LIMING EFFECT ON NITROGEN USE EFFICIENCY AND NITROGEN OXIDE EMISSIONS IN CROP FARMING

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Abstract
Liming soils make both direct and indirect effects on greenhouse gas (GHG) emissions. If raising the pH of soil, the amount of N_2O emissions in the result of nitrification decreases; therefore, it is important to perform also maintenance liming if applying nitrogen fertilisers. Liming acidic soils contributes to the absorption of nutrients supplied by means of fertilisers by plants, limits the spread of plant diseases, forms better soil moisture and air regimes for plants, improves the structure of soil and activates microorganisms. The aim of this study was to assess liming effect on nitrogen use efficiency and nitrogen oxide emissions in crop farming. To achieve the aim, this study proceeds in two stages: 1) to analyse the scientific literature on the liming effect on nitrogen use efficiency and nitrogen oxide emissions in other countries, as a few such research studies are available in Latvia; 2) to calculate potential gains and losses from liming acid soils in order to examine the real situation concerning liming and its effects on the economy of farms. The research finds out that at the farm level in Latvia liming gives a positive economic effect (41.6 EUR ha^{-1}) however, it is essential for maintaining soil fertility, increasing yields, and presumably for more efficient circulation of nitrogen, which decreases nitric oxide emissions.
Key words: liming, pH, nitrogen efficiency, GHG emissions.

