FINAL REPORT ON CHALLENGE #7: Regional nutrient balances for better decisions towards nutrient circularity

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INTRODUCTION

Background and full explanation of the challenge #7 of Trans4num project

In Europe, nutrient budgets show significant spatial variation at both the landscape and farm-levels, with certain regions or farms experiencing high nutrient surpluses, while others face nutrient shortages that limit their yield potential. In order to improve sustainability in nutrient management, closing nutrient cycles is needed on different spatial scales.

The trans4num project aims at substantiating and broadly promoting nature-based solutions (NBS) as a sustainable approach to improve nutrient management. With NBS, we understand cost-effective interventions based on innovative solutions that can enhance resilience in agriculture and food production, while mitigating climate change and enhancing nature and biodiversity (Iseman and Miralles-Wilhelm, 2021). Examples for NBS include substituting mineral fertilizers with nutrients from locally available biomass sources and waste streams, application of bio-based fertilizers and the diversification of crop rotations. Collaboration beyond farm level is necessary to coordinate these efforts and for creating a more circular nutrient system. For this, local stakeholders need access to data on the current nutrient balance on different spatial scales ranging from farm to landscape level.

Regional nutrient balances can help to assess the effectiveness of NBS towards improved nutrient circularity. Therefore, we would like to collect data and develop a modeling approach for calculating regional nutrient balances for the trans4num case study sites in Europe (Figure 1). Ultimately, these efforts will feed in a decision-support tool to foster collaboration between farmers and the wider bio-industry.

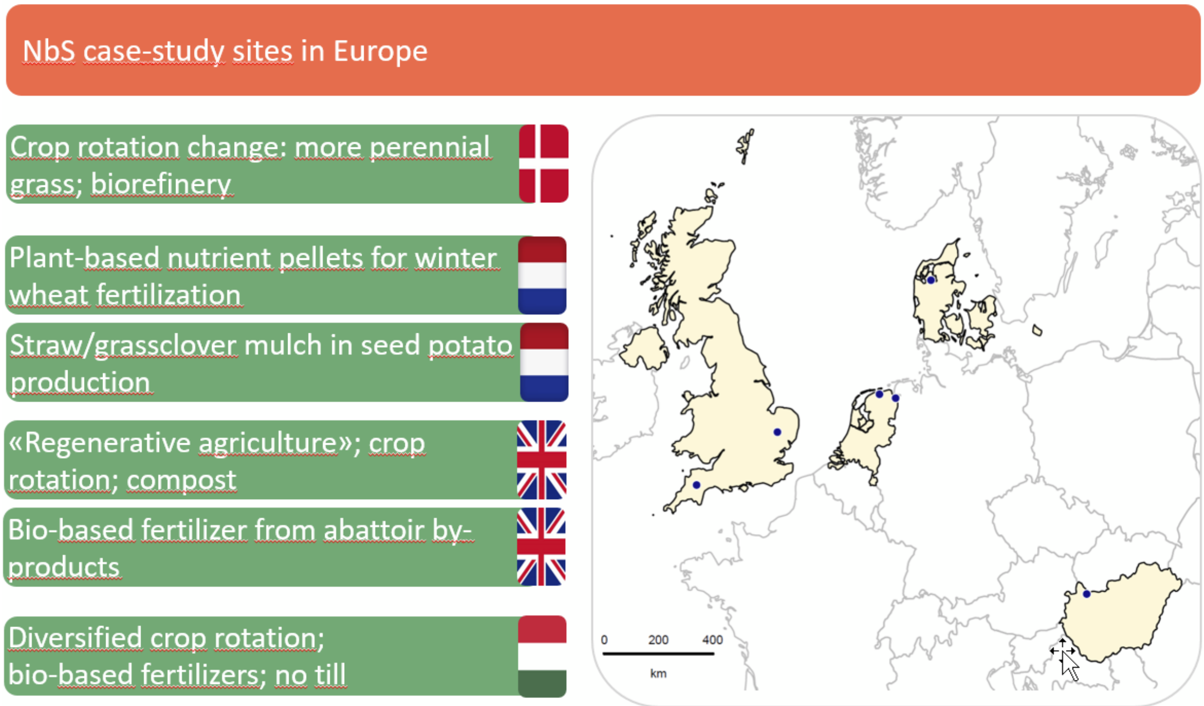

Figure 1: The trans4num NbS case study sites in Europe

METHODOLOGY

Due to the limited number of participants and the diverse background, we decided to focus on the case study site in the Limfjord region, Denmark for the European perspective. Furthermore, we expanded the challenge to also include an African perspective on NBS for improved nutrient management focused on a case study of Burundi Highlands around Burundi land area of Congo-Nil watershed.

