Food for Thought: Towards Circular Nutrient Economy in Agriculture

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Introduction

Agriculture is facing a major challenge of feeding the growing world population. Since the green revolution, the abundant use of fertilizers has been widely regarded as a fundamental tool to address this challenge. However, excessive use of fertilizers is linked to significant pollution and damage to the environment (Ayoub et al. 1999), rendering most current agroecosystems unsustainable and adjacent ecosystems deteriorated.
Switzerland's agriculture, on average, has used excessive amounts of fertilizers at relatively low efficiency (Spiess et al. 2023), indicating the need to improve the nutrient use efficiency of Swiss agricultural production.

In this article we present a thought experiment on how to close nitrogen- and nutrient-cycles in Swiss agriculture and thus foster a more sustainable fertilization.
For simplicity, in the following we will only talk about nitrogen (N), its related processes and the efficiency of its use. Other plant nutrients and related fertilizers such as phosphorus (P) are not discussed in depth here.

History of Fertilizer Use

Before the 19th century the use of organic or natural nutrient sources or fertilizers such as manure, ash, marl and compost was the only possibility to provide plants with additional nutrients. First synthetic fertilizers, such as superphosphate, obtained by treating bones with sulfuric acid, were not efficient and laborious to produce (Russel et al. 1977). Only in the beginning of the 19th century the world experienced a breakthrough in the chemical synthesis of fertilizers. The invention of the Haber-Bosch synthesis of ammonia by Fritz Haber and Carl Bosch, was thought to be the solution for insufficient N-fertilizer quantities in agriculture. The invention brought the needed success (*see Figure 1*), but at the same time levels of man-made nitrogen compounds and their loss to the environment began to skyrocket.

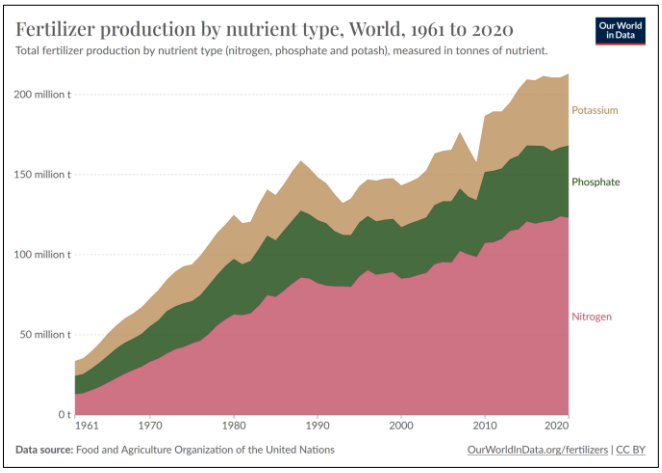

Figure 1; World fertilizer production since 1960.[1]

Following that, a variety of environmental problems began to rise (Stewart et al. 2018). This includes for example acidification of soil, formation of greenhouse gasses and oxygen depletion in freshwater and marine habitats.

Looking at the Planetary Boundaries in 2023 (Richardson et al. 2023) (see *Figure 2*) we see that the biogeochemical flows of nitrogen and phosphorus

[1] Ritchie et al. (2022) - "Fertilizers". Published online at OurWorldInData.org.

appear to be one of the main drivers limiting sustainability on our planet.

