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Agri-environmental aspects of the activity of farms with different production profiles

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Abstract. The results of own research and literature data indicate that the specialization (different production profiles) of farms may contribute to specific threats to the natural environment. Each type of farm exerts pressure on the environment to a greater or lesser extent, which was confirmed by agri-environmental indicators. Accordingly to literature data the greatest threat to the environment (water pollution) pose pig farms due to the high stocking density that contributes to unfavorable (excessive) balances of minerals and soil organic matter. Large positive balances indicate the potential losses of these components, mainly due to their leaching to groundwater and surface waters, and consequently to their pollution (eutrophication). On the other hand, farms with field crops had high risk of decrease in soil fertility due to negative balances of nutrients. The smallest threat to the natural environment and soil fertility were observed for farms with a mixed plant-animal production as well as cattle farms specializing in milk production (with optimal livestock density of about 1 DJP ha^{-1}). Under certain conditions, cattle farms may have too high balances of soil organic matter, and at the same time negative balances of NPK minerals.

Key words: environmental indicators, directions of farm production, effects of specialization, sustainable development

INTRODUCTION

In Poland, special responsibility for environmental protection is assigned to agriculture, which uses about 60% of the total area of the country, and through its production activity causes changes in the properties of water, soil, and air, and contributes to biodiversity transformation in the rural landscape (Duer et al., 2004).

In Poland occurs a clear trend towards the specialisation of farms (Witkowski, 2003; Łączyński, 2012, 2014, 2017; Ziętara, 2014). In 2002, the share of farms specialised in specific agricultural types (separated according to the FADN typology) was 56.3% (Ziętara, 2014), and in the following years, it increased, respectively: 2010 – 62.0%, 2013 – 69.4% and 2016 – 75.7% (Łączyński, 2012, 2014, 2017). Specialisation implies a clear orientation of an agricultural holding towards one branch or activity, and its level is defined by the gross final or gross commodity production structure (Klepacki, 1997). In Polish conditions, a specialisation (unidirectional) farm is considered to be one in which the share of one branch constitutes over 40% in the final production structure and in other units less than 30%. The direction of production (specialisation) comes from the branch that dominates in a given holding. Specialisation aims to improve farming efficiency and gain a competitive advantage through higher productivity or lower production costs, or higher quality products. A prerequisite for specialisation success is correctly adjusting the production to habitat factors and the economic and organisational conditions of the farms and the region. Each type of specialised agricultural holdings is characterised by a certain peculiarity and impact on the natural environment. Specialisation may result in at least two negative features, i.e., increase the risk of farming (decrease in income) or increase the environmental threat (Józwiak, Juźwiak, 2007; Kuś, 2012, 2013a). In recent years, an important issue is the risks generated by agriculture, mainly related to the emission of greenhouse gases such as nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2); (Faber, Jarosz, 2017, 2020).

The study's objective was to determine the impact of farms with different production directions on selected agri-environmental indicators.

MATERIALS AND METHODS

The source material consisted of the research results from 2011–2020, conducted in 7 Agricultural Experimental Stations of IUNG-PIB, and literature data. Farms were

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Table 1. Reference values of indicators useful for assessing the impact of farms on the environment

Assessment indicators	Reference values	Unfavorable values
Diversity of field crops [number of species]	≥ 4	≤ 2
Share of cereals in sown area [% AL]	≤ 50	> 75
Intensity of plant protection [number of measures]	≤ 3	≥ 8
Livestock density [LU/ha UAA]	0.5–1,5	> 2
Balance of mineral elements [kg/ha UAA]:		
N	0–50	debit balance or > 50
P_2O_5	0–25	debit balance or > 25
K_2O	0–50	debit balance or > 50
Balance of organic matter [t DM/ha AL]	0–0.5	debit balance or > 0.5

grouped according to specialisation (cattle, mixed, plant), i.e., the leading production direction. In the structure of gross commodity production of cattle and plant holdings, the main branch of production was over 40%, while mixed holdings were bi-directional with plant and animal production.

The evaluation of farms' environmental impact was carried out on the basis of 8 agri-environmental indicators with defined reference values and unfavourable values for the natural environment (Table 1). The means for determining the values of individual indicators were adopted according to the methodology developed by Harasim (2014). The selection of agri-environmental indicators depended on the availability of data. Correlations between nutrient balances and cereal grain yield, and cereal share in sowings were also studied. A comparative and descriptive method was used to interpret the results of the study.