Team and coordination with other organizations

Team members

Hanna Frick (researcher at Research Institute of Organic Farming (FiBL), Department of Soil Sciences).

Àntoine Kantiza (Legal representative of Promotion of Learning and Education in Distance (PLEAD); Expert in Strategy for Sustainable Agriculture including Building Climate Resilience in Agriculture; Expert in E-learning on Digital Agriculture; Expert in Transforming Agriculture and Food Systems through Data driven Digital; Expert in Environment Law Application in Protected Areas; Featured Member of e-agriculture community (www.e-agriculture.org) since 2011; Smallholder farmer in Burundi Highlands and Researcher editing various scientific topics including papers driven by INSPIRE Hackathon events organized under the leadership of European Union for

African agriculture transformation by smart technologies since 2019 as it is displayed at https://www.linkedin.com/in/antoine-kantiza-44660325).

Collaboration

For the European case study site, we obtained farm registration data from Aarhus University (M. Vestergaard Odgaard) and the Innovation Centre of Organic Agriculture (ICOEL; A. Rasmussen). C. Pfeifer & R. Winterberg (Research Institute of Organic Farming (FiBL), Department of Food System Modelling) supported calculating a regional nutrient balance by providing a core model code linked to open access databases (e.g. IPCC, EUROSTAT, etc.) .

Technical background

Background and introduction of the European case study site

The Danish NBS case study site is located in the Limfjord area, Northern Jutland. The Limfjord suffers from pollution with nitrate originating from agriculture. One idea how to tackle this issue could be to increase the share of perennial grass in order to reduce nitrate leaching.

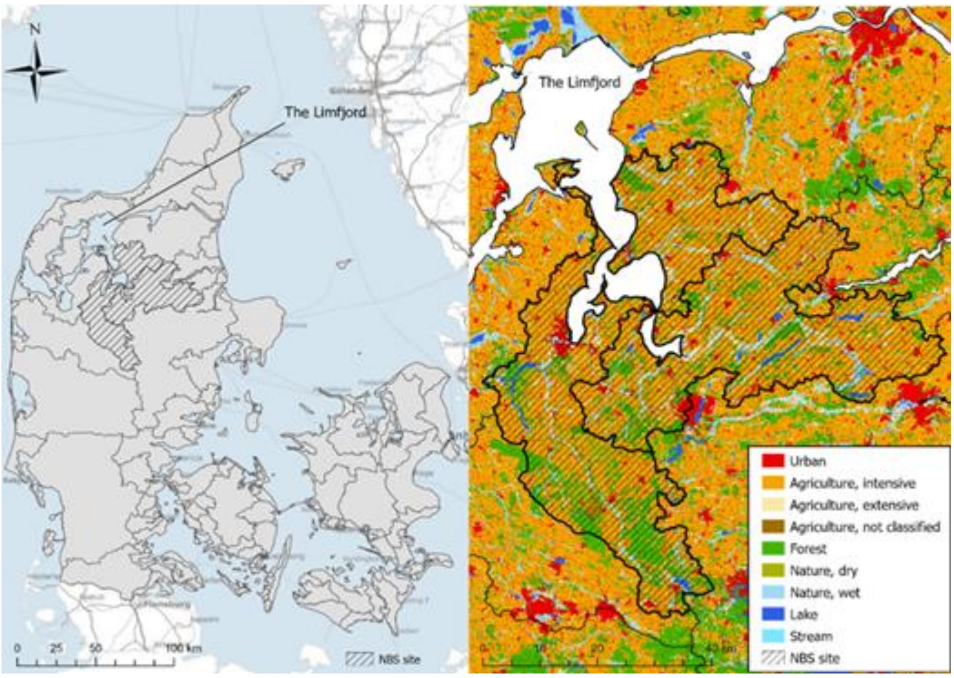

Figure 2: Overview of the NBS site location in Denmark (left) and zoom of the NBS site with overlay of land use (right) (Levin 2019).

