European Research Studies Journal
Volume XXII, Issue 4, 2019

pp. 3-14

The Area of Farms and their Influence on Generating Negative Externalities

Submitted 21/06/19, 1st revision 14/07/19, 2nd revision 30/08/19, accepted 25/10/19

Tomasz Pajewski[1], Barbara Gołębiewska[2], Agnieszka Sobolewska[3]

Abstract:

Purpose: *The aim of the research is to identify and assess the negative external effects of agricultural activity and determine whether their level is dependent on the size of farms, agricultural area expressed, in spatial terms in Poland.*
Design/Methodology/Approach: *The time range of the collected research material covered the years 2008-2015. A synthetic measure of the assessment was used, which enabled ranking the studied regions in terms of the indicator of agri-environmental externalities. In order to verify the accepted hypothesis, an econometric model explaining the relationship between the emerging environmental effects and the surface of farms is proposed. The collected empirical material aggregated in the panel form is used to build the model.*
Findings: *The results indicate significant differences in the generation of negative environmental effects between regions in Poland. It is also found that there is a relationship between the size of agricultural area on farms and the level of negative agri-environmental externalities.*
Practical Implications: *The results obtained may be used for development of the agricultural policy, aimed at agricultural companies, depending on their size, expressed as the area of arable land.*
Originality/Value: *The results are original due to the possibility of being used in any country (region). They enable identification of environmental threats caused by agricultural production, depending on farm agricultural enterprise size. They may be used for development of prospective scenarios for agricultural policy.*

Keywords: *Agriculture farm, environment, externalities, surface area of arable land.*

JEL codes: *Q5.*

Paper Type: *Research Article.*

[1]*Warsaw University of Life Sciences, Poland, tomasz_pajewski@sggw.pl*
[2]*Warsaw University of Life Sciences, Poland, barbara_golebiewska@sggw.pl*
[3]*West Pomeranian University of Technology Szczecin, Poland, Agnieszka.Sobolewska@zut.edu.pl*

1. Introduction

The basic function of agricultural activity is the production of food or raw materials for food production. To produce food, the farmer uses all production factors in a more or less intensive way. A higher level of production intensity usually gives higher incomes, which, however, can lead to negative effects on the environment and people. Research in this area indicates that a higher degree of socio-economic development is associated with a more intensive use of resources of the natural environment (Bertoni and Olper, 2008). Farmers who own or use land have a direct impact on the natural environment (including soil, air, ground and surface water), through fertilization, chemical plant protection or other agrotechnical measures (Gołębiewska *et al.,* 2016). Excessive intensity of these activities can lead to environmental degradation. Bos *et al.* (2013) indicate that intensification in agriculture improves use of natural resources, but also increases emission per hectare, and may be associated with specialization, increase in scale and concentration of production. Shah and Wu (2019) have pointed out that intensive agricultural production, failing to maintain environmental balance, has led to deterioration of soil quality and serious environmental problems.

It is assumed that farm size is one of the factors that determine intensity of agricultural production. Large agricultural enterprises increase their production expenditures, seeking profit. Therefore, it is indicated that large, highly specialized and highly intensive farms may represent a higher environmental risk. Balmford *et al.* (2018), however, have indicated that little research exists on the correlation between farm size, yield and external effects generated. Research conducted by Akpan *et al.* (2017) has confirmed the negative impact of farm size on intensity of use of arable land. On the other hand, increase in fertilizer use, household size and farm output affected land use intensity positively. As it has been noted that high production intensity constitutes an environmental hazard (Novikova 2014; Sayer and Cassman, 2013), increase in farm size should contribute to reduction of negative external effects.

