 from: http://www.stat.gov.pl/cps/rde/xbcr/gus/PW_zatrudnienie_wynagrodzenia_I-IV_kw_2012.pdf.

ZRÓWNOWAŻONY ROZWÓJ GOSPODARSTWA ROLNEGO W POLSCE

Streszczenie. Na podstawie danych GUS o gospodarstwach rolnych w Polsce zbudowano dwa liniowo-dynamiczne wielokryterialne modele optymalizacyjne. Pierwszy model dotyczył produkcji roślinnej, drugi produkcji roślinnej i zwierzęcej. W obu modelach funkcje celu maksymalizowały dochód rolniczy i produkcję rolniczą oraz minimalizowały straty materii organicznej w glebie. Równowaga pomiędzy tymi trzema celami jest istotą zrównoważonego rozwoju gospodarstwa rolnego. Modele rozwiązano za pomocą programowania celowego. W wyniku rozwiązania optymalnego otrzymano taką strukturę produkcji, która daje najwyższy w danych warunkach dochód rolniczy, produkcję o wysokiej jakości i nie degraduje środowiska naturalnego. Celem tego artykułu jest sprawdzenie możliwości zrealizowania równocześnie celu produkcyjnego, ekonomicznego i ekologicznego w przeciętnym gospodarstwie rolnym w Polsce na przestrzeni czterech lat.

Słowa kluczowe: zrównoważony rozwój, produkcja rolnicza, dochód rolniczy, materia organiczna gleby, wielokryterialny model optymalizacyjny

Accepted for print – Zaaakceptowano do druku: 11.07.2016