Introduction

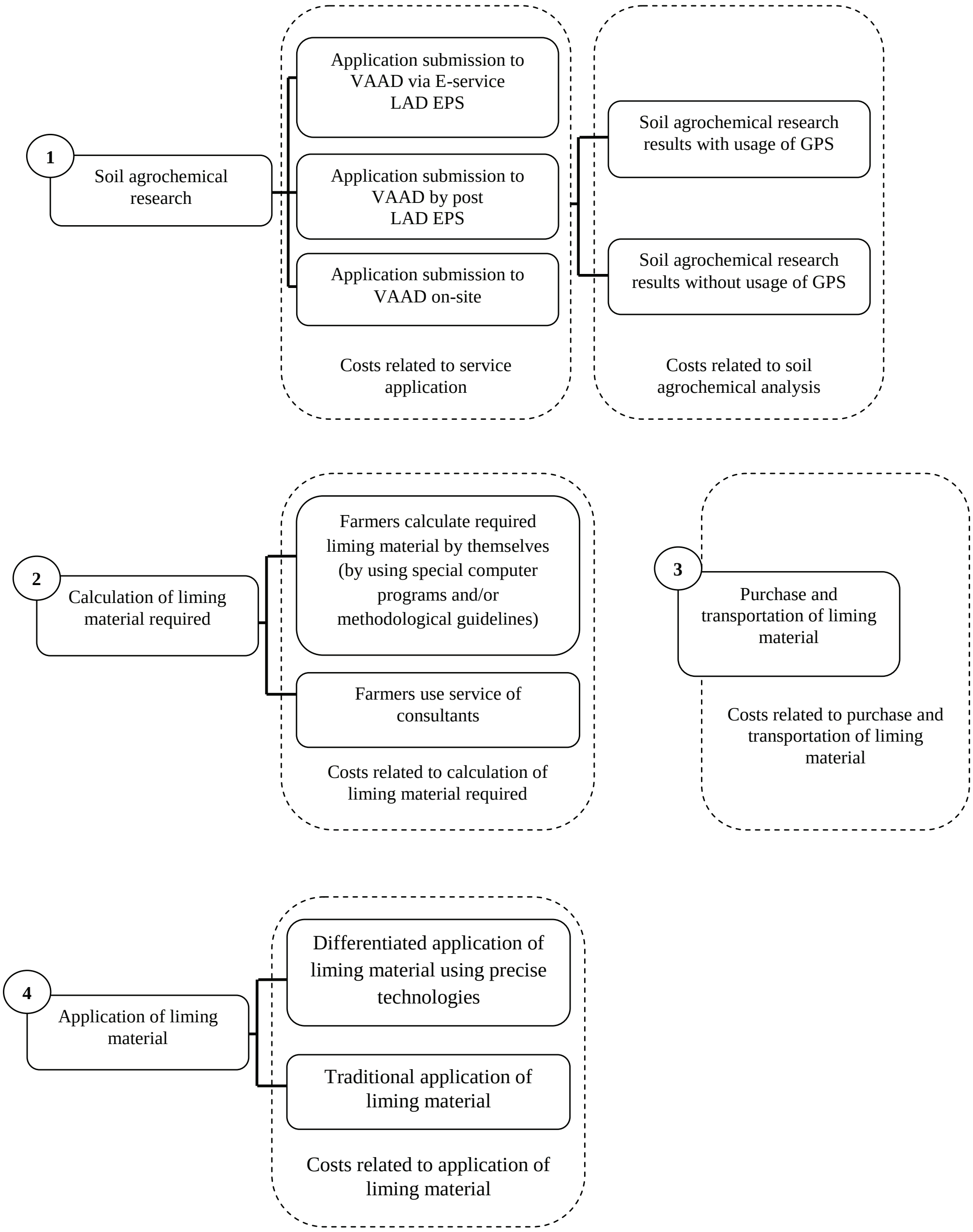
Mineral fertilizers have a significant impact on greenhouse gas (GHG) emissions, but at the same time they also imply a big mitigation potential by contributing to better land productivity and to reducing the need for land use change. By improving nutrient use efficiency, highly productive farming systems contribute to GHG mitigation. The expected decrease in N inputs to soils in the future will also decrease soil acidification. The amount of limestone used in agriculture in several western and northern European countries has decreased substantially. (Velthof *et al.*, 2011). Now in Latvia of the total agricultural land 40% has acidic soils; lime has to be applied to gain high yields of protein crops and other crops. Liming was extensively implemented in Latvia in the period 1986–1988, but even then the $CaCO_3$ balance was negative in Latvia's agricultural areas exploited intensively, as calcium and magnesium compounds were leached from the arable layer by rain waters, removed by crops and neutralised by acidity caused by fertilisers. In Latvia, according to G. Pakalns (2006), if liming 217 thou ha of acidic soils a year, on average, 1007 thou t $CaCO_3$ are brought into soil by means of agricultural lime and organic and synthetic fertilisers, while 1075 thou t are removed by crops, leached and used to neutralise acidic fertilisers; the deficit amounts to 68 thou t, i.e., on average, 34 kg ha^{-1} $CaCO_3$. According to A. Kārkliņš (1996), $CaCO_3$ leaches from clay soils at a rate of 200–250 kg ha^{-1} and from sandy soils at a rate of 60 kg ha^{-1}, while the quantity of $CaCO_3$ needed for the neutralisation of acidity caused by fertilisers depends on the kind of fertilisers and their application rates. Already since 1992 a too small agricultural area was limed, which began affecting the quality of soils. In 1990, an area limed reached 149.2 thou ha, while in 2000 it decreased to 2.5 thou ha. According to the Central Statistical Bureau, approximately 18 777 ha were limed in 2014; yet, the leaching of calcium and its removal by crops continued. In Latvia, 100 thou ha have to be limed in order to prevent soils from becoming more acidic. Liming an acid soil is the first step in creating favourable soil conditions for productive plant growth. Crops vary in their ability to tolerate an acidic (low pH) soil. In addition, evidence has shown that soil acidity may influence other crop management problems such as herbicide activity. Soil pH is a good indicator of the need for liming. A soil pH of 5.5 or lower will often result in significant negative impact on most crops. The general goal of liming agricultural soils continues to be a soil pH of 6.0 to 7.0.

Such situation analysis set the aim for this study – to assess liming effect on nitrogen use efficiency and nitrogen oxide emissions in crop farming. To achieve the aim, two specific research tasks were set: 1) to analyse the scientific literature on the liming effect on nitrogen use efficiency and nitrogen oxide emissions; 2) to calculate potential gains and losses from liming acid soils. The object of this study is potential gains and losses from the liming acid soils.