Research by Wu *et al.* (2018), conducted in China, indicates that small farms tend to overuse chemical plant protection agents. The authors have even stated directly that increase in farm size would substantially reduce consumption of chemical products in agriculture, as well as their environmental impact. Different conclusions have been reached by D'Souza and Ikerd (1996), who have stated that small farms have some substantial environmental advantages over big ones, and small farmers are often more interested in sustainability. Small farms usually utilize many production means created in the farm (the so-called internal cycling), such as manure or compost, while large farms tend to use purchased means of production, such as agricultural chemical products. Farmers operating on a large scale, in large agricultural enterprises, are less engaged in management of other resources, such as environmental resources (e.g. the surrounding forests, water, which are significant for sustainable development of the region (Jordan, 2002). While small farms are of lesser importance in terms of production volumes, their number is high and they constitute an integral part of the rural community. According to data, there is more than 570 million farms all over the world, including more than 475 million farms smaller than 2 hectares (around 84%) (Lowder *et al.*, 2016). Therefore, the issue under discussion is important, and it should encourage us to search for optimum solutions in terms of environmental hazards caused by agricultural production.

2. Literature Review

As far as environmental protection is concerned, there is mainly an increase in the use of both mineral and natural fertilizers (Mangmeechai, 2014) and pesticides (Gatzweiler and Hagedorn, 2003). High production intensity, leading to higher yields, causes production to increase. This is a serious problem in terms of feeding the ever-increasing population of the world. The United Nations Food and Agriculture Organization say that global agriculture will have to produce over 50% more food by 2050 due to the growing population. However, some research results indicate that on larger farms, due to the use of precise production technologies, there is a greater possibility of preserving environmental standards. Research by Bertocchi *et al.* (2016) indicate that environmental and social elements are more dependent on the production system on farms related to their specialization, multi-functionality and size of land area.

The negative effects of agricultural activity, often arising as a side effect of the core activity (external effect), can be very diverse, especially spatially Lewis *et al.* (2008). Due to the fact that they mainly concern the natural environment, there are as many of them as the elements that make up this environment. Pollution generated by agricultural production is released to the environment as a side effect of plant production or animal breeding. Bauer *et al.* (2016) indicate that emissions from farms pose a major threat in the form of atmospheric air pollution. In addition, these emissions exceed all other sources of dust pollution, generated by humans. This is the case mainly in most of the United States of America, in Europe, Russia and China. The phenomenon is caused by the fumes of nitrogen fertilizers and livestock manure (Bauer *et al.*, 2016). According to Steinfeld *et al.* (2006), agriculture is responsible for 14% of global greenhouse gas emissions. In many areas of the US and Europe, intensive cultivation and breeding of animals increases with the growth of the global population and the demand for food.

In recent years, modern production technologies, including livestock production (e.g. modern animal nutrition), have resulted in increased productivity (Msangi *et al.*, 2014), but also increased concentration of animal herds (Aneja *et al.*, 2009; Thornton, 2010; Vaarst *et al.*, 2012). Agricultural production poses a serious threat to water purity (Mateo-Sagasta *et al.*, 2017) and its use (Pimentel *et al.*, 2004). Water scarcity is an uncertainty that must be overcome in the process of socio-economic development (Falkenmark, 2013). Therefore, in the face of its shortages, it is important to look for effective methods of purification (Simmons, 1979) or to prevent pollution. Water management for agriculture is linked to food production, rural development and management of natural resources (Iglesias *et al.*, 2015). During agricultural production, many waste materials are created that can pollute the environment. They can also become a valuable resource. For example, agricultural waste can be used for energy production purposes (Gołębiewski, 2013).

Pollution generated by agriculture constitutes a significant component that reduces social well-being, in particular, in terms of environmental public goods, which are delivered to the society, as pointed out by Brelik (2016), “as a byproduct” of typical agricultural production (Brelik, 2013; 2016). Therefore, the problem is sufficiently important to fit into the framework of soil and natural resources management, including their use in the manner that would allow for their recovery in the future. Thus identification of externalities in agriculture and their impact on resource management remains one of the

A measurement of the level of external effects in agriculture has been proposed by Chen *et al.* (2014) for Finnish agriculture. Similar research has been conducted for the conditions of Polish agriculture, aimed at assessment of the negative externalities of agricultural activity and determining whether their level depends on the size of farms. The study assumed the following hypothesis to be verified:

H1: In regions with a higher average farm area, there is a higher level of negative externalities of agricultural activity.

