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Optimization of Modern Agricultural Crop Production Systems in the Context of Circular Economy

Steliana Rodino[1,2], Ruxandra Pop[1], Vili Dragomir[1*], Ana Ursu[1], Marian Butu[1,2]

[1]Institute of Research for Agriculture Economy and Rural Development, Bucharest, Romania
[2]National Institute of Research and Development for Biological Sciences, Bucharest, Romania
[*]Corresponding author. E-mail: dragomir.vili@iceadr.ro

ABSTRACT

The proper management of nutrient use in modern agricultural practices is of paramount importance. Nitrogen, phosphorus, and potassium, as the three essential nutrients for crop growth, play pivotal roles in ensuring healthy and productive agricultural systems. Farmers meticulously calculate and apply these nutrients to optimize crop yields, but a heavy reliance on synthetic fertilizers can lead to imbalances and environmental challenges. Managing nutrient use efficiently is not only crucial for enhancing crop productivity but also for achieving economic efficiency by reducing input costs and minimizing environmental externalities. With a specific focus on the Circular Economy Action Plan and the "food, water, and nutrients" category, the article highlights the significance of nutrient management, particularly in the agricultural context. It underscores the necessity of moving towards organic farming practices to enhance nutrient cycling and biodiversity. Overall, it provides a valuable overview of nutrient management and its relationship to the circular economy, agriculture and environmental protection.

Keywords: circular economy, sustainable crop production, nutrients circularity.

INTRODUCTION

Circular economy represents a new approach regarding production and consumption, which focuses on extending the life cycle product of product. These implies sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products. Thus, the circular model targets less raw material, less waste and fewer emission (European Parliament, 2023). The new Circular Economy Action Plan (2020) presents the 7 Key Product Value Chains "for a cleaner and competitive Europe: electronics and ICT, batteries and vehicle, packaging, plastics, textiles, construction and buildings, *food, water and nutrients*". The last-mentioned category represents the main theme of these research. According to the new Circular Economy Plan, the European Commission will develop the Integrated Nutrient Management Plan, in order to ensure the sustainability of nutrients application and more important, to develop the markets for recovered nutrients. Not only this document announces the initiative for implementing the Integrated Nutrient Management Plan, but also the European Grean Deal, the Farm to Fork Strategy and the Biodiversity Strategy. The main objective in terms of nutrient management is to reduce nutrients losses by at least 50%, while ensuring that there is no deterioration in soil fertility (EC Initiatives, Nutrients - action plan for better management).

This new document will contribute in order to achieve the European Climate Law and Zero Pollution Plan objectives. Also, several important sustainable development goals (SDS's) are influenced, such as SDG 2 Zero hunger (sustainable food production systems); SDG 12 Sustainable consumption and production; and SDG 13 Climate action (the 2030 Agenda for Sustainable Development). Thus, improving the nutrients circularity has an important impact for global, regional and local strategies and policy decisions.

Agriculture is more than just a important economic sectors, being essential both for the global population and for the path of transition to sustainability. Due to several factors, such as climate, soil, farmers

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experience and tradition, Europe is one of the world's leading producers and exporters of agricultural products, therefore ensuring not only Europeans citizens food security but also for the global population. It is necessary that the world food production to double in order by 2050, in order to ensure population wellbeing (EC, 2017). But how this aspect harms the environment? I order to ensure the balance of these two main challenges, not only at the European level, it is encouraged the transition from the traditional agriculture techniques to organic farming, which implies among others targets to simulate functional local ecosystems, with strong nutrients cycling process, in order to increase biodiversity (Altieri, 2002). Nutrients circularity involves a closed-loop system, with recycling and reusing nutrients process within an ecosystem and ensures the return of nutrients in soil or other ecosystems. This pattern ensures the nutrients preservation and the reducing of the synthetic fertilisers and other harmful inputs (Smit, 2023). Examples of most common fertilisers used for the plant nutrition are nitrogen, phosphorus, and potassium (EPA, 2022).

