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SOIL LIMING AS A TOOL FOR IMPROVING THE ECONOMIC EFFICIENCY OF AGRICULTURAL PRODUCTION AND REDUCING EUTROPHICATION OF SURFACE WATERS

Abstract: Soils along with their properties, climate and mineral fertilisation level are among the most important environmental elements impacting the quality and quantity of agricultural crops. Agricultural practices as well as crop varieties also have an impact on crop quantity and quality, but the method of cultivation of agricultural crops and selection of varieties depend on soil quality and local climate conditions. One of the most important soil parameters is pH. Acidic soils result in a range of negative phenomena that, on the one hand, impact crop quality and quantity, while, on the other hand, place a burden on the natural environment. Most soils used for crop cultivation in Poland originated from noncarbonate rocks and, consequently, are acidic. In order for agricultural production to reach an appropriate level of economic efficiency, systematic deacidifying fertilisation should be applied. However, the level of deacidifying fertilisation in Poland is far too low relative to the requirements of most plants. The necessity of using deacidifying fertilisers in crop production is a known problem and has been described in both scientific and popular scientific literature. Nevertheless, current trends indicate that farmers still use deacidifying fertilisation to a small extend, despite the fact that it is a simple way to significantly increase the quality and quantity of agricultural crops while maintaining the same level of fertilisation by mineral fertilisers. The paper describes, based on the National Agricultural Census 2012–2022, the current level of soil fertilisation by deacidifying fertilisers in Poland and analyses the reasons for this level as well as potential consequences.

Keywords: soil pH level, liming, economic efficiency of farms, soil quality

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Introduction

The properties of soils used for agriculture largely determine the economic aspects of crop production on agricultural land. It is the properties of soils used for agriculture that determine the quality and quantity of crops. For most plants cultivated in Poland, the optimum soil pH for appropriate growth should be neutral or at most slightly acidic.

Soil pH, like most of the other soil properties, depends on genesis (Dobrzański et al., 1995; Hillel, 2012; Mocek, 2015). Soil properties are closely connected with the bedrock from which soils were formed and which impacted their further development. In the area of today's Poland, the Quaternary, or – more precisely – the Pleistocene, when most of our country's surface was covered by glacial sediments, were most important for the formation of soil bedrock. These sediments consisted of strongly acidic material such as sands and noncarbonate clays. Soils that were formed from these sediments are also characterised by acid pH due to lack of carbonates in the bedrock. Other factors that significantly contribute to soil acidification, apart from the lack of carbonates in soil bedrock, are natural biological processes occurring in the soil environment during plant cultivation which contribute to soil degradation as a result of soil decalcification (Hillel, 2012; Rice & Herman, 2012; Mocek, 2015).

In soils used for agriculture, the problem of acidification is compounded by the type of water management, which in Poland's climate results from precipitation outweighing evapotranspiration (Mocek, 2015). Precipitation causes the leaching of calcium and magnesium ions into deeper layers of soil profile. The problem of leaching of alkaline ions is connected, among other things, with the particle size distribution of soils. Highly permeable soils cover not only a significant part of Poland, but also most of the earth's crust. When precipitation outweighs evapotranspiration, light and very light soils, which account for around 2/3 of agricultural areas (Jadczyszyn, 2013), become gradually acidic as a result of decalcification and pedologic processes (Filipek et al., 2015). Analysis of the impact of precipitation on soil acidification demonstrates that for Poland the average dose of calcium fertilisers in the form of CaO necessary for offsetting the decalcification caused by precipitation should be 37.2 kg/ha of agricultural land per year (Fertilisation recommendations part II. Optimum doses of fertilisers on agricultural land, 2022).

The above-listed causes of soil acidification can be classified as natural ones. Equally important causes of soil acidification are anthropogenic ones, connected with intensive drainage of alkaline components with crops, mineral fertilisation and air pollutants emissions such as: SOx, NOx, and NH_3 (Filipek & Skorońska, 2013). The amount of deacidifying fertilisers intended to offset the drainage of calcium and magnesium as a result of these factors will depend not only on the crops produced on such land but also on the level of mineral fertilisation.