Research in this area can serve as an important contribution to the discussion on validity of solutions applied in reducing the negative effects of agricultural activity while ensuring a sufficient amount of food products.

3. Materials and methods

Externalities generated during agricultural production were measured using the index of agri-environmental externalities, developed using the fuzzy set theory (Zadech, 1995). The index consists of seven components that have been assessed by 16 experts to be of utmost importance for development of externalities, and the selected variables have been assigned proper weights. The experts had proper qualifications in the area of environmental threats (scientists and practitioners). Data was also collected on the value of individual variables in years 2004-2015, separately for each of the 16 voivodeships of Poland. The components used to develop the index on the basis of available literature on the subject (Chen 2014) included (Table 1):

Table 1. *Index components*

No.	Variable description	Weight (%)
x_1	nitrogen balance	20
x_2	phosphorus balance	15

x_3	cattle density (in equivalent of the number of animals per arable land area),	13
x_4	pig population density (in equivalent of the number of drove per arable land area),	14
x_5	share of land set aside in arable land area	10
x_6	share of permanent pastures in arable land area	14
x_7	share of environment-friendly crops in arable land area	14

Variables x_1, x_2, x_3, x_4 exert positive impact on generation of negative externalities, therefore their maximum level has been determined at fuzzy membership level of 1. This indicates their key role in generating negative externalities (of agri-environmental nature). Fuzzy membership level of 0 corresponds with minimum contribution to these externalities. On the other hand, variables x_5, x_6, x_7 have negative impact on negative agri-environmental externalities. Therefore, fuzzy membership was determined to be 0 for the highest values and to be 1 for the lowest values of these variables. Individual xi indexes for all voivodeships in the matrix were then combined (Chen *et al.*, 2014):

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{116} \\ \vdots & & \ddots & \vdots \\ r_{71} & r_{72} & \cdots & r_{716} \end{bmatrix} \tag{1}$$

where: rij = μ(x), i = 1,2, …,7 variables and j = 1,2,…,16 regions.
The weights assigned by experts to individual variables were recorded as follows: A = (a_1, a_2, a_3, a_4, a_5, a_6, a_7), where $\sum_{i=1}^{7} a^i = 1$.
The synthetic measure of agri-environmental externalities assumes values within the range < 0:1>.

For the purpose of verification of the hypothesis developed, an econometric model was applied, explaining, at a certain level of probability, the correlations between the emerging environmental effects and the farm size. The model was developed on the basis of empirical material gathered, aggregated in panel format. A static linear model for panel data can be expressed using the following formula:

$$y_{it} = \alpha_i + \boldsymbol{x}_{it}^T \beta + \varepsilon_{it}, \tag{2}$$

where y_{it} is the dependent variable (externalities index) $\boldsymbol{x}_{it}$ is the vector of external variables α_i is the individual effect for each unit examined, β is the vector of parameters in the model, and ε_{it} is the random model component. Two types of estimation are used: for fixed effects and for random effects (Verbeek, 2004). A 1-way model with random effects takes the form illustrated by formula:

$$y_{it} = \mu + \alpha_i + \boldsymbol{x}_{it}^T \beta + \varepsilon_{it}, \tag{3}$$

where y_{it} represents the dependent variable, $\boldsymbol{x}_{it}$ represents the vector of external variables, α_i is the individual effect for each unit examined, β is the vector of structural parameters in the model, ε_{it} is a random component and μ is the free term in the model. The effects in this model are random, and thus it is not necessary to estimate any additional parameters. The model can be presented as:

