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SPATIAL VARIABILITY AND ECONOMIC AND ENVIRONMENTAL CONSEQUENCES OF AGRICULTURAL ACIDIFICATION OF SOILS IN THE PROVINCE OF WARMIA AND MAZURY

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ABSTRCT: The aim of this study has been to identify the spatial variability in the acidification of soils and the liming needs as well as the soil availability of fertiliser components in the Province of Warmia and Mazury (województwo warmińsko-mazurskie). The soil spatial variability has been analysed according to the division into administrative districts. The choice of this spatial division pattern was justified by the availability of data and the research subject. The data were obtained from Reports on the Environmental Conditions in the Province of Warmia and Mazury, the database of the Regional Agricultural Chemical Station in Olsztyn and from the Programme for Environmental Protection in the Province of Warmia and Mazury until 2020. The research results showed large differences between the districts, which were mostly due to natural conditions. Because of the high demand for nutrients, it would be advisable to prepare fertilisation plans and to adhere to Good Agricultural Practice recommendations, as this would control the causes and alleviate the consequences of soil acidification induced by farming.

KEY WORDS: soil acidification, consequences, agricultural causes

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JEL: Q15, Q56, Q57

Introduction

Soil acidification is affected by both natural and anthropogenic factors. The principal natural conditions include the climate and the type of parent rock. In Poland, including the Province of Warmia and Mazury, over 90% of soil developed on acid rocks transported by glaciers (Hołubowicz-Kliza, 2006, p. 3). The topsoils lying over acid soils are exposed to more intensive leaching of alkaline components, especially in areas where total annual rainfalls are high. The Province of Warmia and Mazury belongs to the coldest regions in Poland, with a short plant growing season and a relatively high, but spatially varied, annual sum of precipitations (400 mm near Ryn and Sępopol, up to nearly 700 mm near Elbląg and Górowo Iławeckie, compared to the Polish average of 600 mm). Also, temperatures across the province are varied. The climate in the western part of the region is shaped under the influence of the Baltic Sea, whereas the eastern parts of the province are exposed to a distinct influence of the continental climate. The plant growing season is 200-201 days long in the west, but shortens to 190-200 days in the north-eastern part of the province, while the yearly average temperature of 6^{o}C in Olecko is by 1^{o}C lower than the average temperature recorded in the environs of Nowe Miasto Lubawskie. The mean annual precipitation reach up to 450 mm. At low temperatures, the CO_2 generated by breathing soil organisms concentrates in soil and adds to soil acidification (Programme…, 2010, p. 10). Another cause of soil acidification is the application of nitrogen fertilisers (Hołubowicz-Kliza, 2006, p. 3). The current predictions up to the year 2050 concerning the consumption of mineral fertilisers in the world implicate a constant growth in their use (Gil, 2013, p. 9).

The Province of Warmia and Mazury is perceived as an agricultural region. Considering the fact that nearly all Poland lies in the so-called sensitive area and the Province of Warmia and Mazury occupies the northern part of Poland, in the vicinity of the Vistula Lagoon, it seemed worth making an analysis to demonstrate how the phenomenon of soil acidification was distributed spatially in the province. Another question was whether the diverse natural conditions observed in the province would be accompanied by the spatial variability in soil acidification, which entails differences in the demand for soil liming and in deficits of mineral components.

Review of literature

Acidity is conditioned by the soil presence of hydrogen ions (H+), which occur either in the soil solution or bound by the soil sorption process.