Acidic pH of soils, which constitute the most important element of agricultural production environment, has a negative impact on the economic efficiency of farms. This impact is significant, as only 0.5% of agricultural areas in Poland have properties allowing them to be in quality class I (the best arable soils), i.e. soils that guarantee crops with minimum needs for deacidifying and mineral fertilisation and agricultural practices. Most of the other soils formed from noncarbonate bedrock belong to lower quality classes. These soils require much more agricultural practices on the part of farmers, with liming being one of the most important ones.

The aim of the paper is to analyse the use of calcium fertilisers based on the results of the National Agricultural Census for 2010-2022 as well as an attempt to verify the factors impacting the low level of calcium fertilisers use by farmers in Poland.

Material and methods

The problem of acidification of soils used for agriculture in Poland and across the world has been thoroughly described in the relevant literature (Pierre & Scarseth, 1931; Mehlich, 1942; Pondel et al., 1979; Siuta, 1974; Curyło, 1996; Dobrzański et al., 1995; Bednarek & Lipiński, 1998; Filipek et al., 2015). Large scale field studies into the effects of deacidifying fertilisation on soils with varying particle size distribution were conducted in Poland in the 1970s and 1980s (Boguszewski, 1980; Fotyma & Zięba, 1988). Analysis of the results of these experiments resulted in creation of scientific foundations for deacidifying fertilisation published as "Zalecenia nawozowe cz. II. Optymalne dawki nawozów na gruntach rolnych" (*Fertilisation recommendations part II. Optimum doses of fertilisers on agricultural land*). These recommendations have been followed throughout Poland to this day and constitute a basis when applying for subsidy for the purchase of calcium fertilisers under "The Polish-wide programme for environmental regeneration of soils through liming" (BIP KSChR, 2022).

This programme is scheduled for implementation in the years 2019-2023 and is coordinated by the National Fund for Environmental Protection and Water Management. The final beneficiaries of the programme are holders of agricultural areas. Holders of agricultural areas can receive aid through WFOŚiGW (Voivodship Fund for Environmental Protection and Water Management).

The last National Agricultural Census (NAC) was conducted across Poland between 1 September and 30 November 2020. The results of the NAC, carried out by Statistics Poland every ten years, provide data that enable statistical analysis of the changes taking place in the Polish agriculture, which makes it possible to conduct appropriate agricultural policy and develop and verify programmes to support agricultural activity, such as: "The Polish-wide programme for environmental regeneration of soils through liming".

In the paper, a comparative analysis of the use of mineral and calcium fertilisers was conducted. Cereals' reactions to mineral fertilisation and pH optimisation of the soils in which they had been grown were compared. The paper also discussed the scale of farmers' use of subsidy for deacidifying fertilisation under "The Polish-wide programme for environmental regeneration of soils through liming". The source data were the results of the National Agricultural Census for 2010–2020.

Results and discussion

One of the most important elements of agricultural production environment is soil, with its properties determining the quality and quantity of agricultural crops, and thus profitability of agricultural production. The properties of the majority of soils in Poland developed in the Pleistocene and the Holocene. Currently, most soils in Poland used for agriculture are soils formed from intensely leached and sorted glacial sediments. Due to their genesis, these sediments are mostly characterised by lack of carbonates. The lack of carbonates in the bedrock of soils used for agriculture determines the pH of such soils. Over 70% of the soils in Poland are slightly and strongly acidic (pH< 6.5). Unfortunately, this has a negative impact on the yield of plants that are most important for population feeding, including cereals.

According to the literature (Dobrzański et al., 1995; Kabata-Pendias & Pendias, 1999; Lipiński, 2013; Mocek, 2015), at low values of soil pH:

- there is a decrease in the yield of most cultivated plants as a result of decreased assimilability of micro and macro elements from soil solution,
- the capacity of sorptive complex to retain fertilising substances decreases,
- fertilising substances (macro- and micro elements) can be leached into groundwater under conditions of acidic pH resulting in groundwater eutrophication – this applies to such elements as calcium, magnesium, nitrogen, phosphorus and potassium,
- there is increased plant capacity to assimilate heavy metals, which can decrease the quality of crops, including exchangeable aluminium, which can be toxic at low pH values,
- there is decreased activity of various groups of soil microorganisms whose activity impacts the decomposition of crop residues and deposition of humus in soil, which is responsible (along with clay minerals) for soil sorption capacity and water retention.