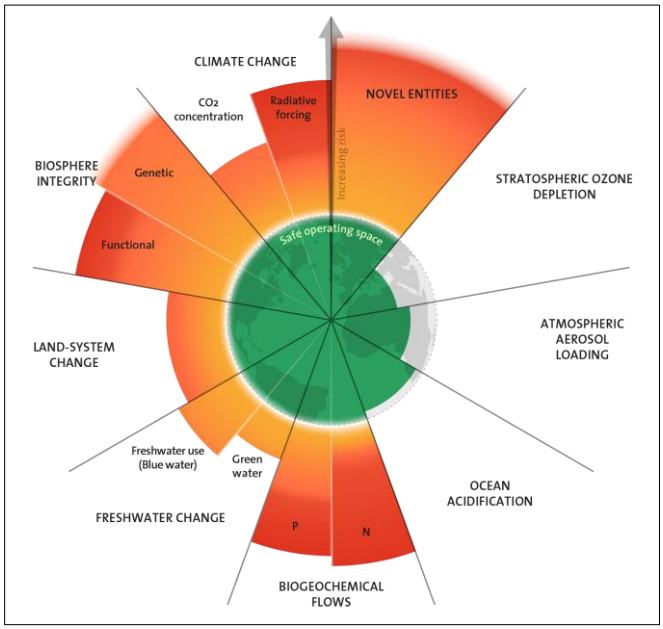

Figure 2; Planetary Boundaries according to Richardson and colleagues. The figure displays different environmental goods and where humanity operates in the risk space [2].

Environmental Damage through Nitrogen

Applied fertilizers have different ways how they can be lost into the environment (Agroscope 2021). In the form of ammonia (NH_3) nitrogen can get into the atmosphere. Whereas through soil leaching, nitrate (NO_3^-) gets washed out of the soil into water streams and groundwater. Unfortunately, applied nitrogen, often in form of ammonium (NH_4^+), undergoes easily a denitrification process and gets converted into nitrate (NO_3^-), which is easier washed out of the soil because of its negative charge.
Ammonia leads to acidification of soils, damages sensitive ecosystems and contributes to poor air quality. Nitrates leach from soil into water systems where they contribute to the eutrophication of water ecosystems or pollute drinking water reserves.

Gaseous nitrogen in the form of nitrous oxide (N_2O) is a potent greenhouse gas that leads to ozone depletion and fosters planetary warming.

In order to minimize such detrimental effects of nitrogen losses to the environment, it is essential to increase the efficiency of fertilizer use and minimize the consequential damage (Gao et al. 2023), (Martínez-Dalmau et al. 2021), whilst providing the agricultural outputs such as food, feed and fiber, and their economic benefits (Langholtz et al. 2021).

Fertilizer Practices and Policies in Switzerland

Looking at the current situation in Switzerland it is striking that regions with intensive agriculture, especially the midland region are heavily affected by excess nitrogen and phosphorus inputs into the environment (Rihm et al. 2016, BAFU 2019, BAFU 2022) reflecting the imbalance of the inputs and outputs into the agricultural system.

This imbalance can be seen at the national level, where Switzerland introduces far more nutrients into the agri-environment than it produces nutrient outputs in the form of agricultural products. This is mainly due to nutrients imported in the form of fodder and mineral fertilizers (Spiess et al. 2023).

In many cases, the imbalance is also present on the field and farm level, reflecting excessive availability and use of fertilizer. This is most pronounced in regions with large manure production indicating an ineffective nutrient accounting and redistribution.

In order to mitigate the negative impacts of excessive fertilizer use, Switzerland employs several guidelines and regulations that should or must be followed. An important regulation instrument is the so-called "Suisse-Bilanz", a nutrient accounting framework which defines a set of guidelines and limits that the farmers need to be compliant with, in order to receive direct payments in

[2] Credit: Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023.

the legal frame of the proof of ecological performance (Direktzahlungsverordnung, DZV, SR 910.13[3]).

The "Suisse-Bilanz" is the central legal enforcement instrument to control nutrient management at farm level and it is outdated with regard to environmental protection and sustainability standards. Firstly, it considers generous losses to the environment resulting in high fertilizer dose thresholds. Secondly, it operates at the farm level only without site specific adjustments for fertilizer demand. Not only does that mean that farms are not treated differently based on the predisposition of their farm and field location, but it also ignores potential imbalances of nutrient management within a farm.

To tackle these problems, we propose to intervene at two different levels. The first one would be at the national policy level, the second would be at the field management level.

