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Fertilizer use efficiency impact on GHG emissions in the Latvian crop sector

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Abstract. Within increasing production activity Latvian agricultural sector has become one of the main sources of greenhouse gas emissions (GHG) in Latvia. In 2013, agricultural sector contributed 21.0% of the total GHG emissions originated in Latvia (2310.1 Gg CO_2eq). Analysis of agricultural GHG emissions by sources shows that direct N_2O emissions from agricultural soils through the usage of synthetic fertilizers are one of the most significant GHG source in Latvia. The usage of synthetic fertilizers is one of the most common widespread agricultural practices in Latvian cropping systems and according to statistical data usage of synthetic fertilizers is constantly increasing, for example, in 2013 it increased by 6.9% if compared with 2012. Taking into account that over-fertilization can lead to negative economic and environmental consequences, such as high production costs, depletion of energy resources, and increased GHG emissions, this research aims to estimate how effective usage of synthetic fertilizers are in Latvian crop farms. In order to achieve the set aim an N fertilizer usage were estimated in four crop farms by giving insight into N balance and N use efficiency (NUE) rate in these farms. Research results suggest that improved N efficiency can be selected as GHG mitigation measure as it reduces N surpluses and the use and production of mineral fertiliser while maintaining yield levels. It was also concluded that improved N efficiency reduces direct N_2O emissions from fertilized soils and indirect N_2O emissions that occur by the release of NH_3.

Key words: GHG, emissions, nitrogen use efficiency, Latvia.

INTRODUCTION

The agricultural sector has historically been the main provider of economic activity in Latvian rural areas. In 2015 32% of total Latvian population have been living in rural areas and for the major part of it agriculture provides employment opportunities – in 2015 agricultural sector provided workplace for 5.2% of the total employees in the country. Agricultural output data shows that Latvian agricultural sector year by year becomes more competitive and stronger player in the global markets. However, within increasing production activity Latvian agricultural sector has become one of the main sources of greenhouse gas emissions (GHG) in Latvia. In 2013, agricultural sector contributed 21.0% of the total GHG emissions originated in Latvia (2310.1 Gg CO_2 eq).

Analysis of agricultural GHG emissions by sources shows that direct N_2O emissions from the agricultural soils through the usage of synthetic fertilizers are the most significant GHG source in Latvia.

The Latvian agriculture has achieved marked progress with regard to cereal production over the past decade. Such an increase is the result, at least in part, of increased application of N fertilizers. The usage of synthetic fertilizers is one of the most common widespread agricultural practices in Latvian cropping systems and according to statistical data usage of synthetic fertilizers is constantly increasing, for example, in 2013 it increased by 6.9% if compared with 2012. Cereals: wheat (winter and summer), rye, barley, oats and triticale consume approximately 80% of the total N used as fertilizer. However, only 30–50% of this applied N is recovered by crop plants (Cassman et al., 2002). For example, NO_3 – N is easily lost from agricultural areas by leaching (Puckett et al., 1999), and high levels of NO_3 – N losses can reduce nitrogen use efficiency (NUE). While N losses cannot be avoided completely, there is certainly a scope to minimize losses with precision N management techniques and technologies. Current situation in Latvia showing fertilized cropland area, amount and rate of used N fertilizers and N_2O emissions are summarized in the Table 1.

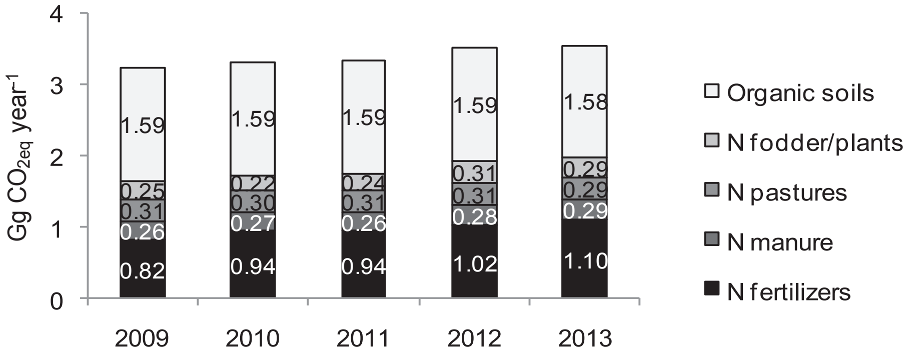
Table 1. Fertilized cropland area, amount and rate of used N fertilizers and N_2O emissions in Latvia, 2014