With a vast tradition in the cultivation of cereals crop and not only, Romania ensures at the European level over 16% of main grains production (wheat, maize and barley) and 12% of the oil's plants (sunflower and rape) (FAO, 2021). In 2020, the organic farming area reached only 2.1% in total utilised agricultural area, value which place Romania far away from the EU's organic share level of 9% and furthermore from 2030 EC's target of 25% (EEA, 2023). These low values mentioned, among with others national vulnerabilities identified at the agriculture sector, strengthen the necessity of improving the nutrients circularity closed-loop systems, at the farm level.

In this context, this study aims to provide an overview of key findings related to nutrient management, circular economy principles, and the state of agriculture in Romania and Europe.

Nutrient management is a crucial aspect of circular agriculture. Our focus was to analyse the statistical data related on how to effectively manage nutrients within crop production systems, emphasizing the reduction of synthetic fertilizer use.

MATERIAL AND METHODS

The study entailed a comprehensive examination of nutrient management practices in modern agriculture, with a particular focus on the utilization of essential nutrients such as nitrogen, phosphorus, and potassium, which are fundamental for robust crop development. A review of the existing literature was conducted to establish a foundation for the study. The research drew on statistical data pertaining to fertilizer usage and nutrient balances in European countries. Analysis of nutrient balances was carried out using methodologies, including the farm-gate balance and gross balance approaches, treating farms or national agriculture sectors as units of observation. The dataset encompassed information on the quantities of synthetic fertilizers and manure applied and removed from cropland hectares, and variations in nutrient balances over time were evaluated. Additional investigation examined the potential of nanofertilizers to enhance crop yield and nutrient efficiency, with an emphasis on cost-benefit analysis. The study also explored the evolving nutrient recycling market, with an assessment of its size, projected growth, and countries leading in this domain. In light of the findings, the study proposed the necessity for a nutrient directive in Europe and the need for more specific regulations to address variations between European states. Ultimately, the study aligned with the European Commission's goal of reducing nutrient losses and improving nutrient management through the development of the Integrated Nutrient Management Plan.