RESULTS

The attributes of the farms did not show significant changes during the study period, so their characteristics are presented as average values from 2011–2020. Individual farm types differed in terms of the area, structure of agricultural land, soil quality and agro-meteorological conditions (Table 2). The largest area (over 400 ha UAA) was distinguished by three farms: cattle (B) and crop (E, G). The cattle farm (B), oriented towards milk production, was characterised by a particularly large share of permanent grassland (48.7% of arable land). Among the investigated farms, three are located on heavy soils (B, D and G), two on medium soils (A, F) and two on light soils (C, E). In terms of total precipitation during the growing season, unfavourable conditions (drought) prevailed in the area of the plant farm location (F), as well as in areas with light soils (farms C, E). The thermal factor was fairly even (14.9–15.5°C), except for farm G with the lowest air temperature (14.1°C). The location of the crop farms (E, F and G) suffered the highest water deficits (more than 220 mm) and the growing season was very dry. Elsewhere, the growing season was dry, with only farm C with mixed production profile – fairly dry. The climatic water balance is considered one of the more common indicators for assessing water deficit or surplus for a given period (Doroszewski et al., 2014; Wierzbicka, 2014).

In the 5-year sub-periods (2011–2015 and 2016–2020), the variability of agro-ecological indicators related to species diversity, share of cereals in sowings, plant protection intensity and animal density in individual farms was relatively low (Table 3).

Table 2. Characteristic of the studied agricultural farms (means from 2011–2020).

Specification	Farm type						
	cattle		mixed		crops		
	A	B	C	D	E	F	G
Area of farm [ha]:							
agricultural land [UAA]	139	476	362	228	401	221	558
arable land [AL]	113	244	341	212	327	158	532
permanent grasslands [PG]	26	232	21	16	74	63	26
Share of PG [% UAA]	18.7	48.7	5.8	7.0	18.5	28.5	4.7
Soil category	medium	heavy	light	heavy	light	medium	heavy
Amount of precipitation [mm]#	254	247	220	264	215	184	230
Average daily air temperature [°C]#	15.2	15.4	15.1	15.5	14.9	15.3	14.1
Climatic water balance [mm]#	-178	-199	-124	-152	-221	-245	-227

means from 2012–2020 in growing season (April–July)

Table 3. Agro-environmental indicators of farms in period 2011–2020.

Indicators	Years	Farm type						
		cattle		mixed		crops		
		A	B	C	D	E	F	G
Number of plant species in sown area	2011–2015	9.2	7.4	5.4	5.0	7.4	4.6	7.2
	2016–2020	9.6	9.4	4.8	4.6	7.8	4.2	8.4
	2011–2020	9.4	8.4	5.1	4.8	7.6	4.4	7.8
Share of cereals in sown area [% AL]	2011–2015	55	32	90	57	70	65	67
	2016–2020	60	36	81	61	73	63	72
	2011–2020	57	34	86	59	72	64	70
Number of plant protection measures	2011–2015	1.3	4.7	1.7	4.8	4.9	6.1	4.5
	2016–2020	2.2	5.8	1.8	4.0	4.4	7.9	4.7
	2011–2020	1.8	5.2	1.7	4.4	4.7	7.0	4.6
Livestock density [LU/ha UAA]	2011–2015	0.81	1.07	0.26	0.08	-	-	-
	2016–2020	0.80	0.98	0.19	0.09	-	-	-
	2011–2020	0.80	1.02	0.23	0.09	-	-	-
Balance of mineral elements [kg/ha UAA]:								
N	2011–2015	-21.4	-41.9	35.1	37.1	48.6	31.8	54.8
	2016–2020	-0.9	-19.5	45.6	70.5	51.4	42.9	75.2
	2011–2020	-11.2	-30.7	40.3	53.8	50.0	37.4	65.0
P_2O_5	2011–2015	8.5	-17.6	8.4	2.0	15.7	-10.8	-25.3
	2016–2020	18.0	-6.7	4.1	22.2	-0.1	-15.2	0.7
	2011–2020	14.5	-12.2	6.6	12.1	7.8	-13.0	-12.3
K_2O	2011–2015	-25.2	-76.7	31.7	-12.0	43.3	-8.0	-12.3
	2016–2020	10.4	-36.0	32.8	7.6	58.1	-15.5	45.0
	2011–2020	-7.4	-56.4	32.2	-2.2	50.7	-11.7	13.6
Balance of organic matter [t DM/ha AL]	2011–2015	0.53	0.65	0.03	0.14	0.30	0.20	0.04
	2016–2020	0.66	0.61	0.17	0.24	0.06	0.19	0.47
	2011–2020	0.60	0.63	0.10	0.19	0.16	0.20	0.26