Type of crop	Area, thous ha	N, thous t	N application rate, kg ha^{-1}	N_2O emissions kg ha^{-1}
Cereals	511.70	57.90	113.15	1.78
Potatoes	13.80	0.80	57.97	0.91
Industrial crops	87.70	10.50	119.73	1.88
Vegetables	5.90	0.30	50.85	0.80
Fodder crops	69.40	3.10	44.67	0.70
Total	688.50	72.60	X	X

Source: authors' calculation after data from Central Statistical Bureau of Latvia

In Latvia fertilized cropland area in 2014 has reached 688.50 thous ha, which if compared with 2009 has increased by 23%. Within cropland area increases although N application rate has increased by 16% reaching 113.15 kg ha^{-1} in 2014. N fertilizer use has contributed to the total growth of N_2O emissions from Latvian agricultural soils (Fig. 1).

In 2013 managed organic soils formed the major part of total N_2O emissions (44.7%) following by emission from application of N fertilizers (30.9%). The N fertilizer use emissions over the last five years have increased by 25% reaching 1.1 Gg CO_{2eq} y^{-1}. Such situation analysis let us presume that in order to reduce negative impact on the environment in Latvia special attention should be paid on effective use of N fertilizers which can be expressed in such term as nitrogen use efficiency (NUE). The NUE for cereal production can be defined from the interplay of the following three different approaches: *economic* - to reduce N fertilizer application costs; *agronomic* – to maintain and increase crop yields without worsening soil qualitative indicators; *environmental and ecological* - to reduce the losses of N fertilizers and the N_2O emissions into the environment produced by the N fertilizers.



Source: authors' calculations after Latvia's National Inventory report, 2015

Figure 1. Main sources of N_2O emissions (Gg CO_{2eq} y^{-1}) in Latvia, 2009–2013.

Taking into account such considerations this research aims to estimate how effective usages of synthetic fertilizers are in Latvian crop farms. In order to achieve the set aim an N fertilizer usage were estimated in four crop farms by giving insight into N balance and N use efficiency (NUE) rate and its correlation with GHG emissions in these farms. It should be noted that in this study the NUE was used as an agro-environmental indicator (Johnston & Poulton, 2009), which is a well-known approach and commonly used in the agro-policy context (Brentrup & Palliere, 2010). From this perspective NUE can be calculated as the ratio between the amount of N removed by the crop and the amount of N fertilizer applied (Kārkliņš & Ruža, 2013).

MATERIALS AND METHODS

This study is part of a broader research aiming to assess the agricultural sector GHG emissions reduction potential and it represents initial findings about current situation in case studies of 4 crop farms in Latvia. To achieve the set aim and tasks of the research, the authors have used the publications and studies of foreign scientists, statistical data from the Central Statistical Bureau of Latvia. 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.

However, primary data source in this research were case studies carried out in 4 agricultural farms in Latvia in 2014. The main aim of these case studies was to collect specific data, like land use, cropland management and fertilization practices, necessary for estimating GHG emissions from farming practices. These farms were selected on the basis of cluster analysis made in previous research (Naglis-Liepa et al., 2015) that shows that Latvian agricultural farms can be divided in four different clusters. In these case studies were selected farms representing large-scale intensive crop production farms, which is quite small in terms of number of farms, but impressive in terms of output.

Description of farms

In order to meet the set tasks of the study 4 crop farms in Latvia were surveyed. These farms can be characterized as very large and intensive grain production farms where utilized agricultural area comprises from 443 till 1,313 ha. These farms focus mainly on wheat (summer and winter), barley, as well as rape (mainly winter rape) production. However, yields of different crop cultures, if compared between farms, differs quite significantly (Table 2), which could be important factor when estimating N use efficiency at farm scale.

