FERTILISATION PLANNING AS EFFECTIVE TOOL FOR BALANCED ECONOMIC AND ENVIRONMENTAL BENEFITS IN CROP FARMING

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Abstract
Since the middle of the last century rapid intensification of agricultural production systems has resulted in dramatic increase in fertilizer consumption as fertilizer has been considered as one of the most important factors for increased yields. However, not all the nutrient ions in a fertilizer applied to soil are taken up by crops, thus certain amount of the applied fertilizer is lost from agricultural fields leading to increases in nitrogen surplus, nitrogen losses to the environment and harmful impacts on biodiversity, air and water quality. This study aims to focus on crop fertilisation planning which is based on the knowledge of physical and chemical properties of soil and involves performing soil tests, designing a fertilisation plan and its practical implementation as well as calculating the balance of N, and to evaluate crop fertilisation planning as a tool for achieving balanced economic and environmental benefits in crop farming, which play an important role in efficient farming. In this study, the authors have analysed current situation in Latvia regarding requirements for fertilization planning in crop farms and have assessed potential costs and benefits from fertilisation planning. The research finds out that total cost of introducing of fertilisation planning ranges from 34 to 22 EUR ha^{-1}, however, fertilisation planning is a neutral measure where costs are compensated by savings from N inputs which ranges from 10 to 40 kg N ha^{-1}.Fertilisation planning generates environmental benefits, i.e. – reduces direct N_2O emissions from agricultural soils by 47 – 187 kg CO_{2eq} ha^{-1} through reduced N fertilizer inputs.
Key words: fertilisation planning, nitrous oxide, GHG emissions, savings.

Introduction

Agricultural production fulfils important needs of human beings, most importantly the production of essential nutritional products, supplying raw materials for industrial purposes, producing bioenergy and environmental stewardship (Kirchmann & Thorvaldsson, 2000). However, agriculture faces with a range of challenges, like, weather, infestation, manpower and environmental problems, where environmental problems have been considered as topical once (Kirchmann & Thorvaldsson, 2000; Tilman *et al*., 2002). According to H. Kirchmann & G. Thorvaldsson (2000), some of environmental problems are caused by natural conditions (high native heavy metal content, drought, volcanic eruptions, etc.), others depend on agricultural practices (leaching of nutrients and pesticides, etc.), and some are related to human influence in other areas (air pollution).This means that in modern agriculture farmers should produce adequate amounts of a high-quality product, protect its resources and be both environmentally friendly and economically profitable (Valkama *et al*., 2013).However, according to D. Tilman and co-authors (2002) modern agricultural practices that have greatly increased global food supply have had inadvertent, detrimental impacts on the environment. The rapid intensification of agricultural production systems since 1950 has resulted in a dramatic increase in inputs in general, and in fertilisers in particular (Van Alphen & Stoorvogel, 2000). It has been even revealed that in order to ensure that the yield potential could be reached each year, farmers often applied quantities of nitrogen (N) fertiliser that were far greater than the amount actually required to achieve the yield potential (Lemaire, Jeuffroy, & Gastal, 2008). At the same time it has been also estimated that only 30–50% of applied nitrogen fertilizer (Smil, 1999) and approximately 45% of phosphorus fertilizer (Smil, 2000) are taken up by crops. Moreover, incorporation of excessive nitrogen fertilizer rates contributes to nitrate accumulation in soil (Līpenīte & Kārkliņš, 2015).It means that a significant amount of the applied nitrogen and a smaller portion of the applied phosphorus are lost from agricultural fields. In turn, excess fertilizer application leads to increases in nitrogen surplus, nitrogen losses to the environment and harmful impacts on biodiversity, air and water quality (Goulding, Jarvis, & Whitmore, 2008; Līpenīte & Kārkliņš, 2015). Such findings have highlighted the need for more sustainable agricultural methods and many scientific studies of different aspects of sustainable agricultural methods have been carried out. For example, many countries such as Belgium, Denmark, Germany, the Netherlands, Norway, Switzerland (OECD, 2008), and Finland (Valkama *et al*., 2013) show further potential to reduce agricultural N surpluses to levels that are not potentially environmentally damaging. Some findings reveal that in order to maintain high yields while reducing environmental impact, it appears necessary to increase N-use efficiency through the promotion of good farming practices (Dumont *et al*., 2015). Widespread approach in Europe and North America for adjusting the N fertilization is soil sampling at the start of the growing period in order to analyze the amount of NO_3^--N (and NH_4^+-N). However, such a procedure is time-consuming and costly and fails to take into account additional N from mineralization during the coming season (Valkama *et al*., 2013).