A greater number of plant species in the crops of cattle farms (A, B) is associated with the need to produce fodder on arable land (Table 3). The natural fodder base (meadows, pastures) was most often supplemented by growing maize for silage and legume-grass mixtures (lucerne or red clover with grasses). The structure of sowings in agricultural holdings of IUNG-PIB was generally characterised by the correct species diversity of plants grown on arable land (Table 3). According to the principles of good agricultural practice, a rational crop rotation should include 3–4 plant species on light soils and 4–5 species on heavier soils (Duer et al., 2004). Across the surveyed farms, an average of 4–10 plant species were present in the crops. The highest diversity of cultivated plants was found in cattle holdings (A, B). Moreover, diversity plays an important role in maintaining a good level of agroecosystem productivity, soil fertility and plants' soil-protective function. On the other hand, specialisation, concentration and intensification of agricultural production (plant and animal) limit the number of plant species cultivated on arable land, leading in many cases to monoculture crops and monotony of the landscape (Koc et al., 1994; Kęsik, 2008; Feledyn- Szewczyk, 2014; Matyka, 2017).

Along with the sowing structure, the structure of agricultural land is also an essential element of rural biodiversity (Pajewski, 2017). A favourable share of cereals in sowings occurred in single-crop farms with dairy cattle rearing (A, B), while in planted and mixed farms cereals were the dominant plant group in sowings (Table 3). A particularly large share of cereals (86% of sown area) was characteristic of the mixed-profile farm C, operating on light soils. Also, many cereals (64–72%) were grown in the crop farms (E, F and G).

In the sustainable agriculture system, an urgent role is attributed to reducing the use of chemical plant protection products by taking into account the thresholds of pests' harmfulness and reducing pesticide doses, as well as combining different plant protection (Pruszyński, Mrówczyński, 2002). The number of treatments performed is considered a reliable indicator of the intensity of chemical plant protection (Mierzejewska, 1998; Fotyma, Kuś, 2000; Harasim, 2019). In farm A focused on production by organic methods, and in farm C with a mixed production profile on light soils, less than two treatments were performed per 1 ha of sown arable land (Table 3). In the remaining agricultural holdings, the intensity of chemical plant protection was higher (4–8 treatments), mainly due to a considerable share of sugar beet and winter rape in crops. Similar patterns were also found in other studies (Harasim, 2019). Cattle farms with permanent grassland and fodder crops for animal feed are generally characterised by low chemical plant protection intensity (Harasim, 2019). An evaluation of regional variation in sowing structure shows that, nationally, the three voivodeships: Opolskie, Dolnośląskie and Podlaskie were distinguished by the least favourable sowing structure (Matyka, 2017). In the case of Podlaskie voivodeship, the low diversity and uniformity of the sowing structure result from its adaptation to the concentration of breeding dairy cows.

Farms focused on dairy cattle rearing (A, B) were significantly more stocked with animals than farms engaged in mixed production. According to Baum (2011), a livestock density in the range of 0.5–1.5 LU ha^{-1} is appropriate for proper management. Following the Code of good agricultural practice, the recommended livestock density in a holding should not exceed 1.5 LU ha^{-1} (Duer et al., 2004). An excessive stocking density entails specific threats to the environment or the necessity of surplus natural fertilisers (manure, slurry) disposing outside the holding.

