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UTILIZATION OF SUPPLY BENEFITS OF AGROECOSYSTEMS IN FARMS WITH VARIOUS PRODUCTION PROFILES

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ABSTRCT: The goal of this work is to valuate ecosystem benefits on the example of an average farm in the Zachodniopomorskie voivodship.
Based on the Central Statistical Office's data on agriculture in the Zachodniopomorskie voivodship, two multicriteria optimization models have been constructed. The first model related to a farm dealing only in plant cultivation. The second model described a farm with livestock. In both of them, production was based on the principles of sustainable development. Their extensive activity contributes to an increase in benefits of agroecosystems.

KEY WORDS: farm income, agricultural production, soil organic matter, valuation ecosystem.

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Introduction

Agriculture is a branch of national economy closely related to the natural environment.

Sustainable development of agricultural areas is aimed at maintaining continuity of ecosystem benefits (Mizgajski, Stępniewska, 2009). There are many definitions of ecosystem benefits (services), (Kronenberg, et al., 2011; Solon, 2008 ; Boyd, Banzhaf, 2007). They all relate to the benefits the society and economy draw from the environment. Hanson et al. (2008) have thoroughly characterized these benefits and broken them down into categories. Table 1 presents only the ecosystem benefits related to agriculture.

Table 1. Agroecosystem benefits

Benefit	Definition	Examples
Category: supply benefits		
Food	plants cultivated for human and animal food	grains, vegetables, fruits
	livestock for consumption and use both domestically and commercially	poultry, swine, sheep
Biological raw material	products of trees felled in crops	beams, wood pulp
	processed leather of cattle, sheep, pigs	bedspreads, clothing
Biomass as fuel	biological material of plant or animal origin as an energy source	firewood, grain ethanol
Natural medicine	medicine, food additives extracted from crops for private or commercial use	garlic, onion, herbs
Category: regulatory benefits		
Water control	they affect the time and size of outflows, the thickness of aquifers	permeable soil absorbs excess water
Erosion control	they play a role in retaining and renewing the soil	cultivation prevent loss of soil due to wind and water
Soil quality maintenance	they participate in maintaining the biological activity of soils, its productivity and diversity, in circulation of mineral and organic substances, and gasses	many organisms take part in the breakdown of crop residues, haulms
Pollination	carrying pollen, supplying food	bees pollinate crop plants and acquire food
Category: cultural benefits		
Recreation, agricultural tourism	the pleasure a person derives from rural and agricultural landscape	tours, agricultural tourism

Benefit	Definition	Examples
Ethnic, spiritual values	the meaning a person attributes to agricultural landscapes	love for the land, mood improvement
Educational values	the source of knowledge, intellectual development, cultural and artistic inspirations	school trips, folk art
Category: supporting benefits		
Habitat	semi-natural areas where populations occur	meadows and pastures are the breeding areas and food source of many organisms
Flow of elements	flow of elements (e.g. phosphorus, nitrogen, sulfur and carbon)	papilionaceous plants bind nitrogen from the atmosphere and supply it to the soil
Water circulation	the flow of water in its solid, liquid and gas state	water transfer from the soil to plants, from plants to the atmosphere, and from the atmosphere into rain

Source: based on Hanson et al., (2008).

Particular attention was given to supporting benefits in this work, as they can be expressed in measurable units. Multicriteria optimization models of farms were used for their valuation (Zaród, 2015).

The goal of this work is valuation of ecosystem benefits on the example of an average farm in the Zachodniopomorskie voivodship, where production is based on the sustainable development principles. These principles have been described by Kuś, Krasowicz (2001).

Research methodology

The main research method involves multicriteria optimization models. These models are composed of (Trzaskalik, 2000): balance conditions (limiting):

$$Ax \leq b,$$

boundary condition:

$$x \geq 0$$

and objective function (objective criterion):

$$F = \max\{F_1, F_2, ..., F_k\}$$

where:
A – technical and economic parameters' matrix,
b – limits vector (absolute terms),
x – vector of decision variables.

Technical and economical parameters in a farm model are composed by: sowing structure, crop rotation, crop yields, livestock's nutritional requirements, fertilization, demand for service hours in growing certain types of plants and animals. Decision variables are: acreage of cultivated plants, permanent grassland area, animals of appropriate classes and species, sale of agricultural products, purchase of production means and feed. The limitations (absolute terms), in turn, include the sown area, farm meadows and pastures' area, the amount of livestock of appropriate classes and species, the number of people employed at the farm.

The work takes three objective criteria into account.

F_1 objective criterion concerns gross agricultural income and is expressed by a formula:

$$F_1 = c^T x \to \max$$

where:

c – vector of individual income for variables indicating inventory activities or individual expenses incurred in case of non-inventory activities.

F_2 objective function, for maximization of agricultural production, is expressed as:

$$F_2 = g^T x \to \max$$

where:

g – vector of individual efficiency of plant and livestock production.

F_3 is an objective criterion which maximizes the amount of organic substance in the soil:

$$F_3 = p^T x \to \max$$

where:

p – vector of individual coefficients of soil reproduction or degradation.