Such situation analysis set the aim for this study – to evaluate crop fertilisation planning as a tool for achieving balanced economic and environmental benefits in crop farming. This aim goes in line with the key purpose of crop fertilisation planning which is focused on ensuring optimum crop fertilisation, as the lack of basic elements can reduce crop growth and yields, while the unabsorbed amount of N results in economic and environmental losses, as N_2O emissions are produced. In order to achieve the aim, two specific research tasks were set: 1) to analyse current situation in Latvia regarding requirements for fertilization planning in crop farms; 2) to assess potential costs and benefits from introducing fertilisation planning in farms.

Materials and Methods

This study is part of a broader research aiming to assess the agricultural sector greenhouse gas (further in text – 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 current situation in Latvia regarding requirements for fertilization planning in crop farms in order to examine the real situation concerning fertilisation planning; 2) to assess potential costs and benefits from fertilisation planning in order to estimate its effects on the economy of farms.

In order to analyse the current situation in Latvia regarding requirements for fertilization planning in crop farms, authors have used various sources of materials and data: the scientific literature, legislation, reports and recommendations, as well as websites.

In order to calculate potential gains and losses from fertilisation planning, the main costs related to implementation of fertilisation planning were made. Introduction of fertilisation planning consists of several processes:

1. Agrochemical soil testing;
2. Development of crop fertilization plan;
3. Calculation of nitrogen balance.

Agrochemical soil testing

Assessment of the agrochemical properties of the soil is the first step in the fertilisation planning process. Soil agrochemical composition is important information that should be considered when choosing crops to be grown and planning use of fertilizers. If farmers grow crops without knowing the soil agrochemical properties, then it may happen that the crop is unable to take full advantage of all the fertilizer inputs. Agrochemical test must be carried out every 6 years.

In Latvia, the official authority competent of soil and authority where agrochemical soil testing can be carried out is State Plant Protection Service. Soil agrochemical testing is set of measures which include:

- a professional soil sampling with specific probes, according to the Latvian State Land Service soils maps indicated soil type and particle size distribution;
- soil agrochemical measurement in accredited laboratory of soil analysis carried out methods approved by the Ministry of Agriculture;
- the data are entered and stored at Soil agrochemical research database;
- the analytical results developed by Latvian scientists are evaluated and groups of agrochemical indicators approved by the Ministry of Agriculture;
- agrochemical soil testing materials include chemical studies of soil maps, the preparation and issuance to the customer;

Taking into account the farmers' interest in precision agriculture and in receiving agrochemical soil test results in digital format, starting from 2013 State Plant Protection Service offers agrochemical soil testing with usage of geographical positioning device (GPS) to farmers.

Crop fertilization plan

The next step in the fertilisation planning is to estimate the amount of nutrients that the crop needs and to develop crop fertilization plan. In order to develop crop fertilization plan and to calculate the necessary amount of fertilizers, several important factors should be taken into account:

- crop specie planned to grow in the field, realistic yield potential;
- crop specie grown in the field in the previous season;
- soil properties of the field (using data from agrochemical soil tests).

In order to provide effective farming practice, crop fertilization plans should be developed for all farms that use fertilizers in crop cultivation. In Latvia, farmers have several options how they can develop crop fertilization plans:

1. farmers can use on-line fertiliser planning system offered by Rural Support Service Electronic Application System (further in text - E-service LDS EPS);
2. farmers can do calculations themselves by using specific normative tables (Kārkliņš &Ruža, 2013) drawn up on the basis of experimental data obtained or by using the software provided by different services;

3. farmers can use consulting services of Latvian Rural Advisory and Training Centre.

Calculation of nitrogen balance

Nitrogen balance is necessary for keeping track of the nitrogen flows on the farm, and the 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 helps 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.

To achieve the set aim and tasks of the research, the appropriate research methods have been used in the research study, mainly qualitative and also quantitative: monographic; analysis and synthesis, data grouping, abstract analysis, logical construction etc.