$$y_{it} = \mu + \boldsymbol{x}_{it}^T\beta + v_{it}, \tag{4}$$

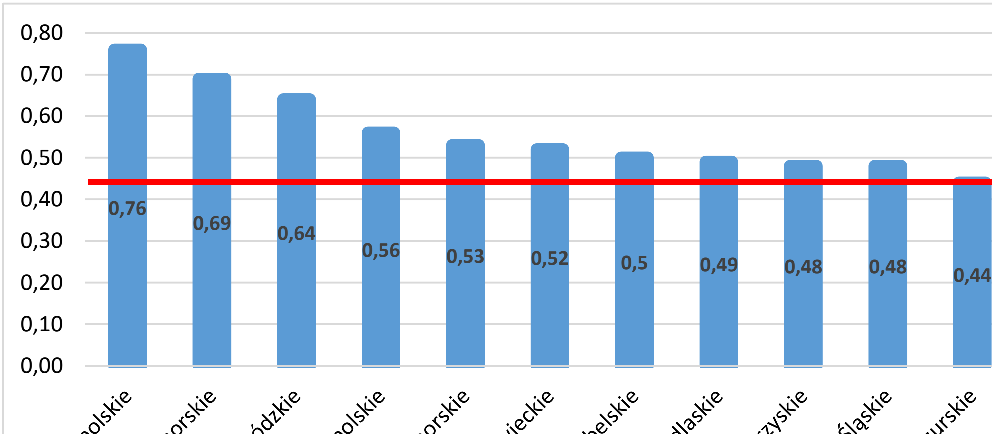
$$v_{it} = \alpha_i + \varepsilon_{it}, \tag{5}$$

for $i = \overline{1, N}, t = \overline{1, T}$, where v_{it} is the sum of random individual effects (that is, α_i) and random noise (that is, ε_{it}) (Verbeek 2004, Gelman, 2005).

4. Results and Discussion

A synthetic index of agri-environmental effects was established for each region (voivodship) in Poland. As a result, it was possible to rank the voivodeships in terms of environmental effects generated by agriculture (Figure 1).

***Figure 1**. Average level of the environmental effects indicator in Poland, by voivodeship (in 2004-2015)*



The Wielkopolska voivodeship was characterized by the highest level of negative externalities, in which the level of the negative external effects index was more than 2.5 times higher than in the Podkarpackie Voivodeship. This indicates a wide variety of external effects generated by agriculture at a regional level. This is mainly due to the fact that small (surface) farms in southern Poland (Małopolskie and Podkarpackie voivodeship) were characterized by a low stocking density and a favorable structure of agricultural land (a large share of meadows, pastures and organic farming areas). Agriculture in these regions is extensive.

The average area of farms was also determined in individual provinces. Agricultural holdings in Poland are characterized by a large spatial diversity in terms of agricultural area. Such differentiation was also demonstrated by Kopiński and Matyka (2016). The research attempts to answer the question about the importance of the area of farms in shaping the indicator of environmental effects. An econometric linear model for panel data was used. In order to verify the assumed hypothesis, the following variables were used: the dependent variable (explanatory): agri-environmental externalities index by voivodeships and an independent variable (explanatory): the average area of agricultural land [ha] on farms in individual voivodeships. The independent variable was logarithmized (for easier interpretation of the results). Non-linear relations between the explanatory variable and the explanatory variable were also examined, e.g. a square relationship (i.e. a parabolic relation). The information presented in Figure 2 indicates the validity of checking the value of the mean square-to-square area in the model.

Figure 2. *The level of agri-environmental effects and the logarithmized average area of UAA on farms*

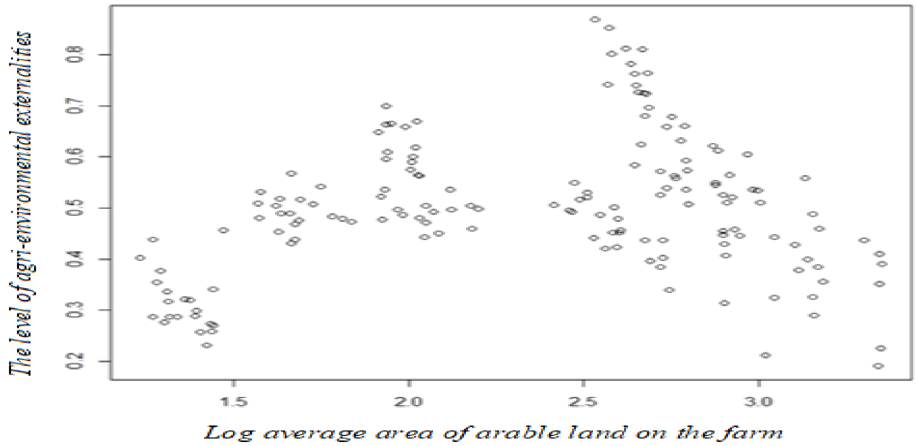


Table 1 presents the results of tests examining the significance of the individual effect (voivodeships) and the variation in value over time.