Depending on what hydrogen ions are present, i.e. in the soil solution or absorbed by the soil complex, two types of acidity are distinguished: active acidity and potential acidity. Acidity fluctuates considerably during an annual cycle, as seasons of the year change. It tends to be the highest in summer, when soil microorganisms are the most active and plants grow most intensively. The natural acidification processes take place all the year and do not pose a threat (Boguszewski, 1980, p. 176; Fotyma, Zięba, 1988, p. 250; Filipek, 2001, p. 5; Filipek, Skowrońska, 2013, p. 284); however, when they coincide with certain anthropogenic measures they can become dangerous to agricultural ecosystems. The anthropogenic source of soil acidification stems mostly from combustion of energy generating resources, mainly coal and crude oil derivatives (Filipek, 2005, p. 67; Filipek, Skowrońska, 2013, p. 284). Another cause that cannot be neglected is the influence of agriculture on soil pH. The main factor of soil acidification related to agriculture is mineral fertilisation. A consequence of this process is the growing fertiliser demand of plant production, that is the increasing consumption of mineral fertilisers per basic crop production unit, such as 100 kg of cereal grain (cereal unit (c.u.)). A direct effect of excessive fertiliser consumption, beside the lowered effectiveness of inputs into the production, is a greater risk to the soil and water environments. A team working at the IUNG Research Institute have calculated from equations (regression functions) developed by Grzebisz et al. (2008, p. 49) the so-called yield loss coefficient, which equals 25% and 15% for very acid and acid soils, respectively (Ochal et al., 2017, p. 5).

Although in the 1990s it was possible to observe a decrease in the consumption of fertilisers in Poland, mostly phosphates and potassium ones, the amount of fertilisers used in agriculture has increased by 31% following Poland's access to the EU, while the total crop prodution has risen by just 5% (Kopiński, 2012, p. 95; Gil, 2013, p. 9).

There is a considerable variability in soil acidity and soil content of available forms of macronutrients across Poland (Kopiński, 2012, p. 95; Ziętara, 2009, p. 190). For years, the share of very acid and acid soils in Poland has been exceeding 50% on average of all farmland and still tends to increase (Siebielec et al., 2017, p. 27).

The highest share of acidified soils (pH<5.5) is in the Provinces of Podkarpacie and Małopolska (*województwo podkarpackie* and *małopolskie*). The least of such soils can be found in the Province of Kujawy and Pomerania (*województwo kujawsko-pomorskie*) (Hołubowicz-Kliza, 2013, p. 5). The results of the studies conducted by the IUNG in 2014-2015 suggest that 28.9% of the analysed soil samples were very acidic in reaction (pH over 4.5), and another 28.3% had acid reaction.

According to Filipek and Skowrońska (2013, p. 283), special attention should be paid to an inadequate N:P:K ratio and a share of nitorgen in NPK fertilisers. Among potassium fertilisers, potassium chloride ones contribute the most to soil acidification due to the ease of Cl-ion leaching. Phosphate fertilisers soluble in water can also favour soil acidification, although to a lesser extent than nitrogen ones. From the point of view of farmers, consequences of soil acidification are extremely grave. They include depressed availability of nutrients, especially phosphorus, magnesium and molybdenum, which leads to a decline in yields (Grzebisz et al., 2005, p. 36; Igras et al., 2010, p. 9) and poses a threat to the soil and water environments. Moreover, the mobility of soil components increases, which can create a hazard of their excessive accumulation, particularly heavy metals and mobile aluminium (Hołubowicz-Kliza, 2013, p. 5). Another consequence is the depressed intensity of the uptake of free nitrogen from the atmosphere and nutrients into deeper soil horizons. As a result, the soil fertility and quality are impaired. Acidity is one of the major soil qualities which decide about the course of soil processes, and the lowered effectiveness of mineral fertilisers can only partially be attributed to worse soil and climate conditions (Blake et al., 1999, p. 400; Kaczor, Kozłowska, 2000, p. 55; Filipek, Skowrońska, 2009, p. 25; Kopiński et al., 2013, p. 53). An in-depth study into the influence of weather conditions and soil acidification on productivity has been conducted by Kopiński et al. (2013 p. 53). In 2006-2011, the plant production potentially lost due to the unregulated soil reaction was 4.3 c.u. per ha^{-1} of arable land in dk on average per year, and tended to be twice as high as the production lost due to unfavourable weather conditions. These data support the opinion expressed by Krasowicz (2009, p. 9), who maintained that organisational factors rather than natural conditions, including the weather, had a greater impact on the economic and production results in farming. Moreover, the inputs into fertilisation constitute a considerable share of total plant production costs. Management of fertilisers in agriculture has both economic and ecological importance. Particularly noteworthy in the context of environmental effects are, according to Gaj (2013, p. 5), nitrogen and phosphorus. In the Province of Warmia and Mazury, the level of mineral fertiliser consumption is lower than the country's average (figure 1).