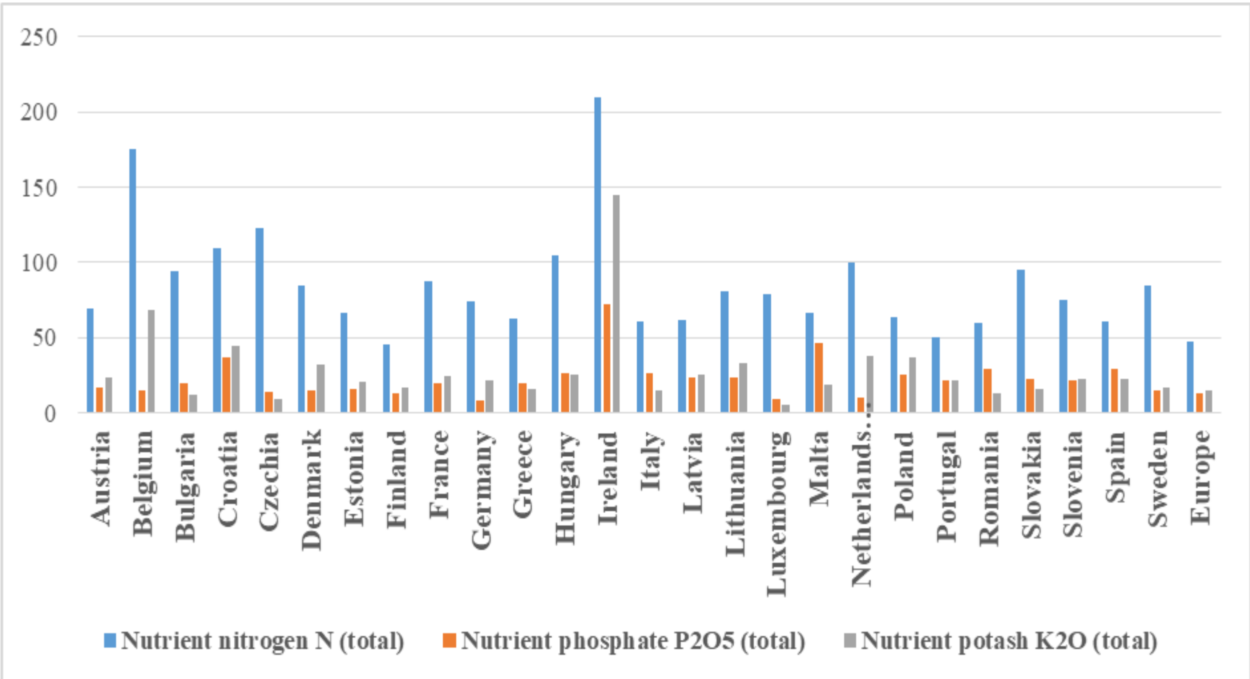
RESULTS AND DISCUSSION

The proper management of the use of fertilizers per nutrient plays a pivotal role in modern agricultural practices. Nitrogen, phosphorus and potassium are the essential nutrients that enable healthy crop growth.

Nitrogen, with its vital role in photosynthesis and protein synthesis, often leads the list in terms of usage. Phosphorus, crucial for root development and energy transfer within plants, is another key component. Finally, potassium, responsible for overall plant health and resilience, completes the trio. Farmers carefully calculate and apply these nutrients to optimize crop yields. However, an overreliance on synthetic fertilizers can lead to nutrient imbalances and environmental issues, highlighting the need for sustainable and precise nutrient management practices in agriculture. Efficient nutrient management not only enhances crop productivity but also contributes to economic efficiency by reducing input costs and minimizing environmental externalities (Ghinea et al., 2007; Matos et al., 2016; Agapie et al., 2023).

Excess nutrients is one of the main vulnerability exercised by the crop production over the environment and food security. Regarding this issue, natural nutrient cycle must be improved. The main focus of others published studies is on phosphorus (P), and secondly nitrogen (N), potassium (K) and carbon, but not all the studies combine all this elements balance analysis. According to Wiel et al. (2019), in order to restore nutrient circularity, more significant is the component of agro-food-waste system and the policy level implement degree, than the territorial coordinates.

In Figure 1 is presented the use of fertilizers per nutrient (2021) at the European member states level, by country. As it can be observed, the use of nitrogen reaches the highest values, at the European level, and in countries like Ireland, Belgium and Czechia. The use of phosphate is highlighted in Ireland, Malta, Croatia and Romania. Ireland, Belgium, Croatia and Netherlands are identified as the main representatives countries in terms of potash used as fertilizer per area for cropland.



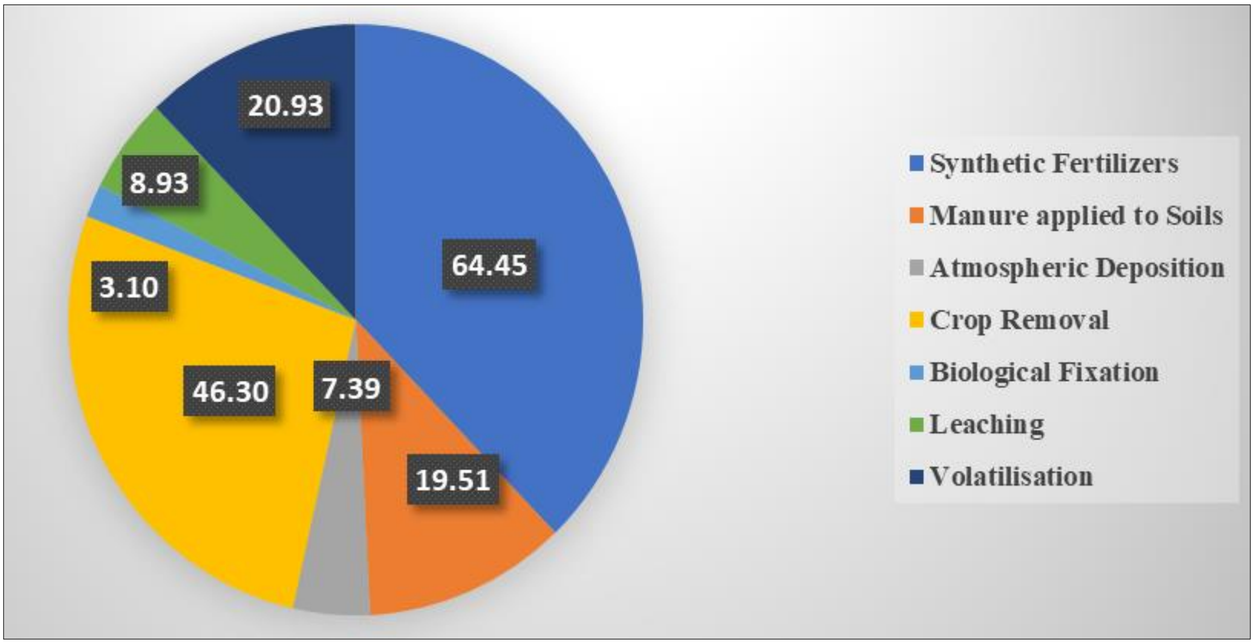
Source: FAO data, Fertilizers by Nutrient Time Series, Use per area of cropland.