Fertiliser balances are critical determinants for assessing the environmental responsibility of agriculture (Wrzaszcz, Kopiński, 2019). At the farm level, determining fertilizer nutrient balances is important as indicators to evaluate their potential environmental risk. A sizeable positive balance may indicate potential losses of components, mainly through movement to ground and surface waters, and cause their pollution (eutrophication). On the other hand, a negative balance indicates insufficient doses of fertilisers to the plants' nutritional needs, contributing to the degradation of soil fertility due to the depletion of nutrient reserves. Unfavourable negative balances of fertilisation components (N, P, K) were generally found in farm with dairy cattle rearing (B), as well as concerning phosphorus and potassium in two plant holdings (F, G) and potassium in the farm D with mixed production profile (Table 3). In farm A (organic production), the level of phosphorus and potassium fertilisation on arable land was reduced, and insufficient doses of mineral fertilisers were applied to permanent grassland. Farm B, on the other hand, with a fairly high dairy cattle density and about 50% share of permanent grassland in the arable area, relied on natural fertilisation. Under the high soil nutrient content, mineral fertilisation was quite severely reduced, which resulted in a very unfavourable negative NPK balance. Similarly, other studies have shown that a reduction in the intensity of mineral fertilisation occurs in farms with a high share of permanent grassland (Harasim, Madej, 2008). The fact that farms without animal production (F, G) located on better quality soils hardly achieving positive phosphorus and potassium balances is also confirmed by the results of an earlier study (Harasim, 2012). Farm C, operating on light soils, exhibited quite correct (positive) balances of fertilizer components. In the case of mineral nutrient balances, there were significant differences in the values of these indices in the 5-year sub-periods (Table 3). In 2016–2020 and the whole research period 2011–2020, in two farms: mixed farm D and crop farm G, the nitrogen balance exceeded the reference value of 50 kg N ha^{-1} (Table 1).

In the fertilizer management of individual farms in Poland, increasing consumption of nitrogen is observed in relation to the other fertilizer macronutrients, i.e., phosphorus and potassium (Wrzaszcz, Kopiński, 2019). In the above situation, the deepening of unfavourable relations between macronutrients (N, P, K) indicates a limitation of plant productivity and increased environmental threats from unused nitrogen. In the case of very low balances of essential nutrients, fertilizer management in Poland, under the crop farms conditions (without inventories), generates environmental pressure by reducing soil resources of the remaining macronutrients (Wrzaszcz, Kopiński, 2019).

The results of the study indicate (Table 4) that there was a high correlation (r = 0.71) between N and K_2O balances and, to a significant extent (r = 0.58) also between P_2O_5 and K_2O balances in 2011–2020 in the total number of farms. A medium correlation (r = 0.42) was shown between N and P_2O_5 balances. Moreover, it was found that the N and K_2O balances were significantly influenced (r = 0.55 and 0.65) by the share of cereals in the sowing; an increased percentage of cereals contributed to an increase in the value of NPK mineral nutrient balances. On the other hand, there was an average negative correlation (r = -0.33) between the yield of grain of cereals (x_1) and cereal share in crops (x_2), as well as a negative correlation between the yield of grain cereals and the balances of P_2O_5 and K_2O (r = -0.29 and -0.25, respectively). Cereal share in sowing (x_2) interacted significantly with mineral nutrient (NPK) balances; (Table 4). It can be concluded that for small cereal grain yields under drought conditions, with a reasonably stable level of mineral fertilisation, there is an increase in mineral nutrient (NPK) balances. Cereals under such conditions did not fully take up the components applied in fertilizers, increasing N balances in mixed and plant farms (Table 3).

Table 4. Correlation between mineral components balances Y_1 – N, Y_2 – P_2O_5, Y_3 – K_2O) and cereal yields (x_1) and cereal share in rotation (x_2); (n = 70)

Variable	Y_1	Y_2	Y_3	x_1	x_2
Y_1	1.00	0.42*	0.71*	0.09	0.55*
Y_2	0.42*	1.00	0.58*	-0.29*	0.24*
Y_3	0.71*	0.58*	1.00	-0.25*	0.65*
x_1	0.09	-0.29*	-0.25*	1.00	-0.33*
x_2	0.55*	0.24*	0.65*	-0.33*	1.00

* correlation significant at α = 0.05

The balance of soil organic matter, taking into account the structure of sowings and the use of natural and organic fertilisers, complements the assessment of the agri-environmental sustainability of farms. The correct management of organic matter, apart from maintaining soil fertility, is essential in protecting the environment and limiting the greenhouse effect (Kuś, Kopiński, 2012). A decrease of OM content in the soil (degradation) enhances the emission of greenhouse gases, whereas an increase of OM content in the soil (sequestration) contributes to limiting the GHG effect. In agricultural practice, one should aim to maintain a positive balance of soil organic matter. All the farms studied had a positive organic matter balance (Table 3). However, positive organic matter balances above 0.50 t DM ha^{-1} (i.e., 300 kg Corg. ha^{-1}) pose a potential risk of groundwater and surface water contamination with nitrogen and phosphorus compounds (Körschens, 2004). According to the criterion, cattle farms (A, B) posed a threat to the environment. Thus, mainly due to unfavourable balances (excess or deficiency) of mineral nutrients (NPK), individual farm types posed specific dangers to the natural environment. The most unbalanced mineral nutrient and soil organic matter balances were found in cattle farms focused on milk production.