Table 2. Characteristic indicators of surveyed crop farms in Latvia, 2014

Indicator	Farm A	Farm B	Farm C	Farm D
Total UAA area, ha	530	443	801	1,313
Area of crop cultures, ha				
Winter wheat, ha	226	333	79	259
Summer wheat, ha	119	-	340	346
Summer barley, ha	95	145	185	226
Field beans, ha	28	-	38	30
Winter rape, ha	118	14	33	143
Summer rape, ha	-	-	99	-
Rye, ha	-	-	-	139
Potatoes, ha	-	-	-	131
Yield of crop cultures, t ha^{-1}				
Winter wheat, t ha^{-1}	6.5	5.8	5.0	3.1
Summer wheat, t ha^{-1}	4.5	-	7.1	5.0
Summer barley, t ha^{-1}	3.0	5.9	6.4	4.2
Field beans, t ha^{-1}	3.0	-	6.5	3.1
Winter rape, t ha^{-1}	3.0	2.9	1.8	1.0
Summer rape, t ha^{-1}	-	-	2.7	-
Rye, t ha^{-1}	-	-	-	6.1
Potatoes, t ha^{-1}	-	-	-	40.0

Source: authors' summarization after survey results.

Calculation of nitrogen balance and NUE rate

In this research fertilizer use efficiency were assessed using two different agro-environmental indicators – nitrogen balance and nitrogen use efficiency (NUE) index.

The N balance is already an established OECD indicator (OECD, 2008). It shows the difference between N inputs (fertilizer, manure etc.) and N outputs (arable, permanent and fodder crops) and in this research was expressed in kg N per hectare. Nitrogen balance has been widely acknowledged (Ribaudo et al., 2011) as key for improved nitrogen use efficiency and reduced risk of nitrogen losses on the farm. Nitrogen balance informs farmers about their degree of nitrogen utilisation and help to identify the risk of nitrogen leaching and other losses from the field and the whole farm. The work with nitrogen balance provides important information for improved fertiliser planning and improved farm finances.

A positive or surplus balance means that less nitrogen have been taken out of the field with the harvest than have been added e.g. in the form of fertilisers. Some of the nitrogen that left in the field will contribute to the build-up of soil organic and inorganic matter, but they may also contribute to an increased risk of nutrient leaching. A significant surplus is also economically unprofitable. In contrast, if the balance is negative or in deficit, more nutrients have been taken from the field than have been added. If the balance is negative for a long time, soil fertility will be weakened, which in turn will reduce possible yields. The ideal situation is for the nutrient uptake of plants and the supply by fertilisation to be in balance and the value of the field balance to be close to zero.

In the context of this research nitrogen balance were calculated using Eq. 1:

$$N_{balance} = \frac{N_i - N_o}{A} \quad (1)$$

where: N_i – total nitrogen input (kg); N_o – total nitrogen output (kg); A – utilized agricultural area (ha).

Total nitrogen output, i.e. nitrogen removed with crops, N_o was calculated using Eq. 2 (Kārkliņš & Ruža, 2013):

$$N_o = O_p + (O_b \times RA) \times F \quad (2)$$

where: O_p – N recovered in product (kg); O_b – N recovered in by-product (kg), RA – product and by-product ratio; F – production yields (kg ha^{-1}).

Total nitrogen input N_i was calculated using Eq. 3:

$$N_i = I_s + I_m + I_f + I_{fix} \quad (3)$$

where: I_s – N content in seeds (kg); I_m – N content in manure (kg); I_f – N content in fertilizer (kg); I_{fix} – N fixation with legumes (kg).

With a nutrient balance, it is easy to review the flows of nutrients to and from the farm. Thus nitrogen balance has been identified as a principal agro-environmental indicator that provides information on the potential loss of N to the air and to surface or groundwater. For example, in Nordic conditions and in the UK, a decrease in N balance of 10 kg N ha^{-1} $year^{-1}$ implied a decrease in measured N runoff of 1.5–5.7 kg N ha^{-1} $year^{-1}$ (Salo & Turtola, 2006).