Soil liming recommendations have been repeatedly published in numerous scientific periodicals as well as instructional and popular scientific publications (Zalecenia nawozowe, 2010; Igras et al., 2013; Filipek et al., 2015; Jadczyszyn, 2021; Jadczyszyn & Lipiński, 2022). However, the level of theoretical knowledge does not translate into the appropriate level of liming applied in practice by farmers to agricultural areas. Based on data from chemical and agricultural stations, interviews with agricultural and environmental advisers and employees of Agricultural Advisory Centres (own studies), it can be concluded that farmers have increased the amount of applied calcium fertilisers over the last 10 years. However, as the results of the 2020 National Agricultural Census demonstrated, between 2019 and 2021, soil liming was only applied in just over 21% of farms. According to the Code of Agricultural Good Practice (Jadczyszyn & Lipiński, 2022), soil liming should be applied once every 2–4 years depending on soil type. Farmers do not examine the soils to determine their liming needs often enough, and systematic liming is even a less frequent practice.

Analysis of the amount of used calcium fertilisers showed that the biggest increase in their use was recorded in 2020. This increase was a result of "The Polish-wide programme for environmental regeneration of soils through liming", which was launched in 2019 by the Management of the National Fund for Environmental Protection and Water Management Under the programme, farmers can apply for subsidy for the purchase of calcium fertilisers in the amount of PLN 100 to 300 per tonne of pure deacidifying component (CaO and MgO), depending on the size of the farm and value of soil pH.

The number of the applications submitted by farmers was gradually increasing within the duration of the program. In 2019, farmers submitted 5788 applications for liming subsidy, whereas in 2020 the figure increased to 13509, and in 2021 – it was 14797. This amounts to a total of 34 094 applications submitted by farmers in the 3 years of the programme's duration, which is a very small number. It accounts for only a small percentage of 1 317 000 farms registered in Poland (Table 1).

Table 1. The number of applications for liming subsidy under "The Polish-wide programme for environmental regeneration of soils through liming" in the period 2019–2021

Number of applications	Years		
	2019	2020	2021
	5788	13509	14797

Source: own study

Given the number of applications submitted under the programme by 2021, it can be concluded that farmers do not take full advantage of this instrument which would allow them to reduce liming costs. Farmers also do not use their own funds to apply sufficient amounts of calcium fertilisers to increase the soil pH to an optimum level. This is puzzling as the impact of soil pH on the yield is unquestionable and has been thoroughly described in numerous scientific and popular scientific publications. This problem is also a subject of a great deal of training courses offered to farmers.

A positive effect of deacidifying fertilisation applied systematically in certain farms has been confirmed by the results of the National Agricultural Census (2020). Analysis of data for the years 2010–2020 shows that soil fertilisation with calcium fertilisers increased more than twice. The increase in soil fertilisation with calcium fertilisers should be associated with the 20% increase in cereal yields, including the 34% increase in wheat yields (Fig. 1).

It should be stressed that this increase occurred while there was a low increase in fertilisation by mineral NPK fertilisers NPK (by only 10.2%), (Fig. 2), thus it can be assumed that it resulted from increasing the pH level of soils used for agriculture.