Materials and Methods

This study is part of a broader research aiming to assess the agricultural sector GHG emissions reduction potential and to make costbenefit analysis for GHG abatement measures and make recommendations for policy planning in the field of emission reduction. This study proceeds in two stages: 1) to analyse the scientific literature on the liming effect on nitrogen use efficiency and nitrogen oxide emissions in other countries, as a few such research studies are available in Latvia; 2) to calculate potential gains and losses from liming acid soils in order to examine the real situation concerning liming and its effects on the economy of farms.

According to scientific literature (Soon & Arshad, 2005; Valkama *et al*., 2013), liming acid soils can be used as one of the GHG mitigation measure. However, current situation in Latvia has showed that agrochemical research of soils was conducted only in less than 10% of the utilised agricultural area (UAA), mainly in very sensitive territories. Therefore, in order to estimate the real situation concerning liming and its effects on the economy of Latvian farms, calculations of potential gains and losses from liming were performed in this study. In order to understand the main costs, positions related



Abbreviations: LAD - Rural Support Service; EPS - electronic application system; VAAD – State Plant Protection Service.
Source: created by authors.

Figure 1. Mapping of costs related to implementation of liming.

to implementation of liming mapping of costs were made (see Figure 1).

To achieve the set aim and tasks of the research, the authors have used the publications and studies of foreign and Latvian scientists, legislation, reports and recommendations. The research authors have widely applied generally accepted research methods in economics, i.e. monographic descriptive method as well as analysis and synthesis methods to study the problem elements.

Results and Discussion

Analysis of the scientific literature on the liming effect on nitrogen use efficiency and nitrogen oxide emissions

It has been scientifically proved that soil N transformations and fluxes can be affected by soil pH (Soon & Arshad, 2005). According to P.W. Moody and co-authors (1995) and C.A. Rosolem and co-authors (1995), the flow of N through processes such as mineralization, nitrification and microbial immobilization influences N availability, and thus when acid soils are limed, crop uptake of N can increase through enhancement of soil N turnover and root and shoot growth. Some research findings (Barton, Murphy, & Butterbach-Bahl, 2013) show that the largest nitrous oxide (N_2O) emissions arise from soils lying fallow after a rain period, compared with the emissions from nitrogen fertilisers produced during the crop growing period. N_2O emissions from acidic soils increase during nitrification. Besides, N_2O emissions from dry soils reach 0, but with moisture increasing in soils, the emissions can increase up to 0.065 μg N_2O owing to both nitrification and denitrification. With the pH of soil increasing, N_2O emissions decrease. According to research studies, increasing the pH of soil decreases N_2O emissions from acidic soils during rainfall periods when the emissions are caused by nitrification (Barton, Murphy, & Butterbach-Bahl, 2013). Australian scientists, in their research on lupine-wheat and wheat-wheat rotations with using N fertilisers, have also proved that liming contributes to decreases in GHG emissions from farms, as the flow of N_2O declines and the absorption of CH_4 increases (Barton, Murphy, & Butterbach-Bahl, 2013).

Under the conditions in Latvia there can be performed two types of liming – correction liming and maintenance liming. Correction liming is aimed at radically raising soil reaction in the entire arable layer for a long period. It is performed if the reaction of mineral soils is below pH KCl 5.5, while for peat soils it is pH KCl 5.0. A lime fertiliser is brought into soil while doing correction liming functions only for a limited period; therefore, liming has to be periodically repeated. In order to compensate acidification processes caused by application of acid fertilisers, runoff of Ca and by acid rain a repeated liming operation is needed even if the soil was very acidic and the correction liming operation did not result in optimum soil reaction. Unfortunately, there are no recent researches about effect of liming on yield. However, experiment results from trials made in 1982–1983 showed that after performing liming in fields with pH 5.5, an increase in barley yield by 0.3 – 0.5 t ha^{-1} (Štikāns, 1992) was observed. Maintenance liming is performed to periodically offset the loss of Ca and Mg in the arable layer of soil and to maintain the pH of soil at optimum level. Maintenance liming is usually recommended to be done once in three years, spreading from 1.0 to 1.5 t of $CaCO_3$ per hectare. According to research studies by J. Vigovskis (2014) in Skriveri: in the area where a higher lime rate was applied, soil acidity decreased to a pH of 5.2, while in the area with a low lime rate the pH of soil decreased to a lower level (pH 4.6) than it was before (pH 4.8). In the area that was not limed the soil reaction also continued gradually declining (from pH 4.8 to pH 4.4.) The experimental results convincingly prove that without carrying out maintenance liming operations, soils became more acidic by pH 0.7 – 0.8.