Food for Thought: A New Concept for a National Nutrients' Cap and Trade Policy

The general idea is to steer the quantity of nutrients introduced to the Swiss agroecosystem. More specifically introducing new nutrients will become regulated, finite and gradually decreasing until the sustainability goals for nutrients in agriculture are met. The appropriate sustainability goals would determine the nutrients' market cap.
Within the boundaries of the nutrient market, the trading of nutrients could be established through the government issuing certificates for nutrients as a commodity. Such certificates can then be linked to products entering the Swiss agroecosystem, e.g. mineral fertilizers. The certificates can be split or combined along the value chain as quantities of the underlying commodity can change. The price of the certificate will be determined by the market value at the time of purchase.

The main goal of this policy is to put a ceiling on how many nutrients can be introduced to a national agroecosystem. The government would impose a cap on the influx of nutrients in the form of mineral fertilizers, manure and fodder which are being imported or synthesized and enter the Swiss agroecosystem for the first time. The cap would be scheduled and optimized based on the national long-term sustainability goals and agricultural output. A gradual decrease over time would push for a smooth transition in nutrient management practices as it defines a clear long-term trend and provides a timeline for adoption of new practices, technologies and creation of novel nutrient value chains. The implementation of such policy is inspired by the EU Emissions Trading System (EU ETS)[4], where the Government annually issues new batches of "nutrient certificates", which correspond to the current yearly cap. As a result, the price of the certificates and then of the agricultural products containing nutrients will rise if the nutrient efficiency of Swiss agriculture remains the same. Upon the entry into the agroecosystem, the government will collect the revenue from initial purchase of the certificates. The revenue will be used for financing research, investment in innovation of the nutrient trade policy and redistributed to farmers based on nutrient efficiency. In addition, price of manure will rise since in contrast to other forms of fertilizers it won't be subjected to another acquisition of "nutrient certificate". This will make manure and organic fertilizers into a profitable resource for the farmers and eventually fertilizer manufacturers. In contrast to the current oversupply and disposal of manures, this can create a post-processing value chain and thus foster efficient use of such nutrient resources. For a visual overview of the policy's interaction see *Figure 3*.

[3] SR 910.13: Verordnung über die Direktzahlungen an die Landwirtschaft (Direktzahlungsverordnung, DZV), https://www.fedlex.admin.ch/eli/cc/2013/765/de

[4] Overview of the EU Emissions Trading System: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