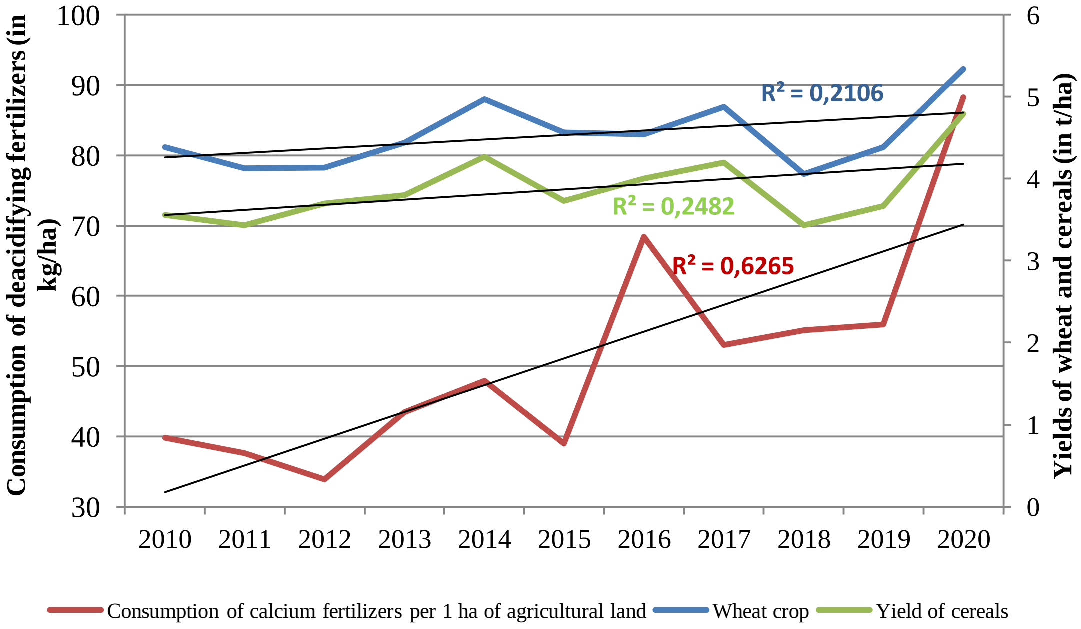

Fig. 1. Total yields of cereals, including wheat, depending on the level of application of calcium fertilizers (2010–2020)
Source: GUS, 2020

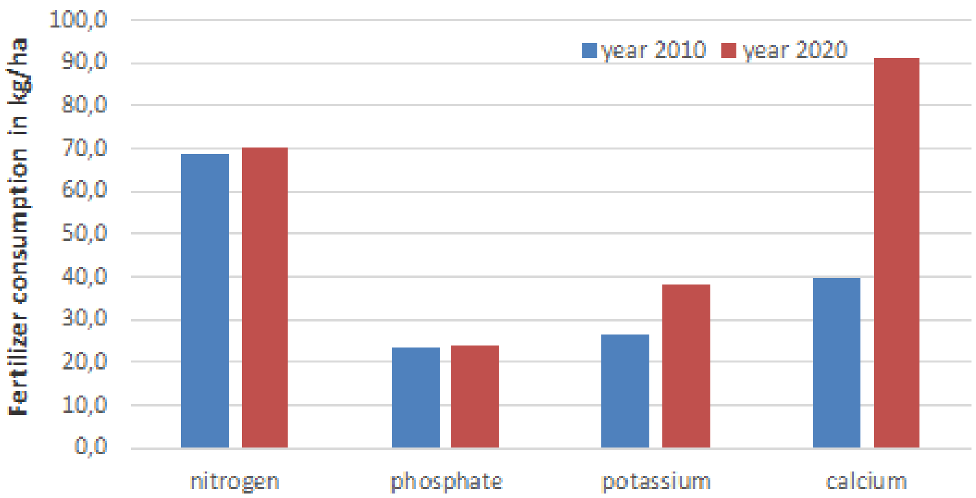

Fig. 2. Consumption of mineral and calcium fertilizers (2010–2020)
Source: GUS, 2020

According to data from Statistics Poland (2020), there is a significant spatial variation in plant production and its intensity in Poland. There is also variation in the level of soil fertilisation – the largest amounts of calcium fertilisers in 2020 were used in Opole Voivodeship, whereas the smallest in Świętokrzyskie and Lesser Poland Voivodeship (Fig. 3).