Results and Discussion

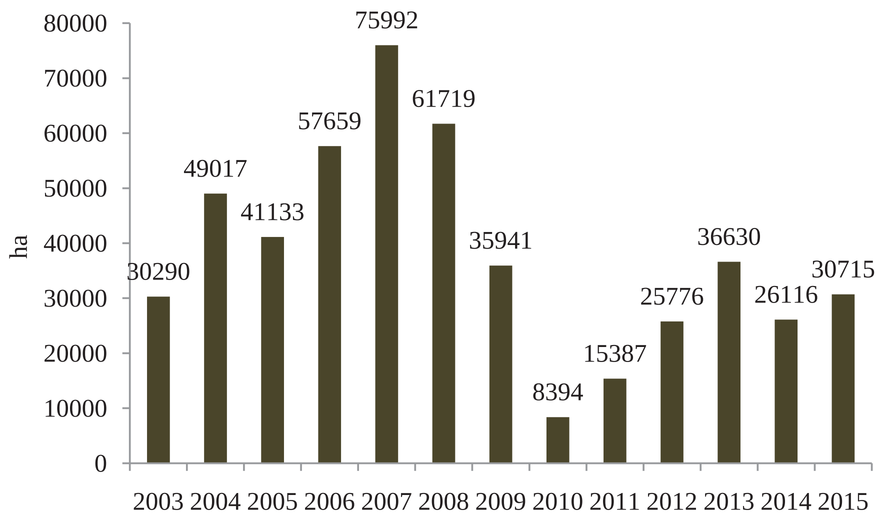
Current situation in Latvia regarding requirements for fertilization planning in crop farms

In the scientific literature (Goulding, 2000; Tilman *et al*., 2002; Valkama *et al*., 2013; Dumont *et al*., 2015) there can be found various examples of best management practices for N management, like choosing of the highestyielding variety appropriate to maximize the use of the available nutrients; maintaining a green cover as much as is practicable to retain N; making regular soil analyses for pH, P, K and Mg and possibly trace elements; using lime to maintain the appropriate pH for optimum nutrient supply; calculating fertilizer requirements using a recommendation system; avoiding unnecessary autumn and early spring applications of N; applying fertilizers and manures evenly, and well away from watercourses, with a properly calibrated spreader.

Thus, fertilization planning which in the frame of this study has been understood as set of three activities - agrochemical soil testing, development of crop fertilization plan, and calculation of nitrogen balance - is one of possibilities how to meet the best management practices for N management.

Soil agrochemical testing is a key to soil nutrient management or the first step in planning an economical and environmentally sound fertilization program. Information about soil properties provides a farmer with an estimate of the amount of fertilizer nutrients needed to supplement those in the soil (Baker, Ball, & Flyn, 2002). Applying the appropriate type and amount of needed fertilizer will give to agriculture farmer a more reasonable chance to obtain the desired crop yield. According to information provided by State Plant Protection Service (the official authority competent of Latvian soil and authority where agrochemical soil testing can be carried out), over the past six years agrochemical tests have been made only for 10% of agricultural land soil (Rulle, 2014). It means that a large part of Latvian farmers grows crops without knowing the soil agrochemical properties. In contrast, in the neighbouring country Estonia, where soil agrochemical testing is a condition of national and EU support system, farmers have information about 80% of agricultural land soil agrochemical properties (Astover & Rossner, 2013).

As regards development of crop fertilization plans, currently in Latvia crop fertilization plans are mandatory for two kinds of farmers:



Source: Rulle, 2016.

Figure 1. Dynamics of agricultural land (ha) in which agrochemical soil testing has been carried out in Latvia, 2003 – 2015.

- For those farmers whose farms are located in nitrate vulnerable zones and use 20 ha or more of agricultural land, but for horticulture and vegetable growing farms – 3 ha or more of agricultural land.
- For those farmers who are professional users of plant protection products of second registration class (about 17000 farms).

For the rest of farmers, this activity is voluntary and farmers don't receive any financial support. Similarly, it is with calculation of nitrogen balance; this is voluntary and depends on farmer's interests. Therefore, the dynamics of agricultural land area in which agrochemical soil testing has been carried out over the years is very uneven (see Fig. 1).

Information provided by State Plant Protection Service about changes in proportion of different agrochemical characteristics of the agricultural land in Latvia is summarized in Figure 2. This information should be considered as indicative because monitoring sites differ from year to year and do not reflect the situation in constant area. However, from the soil monitoring results summarized in Figure 2 can be concluded general observations: Latvian agricultural land has a tendency to acidification of soil; agricultural land is generally poorly served by phosphorus, where one of the most important reasons for the low phosphorus content could be unbalanced fertilizer use; potassium available for plants in soil tends to get worse.

In the context of fertilisation planning, these tendencies are very unwanted as nutrient imbalance and acid soil have negative impact on N uptake by crops.