The consumption of lime as a fertiliser has decreased drastically since 2005, both in Poland and in the Province of Warmia and Mazury. At the same time, according to the IUNG data, around 32.5% of the analysed soil samples are distinguished as the ones which must be limed, 17.2% – should be limed, 12% – need some liming and 25% – do not need any liming (Ochal et al., 2017, p. 11). The provinces where the percentage of soils that require liming is the highest are: *małopolskie* (77.5%), *podkarpackie* (73.4%), łódzkie

(59.7%), as well as *dolnośląskie*, *mazowieckie*, śląskie, *podlaskie*, *lubelskie*, *warmińsko-mazurskie* (from 54.2 to 50.9%).

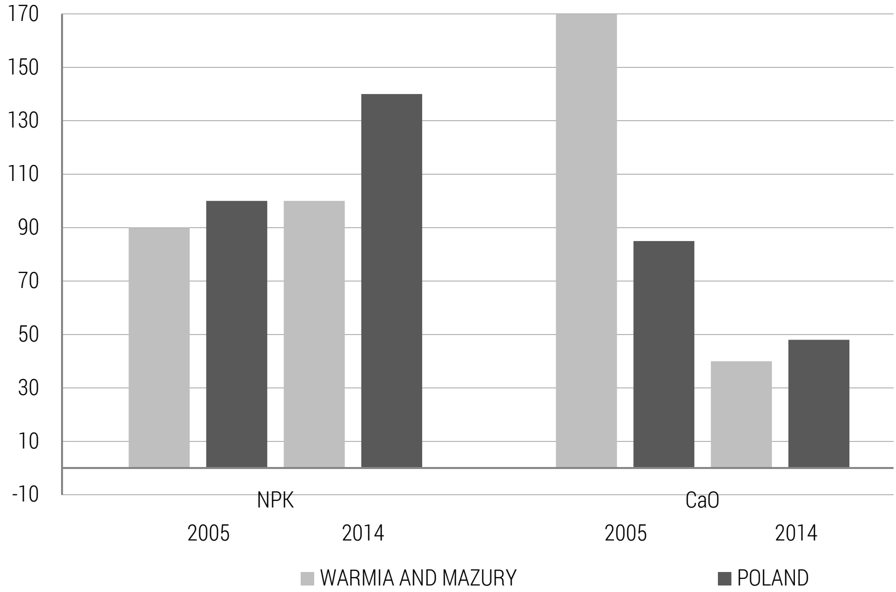

Figure 1. Consumption of mineral fertilisers and lime in the Province of Warmia and Mazury and in Poland in 2005-2014

Source: author's own work based on data of the Main Statistical Office (GUS).