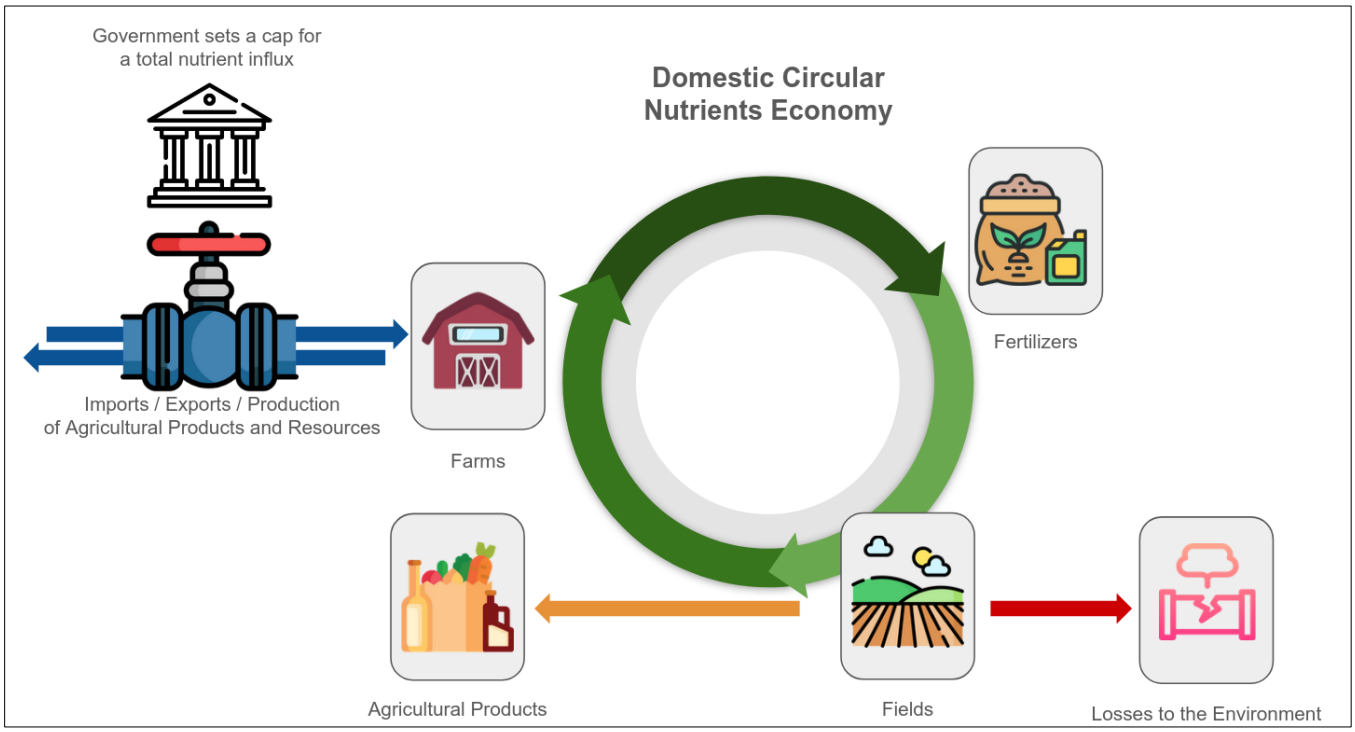

Figure 3; Overview of the proposed National Nutrients Cap and Trade Policy [5]

Food for Thought: A New Concept for a Fine-Grained Nutrient Use Efficiency Evaluation

The Swiss agroecosystem is not only very diverse in terms of farm organization and structure but also in terms of landscape and soil types. Thus, a "one fits all" solution seems not realistic to foster sustainable management of nutrients as on the one hand local soil requirements need to be considered, and on the other hand the environment needs to be protected at the correct scale. For the assessment of the nutrient use efficiency, it is not sufficient to consider it on farm level only, because some field parts can be underperforming whereas some other parts can be excessively fertilized leading to large loss of nutrients to the environment, whilst the farm appears to be working efficiently.

We propose an assessment framework, which considers small grids instead of whole fields or farms and also takes temporal factors of the involved processes into account. For each part of the assessed grid, the inputs and outputs can be monitored over multiple years in a moving time window manner oriented along the crop rotations. Such analysis will allow more efficient fertilizer dosing as effects from previous nutrient practices such as crop rotation or last year organic fertilizer applications carry over to the following season. Such input-output assessment can be complemented by less frequent calibration measurements checking the nutrient status and soil health. For an overview of involved working steps see *Figure 4*.

This assessment approach should provide a more accurate evaluation of the available nutrients in the soil at a granular level, so that losses to the environment can be minimized even on a small scale. The resulting efficiency can then be grouped into understandable efficiency classes aligned with sustainability goals.

The benefit of such a simplified and understandable metric would involve retailers and consumers who could utilize this additional information in the purchasing decision process. The customers would be able to see under which conditions the products that they buy were produced. This could be done for example by putting labels, similar to the EU energy label which present key facts and classifications, onto the product packaging.

[5] Icons designed by Freepik (www.freepik.com)