The total agricultural area is roughly 175.000 ha and is managed by a total of 2560 farmers. The mean farm size is about 70 ha (median: 23 ha). About 25 % are livestock farms, 15 % are crop farms and the rest (60 %) can be considered as mixed crop-livestock farms. Considering the whole farmed land in the region, about half is cropped with cereals, approx. 25 % are permanent or rotational grassland and 12 % are maize (Figure 3).

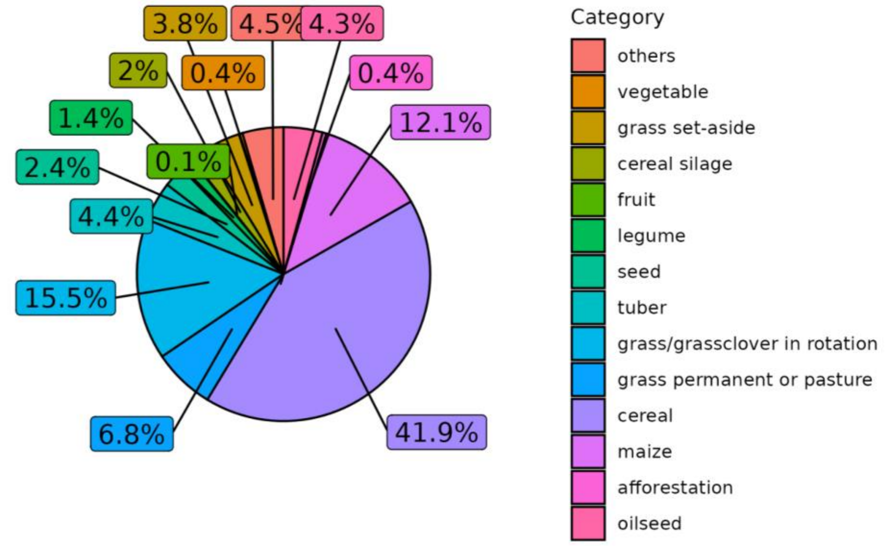

Figure 3: Distribution of crop shares in the Limfjord region (total area: 177.210 ha; data from 2021).

<u>Background and introduction of the African case study site</u>

African soils are less productive than in the former times. Indeed, the African soil is under the hazards of land degradation due to climate change or the long-term overuse of the soil without adding fertilizers before seeding. Climate change has driven erosion while the arable land is shrinking due to desertification or prolonged dry seasons.

Figure 4: Map of Burundi. (https://www.worldatlas.com/maps/burundi)

Many African smallholder farmers are still using NBS including bio-based fertilizers derived from animal manure or any vegetal residues from plants after harvesting and they protect their arable lands against the effects of climate change like planting anti-erosive herbs which can be used for feeding domestic animals. Synthetic fertilizers are used to add nutrients on the fields, but those chemicals are costly for African smallholder farmers without enough income. Also, African smallholder farmers still believe that the soil becomes unproductive once they stop the use of chemical fertilizers. Smallholder farmers who have means, use organic fertilizers mixed with mineral fertilizers produced by Burundi FOMI company (founded 10 years ago).

Burundi Highlands have almost the same climate and soil nutrient as European lands which makes it a comparable case study site. The Burundi Highlands cover almost a third of the total Burundi land area (27.830 km^2). Almost seventy percent of the population are involved in farming. The average farm size of smallholder farmers is about three acres. Common crop rotations include maize, wheat, potatoes, cassava, beans, banana and different vegetables.

Current fertilization practice in the Burundi Highlands includes bio-based fertilizers and mineral fertilizers. It is worth mentioning the African traditional practices of mixing crops in the same field complementing the nutrient needs of the individual crops. For instance, beans planted inside the fields of maize help fixing additional N in the soil allowing a better productivity of maize compared to monocropped fields with only maize.

Potential solutions include introducing innovative bio-based fertilizers and the protection of arable lands with sustainable anti-erosive measures by plantation of trees simultaneously saving the ecological land system and helping with the climate regulation. These aspects should be put at the forefront of efforts in the framework of the European perspective supporting African smallholder farmers for increasing the agriculture transformation by the NBS way of nutrient management for soil productivity supporting the achievement of the second Sustainable Development Goal focused on food security and ending hunger worldwide by 2030.

