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Determinants of Soil Liming in Poland: Economic, Social and Behavioral Drivers

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Abstract:

Purpose: *The aim of this study is to identify the economic, social, and behavioral determinants of soil liming practices among Polish farmers.*
Design/Methodology/Approach: *The analysis is based on a survey conducted in 2022 among 443 farmers from four regions of Poland. A CHAID classification tree model was used as an exploratory analytical tool to identify factors differentiating three main liming strategies: systematic liming, sporadic liming, and the abandonment of liming practices.*
Findings: *The results indicate that the primary determinant of liming strategies is the share of farm income in total household income. Technological orientation of farms, farmers' knowledge of soil pH, and the influence of the local farming environment also play important moderating roles.*
Practical implications: *In Poland, soils classified as acidic or very acidic account for more than 40% of agricultural land. Despite this, the level of lime application remains far below recommended levels, with some regions reporting annual application rates of only several tens of kilograms per hectare.*
Originality/value: *The findings highlight the importance of economic incentives, advisory services, and knowledge transfer mechanisms in promoting sustainable soil management practices.*

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1. Introduction

One of the key characteristics determining soil suitability for crop production is soil reaction (pH), which strongly influences nutrient availability, fertilizer efficiency, and crop productivity (Pierre and Scarseth, 1931; Mehlich, 1942). In many regions of the world, including Central and Eastern Europe, agricultural soils are subject to progressive acidification caused by both natural soil-forming processes and human agricultural activity (Filipek and Skowrońska, 2013; Filipek *et al.,* 2015; Ochal and Smreczak, 2020).

Intensive fertilization, long-term cultivation, and atmospheric deposition of nitrogen compounds contribute to a gradual decline in soil pH, reducing the efficiency of agricultural production systems (Goulding, 2016).

In Poland, soil acidification is a widespread phenomenon. Due to the geological origin of many Polish soils, which were largely formed from carbonate-free glacial sediments, a substantial share of agricultural land exhibits naturally acidic reactions (Siuta, 1974; Lipiński, 2005).

Estimates indicate that soils classified as acidic or very acidic constitute more than 40% of the agricultural area in the country (GUS, 2021). As a result, maintaining an optimal soil pH through systematic liming is widely recognized as an essential soil management practice for ensuring stable crop yields and efficient nutrient use (Filipek *et al.,* 2015; Ochal and Smreczak, 2020).

The consequences of soil acidification extend beyond agronomic productivity. Low soil pH reduces nutrient availability and decreases fertilizer efficiency, which may lead to higher production costs and lower crop yields (Goulding, 2016). Inefficient nutrient uptake may also increase environmental pressures through nutrient losses to water systems (Addiscott and Thomas, 2000).

Despite the well-documented agronomic benefits of soil liming, its adoption among farmers remains uneven. Statistical data indicate that lime application in Polish agriculture remains significantly below recommended levels (Tkaczyk *et al.,* 2020). This discrepancy suggests that farmers' decisions regarding soil liming are

influenced not only by agronomic considerations but also by economic conditions, knowledge, attitudes, and the broader social environment in which farms operate.

Understanding the determinants of farmers' liming decisions is therefore essential for designing effective agricultural policies and advisory systems that promote sustainable soil management (Cristea *et al.,* 2022). While previous studies have extensively examined the agronomic effects of liming and its role in improving soil fertility (Goulding, 2016; Holland *et al.,* 2019), much less attention has been devoted to the socio-economic and behavioral determinants of farmers' liming practices, particularly in the context of Central and Eastern European agriculture.

This study investigates the economic, social, and behavioral determinants of soil liming decisions among Polish farmers using a CHAID classification tree model based on survey data from four regions of Poland.

2. Literature Review

2.1 Economic, Social and Environmental Effects of Soil Acidification

Soil fertility is one of the fundamental determinants of agricultural productivity. Among the parameters used to assess soil fertility, soil pH plays a particularly important role because it directly affects nutrient availability and the efficiency of fertilization practices (Pierre and Scarseth, 1931; Mehlich, 1942).