Research methods

The purpose of this study has been to identify the spatial variability in the acidification of soils and their richness in available forms of nutrients in the area covered by the Province of Warmia and Mazury (*województwo warmińsko-mazurskie*). The spatial variability was analysed according to the division into administrative districts (excluding towns with the status of a district). The choice of this spatial division pattern was dictated by the accessibility of data and the research subject. The data were obtained from reports on the condition of the environment in the Province of Warmia and Mazury, the database of the Regional Agricultural Chemical Station (OSCHR) in Olsztyn and from the Programme for Environmental Protection in the Province of Warmia and Mazury until 2020. The assessment of acidifcation of soils performed by the OSCHR was based on pH tests correlated with the agronomic classes of soil. On the basis of the pH in KCl reaction, soils are then divided into 5 classes: very acid pH< 4.5, acid pH 4.6-5.5, slightly acid pH 5.6-6.5, neutral pH 6.6-7.2 and alkaline pH > 7.2. According to the pH value and agronomic class of soil, soil demand for liming was estimated on a five-degree scale: liming is necessary, needed, recommened, limited and useless. Moreover, it was calculated by how many percent points in the time periods analysed the abundance of soils changed with respect of available forms of macronutrients: phosphorus (P_2O_5), potassium (K_2O), and magnesium (Mg). The analyses published in the Reports were made on the basis of analytical results delivered by regional agricultural chemical stations in 2007-2010 and in 2011-2016 in the area covered by the Province of Warmia and Mazury.

Research results

The total area of farmland contained in the farms located in the Province of Warmia and Mazury in June 2015 was 1096.1 thousand ha, of which 87.3% was the farmland owned by family farms. 89.7% of the agriculturally used land belonged to well-maintained farmland.

The variability of soils in the province is due to the variability of partent rock, diverse land relief and various climate and hydrological conditions. It is possible to notice changes progressing through certain zones from the north to the south of the province.

According to the analyses made by the Regional Agricultural Chemical Station in Olsztyn in 2011-2014, 33% of the land used for agricultural purposes in the Province of Warmia and Mazury either had to or needed to be limed. The studies also showed that the share of very acid and acid soils decreased in comparison to the previous research time periods and their distribution in the whole province was uneven.

Figure 2 shows results of the soil analyses in 2007-2010 (the lower bar) and in 2011-2016 (the upper bar) for particular districts. The reaction of over half of the samples (55%) collected from the the area submitted to analyses was very acid or acid. Slightly acid reaction was detected in 26% of the soil samples, while neutral and alkaline reaction was demonstrated in just 19% of the samples obtained from the analysed farmland. Similar results have been reported by Brodzińska (2009, p. 37-42).

However, the spatial variability and changes between the two time periods are evident. In most districts a decrease in the constribution of acid and very acid soils can be noted.

Soil acidification entails the necessity to implement soil liming (figure 3). In the Province of Warmia and Mazury, the highest demand for soil liming was diagnosed in the districts: *braniewski*, *lidzbarski* and *elbląski*.

Soil acidification is also closely connected with the leaching of nutrients, mainly alkaline compounds, to deeper horizons of soils. This leads to deficits