Table 1. *Significance of the individual effect: voivodeship, years*

Tested effect	Test statistic	Degree of freedom number	Significance (p – value)
Voivodeships	38.024	15 ; 157	< 0.001*
Years	2.868	9 ; 157	0.004*

**significant at a level of p<0,05.*

The F test statistic for the significance of the province effect is equal to F (15; 157) = 38.024. The significance of the test is close to zero (p < 0.001). Therefore, with the assumed 5% level of significance (α = 0.05), it should be stated that the voivodeship effect is significant and should be included in the panel model. The F test statistic for the significance of the Year (time) effect is F (9; 157) = 2.868. The significance of the test is p = 0.004. Thus, with the assumed 5% significance level ($\alpha = 0.05$), the effect of the Year (i.e. time) is important and should be included in the panel model.

In order to select the effect in the econometric model, which will be the proper phenomenon (choice between constant and random effect), the Hausman test was carried out. The $\chi 2$ statistic of the Hausman test showing the effect (permanent or random) that should be used in the econometric model is equal to $\chi 2$ (2) = 31.136. The significance of the test is close to zero ($p < 0.001$). Thus, with the assumed 5% significance level ($\alpha = 0.05$), it is concluded that a model with a constant effect is appropriate.

To test whether the variance of residues between voivodeships is significantly different from each other, i.e. whether there is a heteroskedasticity effect that negatively affects the correctness of the significance assessment of the model parameters, the Breusch-Pagan test was conducted. The value of the Breusch-Pagan test statistic is equal to 61,341 at 17 degrees of freedom. The significance of the test is close to zero ($p < 0.001$). Therefore, with the assumed 5% level of significance ($\alpha = 0.05$), one should reject hypothesis zero H0 which assumes the equality of residual variances between voivodeships (homoscedasticity) in favor of the alternative hypothesis H1 proclaiming the occurrence of this effect (heteroscedasticity of the random component).

The value of the F statistic of the test for model significance is F (2; 142) = 36.16. Its significance is close to zero ($p < 0.001$). Therefore, with the assumed 5% significance level ($\alpha = 0.05$), it should be stated that the model being constructed significantly explains the variability of the explained variable. The value of the determination coefficient R^2 equal to R^2= 25.81% means that the model at approx. 25.81% explains the variability of the explained variable, i.e. the variability of the index of agri-environmental externalities. Table 2 presents the values of the estimated parameters, estimation errors of these parameters as well as the value and significance of tests examining whether their impact is significant.

***Table 2**. Model characteristics*

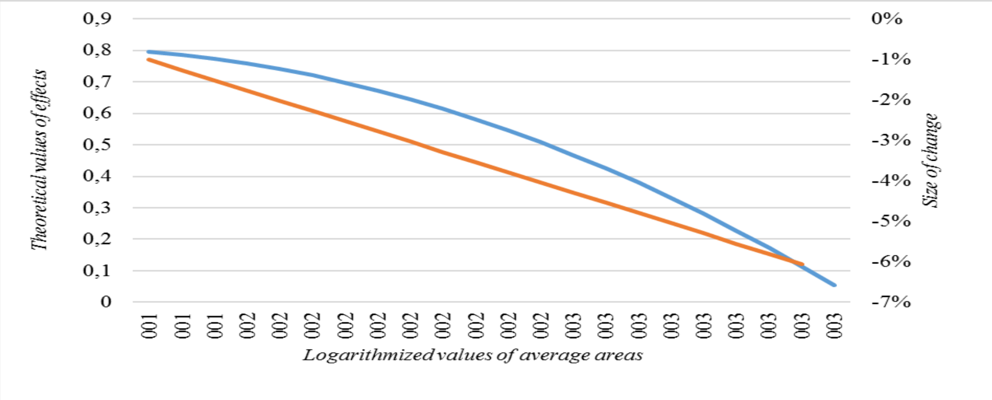
Variable in model	Parameter	Parameter estimation error	Statistic value t	Significance (p – value)
Average area	0.221	0.276	0.802	0.424
Square of the average area	-0.126	0.053	-2.391	0.018*