Figure 2. The use of fertilizers by nutrient (kg/ha), per area for cropland, in the 27 EU Member States, 2021

The quantity of used fertilizers is influenced by the crop structure, the soil degradation degree stage, the climate condition and others natural factors specific at each country's level. Using the same data source, it can be observed the use of fertilizers dynamic between 2015-2020. Overall, it can be state that majority of UE member states have increased the applied quantity of fertilizers by nutrient, especially for nitrogen fertilizers category. Countries that are excepted regarding this statement are Austria, Belgium, Germania, Czechia, France, Poland and Portugal. Therefore, it can be state that the countries that are closer to reaching the target of the European directives regarding organic agriculture had considerably decreased the amount of fertilizers used in the period 2015-2020.

According to OECD and Eurostat (2017), two main types of method are identified in order to calculate the nitrogen balance: the farm-gate balance and the gross balance. Both of the mentioned methods treats the farm or the national agriculture sector as the unit to be observed, but the approach are different. The second method calculate all inputs and outputs from this unit, the amount of nitrogen used by the farm (e.g. fertilisers, animal manure), through atmospheric deposition, fixed in the soil through biological process, and removed from the soil (in crops and through grazing).

In Figure 2 we can observe the elements used among the gross nitrogen balance as it was previously described, according to FAO data, for Romania, in 2021.