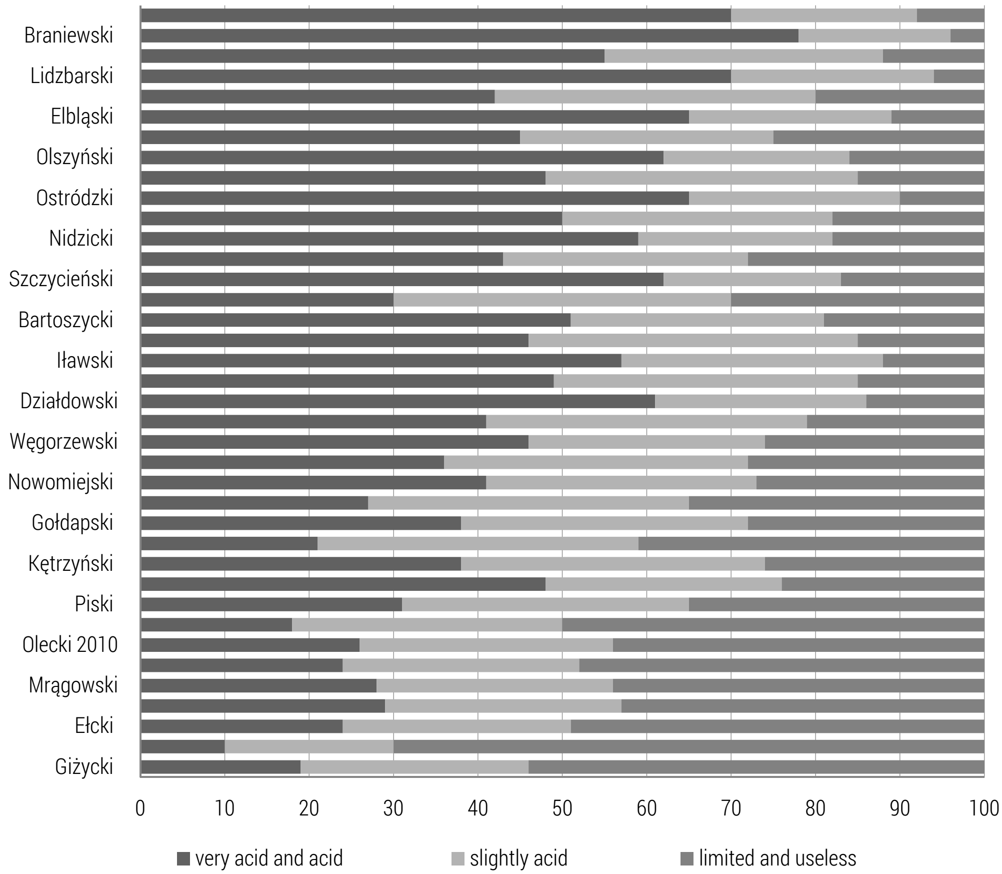

Figure 2. Reaction of soil under farmland in the Province of Warmia and Mazury

Source: author's own work based on data from the Regional Enrvionmental Protection Inspectorate in Olsztyn (WIOŚ) and the Regional Agricultural Chemical Station in Olsztyn (OSCHR).

of nutrients. In the province of Warmia and Mazury, the analysed soils demonstrated large differences in the content of available forms of fertiliser elements (phosphorus, potassium, magnesium), due to the natural conditions or the applied levels of fertilisation. In the case of the districts with the highest demand for soil liming, and particularly the districts *braniewski*, *węgorzewski* and *lidzbarski*, the soils were found to be very low or low in phosphorus (32%, 50% and 46%, respectively, in 2008), and the soil content of this element even declined in the subsequent years, by 7.13 and 2 percent points. The districts where soils have a low content of available forms of nutrients are also characterised by a high share of acid and very acid soils. Same as in the case of climate and soil-related conditions, it is possible to