The second parameter that where calculate was N use efficiency which is a critically important concept in the evaluation of crop production systems. It can be greatly impacted by fertilizer management as well as by soil, plant and water management. The objective of N use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing N losses from the field. NUE addresses some, but not all aspects of that performance. Therefore system optimization goals necessarily include overall productivity as well as NUE. The index NUE gives the ratio of output N to input N indicating how well the given N-management strategy performs in recovering the applied N. The national and regional

NUE values may reflect the particular mix of farming systems within those areas. NUE is calculated using Eq. 4 (Drechsel et al., 2015).

$$NUE = \frac{N_o}{N_i} \quad (4)$$

where: N_o – total nitrogen output, i.e. nitrogen removed with crops (kg); N_i – N fertilizer applied to crops (kg).

A complication of NUE estimates is the consideration of crop rotations. Where wheat and legumes are rotated on the same field annually, for example NUE would have to be calculated for a two-year rotation cycle in order to account for the N inputs from legumes in one year that could remain as inputs to the wheat crop the follow year. Where longer and more complex crop rotations are employed NUE estimates would need to consider the whole crop cycle and not just crops in isolation. When NUE = 1, the amount of nutrient removed equals the input of N. When NUE < 1, more N is being applied than is being removed, and the N not removed could either be stored in the soil and/or flow through to the environment causing ecosystem degradation. When NUE > 1, more N is being removed than is being supplied, which indicates that the soil is being mined of nutrients, eventually depleting soil fertility (Norton et al., 2015). NUE index values for winter wheat are summarized in Table 3.

Table 3. NUE of different mineral fertilizer application rates in a long-term field trial with winter wheat

N_i (kg N ha^{-1})	N_o (kg N ha^{-1})	NUE	Interpretation
0	26	-	Soil over-fertilization
48	56	1.16	Soil over-fertilization
96	92	0.96	Risk of soil over-fertilization
144	126	0.88	Balanced in- and outputs
192	151	0.79	Balanced in- and outputs
244	166	0.69	Risk of high N losses

Source: Brentrup, 2004.

Countries with intensive agriculture such as US, Germany, UK and Japan generally show increasing NUE as a result of stagnant or even decreasing N use and increasing crop yields (Drechsel et al., 2015).

Calculation of N_2O emissions

Nitrous oxide (N_2O) emissions for surveyed crop farms were calculated following the IPCC (2006) guidelines at Tier 1 level. According to the IPCC guidelines for calculation of N_2O emissions from agriclultural soils equation (5) were used:

$$N_2O_{SNDirect} - N = \left[N_2O - N_{Ninput}\right] = \mathrm{F_{SN}} \cdot EF \quad (5)$$

where: $N_2O_{SNDirect}$–N – direct emissions from mineral fetilizers used in crop farming (kg N_2O–N year^{-1}); F_{SN} – mineral fetilizers used in crop farming (kg N year^{-1}); EF – emission factor for direct N_2O emissions from mineral fertilizers (kg N_2O–N kg^{-1}).

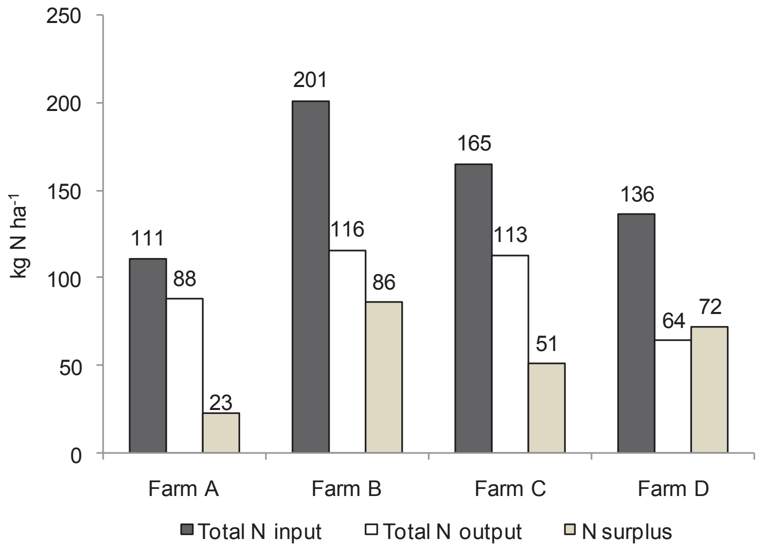
Calculated N_2O–N emissions from used fertilizers were converted in N_2O emissions after equation (6):