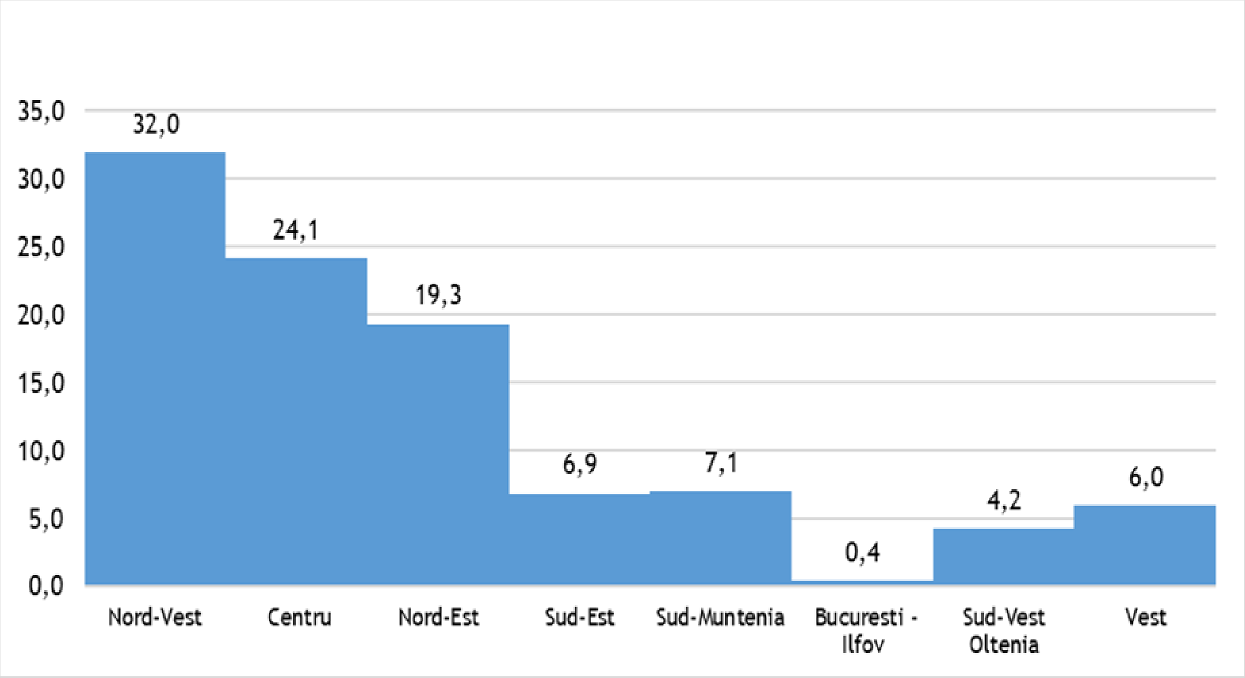


Source: FAO data, Cropland Nutrient Budget, Cropland Nitrogen.

Figure 2. Cropland Nitrogen Budget, (kg/ha), per area, in Romania, 2020

Therefore, 65 kg of synthetic nitrogen fertilizers and 21 kg of manure is applied for one cropland hectare, but only 46.30 kg are removed from the field by crops. Also, according to the same source, at the European level, the quantity of synthetic fertilizers reaches 51 kg/ha and the manure applied to soil register 22 kg/ha, a superior value comparing to national situation.

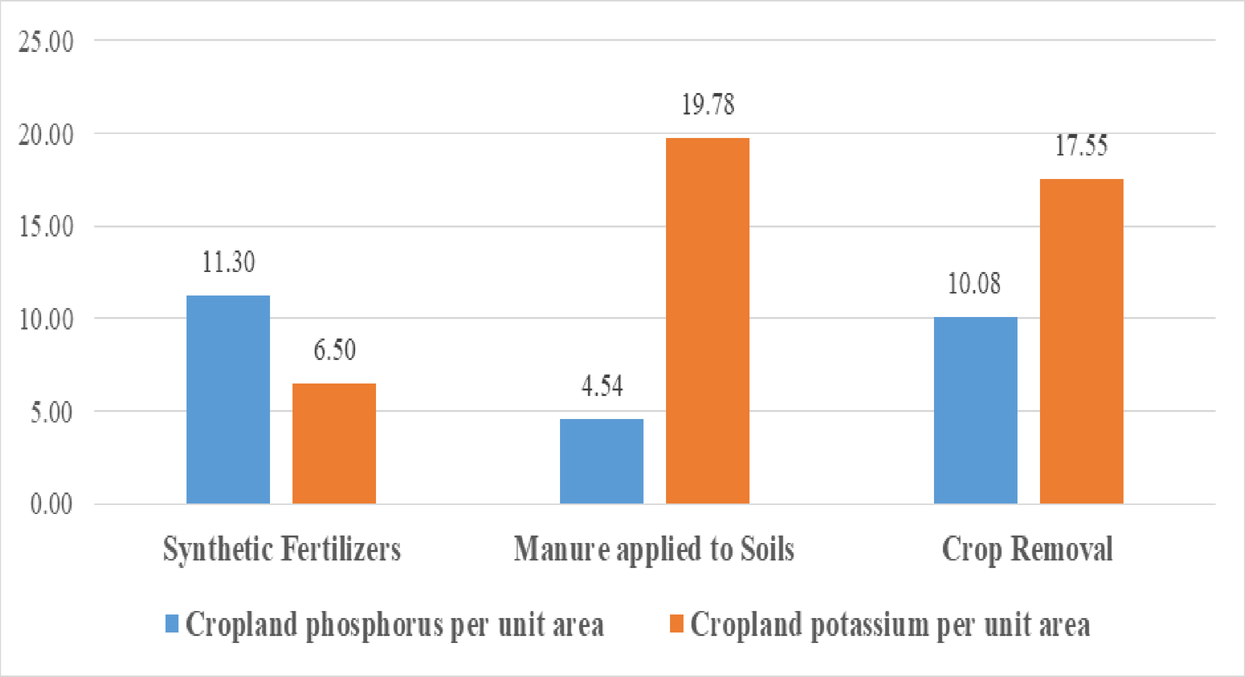
The area on which natural fertilizers were In Romania applied increased by 750 thousand hectares (+73.3%), in 2022 compared to 2014. In the North-East region, the surface increased by 227 thousand hectares (+231.8%), in the South-West region (+78.4%), and in the west of the country with 251 thousand ha (+53.4%) (Figure 3).