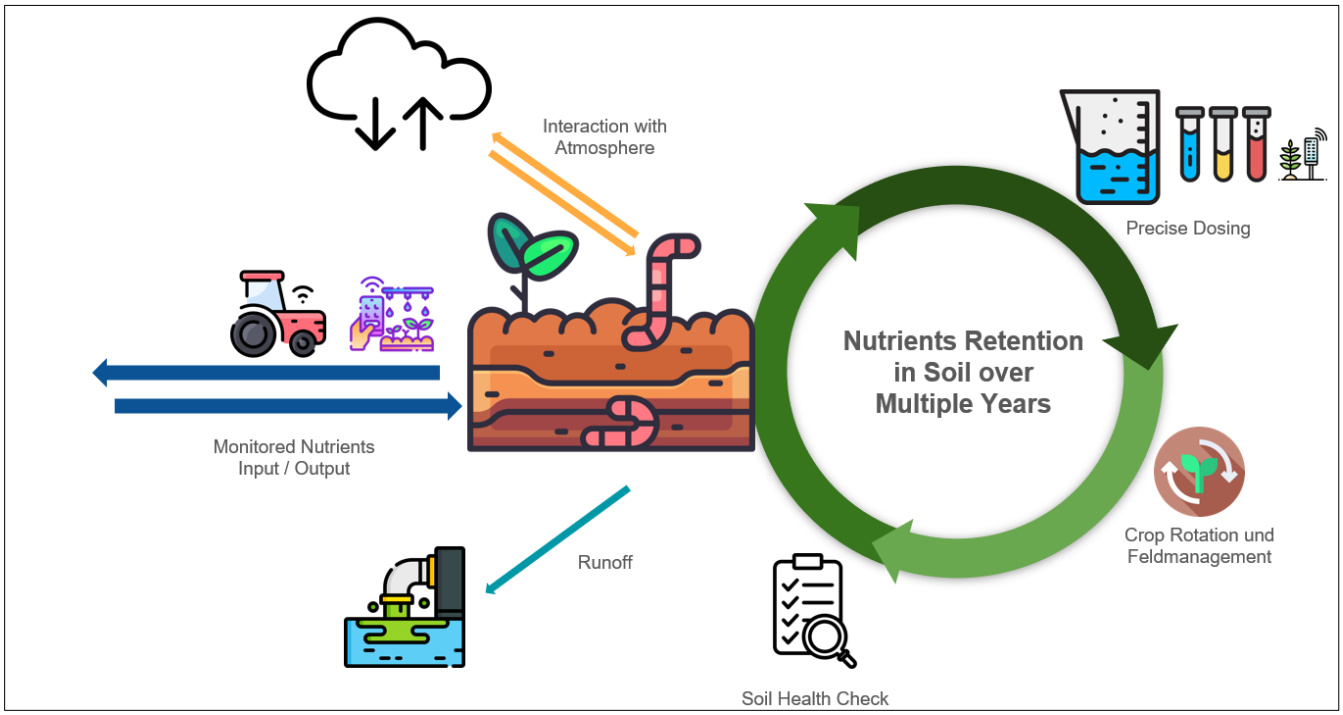

Figure 4; Overview of the proposed fine-grained nutrient efficiency use assessment[6]

Interaction with Farmers

The adoption of novel technologies and acceptance of newly introduced policies highly depends on the effects for the target group and their user experience. Most farmers today operate with little economical and operational flexibility for taking risks and have little options for investment in tools outside of their core business. However, the missing pieces of information for the rollout of a *National Nutrients Cap and Trade Policy* and *Fine-Grained Evaluation of Nutrient Use Efficiency* are either already being collected in non-digitized, respectively not centralized manner or they will become available at no additional effort through technology ready for precision agriculture.

The role of the government in enabling such policies is the delivery of tools for the farmers which unify multiple streams of data to one platform. This can then be used not only for the farmers to track and predict their nutrient management efficiency but also interact with the government, commercial businesses and for proof of compliance with the policies and eligibility for direct payments or other forms of subsidies. Through this the farmers would save time and get a transparent feedback loop. For an example of combined data streams and interaction with farmers see *Figure 5*.

[6] Icons designed by Freepik (www.freepik.com)