Many authors studies' also reveal the farm specialisation (direction of production) has a tremendous environmental impact:

– plant-oriented farms focused on arable crops pose a risk of decreasing soil fertility and biological activity (Kuś, 2013b);

– farms with a mixed plant-animal production direction present a low threat to the environment and soil fertility (Kuś, 2013b; Ulén et al., 2013);

– pig farms are generally exhibiting high animal stocking rates and significant positive fertiliser nutrients (NPK) balances, posing a risk of groundwater and surface water pollution by these nutrients (Pietrzak et al., 1997; Kupiec et al., 2010; Kuś, 2013b; Ulén et al., 2013);

– cattle farms specialising in milk production, with a stocking rate of about 1.0 LU ha^{-1}, do not pose a threat to the environment with excess NPK components, yet in our study, they were characterised by too high soil organic matter balances (Table 3).

Therefore, it may be concluded that arable farms with field crops and multidirectional farms exert much less pressure on the environment than farms specialising in livestock production.

CONCLUSIONS

1. Farms' specialisation in different production directions may contribute to specific threats to the natural environment, as each type of farm exerts pressure on the environment to a greater or lesser extent.

2. Pig farms pose the most severe environmental hazard due to the high livestock density, which contributes to unfavourable (excessive) balances of mineral nutrients and soil organic matter.

3. Large positive balances of nitrogen indicate the potential loss of this nutrient, mainly through leaching to groundwater and surface water and subsequent pollution (eutrophication).

4. Arable farms with field crops pose a risk of reducing soil fertility due to negative nutrient balances.

5. Farms with mixed plant and animal production and cattle farms specialising in milk production under conditions of optimal livestock density (about 1 LU ha^{-1}) cause the lowest threat to the natural environment and soil fertility.

6. Cattle farms under certain conditions (low mineral fertilization levels with a predominance of manure and slurry) can have excessive soil organic matter balances and negative NPK mineral nutrients balances.

REFERENCES

Baum R., 2011. Ocena zrównoważonego rozwoju w rolnictwie (studium metodyczne). Uniwersytet Przyrodniczy w Poznaniu, 234, 258 pp.

Doroszewski A., Jóźwicki T., Wróblewska E., Kozyra J., 2014. Susza rolnicza w Polsce w latach 1961-2010. IUNG- PIB Puławy, 144 pp.

Duer I., Fotyma M., Madej A. (ed.)**, 2004.** Kodeks dobrej praktyki rolniczej. FAPA Warszawa, 93 pp.

Faber A., Jarosz Z., 2020. Czy rolnictwo może być zeroemisyjne pod względem gazów cieplarnianych? Studia i Raporty IUNG-PIB, 62(16): 233-342.

Faber A., Jarosz Z., 2017. Potencjały redukcji emisji gazów cieplarnianych w polskim rolnictwie w świetle literatury. Studia i Raporty IUNG-PIB, 52(6): 45-56.

Feledyn-Szewczyk B., 2014. Bioróżnorodność roślin jako element zrównoważonego rozwoju rolnictwa. Studia i Raporty IUNG- PIB, 40(14): 163-177.

Fotyma M., Kuś J., 2000. Sustainable development of the farm. Pamiętnik Puławski, 120(I): 101-116. (in Polish + summary in English)

Harasim A., 2012. Crop production on arable lands: a long term single-farm case study. IUNG- PIB Puławy. Monografie i Rozprawy Naukowe, 34, 61 pp. (in Polish + summary in English)

Harasim A., 2014. Przewodnik do oceny zrównoważenia rolnictwa na różnych poziomach zarządzania. IUNG-PIB Puławy, 91 pp.

Harasim A., 2019. Plant protection intensity in various types of farms. Polish Journal of Agronomy, 39: 3-9, doi: 10.26114/pja.iung.402.2019.39.01. (in Polish + summary in English)

Harasim A., Madej A., 2008. Evaluation of sustainable development of cattle farms with varied percentage of grasslands. Roczniki Nauk Rolniczych, Seria G, 95(2): 28-38. (in Polish + summary in English)

Jóźwiak W., Juźwiak J., 2007. Rolnictwo wielostronne czy wyspecjalizowane? Wieś i Rolnictwo, 4: 9-20.

Kęsik T., 2008. Cropping pattern and its influence on agricultural ecosystem. Zeszyty Problemowe Postępów Nauk Rolniczych, 527: 39-50.