In acidic soils, the availability of essential nutrients such as phosphorus, potassium, calcium, and magnesium decreases, while the mobility of potentially toxic elements increases (Goulding, 2016; Ochal and Smreczak, 2020). As a result, soil acidification may significantly reduce crop yields and limit the efficiency of fertilizer use.

From an economic perspective, soil acidification reduces the productivity of agricultural inputs. Lower nutrient availability may lead farmers to increase the use of fertilizers or plant protection products in order to maintain production levels. Such responses increase production costs and reduce the overall economic efficiency of agricultural activity (Addiscott and Thomas, 2000). Soil acidification also has broader environmental consequences, as inefficient nutrient uptake may increase nutrient losses through leaching and runoff, contributing to water pollution and eutrophication (Addiscott and Thomas 2000; Tkaczyk *et al.,* 2020).

2.2 Regional Differences in Soil Liming in Poland

The level of soil acidification and the intensity of liming vary significantly across regions of Poland. In many areas, acidic soils constitute more than 60% of agricultural land, with particularly high shares observed in southern regions such as Podkarpackie and Małopolskie voivodeships (GUS, 2021).

Despite widespread soil acidification, calcium fertilizer use in Polish agriculture remains relatively limited. According to data from the National Agricultural Census, only about one fifth of farms reported applying lime in 2020, and the average level of calcium fertilization remained considerably below recommended levels (GUS, 2021; Tkaczyk *et al.,* 2020).

Regional differences in liming intensity are influenced by both natural and structural factors. Higher lime application levels are generally observed in regions with larger farms and more intensive agricultural production, while lower levels are typical of areas dominated by small family farms.

Agricultural policy instruments may also influence the level of liming. In recent years, Poland has introduced financial support for soil regeneration through liming under a national soil improvement program. The program provides subsidies for calcium fertilizers and aims to improve soil quality in areas affected by acidification (Nicia *et al.,* 2023).

2.3 Liming as Part of a Comprehensive Agronomic Strategy

Soil liming is an important component of a broader set of agronomic practices designed to enhance soil fertility and support sustainable agricultural production. By neutralizing soil acidity, liming improves nutrient availability and increases the effectiveness of mineral fertilization (Goulding, 2016; Holland *et al.,* 2019).

However, the effectiveness of liming depends on its integration with other elements of farm management. Liming is most effective when combined with appropriate fertilization strategies and crop management practices (Filipek *et al.,* 2015). Without proper fertilization, liming alone may not lead to sustained improvements in soil fertility, while intensive fertilization without liming may accelerate soil acidification (Ochal and Smreczak, 2020).

The agronomic benefits of liming are therefore closely linked to the broader technological orientation of agricultural production. Farms that implement integrated soil management strategies typically combine liming with fertilization, crop rotation, and plant protection practices (Lacoste *et al.,* 2016). Liming requires additional financial investments and long-term planning. For some farms, particularly smaller or less specialized ones, these costs may discourage the adoption of systematic liming practices.

3. Materials and Methods

3.1 Study Area and Survey Data

The empirical analysis was based on a 2022 survey of farmers from four Polish regions with different levels of soil liming intensity: Małopolskie, Opolskie,

Podkarpackie, and Zachodniopomorskie. The study areas were selected through a multi-stage procedure in which counties were first classified by calcium fertilizer use and then paired within each region to capture regional variability in liming practices. Additional selection criteria included agricultural production potential, land-use structure, and farm size distribution.

Within each voivodeship, pairs of counties with clearly different levels of calcium fertilization were identified in order to capture regional variability in liming practices. The selection of the study areas also considered additional factors such as agricultural production potential, land use structure, and farm size distribution.

A structured questionnaire survey was conducted among farm owners operating in the selected counties. The questionnaire included questions concerning soil pH testing, soil liming practices, knowledge about the effects of soil acidity, and perceived barriers to the use of calcium fertilizers.