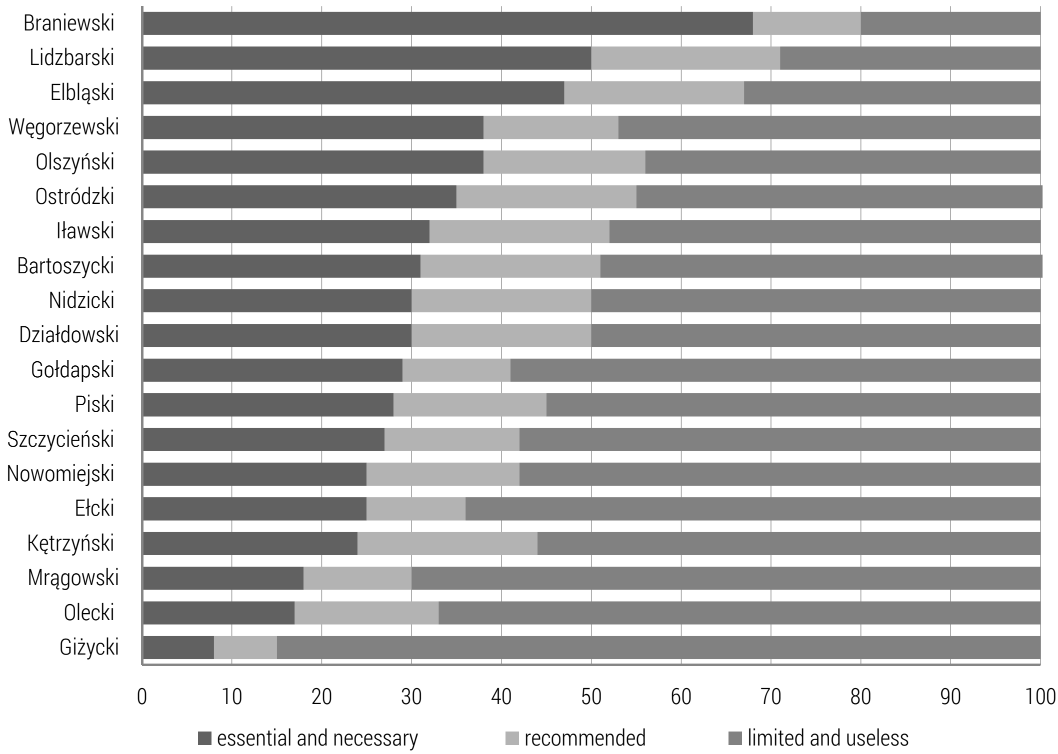

Figure 3. Liming demand in districts of the Province of Warmia and Mazury

Source: author's own work based on data from the WIOŚ in Olsztyn.

observe a certain tendency in the spatial distribution of districts, creating zones along the north-south axis.

The unbalanced richness of soils and the unused nutrients may have a negative influence on the water environment and quality of air. As well as having a negative effect on the maintenance of productive functions of soil, depleted resources of soil humus diminish the role of soils in the sequestration (binding) of carbon from the atmosphere. Polycyclic aromatic hydrocarbons, heavy metals and other harmful substances from polluted soils which are absorbed by plants either poison the yields or deteriorate the quality of agricultural production, have a negative impact on the environment, and via the food chain can accumulate in animal bodies, adversely affecting their condition and health. These substances can cause toxic, cancerogenous and mutagenic pathological conditions in humans (Programme..., 2016, p. 306).

Conclusions

The soil reaction is a principal factor that conditions an efficient use of macronutrients, secondary elements and micronutrients contained in the soil by plants. Various natural and man-made factors can cause an increase in the acidity of soils, reducing the availability of nutrients and deteriorating the conditions for an optimal growth of plants, hence affecting the volume and quality of yields produced by agricultural crops and forestry plants as well as the health of wild plants. In the districts where the share of very acid and acid soils was high and the demand for soil liming was likewise high, a large percentage of soils with low and very low richness in available elements, especially phosphorus, was identified. Another important contributor to soil acidification is agricultural practice, especially unreasonably high fertilisation with nitrogen fertilisers. The variability of soil types, from compact black soils near Kętrzyn through brown soils in Sępopolska Lowland and muddy soils in the environs of Elbląg, to light sandy soils in the south of the province means that different levels of fertilisation and liming are in order.

Literature

Blake L. et al. (1999), *Changes in soil chemistry accompanying acidification over more than 100 years under woodland and grass at Rothamsted ExperimentalStation. UK. European*, "Journal of Soil Science" No. 50, p. 400

Boguszewski W. (1980), *Wapnowanie gleb*, Warszawa, p. 176

Brodzińska K. (2009), *Środowiskowe uwarunkowania konkurencyjności rolnictwa Warmii I Mazur, „*Roczniki Naukowe SERIA" No. 4, p. 37-42

Filipek T. (2001), *Przyrodnicze i antropogeniczne przyczyny oraz skutki zakwaszenia gleb,*„Nawozy i Nawożenie" No. 8, p. 5-26

Filipek T. (2005), *Dynamika antropogenicznych przyczyn zakwaszenia gleb w Polsce w ostatnich latach*, „Nawozy i Nawożenie" No. 23, p. 67-68

Filipek T., Skowrońska M. (2009), *Optymalizacja odczynu gleby i gospodarki składnikami pokarmowymi w rolnictwie polskim*, „Postępy Nauk Rolniczych" No. 1, p. 25-37