**significant at level p<0,05.*

The value of the test t statistic for the significance of the parameter at a logarithmic variable describing the average surface is equal to t = 0.802, and the significance of the test is equal to p = 0.424. Therefore, given the 5% significance level (α = 0.05), it should be noted that this variable does not have a significant impact on the value of the agri-environmental externalities indicator.

However, the value of the test t statistic for the significance of the parameter at the square of a logarithmic variable describing the average surface is equal to t = -2.391 and the significance of the test is equal to p = 0.018. Therefore, with the 5% level of significance (α = 0.05) adopted, it should be assumed that the variable significantly affects the value of the indicator of agri-environmental externalities. The following interpretation of parameters in the model has been adopted: The parameter at the square of the logarithmic variable - average area - is equal to -0.126. It is a technical variable, which means that the relationship between the values of the agri-environmental externalities index and the average surface area is square (not linear, and the relation is described in the reverse parabola). This means that the agri-environmental externalities index value changes depending on the average farm area. Due to the non-linear character of this correlation, it can be stated that increase in the level of externalities described by the index takes place only up to a certain UAA area of the farm. After this level has been exceeded, the index value starts to decrease. This relationship is presented in Figure 3.

Figure 3*. Relationship between agri-environmental effects indicator and average surface area*



It can be concluded that the surface of the farm has a significant impact on the level of external effects generated by agriculture. Wilk and Lebiecka, however, pointed out, after examining large farms (large-area farms), that their activities do not necessarily have to be connected with environmental threats. While examining the level of sustainability, it was found that although it is easier for smaller farms to maintain the environmental balance, large farms are also able to maintain this balance (Wilk and Lebiecka, 2006). Small farms also may not always obey environmental protection rules (they may be environmentally unsustainable) (Pajewski, 2018).

5. Conclusion

Production in agriculture occurs with the use resources from the natural environment. It is important, therefore, that these resources serve humankind for as long as possible. In this context, the assessment of the negative effects of agricultural activity which sometimes lead to the degradation of this environment is an important and contemporary problem. The conducted research into the emergence of agri-environmental externalities in agriculture, supported by a detailed analysis of the collected material, confirm the validity of the adopted research hypothesis. The construction of a synthetic indicator made it possible to assess the emergence of environmental effects at a regional level. It was proven that there is a relationship between the size of agricultural area on farms and the level of negative agri-environmental externalities.

Based on the constructed model verifying the hypothesis, it can be concluded that along with an increase in the average area of farms, the index values decreased, and this decrease was not linear but square. This means that with small to medium-sized areas, the value is larger than with a large to medium area of farms. It is possible to reconcile the problems of environmental threats in agriculture with a high level of production and efficiency achieved using modern manufacturing technologies. Modern production technologies, in large farms, allow limiting negative externalities.

References:

Akpan, S.B., Umoren, A.A., Nkeme, K.K., Udom, S.D. 2017. Determinants of agricultural land use intensity among small scale arable crop farmers in Oruk Anam Local Government Area, Akwa Ibom State, Nigeria. Nigeria Agricultural Journal, 48(1), 1-9.

Aneja, V.P., Schlesinger, W.H., Erisman, J.W. 2009. Effects of Agriculture upon the Air Quality and Climate: Research, Policy and Regulations. Environmental Science & Technology, 43(12), 4234–4240. doi:10.1021/es8024403.

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., … Eisner, R. 2018. The environmental costs and benefits of high-yield farming. Nature Sustainability, 1(9), 477–485. doi:10.1038/s41893-018-0138-5.