Description of the process of solution

The joint effort on this challenge includes three approaches:

- Online discussion between participants.
- Individual work on the two case studies, supported by external collaborators.
- Joint work on the final report and discussions about differences and commonalities between the two case study sites.

Data & Equipment list

Denmark

For characterizing the farm population and the crop cultivation in the case study area, data from 2021 was used (Table 1). The data set originates from the official reporting and contains information on crops, soil type and retention potential on field level. Livestock numbers and fertilizer purchases are registered on farm level.

The system boundaries for the current analysis were set along two subcatchment areas of the Limfjord region and contain all fields that fall completely within the region.

Thus, while it allows for a precise picture on the crops grown in the region, it overestimates the livestock numbers and fertilizer inputs to the area as it contains all the livestock owned by farmers with at least one field in the region. Therefore, the number of livestock and fertilizer had to be approximated. For this, the proportion of fertilized land of each farm falling within the system boundaries was determined and the livestock numbers and fertilizer inputs of each farm multiplied by this proportion. It must be noted that this approach neglects the fact that not all crops receive the same amount of fertilizer.

Table 1: Databases and model assumptions used for calculating the regional nutrient balance. (AU = Aarhus University)

Country	**Region**	**Parameter**	**Year**	**Spatial resolution**	**Source**
Denmark	Limfjord catchment	Crop type and area	2021	field	dataset AU (based on registration)
Denmark	Limfjord catchment	Livestock category and numbers	2021	farm	dataset AU (based on registration)
Denmark	Limfjord catchment	N applied with manure	2021	farm	dataset AU (based on registration)
Denmark	Limfjord catchment	N applied with mineral fertilizer	2021	farm	dataset AU (based on registration)
Europe	-	N content in crops	-	-	Einarsson et al. 2021
Europe	-	Byproduct factor and utilisation rate	-	-	Herrero et al. 2012
Europe	-	Biological N fixation	-	-	De Vries et al. 2021
Denmark	DK04	Crop Yield	-	NUTS2	Eurostat
Denmark	-	Crop Yield	-	-	Danish norm yield
Denmark	-	N excretion of livestock	2021	-	Normtal (Danish norm values)

Burundi Highlands

For the African case study based on Burundi Highlands, we use data collected locally as well as information available in scientific research published online including papers related to Burundi FOMI company involved in organic and mineral fertilizer industry participating in restoring nutrient balance against the land degradation observed mostly in Burundi Highlands after heavy rain.

Detailed implementation plan

Denmark

In Denmark, detailed data on field and farm level is available (see Table 1). In addition, a model code was provided by FiBL colleagues (developed within PATHWAYS https://pathways-project.com/). The existing code works with open access data from sources such as Eurostat, IPCC and published data sets and scales that down to NUTS2 level (Table 1).

This code was used as a starting point and customized by overwriting default data with more specific data of the Limfjord region, especially concerning crop areas, livestock numbers and the applied amount of manure N and fertilizer N.

Burundi Highlands

More than 70 % of Burundi Highlands soil is highly acidic with pH values < 5,5 due to the long rain season washing out the agricultural nutrients like N, P and K. Therefore, smallholder farmers of Burundi Highlands have to search for new bio-based fertilizers for restoring the soil nutrient balance before and during each agricultural season in order to achieve good productivity.

The endeavour for each smallholder farmer is to restore the soil nutrient balance by the regularly inputs of bio-fertilizers before and during the flowering of fields what Burundi FOMI has innovated by producing BAGARA fertilizers full of potassium (K) and phosphor (P); TOTAHAZA fertilizers with a high ratio of nitrogen (N) and IMBURA full of agricultural lime reducing the soil acidity. Those three kinds of FOMI fertilizers bring their specific nutrients to be added in the soil in accordance with the step of plants growing in order to restore the soil nutrients balance.

Analysis of needs of stakeholder groups

Denmark

Farmers in the Limfjord region are aware of the nitrate leaching problem. They are increasingly under pressure from regulations by authorities. Usually, the farmer`s focus is on improving their own farm business. However, environmental issues such as nitrate leaching losses are usually affecting the landscape level and require an overview on the nutrient situation of the whole region.