Filipek T., Skowrońska M. (2013), *Aktualnie dominujące przyczyny oraz skutki zakwaszenia gleb użytkowanych rolniczo w Polsce, „*Acta Agrophysica" No. 20(2), p. 283-294

Fotyma M., Zięba S. (1988), *Przyrodnicze i gospodarcze podstawy wapnowania gleb*, Warszawa, p. 250

Gaj R. (2013), *Efektywne wykorzystanie nawozów mineralnych we współczesnym rolnictwie*, Centrum Doradztwa Rolniczego w Brwinowie Oddział w Poznaniu, p. 42

Grzebisz W., Szczepaniak W., Diatta J.B (2005), *ABC wapnowania gleb uprawnych,* Poznań, p. 36

Grzebisz W., Szczepaniak W., Diatta J.B. (2008), *ABC wapnowania gleb uprawnych*, Poznań, p. 49

Harasim A. (2006), *Przewodnik ekonomiczno-rolniczy w zarysie*, IUNG-PIB Puławy, p. 171

Hołubowicz-Kliza G. (2006), *Wapnowanie gleb w Polsce,* Puławy, p. 3

Igras J. et al. (2010), *Zużycie nawozów mineralnych w Polsce w układzie regionalnym,* „Studia i Raporty" No. 25, p. 9-19

Kaczor A., Kozłowska J. (2000), *Wpływ kwaśnych opadów na agroekosystemy,* „Zesz. Nauk. AR w Szczecinie", p. 55

Klepacki B. (1997), *Wybrane pojęcia z zakresu organizacji gospodarstw, produkcji i pracy w rolnictwie*, Warszawa, p. 148

Kopiński J. (2011), *Tendencje zmian intensywności produkcji rolniczej w Polsce w aspekcie oddziaływań środowiskowych,* „Zeszyty Naukowe SGGW" No. 11(4), p. 95-104

Kopiński J. (2013), *Stopień polaryzacji intensywności i efektywności produkcji rolniczej w Polsce w ostatnich 10 latach,*„Roczniki Naukowe SERiA" No. 15(1), p. 97-103

Kopiński J., Nieróbca A., Ochal P. (2013), *Ocena wpływu warunków pogodowych i zakwaszenia gleb w Polsce na kształtowanie produkcyjności roślinnej,* „Woda – Środowisko – Obszary wiejskie" No. 2(42), p. 53-63

Krasowicz S. (2009), *Regionalne zróżnicowanie zmian w rolnictwie polskim*, „Studia i Raporty IUNGPIB" No. 15, p. 9-36

Ochal P. et al. (2017), *Środowiskowe aspekty zakwaszenia gleb w Polsce,* Puławy, p. 43

Program Działalności Ośrodka Warmińsko-Mazurskiego Ośrodka Doradztwa Rolniczego w Olsztynie (2010), M. Micińska M (ed.), p. 63

Program Ochrony Środowiska Województwa Warmińsko-Mazurskiego do roku 2020, (2016), Zarząd Województwa Warmińsko-Mazurskiego, Olsztyn, p. 306

Raport o stanie środowiska województwa warmińsko-mazurskiego w 2016 roku, Inspekcja Ochrony Środowiska. Wojewódzki Inspektorat Ochrony Środowiska w Olsztynie, http://www.wios.olsztyn.pl/fileadmin/user_upload/monitoring/raporty/Raport_WIOS_2016_internet.pdf [30-09-2018]

Siebielec G. et al. (2017), *Raport z III etapu realizacji zamówienia monitoring chemizmu gleb ornych w Polsce w latach 2015-2017*, praca finansowana ze środków Narodowego Funduszu Ochrony Środowiska i Gospodarki Wodnej, IUNG, p. 190

Ziętara W. (2009), *Uwarunkowania rozwoju gospodarstw wielkotowarowych w Polsce,*„Roczniki Naukowe SERIA" No. 9(1), p. 490-496