As regards development of crop fertilization plans, then currently in Latvia crop fertilization plans are mandatory for two kinds of farmers:

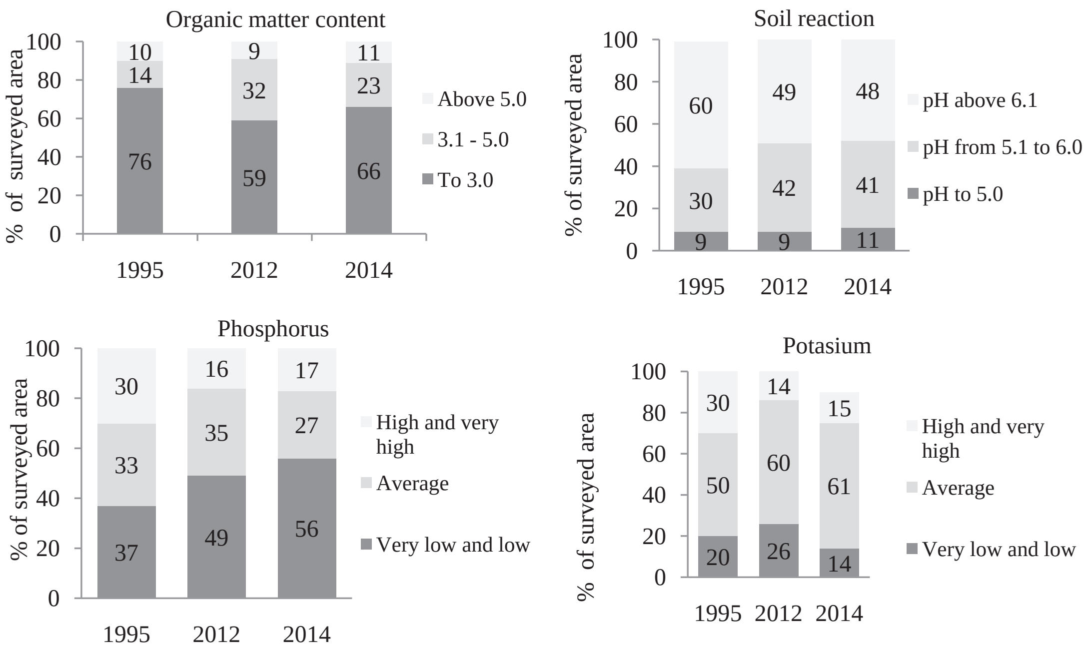
- those farmers whose farms are located in nitrate vulnerable zones and use20 ha or more of agricultural land, but for horticulture vegetable growing farms – 3 ha or more of agricultural land;
- farmers who are professional users of plant protection products of second registration class.

For rest of farmers this activity is voluntary. Similarly with calculation of nitrogen balance, this is voluntary and depends on farmer's interests.

Such situation in Latvia shows that fertilization planning has to be included on the list of national agricultural activities eligible for support, which would motivate farmers and contribute to maintaining the quality of soils, increasing yields, accumulating and updating information on the condition of soils, fertilization practice and nutrients balance.

Potential costs and benefits from introducing fertilisation planning in farms

Fertilisation planning is essential to obtain the best balance of economic and environmental benefits in each farm as lack of certain plant nutrients can reduce



Source: authors' calculations after Rulle, 2014; 2016.

Figure 2. Proportion of different agrochemical characteristics of the agricultural land in Latvia in 1995, 2012 and 2014.

Table 1

Potential costs and benefits from introducing fertilisation planning in farms

Fertilisation planning activities	Implementation costs, EUR ha^{-1}	Economic benefits	Environmental benefits
		Savings in N input rates, kg N ha^{-1}	GHG reduction potential, kg CO_{2eq} ha^{-1}
Agrochemical soil tests	From 28 to 16	X	X
Development of crop fertilization plan	3	X	X
Development of nitrogen balance	3	10 – 40	47 – 187
Total	34 – 22	10 – 40	47 – 187

Source: authors' calculations after Valkama *et al*., 2013; Domingo *et al*., 2014.

plant growth and lower yield, but surpluses can be costly both from an environmental and an economic perspective.

Nitrous oxide (N_2O) is a greenhouse gas with a global warming potential 298 times higher than carbon dioxide (CO_2) on a per mass basis, and is the largest stratospheric ozone-depleting substance (IPCC, 2015). Agricultural soils are the main anthropogenic source of N_2O emissions, primarily as a result of the addition of synthetic N fertilizers and animal manures to soil (Bouwman, Boumans, & Batjes, 2002). The potential for mitigation of N_2O emissions arising from fertilizer management practices has been scientifically assessed in recent decades. Given the strong association between fertilizer management and crop productivity, which to a large extent determines farmers' willingness to adopt such practices, it is essential to incorporate the impacts on yields before any mitigation practice can be recommended (Abalos *et al*., 2016). Yet, the potential consequences of N_2O mitigation practices on crop yield remain largely unexplored (Millar *et al*., 2010). Both positive and negative effects, depending on the practice, can be expected.