Bauer, S.E., Tsigaridis, K., Miller, R. 2016. Significant atmospheric aerosol pollution caused by world food cultivation. Geophysical Research Letters, 43(10), 5394–5400. doi:10.1002/2016gl068354.

Bertocchi, M., Demartini E., Marescotti, M.E. 2016. Ranking farms using quantitative indicators of sustainability: the 4Agro method. Procedia – Social and Behavioral Sciences, 223, 726-732.

Bertoni, D., Olper, A. 2008. The Political Economy of Agri-Environmental Measures: an Empirical Assessment at the EU Regional Level, APSTRACT: Applied Studies in Agribusiness and Commerce, AGRIMBA, No 3, 1-12.

Bos, J.F.F.P., Smit, A. (Bert) L., Schröder, J.J. 2013. Is agricultural intensification in The Netherlands running up to its limits? NJAS - Wageningen Journal of Life Sciences, 66, 65–73. doi:10.1016/j.njas.2013.06.001.

Brelik, A. 2013. Agro-Tourism as Public Good in Rural Areas: A Case Study. European Research Studies Journal, 16(1), 67-74.

Brelik, A. 2016. Organic farming in Poland in aspects of bioeconomy and sustainable agriculture. Annals PAAAE, 18(4), 25-30.

Chen, Q., Sipiläinen, T., Sumelius, J. 2014. Assessment of Agri-Environmental Externalities at Regional Levels in Finland. Sustainability, 6, 3171-3191. doi.org/10.3390/su6063171.

D'Souza, G., Ikerd, J. 1996. Small Farms and Sustainable Development: Is Small More Sustainable? Journal of Agricultural and Applied Economics, 28(01), 73–83. doi:10.1017/s1074070800009470.

Falkenmark, M. 2013. Growing water scarcity in agriculture: future challenge to global water security. Philosophical Transactions of the Royal Society: Mathematical, Physical and Engineering Sciences, 371, 20120410–20120410. doi:10.1098/rsta.2012.0410.

Gatzweiler, F. Hagedom K. (eds.). 2003. The Challenge of the Nitrate Directive to Acceding Countries: A comparative analysis of Poland, Lithuania and Slovakia. Institutional Change in Central and Eastern European Agriculture and Environment, Central and Eastern European Sustainable Agriculture, vol. 2, FAO. Humboldt University of Berlin.

Gelman, A. 2005. Discussion paper analysis of variance—why it is more important than ever. The Annals of Statistics, 33, 1, 1–53. doi:10.1214/009053604000001048.

Gołębiewska, B., Chlebicka, A., Maciejczak, M. 2016. Agriculture and Environment, Biodiversity and environmental innovations in agricultural development. Wies Jutra, Warsaw.

Gołębiewski, J. 2013. Sustainable bioeconomy - potential and development factors, In: IX Congress of Polish Economists, Economics for the future. Discovering the nature and causes of economic phenomena. PTE, Warsaw.

Iglesias, A. Garrote, L. 2015. Adaptation strategies for agricultural water management under climate change in Europe. Agricultural Water Management, vol. 155, 113-124.

Jordan, C.F. 2002. Genetic Engineering, the Farm Crisis, and World Hunger. BioScience, 52(6), 523. doi:10.1641/0006-3568(2002)052[0523:getfca]2.0.co;2.

Kopiński, J., Matyka, M. 2016. Assessment of regional diversity of correlations between environmental and organisational-production factors in polish agriculture. Problems of Agricultural Economics, 1(346), 57-79.

Lewis, D.J., Barham, B.L., Zimmerer, K.S. 2008. Spatial Externalities in Agriculture: Empirical Analysis, Statistical Identification, and Policy Implications. World Development, 36(10), 1813–1829. doi:10.1016/j.worlddev.2007.10.017.

Lowder, S.K., Skoet, J., Raney, T. 2016. The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. World Development, 87, 16–29. doi:10.1016/j.worlddev.2015.10.041.