The size of farms is not important for liming acidic soils, but the choice of a lime fertiliser, depending on the amounts of Ca and magnesium (Mg) available in soil, is essential. From the perspective of soil reaction, there are two types of soils in Latvia: soils that are formed on dolomites and soils that are formed on limestone. For example, along the rivers of Daugava and Lielupe and in some other areas – on dolomites – where soil acidity should be normal, it often lacks Ca, as the ratio of Ca to Mg is inappropriate. For example, near Saulkalne where Mg in soil is available in too large amounts, applying dolomite powder brings more Mg into soil, which is not necessary; the most appropriate substance in this case is limestone powder. In contrast, in Southern Kurzeme – in the vicinities of Saldus and Liepaja – the situation is opposite, as there is a lack of Mg in soil and dolomite powder is appropriate for liming. A very important indicator in the assessment and choice of lime fertilisers is their contents of Ca and Mg and the ratio of these elements. If an inappropriate lime fertiliser is chosen, the expected result will not be achieved neither on large nor small farms if the purpose is only to adjust the pH of soil by liming without taking into consideration the ratio of Ca to Mg in the soil (Nollendorfs, 2004).

Calcium together with humus forms the structure of soil and determines soil water and air capacities and soil reaction. Acidic soils do not have enough Ca, but it is the most essential nutrient for plant growth. If soils are not limed, their structure degrades, they become dense faster and unfavourable moisture and air regimes emerge in the soils; nitrification in acidic soils is also hindered – the activity of microorganisms declines and plant diseases spread. Consequently, crop yields decrease as well. Plant nutrients brought into soil by means of fertilisers do not perform effectively in acidic soils, and the absorption of microelements is obstructed. For example, phosphorous forms compounds difficult to reach and absorb by plants. Molybdenum is actually unabsorbed too. If soils are acidic and lack calcium, even the contents of potassium and magnesium decrease in plants. In contrast, the absorption of radioactive substances and heavy metals (lead, zinc, cadmium, arsenic), which are dangerous for human health, increases. They can accumulate in plants to toxic rates. Accordingly, one can conclude that liming is a way of achieving higher yields and better product quality on any crop farm. On livestock farms, feed produced in limed soils has higher contents of Ca and protein; therefore, there is an opportunity to achieve greater agricultural output and higher product quality (Hylander, 1995; Mandai, Pal, & Mandai, 1998).

With acidity rising and the content of organic matter declining in soil, plants can absorb less nutrients, whereas the absorption of pollution by plants increases. Consequently, one can find that liming acidic soils is urgent for any kind of farms. It is of great importance to enterprises of intensive farming due to high rates of nitrogen fertiliser application and relatively high rates of Ca removal from soil, while the formation of organic matter in soil, which is hindered in an acidic environment, is important to organic farms. For example, liming soils in Scandinavia is very important; it is estimated that up to 300 kg calcium (Ca) per hectare have to be annually brought into soil. For this reason, crop yields in Sweden, where soils have formed mainly on rock, are higher than in Latvia (Fornara *et al*., 2011).

Under the conditions in Latvia due to denitrification, N_2O and N_2 turn into 10% of the mineral nitrogen present in soil. Soil affects GHG emissions and their absorption. Therefore, GHG monitoring, simulations of expected GHG changes and forecasts of the potential effects on climate change, vegetation, etc. are not possible without information on the most important soil properties (Kasparinskis, Nikodemus, & Kārkliņš, 2016). However, limited information is available on liming effects on crop production and nitrogen (N) cycling in acid soils in Latvia. Therefore, experience of other countries can be very relevant for estimating liming effect on nitrogen use efficiency and nitrogen oxide emissions.