Source: Own calculations based on the data of the National Institute of Statistics.

Figure 3. Share of the area on which natural fertilizers were administered, in the total area, by region, average of the period 2014-2022

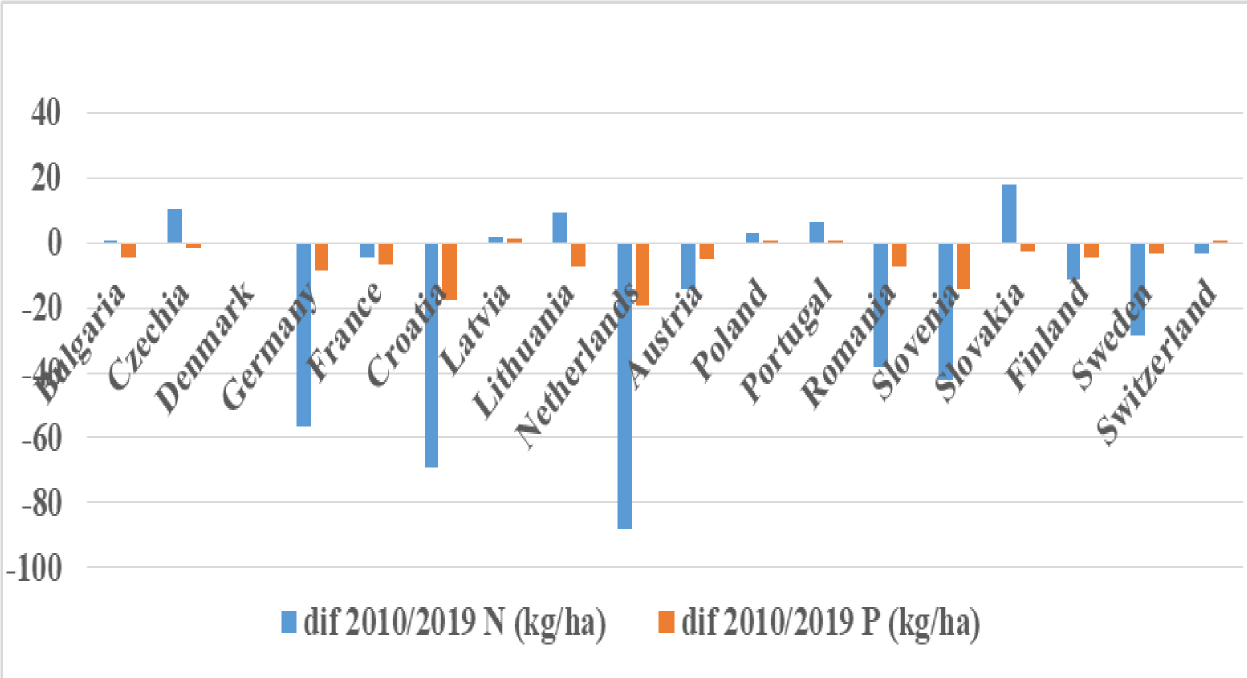
Regarding the others fertilizers often used in agriculture (phosphorus and potassium), according to statistical data, Figure 4 shows the synthetic fertilizers and manure country in Romania, 2020. Thus, it is showed that only 10 kg (phosphorus)/cropland ha is removed from the field and 17 kg (potassium)/cropland ha, from a total quantity of 15.84 kg/ha of phosphorus and 26.28 kg/ha of potassium.



Source: FAO data, Cropland Nutrient Budget, Cropland Nitrogen.