Besides an overview on the current nutrient balance, allowing for visualizations of alternative scenarios could help to foster the discussion on joint efforts in reducing nitrate leaching. In addition, finding an optimal placement of NBS (such as converting cereal fields to grassland) on those fields that have the lowest retention would help to effectively reduce nitrate leaching while minimizing negative impacts on farm productivity.

Burundi Highlands needs

- Improved seeds
- Livestock support for poor smallholder farmers
- Innovative bio-based fertilizers
- Updated and not expensive agriculture tools of preparing fields
- Factories for agricultural transformation
- Infrastructures for supporting farmers like storekeeper for seeds, fertilizers and medicines for farming tasks in rural zones

Experimental results

Denmark

Different approaches of calculating a regional nutrient balance of the status quo in the Limfjord region based on the available data were tested. **It is important to highlight that within the scope of this challenge, the calculations could not be validated! This is needed before using the results with stakeholders.**

The outcome of the calculations can be visualized as shown in Figure 5. The code is flexible in terms of testing different alternative crop shares, livestock numbers etc. and by that show potential effects of implementing NBS on the regional nutrient balance.

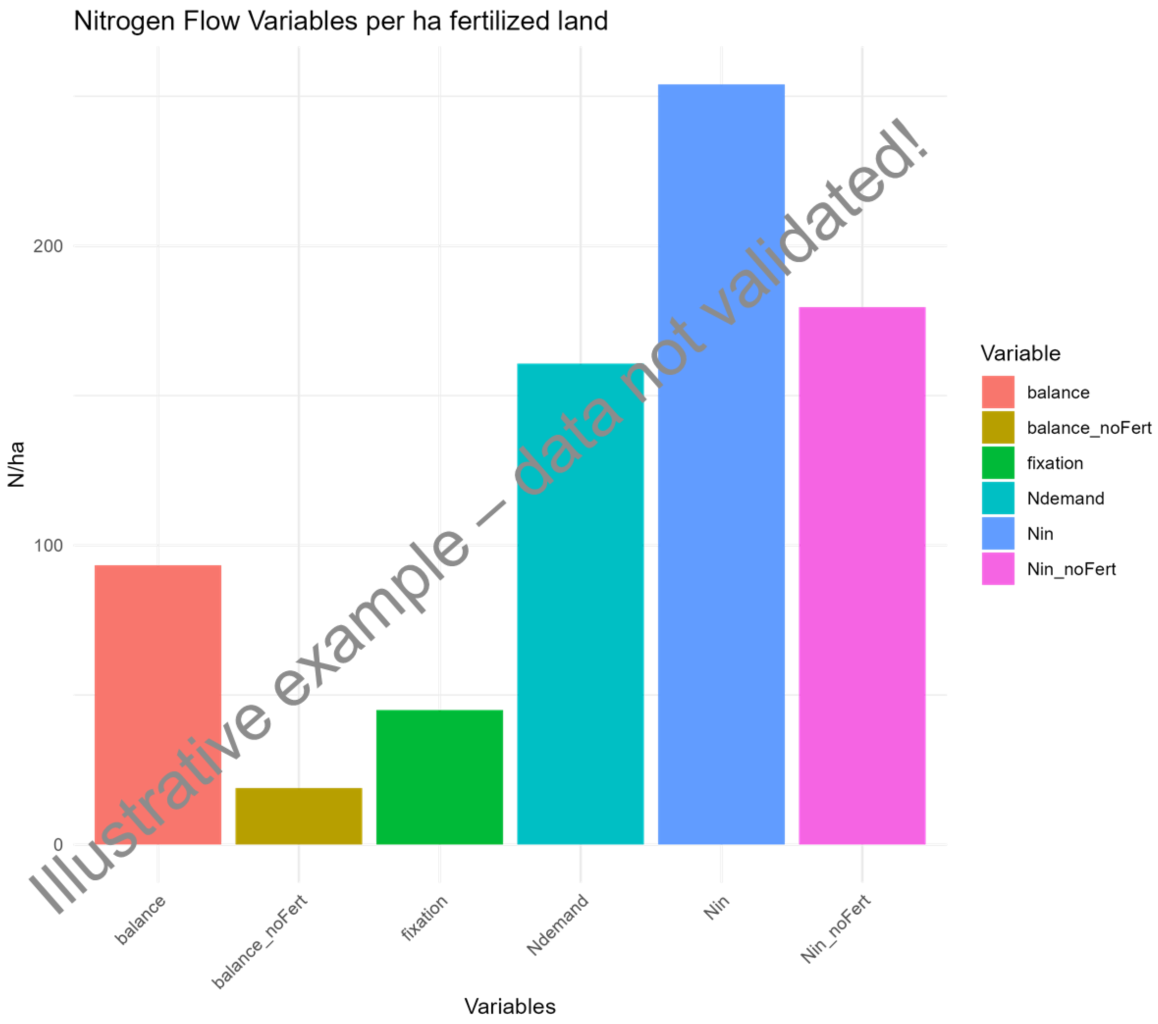

Figure 5: Illustrative example for the outcome of a regional nutrient balance. Numbers are given in kg N/ha. Fixation = biological N fixation; N demand = N demand based on fertilizer recommendations; Nin = total N input with N fixation, mineral fertilizer application and animal manure application; Nin_noFert = N input without mineral fertilizer application; balance = total balance (Nin - Ndemand)

<u>Burundi Highlands</u>

The accurate calculation of nutrient balances in the Burundi Highlands is possible in some experimental fields. However, these fields do not display the real situation of the deficit of necessary nutrients in fields exploited by many poor smallholder farmers.

The precarity of the regular monitoring of the nutrient balance remains a big challenge in the arable land of whole Africa, especially as the practices of remote sensing are still in experimental phases in the whole continent.

The time scheduled for this current challenge did not allow to collect and to analyze the full balance sheet of arable land nutrients across Burundi Highlands.

FINDINGS & CONCLUSION

Denmark

We have a core model code that still needs some improvements. Currently, assumptions are very rough.

Potential improvements:

- calculations with different assumptions (e.g. yield levels, N excretion by livestock, etc.) to test sensitivity of calculations