$$N_2O = N_2\text{O - N} \cdot \frac{44}{28} \qquad (6)$$

RESULTS AND DISCUSSION

Nitrogen balance

Taking into account that direct and indirect N_2O emissions were among main GHG emissions sources in the all surveyed farms and that primary reason for N_2O release from cultivated soils are N inputs by mineral fertilizers, analysis of N balance were performed. The total N input from synthetic fertilizer, organic fertilizer and crop residues at the surveyed farms varied between 111 and 201 kg per ha per year (Fig. 2).



Source: authors' calculations

Figure 2. Nitrogen annual flow in the surveyed Latvian crop farms (kg N ha^{-1}), 2014.

The highest N surpluses were found in Farms B, C and D, respectively 86, 51 and 72 kg N ha^{-1}, indicating that in these farms N losses to the environment through N_2O emissions could occur as each kilogram of N fertilizer results in 0.016 kg N_2O emissions. It means that more attention should be paid on the improvement of N management. Results summarized in Figure 2 also shows that in Farm A there can be observed almost balanced usage of N fertilisers as N surplus is 23 kg N ha^{-1} thus showing that in this farm nutrient-efficient farming by minimization of nutrient losses to the environment while ensuring the necessary nutrient supply to crops can be observed.

From such obtained results it can be concluded that fertilisation planning is essential to obtain the best balance of economic and environmental benefits in each farm as lack of certain plant nutrients, in the case of this research it is nitrogen, can reduce plant growth and lower yield, but surpluses can be costly both from an environmental and an economic perspective. In order to provide effective farming practice crop fertilization plans should be developed for all farms that use fertilizers in crop cultivation. Currently in Latvia crop fertilization plans are mandatory for those farms that are located in nitrate vulnerable zones and uses 20 ha or more of agricultural land, but for horticulture vegetable growing farms – 3 ha or more of agricultural land, and since 2015 fertilisation planning is obligatory for those farmers who uses professional plant protection products.

N use efficiency rate and GHG emissions

The next indicator that was assessed in surveyed farms was NUE index. According to other similar research results (Hawkesford, 2014) decrease in NUE index does not always guarantee lower N pollution, but it is an essential step for reducing N loss to the environment while maintaining high agricultural productivity. Using NUE as an indicator it will likely reduce N losses to the environment, which will be followed in time by improved indicators of environmental quality, albeit with lags in the system. Indicative results about situation in Latvian large-scale and intensive crop farms regarding NUE index and N_2O emissions from the use of N are summarized in the Table 4.

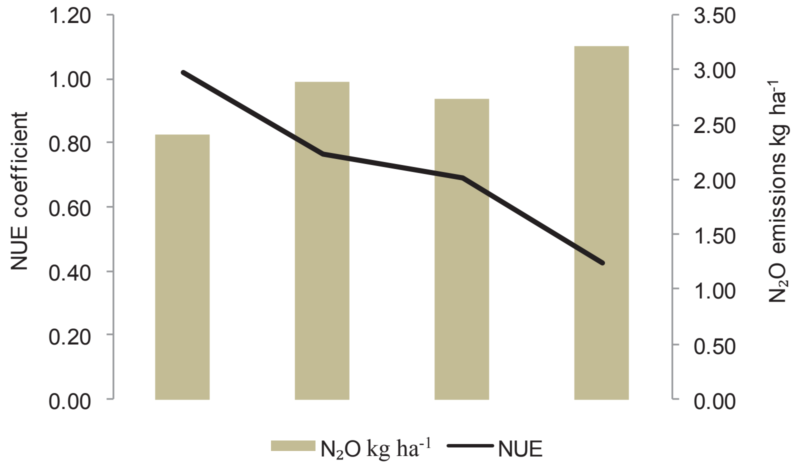
Table 4. NUE index and N_2O emissions from the use of N fertilizers in the surveyed Latvian crop farms, 2014