The final dataset included responses from 443 farmers. Respondents represented farms with different levels of experience, education, and farm characteristics. In terms of economic structure, farms also differed in the share of agricultural income in total household income, enabling analysis of how economic dependence on farming influences liming decisions. The regions were selected to capture diverse production conditions and liming practices rather than to achieve full national representativeness.

3.2 Model Specification

To identify determinants of soil liming practices, a CHAID classification tree was applied. CHAID is a data-mining technique designed to identify relationships between a categorical dependent variable and a set of explanatory variables by repeatedly splitting the dataset into more homogeneous subgroups. The method was chosen because farmers' liming decisions result from interactions among economic, technological, and social factors. The dependent variable in the model represented three main liming strategies declared by farmers:

- systematic liming – regular soil liming performed periodically or following soil pH testing,
- sporadic liming – irregular or occasional application of calcium fertilizers,
- no liming – deliberate resignation from soil liming.

Explanatory variables were derived from survey responses and described four main dimensions of farm functioning:

- farmer characteristics, including age, education, farming experience, and knowledge about soil pH and liming practices,

- household economic structure, particularly the share of farm income in total household income,
- farm characteristics, including farm size, production changes in recent years, and the use of agricultural inputs such as fertilizers or plant protection products,
- environmental and social context, including farmers' engagement with training and advisory services and local prevalence of liming practices.

Model parameters were set according to standard CHAID procedures. The minimum number of observations in a splitting node was set at 10, and the significance level for splitting and merging categories was set at 0.05. Model performance was evaluated using 10-fold cross-validation.

The purpose of the model was exploratory rather than causal. The analysis aimed to identify patterns of conditions linked to different liming strategies and to characterize distinct farmer behavioral profiles related to soil liming.

First, a fully automatic CHAID classification tree was generated under predefined statistical constraints. The resulting model was then examined node by node using the prediction-for-node diagnostic procedure. For each node, only the highest-ranked predictors - characterized by low adjusted p-values and high segmentation usefulness - were considered as alternative splitting variables.

The final tree structure was selected step by step from this limited set of statistically comparable predictors in order to improve interpretability while maintaining similar classification accuracy.

4. Results

Table 1 compares the fully automatic CHAID tree with the final interactive version of the model obtained through the node-by-node refinement procedure described in Section 3.2. Both models achieved a similar level of classification accuracy. The misclassification risk amounted to 0.161 for the automatic tree and 0.173 for the interactive model in the training sample, and 0.226 and 0.231, respectively, in the validation sample. The refined model was adopted as the final model for further analysis because it provided a shorter decision path and greater interpretability.

Table 1. *Structural comparison of automatic and interactive CHAID trees*

CHAID model variant	No. of split/terminal nodes	Max. tree depth	Min. terminal node size (N)	Risk (training)	SE (training)	Risk (CV)	SE (CV)
Automatic	7/9	4	11	0.161	0.018	0.226	0.027
Interactive	8/10	3	10	0.173	0.018	0.231	0.027

Source: *Own study.*

Table 2 presents the statistical characteristics of the splits used in the final CHAID tree. All splits remained statistically significant after adjustment, confirming that the variables selected by the algorithm significantly differentiated farmers' liming strategies.

Table 2. *Split statistics for the final interactive CHAID tree*

Node ID	Parent node	Splitting variable	χ^2	df	Adjusted p-value
1	NA	What percentage of the household's income comes from the farm?	107.846	4	< 0.000001
17	1	What amounts of nitrogen/phosphorus fertilizers were utilized in the past year?	21.169	2	0.000405
18	1	Does soil pH influence plant health and yield?	39.059	2	< 0.000001
19	1	What amounts of nitrogen/phosphorus fertilizers were utilized in the past year?	17.236	2	0.001446
31	17	Plans for the next 10 years?	26.962	4	0.001811
32	17	Is liming a widespread practice?	20.062	2	0.000704
24	18	Has the usage of pesticides changed over the last 5 years?	46.841	4	< 0.000001
20	19	Is liming a widespread practice?	7.228	2	0.031009

Source: *Own study.*

The model considered 64 potential explanatory variables derived from the survey questionnaire. For clarity, Table 3 reports the variables with the highest relative importance in the CHAID procedure. It should be emphasized that the predictor importance ranking reflects the aggregated contribution of variables to the segmentation process across the entire tree, whereas the actual tree splits are determined by local optimization of the chi-square statistic within individual nodes. Consequently, variables ranked highly in the importance list do not necessarily appear as direct splitting variables in the final model.