- improve calculation approach for biological N fixation
- include difference in yields and fertilization practices of organic vs. conventional farming

After validation of the results, the next step should include testing of scenarios (e.g. change of crop shares, livestock numbers, etc.).

In a later stage, the calculation of a regional nutrient balance can be included in a decision support tool (DST) to facilitate dialogue with and between farmers of a region and to provide them with a quantitative overview on the nutrient situation of their region. In order to capture the multitargeted nature of NBS, it should be combined with different other output metrics (such as nitrate leaching, economic outcome etc.).

This DST must be further developed alongside the involved stakeholders in a co-creation process in order to turn it into something that is useful to their needs. Ultimately, the results obtained within this case study area could be adapted to other areas.

Burundi Highlands

As indicated above, the time of the current challenge was too short to do any quantitative assessment. The potential of different mineral-organic fertilizer combinations as a nutrient source has been discussed, however, the available products are not affordable to poor smallholder farmers.

Further investigations on additional bio-based fertilizers from local biomass sources should be done in order to improve the nutrient situation for smallholder farmers. Currently, these bio-based fertilizers remain on the early step of innovation and require some technical equipment. Furthermore, their use is still hampered by traditional behaviors.

Joint analysis of the two case studies

Both case studies face nutrient related challenges in agriculture. In Burundi, as in many African countries, there is a lack of affordable and sustainable nutrient sources for smallholder farmers while soil nutrients are leached out regularly during the rain season. In the Limfjord region, excess N is leading to high nitrate leaching losses and threatens the ecosystem in the Limfjord.

NBS might be a promising way of facing both an imbalanced nutrient budget under an intensive farming situation in Denmark as well as for a situation with a nutrient deficit. In both cases a quantitative overview on the nutrient situation could help to tackle the challenge. Visualizing the nutrient demand of the crops will help to discuss options on how to provide these nutrients in a sustainable way.

In Denmark, a lot of data is available. However, it is time-consuming to process the data. Data availability in Burundi is unclear and potentially more challenging due to very small scale farming practices, including intercropping. Remote sensing might be a viable option to improve databases both in Europe and in Africa.

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