Figure 4. Cropland Phosphorus and Potassium Budget, (kg/ha), per area, in Romania, 2020

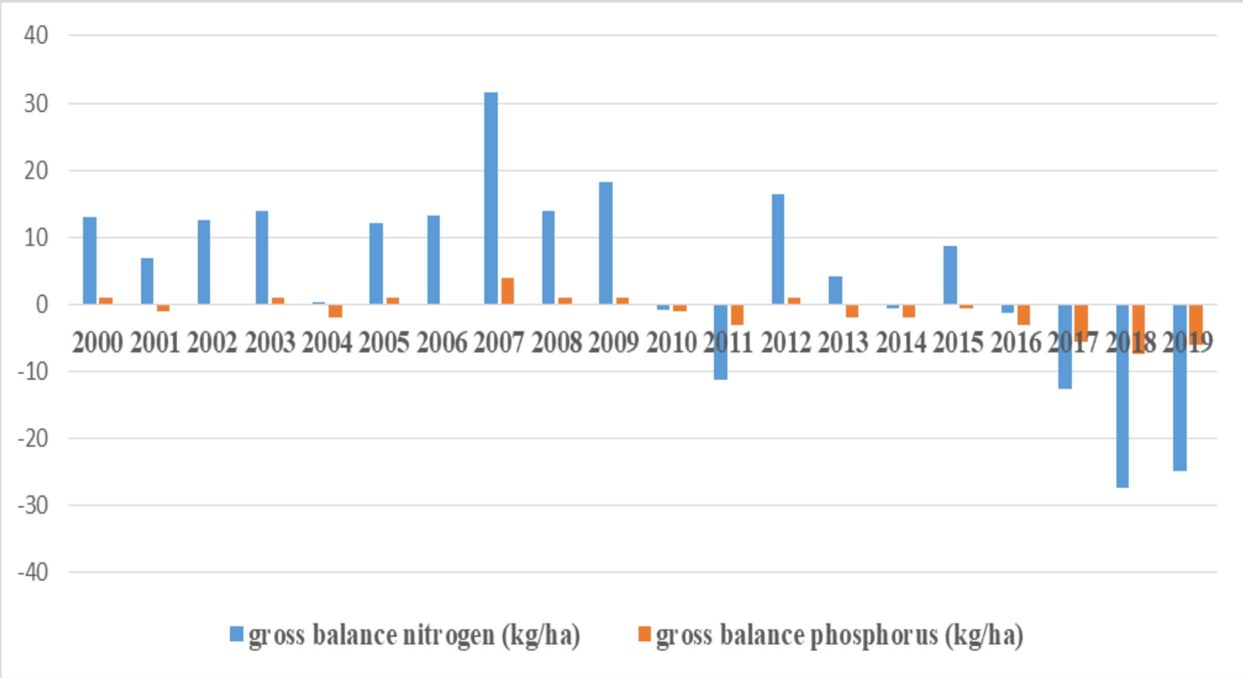
According to Eurostat data, gross balance nutrient varied considerably between 2000 and 2019 in all the European countries and this values are influenced by weather, water availability, tillage practices, residue retention, crop rotation, fertilizer rate, timing, placement, and source (Liyanage et al., 2021). In Figure 4 we present the gross balance nutrient fluctuations, for nitrogen and potassium.



Source: Eurostat data, Gross nutrient balance on agricultural land by nutrient.

Figure 5. Gross Nutrient Balance fluctuations 2010-2019, (kg/ha), in UE-27 countries

In general, the gross nutrient balance for nitrogen and phosphorus registered highest value in 2010, comparative with 2019. According to the data indicator description, a low value of nitrogen or phosphorous may affect the soil fertility, while an excess may cause surface and groundwater (including drinking water) pollution and eutrophication. Ideally, the input/output of nutrition to the soil should be balanced. In Romania, this indicator oscillates between negative and positive balance at nitrogen, with the highest excess in 2007 and low values in 2018-2019. Regarding the phosphorus gross balance, we can observe that until 2009 positive values are registered and starting with 2011 these values are negative (Figure 5).



Source: Eurostat data, Gross nutrient balance on agricultural land by nutrient.

Figure 6. Gross Nutrient Balance fluctuations 2010-2019, (kg/ha), in Romania

To ensure the best result regarding the gross nutrient balance at the farm level, nutrient management should be improved. According to Fronczak (2019), the nutrients management is guide by "4R" - right source, right rate, right time, and right place.

For example, in wheat case, previous research shows that nitrogen fertilization during the growing season is of particular importance for the achievement of economic wheat production and the protection of surface and deep water. However, the excess of nitrogen causes the fall of crops, the sensitivity of wheat plants to diseases, the reduction of production, the increase of costs and the water pollution with nitrates. The lack of nitrogen leads to the decrease of production and the reduction of profit compared to the correctly fertilized surfaces. Unlike phosphorus and potassium fertilizers, nitrogen fertilizers are unstable. Therefore, the necessary nitrogenous fertilizers cannot be administered all at once, but staggered and in different amounts, depending on the growth stages of the plants and their absorption capacity by the wheat plants (Pop, 2019).