Table 3. *Top-ranked explanatory variables considered by the CHAID algorithm*

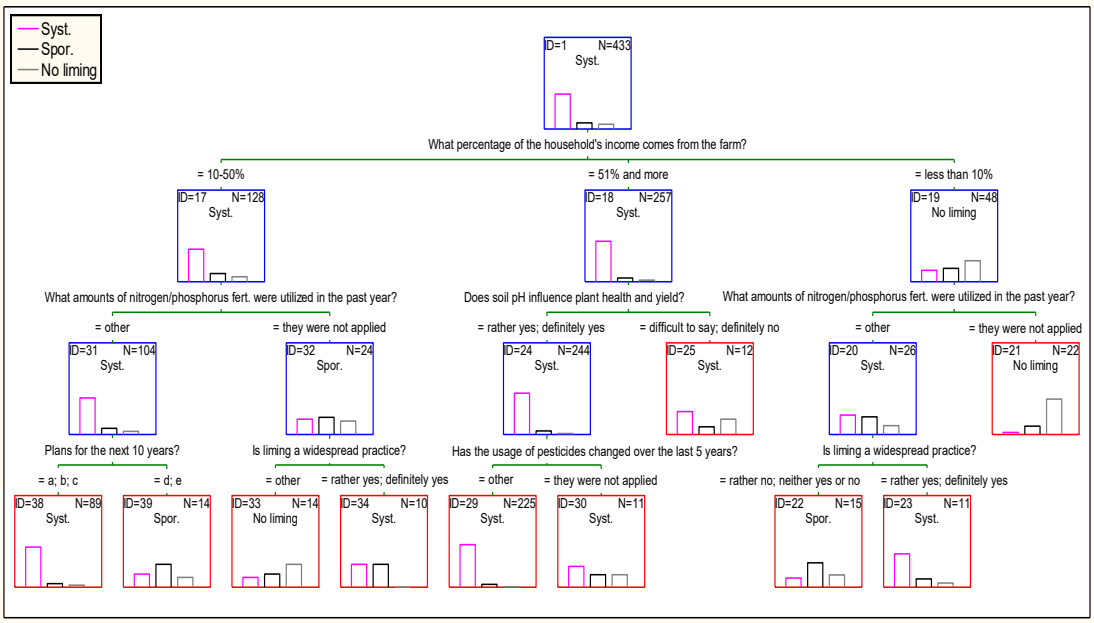
Rank	Predictor	Relative importance
1	Has the usage of pesticides changed over the last 5 years?	1.000
2	Does liming increase the effectiveness of nitrogen fertilizers?	0.788
3	Is liming a widespread practice?	0.714
4	Does liming increase the effectiveness of potassium fertilizers?	0.707
5	Does liming increase the effectiveness of phosphorus fertilizers?	0.657
6	Is soil pH testing a common practice in the locality?	0.622
7	Does liming improve growth conditions for most crops?	0.621
8	Can liming increase yields while reducing the need for other fertilizers?	0.599
9	Has the use of plant growth regulators changed over the last 5 years?	0.581
10	Does soil pH influence plant health and yield?	0.575

11	What amounts of nitrogen/phosphorus fertilizers were utilized in the past year?	0.532
12	Plans for the next 10 years?	0.493
13	Has the use of mineral NPK fertilizers changed over the last 5 years?	0.451
14	Has the use of biostimulants changed over the last 5 years?	0.418
15	Were investments made over the last 5 years?	0.425

Source: *Own study*

The final CHAID tree consisted of eight split nodes and ten terminal nodes. Six terminal nodes corresponded to systematic liming strategies, two represented sporadic liming, and two were associated with the complete abandonment of soil liming (Figure 1).