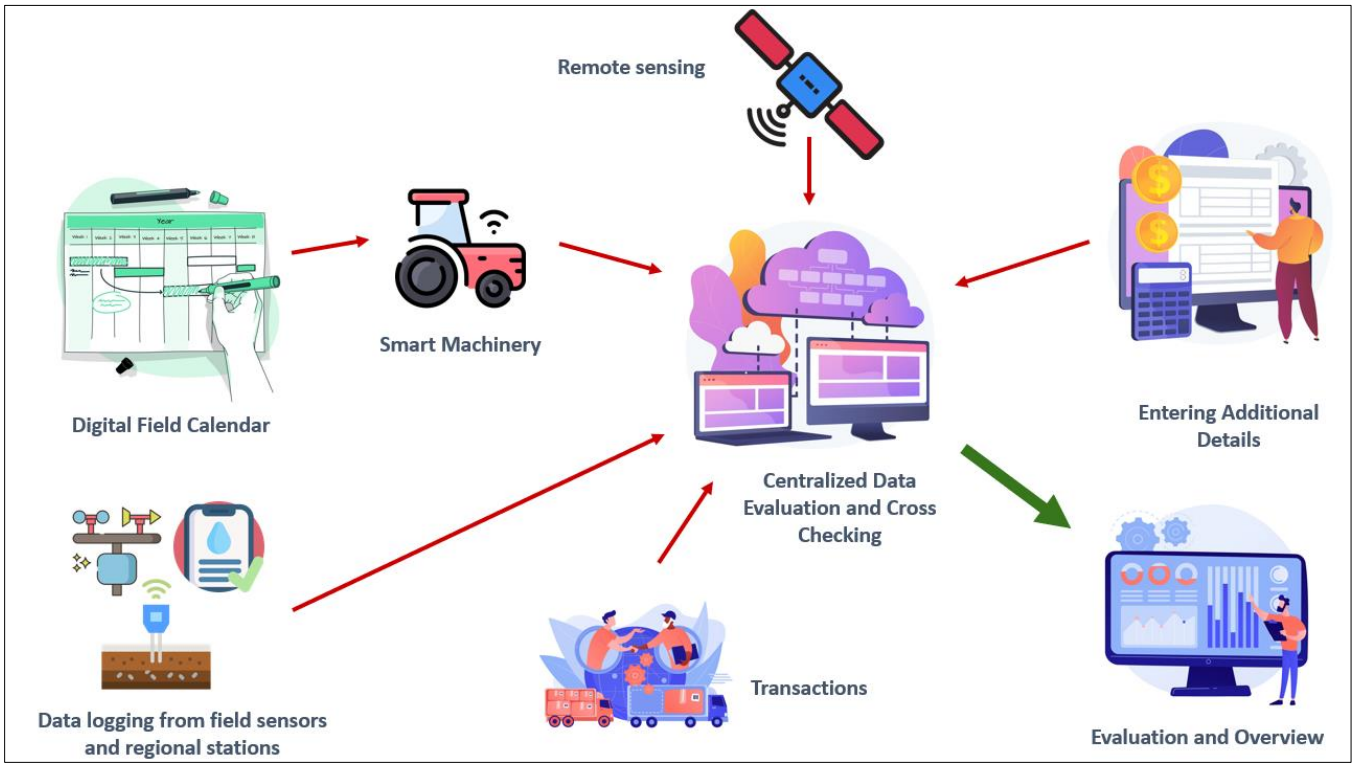

Figure 5; Integration of existing tools for centralized assessment and interaction between farmers, business & government[7]

Conclusions

The current nutrient management is unsustainable and leads to environmental damage and human health risks. On the example of the Swiss agroecosystem we identified potential for improvement and in the form of a thought experiment we presented two potential policies which could transform the processes involved in fertilizer regulation towards more sustainable nutrient management from field to national scale. Our starting points would be, on the one hand at the national level, by introducing a national nutrient cap with a connected trade policy. On the other hand, at the field level, where improvements would be achieved through more precise farming and application methods, combined with a transparent communication under which ecological conditions agricultural goods were produced with regard to fertilizer use.

This thought experiment is of course not fully developed, before consideration it would need deeper analysis and of course time and projects fostering acceptance and implementation of new tools and ways of sustainable nutrient management.

However, we believe that consequent adoption of new and robust technologies and policies can simplify and improve nutrient use efficiency in Switzerland.

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[7] Icons designed by Freepik (www.freepik.com)

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Figures

Figure 1: Hannah Ritchie, Max Roser and Pablo Rosado (2022) - "Fertilizers". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/fertilizers' [Online Resource]

Figure 2: Azote for Stockholm Resilience Centre, based on analysis in Richardson et al. (2023)

Figures 3 – 5: Icons designed by Freepik (www.freepik.com)