Closing nutrients cycles, as a solution in improving nutrient management, could contain several measures, at different scales (Bile et al., 2019):

- developing ecological processing: the crop rotation process is an important aspect regarding the improving of the ecological process; for example, integrating leguminous plants into the crop rotation could fix the nitrogen level in soil. Therefore, farmers should be able to use a lower quantity of synthetic fertilizers;
- integrating crop-livestock model at the local farm level. Therefore, it will be possible for local producers to use more manure fertilizers on crop land and to use plants as food for animals;
- at territory level, production diversification could be also a solution trough cooperation between the live-stock and crop farms.

Practicing crop rotation prevent the loss of soil biodiversity, reduce nitrogen loss through leaching and the environmental pollution, but influence the emissions of greenhouse gases (Tabassum and Rezwana, 2021).

Recent studies and findings state that using nanofertilizers in agriculture could represent a new approach in order to ensure the balance between the population food security, the farmers wellbeing and the environmental protection. According to

Mishra et al. (2023), nanofertilizers is modern technology which helps to increase crop yield and nutrient use efficiency and to reduce excessive use of fertilizers. Regarding the cost-benefits analysis on this approach, there are still too few studies, in order to establish if using nanofertilizers is increasing or not the farmers revenues. But, even if the crop production cost will be higher than applying conventional methods, this loss could be recovered by obtaining higher yields, compared to those specific in conventional agriculture.

According to recent marketing research, the nutrient recycling market size is estimated at 4.7 billions euro in 2021 and the forecast shows that this market will reach to 7.5 billions euro in 2031, with a CAGR of 5.3%, from 2021 to 2031. The same source shows that countries like Denmark, Spain, Finland and Germany are the main recycling nutrients market, due to their higher interest on Net-Zero emissions goal (Transparency Market Research, 2023).

In present, European Commission still promotes “the goal of zero pollution from nitrogen and phosphorus flows from fertilisers through reducing nutrient losses by at least 50%, while ensuring that there is no deterioration in soil fertility. This will result in the reduction of use of fertilisers by at least 20%”. Thus, together with the Member States, the European Commission will develop The Integrated Nutrient Management Plan, with certain objective: ensure more sustainable application of nutrients, stimulate the markets for recovered nutrients, address nutrient pollution at source, and increase the sustainability of the livestock sector (EC, Schilthuis, 2021).

CONCLUSIONS

The critical issue of excess nutrients, which poses a significant threat to both the environment and food security. A critical aspect of addressing this challenge lies in improving the natural nutrient cycle. Past studies have primarily focused on phosphorus, followed by nitrogen, potassium, and carbon, but few have comprehensively combined analyses of all these elements. Moreover, this study emphasizes that the key to restoring nutrient circularity is not limited to geographic coordinates but also involves elements like the agro-food-waste system and the implementation of sound policies.

The utilization of nitrogen, phosphate, and potash as fertilizers across European countries, shedding light on variations driven by factors such as crop structure, soil conditions, and climate. Importantly, it has documented the dynamics in fertilizer use from 2015 to 2020, highlighting a general increase in the application of nitrogen fertilizers across most EU member states. However, exceptions like Austria, Belgium, Germany, Czechia, France, Poland, and Portugal, have shown a reduction, possibly aligning with European directives on organic agriculture.

The study also indicates a growing market for nutrient recycling, with several European countries like Denmark, Spain, Finland, and Germany leading the way due to their commitment to Net-Zero emissions.

This research has emphasized the significance of nutrient management within the agricultural sector, highlighting the need for a more sustainable and circular approach. As the world deals with the dual challenge of ensuring food security for a growing population while mitigating environmental negative effects this study underlines the importance of transitioning from traditional agriculture to organic farming practices, promoting nutrients' circularity and reducing reliance on synthetic fertilizers. These initiatives are not only vital for Europe but also align with broader global sustainability objectives.

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