Luty, L. 2016. Regional diversification of the structure area of utilized agricultural area in Poland. Quantitative Methods in Economics. vol. XVII/I, 62-71.

Maciejczak, M., Faltmann, J. 2017. Sustainable intensification of modern agriculture through production technologies on different readiness levels. In Farm Machinery and Process Managment in Sustainable Agriculture:symposium proceedings: IX International Scientific Symposium, 22-24 November, ed. by Lorencowicz E., Uziak J., Huyghebaert B. University of Life Sciences in Lublin, 216-221.

Mangmeechai, A. 2014. Environmental externalities in relation to agricultural sector in Thailand with trade-linked analysis. Environ. Dev. Sustain, 16, 1031-1040.

Manteuffel, R. 1981. Economics and organization of farms. PWRiL, 2nd edition. Warsaw.

Mateo-Sagasta, J., Zadeh, S.M., Turral, H., Burke, J. 2017. Water pollution from agriculture: a global review. Executive summary. Rome, Italy: FAO; Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE).

Msangi, S., Enahoro, D., Herrero, M., Magnan, N., Havlik, P., Notenbaert, A., Nelgen, S. 2014. Integrating livestock feeds and production systems into agricultural multi-market models: The example of IMPACT. Food Policy, 49, 365–377. doi:10.1016/j.foodpol.2014.10.002.

Novikova, A. 2014. Valuation of Agricultural Externalities: Analysis of Alternative Methods. Research For Rural Development, 2, 199-206.

Pajewski, T. 2018. Economic instruments for reducing negative externalities in agriculture on the example of agri-environmental program. PhD dissertation, Faculty of Economics, Warsaw University of Life Sciences. Warsaw.

Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., … Nandagopal, S. 2004. Water Resources: Agricultural and Environmental Issues. BioScience, 54(10), 909. doi:10.1641/0006-3568(2004)054[0909:wraaei]2.0.co;2.

Sayer, J., Cassman, K.G. 2013. Agricultural innovation to protect the environment. Proceedings of the National Academy of Sciences, 110(21), 8345–8348. doi:10.1073/pnas.1208054110.

Shah, F., Wu, W. 2019. Soil and Crop Management Strategies to Ensure Higher Crop Productivity within Sustainable Environments. Sustainability, 11(5), 1485. doi:10.3390/su11051485.

Simmons, I.G. 1979. The ecology of natural resources, PWN, Warsaw.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. 2006. Livestock's long shadow – Environmental issues and options, Rome, FAO.

Teillard, F.G., Allaire, E.,, Cahuzac, F,. Léger, E. Maigné, M., Tichit, T. 2012. A novel method for mapping agricultural intensity reveals its spatial aggregation: implications for conservation policies. Agric. Ecosyst. Environ., 149, 135-143. In Ruiz-Martinez, I., E. Marraccini, M. Debolini, E. Bonari. 2015. Indicators of Agricultural Intensity and Intensification: A Review of the Literature. Italian Journal of Agronomy, Vol. 10, No 2, 74-84.

Thornton, P.K. 2010. Livestock production: recent trends, future prospects. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2853–2867. doi:10.1098/rstb.2010.0134.

Vaarst, M., Alrøe, H.F. 2011. Concepts of Animal Health and Welfare in Organic Livestock Systems. Journal of Agricultural and Environmental Ethics, 25(3), 333–347. doi:10.1007/s10806-011-9314-6.

Verbeek, M. 2004. A guide to modern econometrics, John Wiley&Sons, Ltd, 345.

Wilk, W., Lebiecka, K. 2006. European size unit of sustainable farms. Annals PAAAE, 8(1), 227-231.

Wu, Y., Xi, X., Tang, X., Luo, D., Gu, B., Lam, S. K., Vitousek, P.M., Chen, D. 2018. Policy distortions, farm size, and the overuse of agricultural chemicals in China. Proceedings of the National Academy of Sciences, 115(27), 7010–7015. doi:10.1073/pnas.1806645115.

Zadech, L.A. 1995. Fuzzy sets and fuzzy system. Electronics Research Laboratory University of California Berkeley, California Report No. 64-44.