Figure 1. *Diagram of a CHAID classification tree for liming strategies.*



Note: *a - continue conducting agricultural activity, b – pass on to the successor, c – sell, d - set aside the land, e – lease*
Source: *Own study.*

4.1 Economic Dependence on Agriculture

The most important determinant differentiating liming strategies was the share of farm income in total household income, which formed the root node of the classification tree. Farmers whose agricultural activity constituted the main source of household income were significantly more likely to apply lime systematically. In this group, the vast majority of respondents reported regular liming practices,

whereas sporadic liming or complete abandonment of this practice occurred relatively rarely.

This result indicates that soil liming is strongly associated with the economic importance of farming activity. Farmers whose income depends largely on agricultural production appear more willing to invest in practices that maintain soil productivity and support the long-term stability of production.

4.2 Technological Orientation of Farms

Another important factor differentiating liming strategies was the technological orientation of farms, reflected, among other things, in the use of mineral fertilizers.

Among farms applying nitrogen and phosphorus fertilizers, systematic liming was far more common than on farms where mineral fertilization was not practiced. This finding suggests that liming is part of a broader set of agronomic practices characteristic of farms operating with more intensive crop production technologies.

At the same time, it should be noted that some variables related to the use of production inputs, including changes in the use of plant protection products, were among the highest-ranked predictors in the importance ranking (Table 3). Their high position in the predictor importance ranking therefore reflects their association with the overall technological intensity of farm management, rather than a direct influence on the choice of liming strategy.

4.3 Farmers' Knowledge and Perceptions

The model also revealed the importance of farmers' awareness of the relationship between soil pH and plant productivity. Farmers who recognized the influence of soil pH on plant health and yield were significantly more likely to apply systematic liming.

In contrast, among farmers who did not regard soil pH as highly important, sporadic liming or the complete abandonment of liming occurred more frequently. This finding highlights the role of knowledge and awareness in shaping decisions related to soil management practices.

4.4 Influence of the Social Environment

Another factor influencing liming strategies was the local farming environment. Farmers were more likely to adopt liming practices when they observed similar practices among neighbouring farms. In areas where liming was perceived as a common practice, both systematic and sporadic liming occurred more frequently. Conversely, when such practices were not observed in the local environment, the probability of abandoning liming increased.

This suggests that farmers' decisions are influenced not only by economic and technological considerations but also by social norms and the behaviour of other farmers within the local agricultural community.

4.5 Future Plans for the Farm

Farmers' future plans regarding the development of their farms also influenced liming strategies. Farmers planning to continue agricultural activity or transfer their farms to successors were more likely to invest in long-term soil management practices such as liming. In contrast, farmers contemplating a reduction or abandonment of agricultural activity were less likely to apply lime systematically. This indicates that investments in soil fertility are more common among farmers who perceive farming as a long-term economic activity.

4.6 Summary of Determinants

Overall, the results indicate that farmers' liming strategies are shaped by interactions among multiple factors. The economic importance of farming in the household income structure plays the primary role, while technological orientation, farmers' knowledge, and the influence of the local farming environment act as moderating factors.

The CHAID model enabled the identification of distinct behavioural profiles among farmers. Farms strongly dependent on agricultural income and characterized by more intensive production practices were much more likely to adopt systematic liming. In contrast, farms with lower economic dependence on agriculture and lower production intensity more often applied liming sporadically or abandoned the practice altogether.

Soil liming strategies are shaped by the interplay of economic dependence on farming, farms' technological orientation and social influence within the local farming environment, which together differentiate farmers into distinct behavioral profiles.

5. Discussion

The results of this study indicate that farmers' soil liming strategies are shaped by the interplay of economic, technological, and social factors. The CHAID model revealed that the most important determinant of liming decisions is the economic importance of agricultural activity within the household income structure.

At the same time, technological orientation of farms, farmers' knowledge of soil pH, and the influence of the local farming environment further differentiate farmers' behaviour.