In Northern Ireland liming has significantly increased perennial ryegrass (*Lolium perenne*) yield and N off take and affects N recovery by swards at both harvests in at least two different ways. During phases of net N mineralization liming stimulates biomass activity and increases the amount of organic N mineralized, but during phases of net N immobilization, liming by increasing Ca availability in the rhizosphere improves the ability of plants to absorb N. Thus, it helps plants to compete with the biomass for mineral N (Baileya, 1995) more effectively. In experiments in Canada, it has been proved that liming improves fertilizer efficiency and increases the activity of soil microorganisms to release organic nitrogen and other crop nutrients from manures and plant residues more rapidly and enhances nitrogen fixation by legumes. Liming improves soil aggregate stability, it is one of the best suppliers of calcium and magnesium to crops; it also reduces toxic aluminium levels, which is very important for alfalfa and other legumes yield performance and longevity (van Roestel, 2014). Lower uptake efficiency of nitrogen and other primary nutrients can be observed in acidic soils (pH 5.0), where the overall fertilizer uptake efficiency is 46%compared with 86% in neutral soils (see Table 1). In acidic soils primary nutrients are strongly attached to soil clay particles and therefore their uptake by crops is much slower; as the result of this the yield and protein content in such crops is lower than in crops grown in neutral soils.

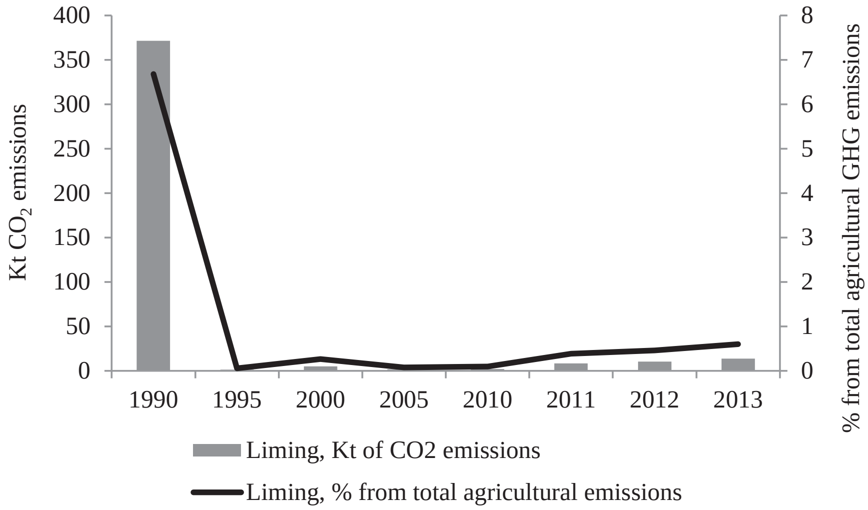
In experiments in Germany, it was concluded that application of nitrogen fertilizer may acidify soil, thus in the selection of liming material type of nitrogen

Table 1

Efficiency of primary nutrients uptake by crops at various soil pH values, %

Soil pH	Nitrogen efficiency, %	Phosphorous efficiency, %	Potash efficiency, %	Overall fertilizer efficiency, %
6.5	95	63	100	86
6.0	89	52	100	80
5.5	77	48	77	67
5.0	53	34	52	46

Source: van Roestel, 2014.



Source: authors' calculations complied with National Inventory Report, 2015.

Figure 2. Dynamics of CO_2 emissions removed from liming in Latvia, 1990 – 2013.

fertilizer should be taken into account. For example, in the case of application of ammonium nitrate, urea and liquid urea ammonium nitrate there will be a need for 1.8 kg $CaCO_3$ per kg N; in the case of application of calcium ammonium nitrate – 0.86 kg $CaCO_3$ per kg N; in the case of ammonium sulphate – 5.4 kg $CaCO_3$ per kg N; but in the case of application of calcium nitrate, there will be no need for liming (Brentrup & Pallière, 2008).

Considering the liming positive effect on nitrogen use efficiency and nitrogen oxide emissions, it should be taken into account that due to dissolution of lime in soils, liming results in release of CO_2 emission. The Intergovernmental Panel on Climate Change (IPCC) has recognised this source of CO_2 in methodology of calculating GHG emissions (IPCC, 2006). Countries are obliged to report the CO_2 emission from limestone and dolomite use in agriculture in the annual national GHG inventories to United Nations Framework Convention on Climate Change (UNFCCC). The use of lime in agriculture is only a minor source of $CO_{2,}$ but at the same time it is much smaller than the N_2O emission from agriculture (Velthof *et al*., 2011). Dynamics of CO_2 emissions removed from liming in Latvia during period 1990 – 2013 is summarized in Figure 2.