Goal programming has been used to solve the multicriteria model (Szapiro, 2000). It entails solving the model, separately for every criterion, by use of linear programming. After acquiring optimal results, each objective function is treated as another limiting condition of the model in the form of:

$$c^T x = dr$$
$$g^T x = pr$$
$$p^T x = so$$

where:

dr – the highest value of agricultural income acquired in the single-criterion model solution, *pr* – the optimal amount of agricultural production acquired in the single-criterion model solution,

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

There is restrictive limitation of quality type which has to be weakened in all three additional conditions. Full weakening of equality is a conversion in which there are variables of deficiency *(u^-)* or excess *(u^+)*. These variables convey the amounts the objective function values acquired in single-criterion models should be decreased or increased by. After conversion, added limiting (elastic) condition assume the form of:

$$c^T x - u^+_1 + u^-_1 = dr$$
$$g^T x - u^+_2 + u^-_2 = pr$$
$$p^T x - u^+_3 + u^-_3 = so$$

Then, many criteria are replaced with a single distance function describing the costs (penalties) of deviations from the target values:

$$F = u^+_1 + u^-_1 + u^+_2 + u^-_2 + u^+_3 + u^-_3 \rightarrow \min$$

This function includes both the variables concerning excess or deficiency of agricultural income and production, as there are no particular recommendations as to the way they are acquired. In turn, deficiency of organic substance in the soil should be minimized so as not to degrade the natural environment.

Construction of multicriteria models for an average farm in the Zachodniopomorskie voivodship

Based on the Central Statistical Office's (Ziółkowska, 2014) data, two multicriteria optimization models have been constructed. One of them described an average farm in the Zachodniopomorskie voivodship in 2014 dealing solely in plant production. The other related to mixed production of plants and livestock. Table 2 presents basic information on such a farm.

The acquired data constituted technical and economic parameters and absolute terms of the models, as well as served as a way to estimate coefficients for the first and second objective criterion.

In the plant-profile model, agricultural income acquired from individual crops was calculated by subtracting production costs, decreased by direct grants, from production value (yields x price). In case of livestock production – plants intended for fodder were burdened in the objective function with cultivation costs decreased by grants. Income was generated by: livestock for sale, milk production, industrial crops and surplus agricultural products above the nutritional needs of livestock. The costs of cultivation and livestock husbandry were estimated based on studies by the Zachodniopomorskie Agricultural Advisory Centre (ZODR, 2014).

Table 2. Selected data on an average farm in the Zachodniopomorskie voivodship in 2014

Specification	Values
Agricultural land area (ha)	30,29
Sown area (ha)	22,76
Grasslands area (ha)	4,67
Pastures area (ha)	0,84
Structure of sown (%) of which:	100
cereals	61,7
industrial crops	21,0
feed crops	9,3
potatoes	1,3
pulses crops	4,3
other crops	2,4
Yields (dt × ha−1):	
cereals	51,4
rape	37,5
sugar beets	726
potatoes	309
grasslands	42,6
pastures	184
Procurement prices (PLN × dt−1):	
cereal grains	64,05
rape	130,21
sugar beets	12,25
potatoes	31,22
pork for slaughter (PLN × kg−1)	5,01
beef for slaughter (PLN × kg−1)	5,94
milk (PLN × l−1)	1,44
Cows (heads)	4
Sows (heads)	2
Consumption of mineral fertilizers per 1ha of agricultural land (kg)	117,3

Source: based on the Central Statistical Office's data

Parameters of the second objective criterion constituted inventory production. In the model of a farm dealing only in plant cultivation, it was crop yields. In turn, in the plant-livestock profile model, acquired inventory production was expressed in monetary units. Because the amount of sold agricultural products (in dt) is expressed in other units than the amount of sold milk (in l) or livestock (in kg).

Coefficients of soil organic substance's reproduction and degradation by Eich and Kindler (Fotyma, Metcik, 1992) were used to determine the third objective function's parameters. These coefficients describe the degree of soil impoverishment or enrichment with organic substance (in $t \cdot ha^{-1}$) for cultivation of a particular plant type or utilization of a specific amount of organic fertilizer.

In order to reproduce processes occurring within a farm as closely as possible, a number of balances ensuring internal consistency have been included in the models. Among others, crop rotation balances ensure good coverage of soils with vegetation and timely completion of agricultural treatments. Yields of fodder plants covered the livestock's need for fodder (Kowalak, 2004). Plowed intermediate stubble crops and straw replenished the losses of organic substance in the soil of a plant-profiled farm. Manure acquired from livestock provided natural fertilization of root crops. The needed amount of working hours for growing plants and husbandry of certain livestock species (Kowalak, 1992) has been balanced with the existing amount of farm labor force.

Optimal solutions for farm models

The result of solving the multicriteria model of a farm dealing only in plant cultivation includes: the area of individual crops, the value of agricultural income, the amount of inventory production and the amount of organic substance provided to the soil. Additionally, solution of the model related to livestock production provided information on the amount of grown livestock (by species and class), the amount of sold agricultural products (surplus over the nutritional needs of livestock) and purchased concentrated fodder. The acquired production volume in this model has been expressed in monetary units. Basic optimal solution results of multicriteria models are included in table 3.