Crop	Farm A		Farm B		Farm C		Farm D	
	N_2O kg ha^{-1}	NUE	N_2O kg ha^{-1}	NUE	N_2O kg ha^{-1}	NUE	N_2O kg ha^{-1}	NUE
Winter wheat	2.40	1.02	2.88	0.76	2.73	0.69	3.21	0.43
Summer wheat	1.49	1.32	-	-	2.94	1.06	3.28	0.67
Summer barley	1.24	0.93	2.65	0.87	2.25	1.10	1.43	1.12
Field beans	0.50	4.89	-	-	2.00	2.66	1.35	1.86
Winter rape	2.07	0.84	3.07	0.54	2.75	0.38	3.11	0.19
Summer rape	-	-	-	-	2.61	0.80	-	-

Source: authors' calculations

Results summarized in Table 4 shows the differences of NUE index for most commonly grown crop cultures in Latvia between different farms. These results show indicative trend developments with regard to N fertilizer use, production of arable and permanent crops and the resulting NUEs. Overall there can be observed alarming indicators showing that in all surveyed farms there is risk of soil over-fertilization. And here special attention should payed on field beans, where NUE index is the most highest among all surveyed farms.

In this research NUE has been viewed not as a final indicator of success, but rather as an important and essential indicator of progress in the agricultural sector in order to control possible N_2O emissions from the use of N. For this purpose authors' have displayed relation between NUE coefficient and N_2O emissions (Fig. 3) as well as calculated correlation coefficient (r). This analysis was performed only for one crop culture, i.e. winter wheat, which is the most common crop among surveyed farms and is the main crop farming output product in Latvia.



Source: authors' calculations

Figure 3. N_2O emissions (kg ha^{-1}) and NUE coefficient associated with winter wheat production in the surveyed Latvian crop farms, 2014.

Fig. 3 shows that correlation between NUE coefficient and N_2O emissions is negative (r = -0.95536). A negative correlation coefficient means that increase in NUE coefficient value is associated with a decrease in N_2O emissions and vice versa. These results go in line with findings of other authors (Cui et al., 2014) thus marking new paradigm for productivity and environmental sustainability.

However, according to Robertson & Vitousek (2009) in intensive cropping systems, the more efficient cycling of N depends on environmental management interactions that influence the balance and rate of microbial processes (e.g. nitrification and denitrification) and transport among plant, soil and environments (e.g. air and water). Thus impact of different environmental management interactions on N balance and N use efficiency should be taken into account in the further research.

CONCLUSIONS

In Latvian cropping systems usage of synthetic fertilizers has been constantly increasing, for example, in 2013 it has increased by 6.9% if compared with 2012, where 80% of the total N fertilizer has been used for cereals' production. However, according to literature only about 50% of this applied N fertilizer has been recovered by crop plants and high levels of NO_3 – N losses can reduce nitrogen use efficiency (NUE). Such indications shows that in Latvia special attention should be paid on effective use of N fertilizers in order to reduce negative impact on the environment.

Research results reflecting nitrogen annual flow in surveyed farms that represents typical large-scale intensive crop production farms in Latvia, indicates that N surpluses ranging from 23 till 86 kg N ha^{-1} can be found in surveyed farms, indicating that in these farms N losses to the environment through N_2O emissions could occur as each kilogram of N fertilizer results in 0.016 kg N_2O emissions. However, these are only indicative results and further research should be proceed.

Assessment of NUE index for most commonly grown crop cultures in Latvia between different farms showed alarming indicative trend developments where in all surveyed farms there can be observed risk of soil over-fertilization. And here special attention should be payed on field beans, where NUE index is the most highest among all surveyed farms. However, these NUE results need an interpretation scheme because very high as well as low NUE values represent unsustainable situations.

In the surveyed Latvian crop farms there can be observed negative correlation between NUE coefficient and N_2O emissions ($r = -0.95536$) which means that increase in NUE coefficient value is associated with a decrease in N_2O emissions and vice versa. These results go in line with findings of other authors thus marking new paradigm for productivity and environmental sustainability.

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