In Latvia, soil liming is voluntary and farmers do not receive any financial support. Therefore, the dynamics of CO_2 emissions removed from liming in Latvia has been very uneven with a growing tendency starting from 2013.

Potential gains and losses from liming acid soils in Latvia

The next step in this study was to examine the real situation concerning liming and its effects on the economy of farms. A problem situation was analysed to illustrate the costs of the activity based on the following assumptions: the analysis period is 8 years, soils are acidic and the corrective liming rate is 5.9 t ha^{-1} for Nordkalk. A repeated liming operation is performed every third year, and the maintenance liming rate is 1 t ha^{-1} every third year. Agrochemical soil test costs are changeable; therefore, it is assumed that the average cost is 18.76 EUR ha^{-1}. It is also assumed that machinery includes a fertiliser seeder; fuel consumption is 9.4 L ha^{-1}, the fuel price is EUR 0.80 per litre, time consumption is approximately 10 min per ha and the wage paid is EUR 850 a month or EUR 5.31 per hour. An annual increase in yields is 0.5 t ha^{-1}. A crop grown is wheat. The price of wheat is 160 EUR t^{-1}. The results obtained are summarised in Table 2.

Table 2

Potential gains and losses from liming acid soils

Activities and effects	Economic costs/gains per year, EUR ha^{-1}
Agrochemical soil tests	2.3
Transaction costs	0.4
Lime fertiliser cost	34.7
Spreading costs (fuel, wages)	1.0
Yield increase	80.0
Relative cost	- 41.6

Source: authors' calculation.

The results summarized in Table 2 show a negative relative costs which means that a farmer has positive benefits from liming. However, liming is essential for maintaining soil fertility, increasing yields, and presumably for more efficient circulation of nitrogen, which affects GHG emissions. There are no data for unambiguous environmental effects, but it is possible to acquire the data from the present research studies. The effectiveness of liming soils remains for several years and is one of the most efficient ways of raising crop yields. According to research studies done by J. Vigovskis, a lime rate of 4 – 6 t ha^{-1} raises grain yields by 0.5 – 0.7 t ha^{-1} a year for a period of 6 – 8 years. However, not always production conditions allow to achieve such results. According to research results made by A. Zemīte, correction liming using 3 – 5 t ha^{-1} liming material resulted in an increased yield – by 0.46 t ha^{-1} for winter wheat and by 0.25 t ha^{-1} for summer wheat (Štikāns, 1992).

Liming has to be included in the list of national agricultural activities eligible for support, which would contribute to maintaining the quality of soils, increasing yields and (if agrochemical tests are eligible for support) accumulating and updating information on the condition of soils.

Conclusions

1. In the scientific literature it has been identified that soil N transformations and fluxes can be affected by soil pH, where increasing the pH of soil decreases N_2O emissions from acidic soils during rainfall periods when the emissions are caused by nitrification as well as liming acidic soils contributes to the absorption of nutrients supplied by means of fertilisers by plants. Lower uptake efficiency of nitrogen and other primary nutrients can be observed in acidic soils (pH 5.0), where the overall fertilizer uptake efficiency is 46% compared with 86% in neutral soils. It is of great importance to intensive agricultural farms due to high rates of nitrogen fertiliser application and relatively high rates of Ca removal from soil.
2. The assessment of potential gains and losses from liming acid soils in Latvia revealed that:
   - on the farm level liming gives a positive economic effect (41.6 EUR ha^{-1}); however, it is essential for maintaining soil fertility, increasing yields, and presumably for more efficient circulation of nitrogen, which decreases nitric oxide emissions;
   - liming has to be included in the list of national agricultural activities eligible for support, which would contribute to maintaining the quality of soils and increasing crop yields, as well as contribute to mitigation of N_2O emissions.

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