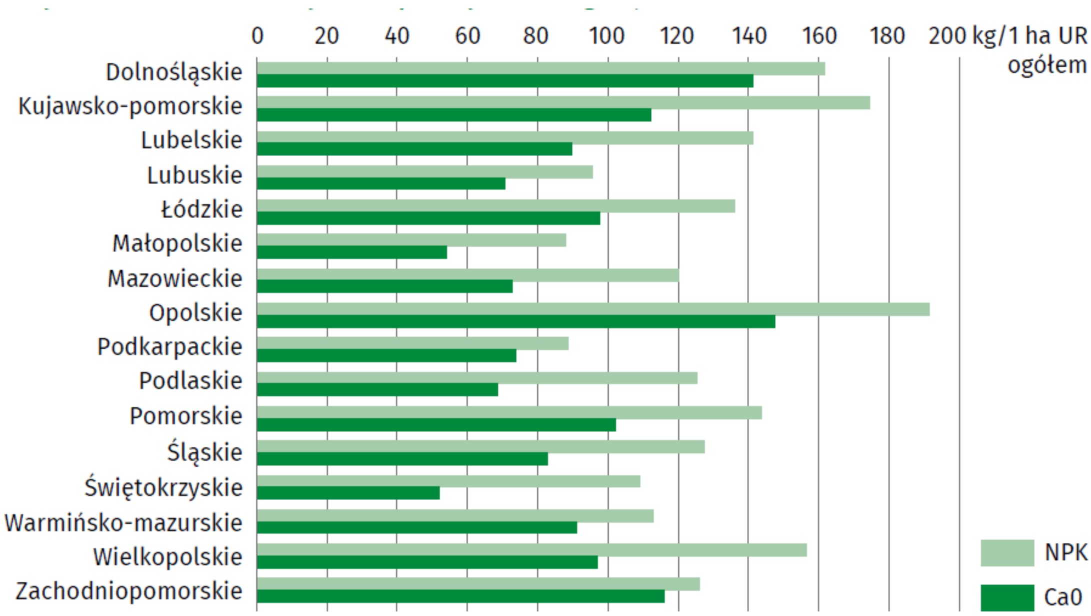

Fig. 3. Usage of mineral and calcium fertilisers by voivodeship in 2020
Source: cited after: Agricultural Census, 2020

Such a large variation in the use of calcium fertilisers in Poland is connected with a number of factors, the most important of which are as follows:

- crops specificity in the different regions of the country,
- the type of soils in which the crops are grown,
- liming needs determined based on soil analysis,
- farm size – larger farms cannot take full advantage of liming subsidy,
- farm fragmentation,
- farmers' knowledge on agricultural technology.

Taking into consideration the genesis of the soils used for agriculture in Poland, lack of carbonates in most of the bedrocks and farming intensity, it can be argued that the above-presented doses of calcium fertilisers are by far too low to ensure appropriate conditions to obtain optimum, much higher yields of high quality agricultural products. The doses of deacidifying fertilisers applied by farmers are often only slightly higher than the losses of calcium and magnesium as a result of them being leached from the soils by precipitation.

The Institute of Soil Science and Plant Cultivation – National Research Institute in Puławy (IUNG), estimates the demand of the national agriculture for lime at around 31 million tonnes of CaO, i.e. around 2 tonnes of CaO/ha of AA on average. This means that the amounts of calcium fertilisers applied by farmers in Poland are a dozen to 38 times lower that they should be.

High acidification of soils used for agriculture, especially in the case of crops sensitive to acidification, leads to a significant decrease in the economic efficiency of farms and, simultaneously, an increased negative impact on the natural environment. According to data contained in the 2022 Krajowy raport o stanie użytków rolnych w Polsce: zakwaszenie gleb oraz ich regeneracja (*National report on the state of* *agricultural areas in Poland: soil acidification and regeneration*), financial losses sustained by Polish farms connected with the leaching of mineral nutrients supplied into acidic soil reach PLN 2–6 billion. The biggest losses resulting from the leaching of fertilising substances supplied into the soil and from reduced quality and quantity of crops are suffered by crops that exhibit a very strong and strong reaction to soil acidification, for example: beetroot, pea, lucerne, clover, corn, wheat, barley, oilseed rape, field bean, white and narrowleaf lupin. Losses per 1 ha of agricultural area as a result of the leaching of fertilising substances may reach PLN 400. They may even be 4 times higher, depending on soil acidification and decrease in the yield of plants sensitive to acidification (the 2020 National report on the state of agricultural areas in Poland: soil acidification and regeneration).