5.1 Economic Dependence on Agriculture

The strongest determinant of soil liming practices identified in the model was the share of farm income in total household income. Farmers whose livelihoods depend primarily on agricultural production were significantly more likely to apply lime systematically.

This result confirms that soil liming can be interpreted as an investment in maintaining the productive capacity of agricultural land. Soil conditions directly affect crop yields and the efficiency of agricultural inputs, which means that maintaining appropriate soil pH is an important factor supporting the economic performance of farms (Goulding, 2016).

Consequently, farms that rely strongly on agricultural income have greater incentives to invest in practices that protect soil fertility and long-term production stability. In contrast, farms characterized by a lower economic dependence on agriculture may treat agricultural production as a supplementary activity. In such cases, investments in long-term soil management practices, including liming, may be perceived as less economically justified.

5.2 Technological Orientation of Farms

Another important factor differentiating liming strategies was the technological orientation of farms. Systematic liming was significantly more common among farms applying mineral fertilizers, which suggests that liming is typically implemented as part of a broader technological system of crop production.

Previous studies have demonstrated that soil liming improves nutrient availability and increases the efficiency of fertilization practices (Filipek *et al.,* 2015; Goulding, 2016). By increasing soil pH, liming enhances nutrient uptake and improves the effectiveness of mineral fertilization, which may contribute to higher crop productivity (Holland *et al.,* 2019).

As a result, farms operating with more intensive production technologies may perceive liming as a complementary practice that increases the efficiency of other agricultural inputs. These findings support the view that soil management practices should be analysed within the broader context of integrated farm management strategies rather than as isolated agronomic decisions (Lacoste *et al.,* 2016).

5.3 Farmers' Knowledge and the Local Farming Environment

The results also highlight the importance of farmers' knowledge and the local social environment in shaping soil liming decisions. Farmers who were aware of the relationship between soil pH and plant productivity were significantly more likely to apply lime systematically.

Previous research has emphasized that knowledge about soil conditions and appropriate management practices is an important factor influencing the adoption of sustainable agricultural practices (Filipek *et al.,* 2015; Ochal and Smreczak, 2020).

At the same time, the prevalence of liming practices within the local farming environment increased the likelihood that farmers would adopt similar practices.

This suggests that farmers' decisions are influenced not only by economic and technological considerations but also by social interactions and information exchange within local agricultural communities.

5.4 Implications for Agricultural Policy

The findings of the study have important implications for agricultural policy and advisory services. Since the adoption of liming practices is strongly associated with the economic importance of agriculture for farm households, financial support mechanisms may play a key role in promoting soil fertility management, particularly among smaller or less specialized farms.

The importance of farmers' knowledge and the local farming environment suggests that advisory services and training programs may significantly influence the diffusion of soil management practices. Strengthening farmer education, soil monitoring programs, and knowledge transfer within local farming communities may therefore contribute to improving soil fertility management in regions affected by soil acidification.

6. Conclusions

This study examined the economic, social, and behavioral determinants of soil liming practices among farmers in Poland using a CHAID classification tree model based on survey data from four regions.

The results indicate that farmers' liming strategies are primarily shaped by the economic importance of agriculture within the household income structure, while technological orientation and the local farming environment further differentiate farmers' behavior.

Farmers whose income depends strongly on agricultural production are significantly more likely to apply lime systematically, which suggests that soil liming is perceived as an investment in maintaining the productive capacity of agricultural land. Liming practices are closely associated with broader technological strategies of crop production, particularly in farms applying mineral fertilization.

The findings also highlight the importance of knowledge and the local social environment in shaping soil management decisions. Farmers who recognize the role

of soil pH in crop productivity and who operate in environments where liming practices are commonly observed are more likely to adopt systematic liming.

These results suggest that policies aimed at improving soil fertility management should combine economic incentives with advisory services and knowledge transfer mechanisms.

Strengthening farmer education and promoting the diffusion of soil management practices within local agricultural communities may play an important role in increasing the adoption of soil liming in regions affected by soil acidification.

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