Klepacki B., 1997. Wybrane pojęcia z zakresu organizacji produkcji i pracy w rolnictwie. SGGW Warszawa, 148 pp.

Koc J., Brodziński Z., Gotkiewicz W., 1994. Wpływ agrotechnologii na bioróżnorodność. pp. 141-150. In: Doradztwo w ekorozwoju obszarów wiejskich; eds. A. Mickiewicz and A. Lewczuk. Akademia Rolnicza Szczecin.

Körschens M. (red.)**, 2004.** Humusbilanzierung. Methode zur Beurteilung und Bemessung der Humusversorgung von Ackerland. Standpunkt VDELUFA, Bonn.

Kupiec J., Zbierska J., Woźniak A., Paluszkiewicz-Flak H., 2010. Nitrogen management of Opolskie voivodship in development farms. Fragmenta Agronomica, 27 (4): 76-85. (in Polish + summary in English)

Kuś J., 2012. Specialization in agriculture as factor increasing risk in the agricultural production and ways of preventing risk. Zagadnienia Doradztwa Rolniczego, 1: 33-50. (in Polish + summary in English)

Kuś J., 2013a. Specjalizacja gospodarstw rolnych a zrównoważony rozwój rolnictwa. pp. 95-127. In: Z badań nad rolnictwem społecznie zrównoważonym (19); ed. J.S. Zegar, IERiGŻ-PIB Warszawa.

Kuś J., 2013b. Specjalizacja gospodarstw rolnych i jej konsekwencje produkcyjne, ekonomiczne i siedliskowe. Studia i Raporty IUNG-PIB, 32(6): 167-185.

Kuś J., Kopiński J., 2012. The soil organic matter management in the contemporary agriculture. Zagadnienia Doradztwa Rolniczego, 2: 5-27.

Łączyński A. (ed.)**, 2012.** Charakterystyka gospodarstw rolnych. PSR 2010. GUS Warszawa, 467 pp.

Łączyński A. (ed.)**, 2014.** Charakterystyka gospodarstw rolnych w 2013 r. GUS Warszawa, 449 pp.

Łączyński A. (ed.)**, 2017.** Charakterystyka gospodarstw rolnych w 2016 r. GUS Warszawa, 389 pp.

Matyka M., 2017. Evaluation of regional diversification in sown area structure in the context of impact on the natural environment. Roczniki Naukowe SERiA, 19(3): 188-192. (in Polish + summary in English)

Mierzejewska W., 1998. Mierniki intensywności chemicznej ochrony roślin. Ochrona Roślin, 9: 8-13.

Pajewski T., 2017. Structure of agricultural land as an agricultural component of biodiversity. Roczniki Naukowe SERiA, 19(2): 182-187, doi: 10.5604/01.3001.0010.1186. (in Polish + summary in English)

Pietrzak S., Sapek A., Michalski W., Perka J., Rybka U., 1997. Nitrogen balance in the farm as object agricultural education. Zeszyty Edukacyjne IMUZ, 4: 57-61. (in Polish + summary in English)

Pruszyński S., Mrówczyński M. (ed.)**, 2002.** Łączne stosowanie agrochemikaliów. IOR Poznań, 174 pp.

Ulén B., Pietrzak S., Tonderski K.S. (ed.)**, 2013.** Samoocena gospodarstw w zakresie zarządzania składnikami nawozowymi i oceny warunków środowiskowych. IT-P Falenty, 99 pp., ISBN 978-83-62416-67-7.

Wierzbicka A., 2014. Changes in climatic water balance for the potato growing season of north Mazovia region in the years 1973–2012. Zeszyty Problemowe Postępów Nauk Rolniczych, 576: 207-215. (in Polish + summary in English)

Witkowski J. (ed.)**, 2003.** Systematyka i charakterystyka gospodarstw rolnych. PSR 2002. GUS Warszawa, 307 pp.

Wrzaszcz W., Kopiński J., 2019. Gospodarka nawozowa w Polsce w kontekście zrównoważonego rozwoju rolnictwa. Studia i Monografie, IERiGŻ- PIB Warszawa, 178, 145 pp., ISBN 978-83-7658-806-3.

Ziętara W., 2014. Concentration and specialisation of agricultural holdings in the process of European Union integration. Zeszyty Naukowe SGGW. Problemy Rolnictwa Światowego, 14(1): 157-169. (in Polish + summary in English)

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