Apart from measurable financial losses connected with the leaching of nutrients from acidic soils, another important issue is soil structure degradation (Mocek, 2015). At acid pH, soil capacity to create soil aggregates decreases, which leads to reduced capacity to store precipitation water. This is a significant problem, especially in the context of physiological drought, a frequent phenomenon in recent years. According to Państwowe Gospodarstwo Wodne Wody Polskie (Polish entity responsible for water management) (2020), the area's most likely to be affected by this phenomenon are: Lublin Voivodeship, Pomeranian Voivodeship, Greater Poland Voivodeship and the West Pomeranian Voivodeship.

When discussing cultivation of agricultural crops on acidic soils, it is necessary to mention eutrophication of surface waters, which takes place as a result of the leaching of fertilising substances from the soils of agricultural areas. In light soils, the sorptive complex, which is characterised by low sorption capacity, is unable to retain the fertilising substances supplied into the soil along with fertilisers (Dobrzański, 1995). As a result of the process of leaching, even 30–50 kg of nitrogen, 70–80 kg of phosphorus and 40–70 kg of potassium from 1 hectare of agricultural areas of acidic soils may end up in surface waters. Along with macroelements, microelements may also be leached into surface waters, including heavy metals, which are very dangerous to the environment and people.

As was already indicated, despite unquestionable advantages of soil deacidification, some farm holders still do not apply deacidifying fertilisers or apply them sporadically, do not have the soil analysed in order to determine the dose of deacidifying fertiliser and do not apply for programmes that provide subsidy for soil liming. As a result, the profitability of agricultural production in their farms is significantly lower, whereas the burden on the environment – greater.

Conclusions

The problem of soil acidification is global in character and connected, just as in Poland, with soil genesis and lack of deacidifying fertilisation. In the EU, acidification was identified as one of key threats to soils, which was articulated in the European Parliament Resolution of 28 April 2021 on soil protection (2021/2548(RSP)).

In this resolution, the European Parliament calls EU member states to ensure sufficient financial support and incentives to promote soil protection, sustainable soil management, soil conservation and remediation as well as innovations and research as part of common agricultural policy, cohesion policy funds, Horizon Europe programme and other available financial instruments.

Given the level of soil acidification of agricultural areas in Poland, decisive steps should be taken to minimise the negative effects of this process. One of the first steps should be taking actions towards an in-depth diagnosis of the reasons for deacidifying fertilisation of soils in our country remaining at a very low level. Factors that may cause farmers' unwillingness to use deacidifying fertilisers and apply for programmes subsidising such activities include:

- erroneous assumptions among farmers regarding liming – they may think that financial investments in these practices will not result in a quick increase in crops,
- failure to spread information about programmes subsidising liming,
- lack of sufficient flow of information between farmers and agriculture-related institutions where a farmer could receive information about liming,
- complicated procedure for obtaining liming subsidy,
- fragmentation of agricultural areas,
- a too high pH of the soils that a farmer wants to lime relative to the requirements specified in the programme,
- limited frequency of subsidising the same plots,
- a too small size of a farm.

A detailed analysis of all existing and potential barriers reducing the level of liming is vital due to the plan to implement the European Green Deal in the EU, which is a strategy for achieving sustainable development of the economy and society. One of the strategic goals of the European Green Deal in the area of agriculture is to reduce the use of mineral fertilisers and pesticides by 20% and 50% respectively in the coming years. Thanks to optimising the pH of soils used for agriculture, meeting the above-described requirements will be easier. A programme that is designed to help optimise the level of fertilisation is the National Strategic Plan for Common Agricultural Policy for 2023–2027, which envisages liming in eco-scheme I 4.4 – Development of and compliance with the fertilisation plan.

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