The values of objective criteria acquired in optimal solutions are the valuation of supply benefits of an agroecosystem. The farm achieved these objectives based on the principles of sustainable development. Extensive production in this farm did not allow for agricultural income and production value comparable to the FADN (FADN, 2016) results. Farmers can compensate for these losses by participation in agri-environmental programs. Acquired agricultural income in the livestock-producing farm is by 31,23% higher than in the one dealing only in plant cultivation.

Table 3. Optimal solutions of a farm's multicriteria models

Specification	Model with production of:	
	plants	livestock
Sown area (ha)	22,76 ha	22,76 ha
Wheat	3,51 ha	3,51 ha
Barley	2,18 ha	2,18 ha
Rye	5,39 ha	4,48 ha
Oats	1,36 ha	2,27 ha
Triticale	1,59 ha	1,59 ha
Rape	4,10 ha	4,10 ha
potatoesPotatoes	1,14 ha	1,14 ha
Sugar beets	3,19 ha	1,88 ha
Feed beets	-	0,40 ha
Other crops	0,30 ha	1,21 ha
Stubble catch crop	5,39 ha	-
Grasslands area	-	2,30 ha
Pastures area	-	0,84 ha
Cows	-	4 heads
Calves	-	3,92 heads
Young beef cattle	-	3,14 heads
Sows	-	2 heads
Piglets	-	32 heads
Pigs for fattening	-	31 heads
Grain sales	671,59 dt	528,12 dt
Potato sales	352,26 dt	339,64 dt
Sugar beet sales	2315,94 dt	1364,88 dt
Concentrated fodder purchase	-	29,72 dt
Straw for plowing	938,48	455,93 dt
Agricultural income	74724,76 PLN	98063,79 PLN
Agricultural production	3619,49 dt	139655,89 PLN
Organic substance in the soil	6,96 t	0,98 t

The sown area of individual crops in a plant-profile farm resulted from the assumed crop rotation (beets, potatoes, oats; wheat, barley; triticale, canola; rye, other crops) and its profitability. At a farm with livestock, it additionally resulted from the nutritional needs of livestock. The fractional amounts of livestock shows that any individual animal did not spend an entire year at the farm.

For comparative purposes, the agricultural production (361,95 tons) acquired from the plant-only model's solution was converted into monetary units. The value of that production amounted to 104019,48 PLN and was by 25,52% lower than the value of inventory production achieved in the livestock model.

Positive balance of organic substances in the farm's soil in both solutions (6,96t and 0,98t) demonstrates lack of degradation of the natural environment. A negative balance of organic matter could cause soil degradation, loss of fertility and productivity. The main source of organic substances supplied to the soil in the plant-profile farm was rape and grain straw and stubble crop. In the farm with livestock, fertilization with manure was supplemented with plowed straw.

There are also actions consolidating the volume of organic substance. They include protective soil cultivation. It incorporates the principle]: "as many cultivation treatments as necessary, as few as possible" (Duer et al., 2004, p. 47).

Too high amount of organic matter supplied to the soil is not desirable, either. It may cause pollution of groundwater and surface water with biogens.

In the analysis, supplied 0,31t/ha (6,96t/22,76 ha) of organic substance in a plant-profile farm and 0,04t/ha (0,98t/22,76 ha) in a farm with livestock will not cause pollution of water.

Acquired supply benefits do not conclude the list of agroecosystem services provided in farms with sustainable development. There are also regulatory benefits, i.e.:

- good coverage of soils with vegetation, cultivation of winter crops, use of catch crop prevents soil erosion (Smagacz, 2000);
- plowing of stubble catch crop, manure, straw and crop residues contributes to the upkeep of high quality soils [16];
- loosened soils better regulate the flow of water;
- fields of rape and other crop plants lure swarms of bees (pollinators) during the flowering period, and the collected nectar and pollen is their food (Pernal, Currie, 2000; Lenda et al., 2010).

There are also supporting benefits in farms with sustainable development, e.g.:

- meadows and pastures are areas of reproduction, development and feeding for many organisms, they are characterized by high biodiversity of flora and fauna (Kuszewska, Fenyk, 2010);
- the symbiosis of papilionaceous plants and rhizobia contributes to the nitrogen cycle in nature (Wielbro, 2003).

In turn, an example of cultural benefits can be chirping of crickets (aesthetic experience) or gathering of storks on meadows and pastures before they fly away. Storks are very closely related to Polish tradition, folk culture, art and rituals (Dolata, 2006).

Conclusions

1. Agricultural income and the value of agricultural production in a farm with sustainable development are lower than the FADN results due to extensive activity. Farmers can compensate for these losses by participation in agri-environmental programs.
2. Positive balance of organic substances in the soil of analyzed farms demonstrates lack of degradation of the natural environment.
3. Regulatory services provided by farms with sustainable development contribute to the upkeep of soil and air quality.
4. Biodiversity of meadows and pastures creates conditions for reproduction and growth of many organisms.
5. Cultural benefits of agroecosystems provide ethical and educational values.

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