The optimum N fertilization is known to vary within the same field and with each growing season as a result of the heterogeneity of soil properties, as well as inter- and intra-annual climatic patterns (Basso *et al*., 2012). Furthermore, the decision-making process linked to N management remains complex because even if a spatial map of soil properties exists, the decision regarding the amount of N fertilizer to apply must be made without any prior knowledge of future weather conditions (Basso *et al*., 2011). In such a context, determining the optimum amount of and the most appropriate timing for N fertilizer is a challenge (Dumont *et al*., 2016).

Application of N fertilizer in Latvia has been determined by the Republic of Latvia Cabinet Regulation No. 834 'Regulation Regarding Protection of Water and Soil from Pollution with Nitrates Caused by Agricultural Activity' where maximum permissible amount of nitrogen, which may be used for crops in one harvest period depending on the planned yield level has been indicated. Current agricultural practice in Latvia shows that those farmers who don't implement fertilisation planning are usually guided by maximum permissible amount of nitrogen, which may be used for crops. However, it has been scientifically proved that in some cases current fertilizer recommendations, which are based on the grower's yield expectation, can lead to significant errors in N management practice. For example, current Finnish N-fertilizer recommendations are uneconomically high for poorly responsive fields, where N input can be reduced by 20 – 75 kg ha^{-1} without economic loss to agriculture. Such improved practices could reduce N balances by 10 – 40 kg ha^{-1} $year^{-1}$. In contrast, the current recommendations may be uneconomically low for highly responsive fields, thus leading to economic losses for the growers (Valkama *et al*., 2013).

Such situation analysis let authors conclude that introduction of such best management practice for N management as fertilisation planning should be associated not only with costs but also with economic and environmental benefits (see Table 1).

The main costs associated with introduction of fertilisation planning are as following:

1. Agrochemical research of soil: these costs depend on size of the farm and farmers choice regarding usage of GPS in research. Thus farmers' costs for agrochemical soil tests can vary from 16 EUR ha^{-1} to 28 EUR ha^{-1}.
2. Development of crop fertilization plan: farmers have several options - farmers can use on-line fertiliser planning system offered by E-service LAD EPS or farmers can do calculations themselves by using specific normative tables (Kārkliņš & Ruža, 2013) drawn up on the basis of experimental data obtained or by using the software provided by different services. In this

case these will be transaction costs. In the case if farmers use consulting services of Latvian Rural Advisory and Training Centre costs will be 3 EUR ha^{-1}.

3. Calculation of nitrogen balance: farmers can do calculations themselves by using specific normative tables (Kārkliņš & Ruža, 2013) drawn up on the basis of experimental data obtained or by using the software provided by different services. In this case these will be transaction costs.

The total cost of introducing of fertilisation planning range from 22 to 34 EUR ha^{-1}. However, according to scientific findings (Valkama *et al*., 2013; Domingo *et al*., 2014)the fertilisation planning would generate savings in N inputs – ranging from 10 to 40 kg N ha^{-1}, which can be considered as economic benefits. Thus fertilisation planning can be considered as a neutral measure where costs are compensated by savings. Fertilisation planning associates also with some environmental benefits – reduced N fertilizer inputs will positively affect GHG emissions through reduced direct N_2O emissions from agricultural soils.

Conclusions

1. Agrochemical soil testing is a key to soil nutrient management and provides a farmer with an estimate of the amount of fertilizer nutrients needed to supplement those in the soil. Situation analysis in Latvia shows that over the past six years only for 10% of agricultural land soil agrochemical research has been made. It means that a large part of Latvian farmers grow crops without knowing the soil agrochemical properties. Thus, fertilization planning has to be included on the list of national agricultural activities eligible for support, which would motivate farmers and contribute to maintaining the quality of soils, increasing yields, accumulating and updating information on the condition of soils, fertilization practice and nutrients balance.
2. The assessment of potential costs and benefits from fertilisation planning revealed that:
   - total cost of introducing of fertilisation planning range from 22 to 34 EUR ha^{-1}, however, fertilisation planning is a neutral measure where costs are compensated by savings from N inputs which range from 10 to 40 kg N $ha^{-1;}$
   - fertilisation planning generates environmental benefits, i.e. – reduces direct N_2O emissions from agricultural soils by 47 – 187 kg CO_{2eq} ha^{-1} through reduced N fertilizer inputs.

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