Project brief

Thünen Institute of Farm Economics[1], Coordination Unit Climate, Soil, Biodiversity[2]

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Nutri2Cycle - Nurturing the Circular Economy

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- **Technologies can play a prominent role in European efforts to close nutrient cycles and reduce GHG emissions.**
- **Farm-scale anaerobic digestion has the potential to reduce EU agricultural GHG emissions by up to 18.8 million tonnes of CO_2 equivalents**
- **The evaluated technologies varied in their impacts on mineral fertilizer utilization, manure application, and nitrogen surplus. This emphasizes the complexities and regional variations inherent in achieving sustainability goals within EU agriculture**

Background and aims

Sustainable agricultural intensification is needed to tackle food insecurity in Europe, but it is also associated with various environmental challenges, such as GHG emissions, acidification and eutrophication. Inadequate manure management and excessive nitrogen and phosphorous fertilizer application lead to eutrophication, contamination of ground and surface water with nitrates. The Horizon 2020 Nutri2Cycle project addresses the current gaps in the Nitrogen (N), Phosphorus (P) and Carbon (C) cycles of different European agricultural systems and the related environmental problems by implementing optimized management systems whilst having a positive trade-off with productivity, quality and environmental impact. The main aims of the project were:

- Map and comprehensively present the current flows and gaps in C, N and P cycles in Europe
- Prioritize and analyze proposed mitigation technologies, aimed at closing nutrient loops
- Extrapolate potential farm level impact to regional and European impact of selected technologies

Approach

We extended the assessed farm-level impact to regional, national, and EU scales, examining the potential for mitigating environmental emissions through technology adoption in Europe by 2030, employing the CAPRI and MITERRA-Europe models. The mitigation effect is quantified for a range of implementation shares of mitigation technologies, ranging from the assumed initial implementation share to the maximum estimated implementation share.

CAPRI (Common Agricultural Policy Regional Impact) is an economic agricultural sector model covering the whole EU at regional NUTS2 level and global agricultural markets. The main objective is the ex-ante impact assessment of agricultural, environmental and trade policies on production, income, markets, trade, and the environment, from global to regional scale. The MITERRA-Europe model is a detailed deterministic nutrient flow and emission model, which calculates greenhouse gas emissions, nitrogen emissions, N and P flows and soil organic carbon stock changes, using emission factors and leaching fractions.

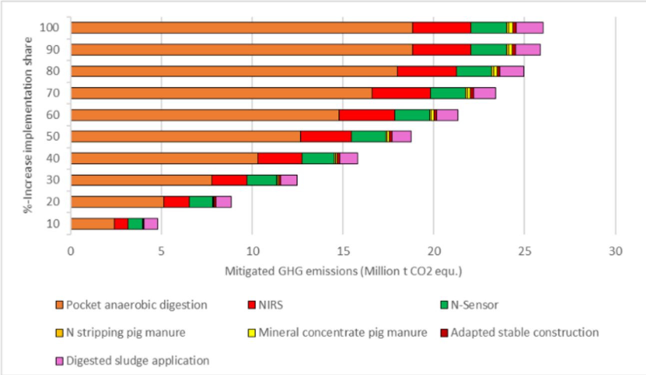
Based on the collected data and analysis provided by farm and field level modelling and Life Cycle analysis (LCA) the following mitigation technologies were selected for analysis with CAPRI and MITERRA-Europe:

(1) Small/Farm-scale anaerobic digestion of pig manure ("Pocket anaerobic digestion")
(2) Stable construction for separated collection of solid manure and urine ("Adapted stable construction"),
(3) Using digestate, precision agriculture and no-tillage ("Digested sludge application")
(4) Near-infrared sensor technology in the nutrient application of liquid manure ("NIRS")
(5) Sensor technology to assess crop N status ("N-Sensor")
(6) Substituting external mineral nutrient input from synthetic fertilisers by recycled organic based fertilizers in arable farming ("N stripping pig manure")
(7) Pig manure processing and replacing mineral fertilizers ("Mineral concentrate pig manure").

Results

Results show that among all modelled technologies "Pocket anaerobic digestion" emerges as a solution, offering the most significant benefits at the EU level with regard to agricultural GHG emissions (Figure 1). The maximum implementation rate of "pocket anaerobic digestion" leads to the mitigation of 18.8 million tonnes (Mt) of CO_2 equivalents (CO_2-eq.), which reduces the agricultural GHG emissions in the EU by 4.8 %. The highest reductions occur in livestock-intensive countries like Germany (6.9 Mt CO_2-eq.), Spain (3.3 Mt CO_2-eq.), Italy (2.2 Mt CO_2-eq.), France (1.7 Mt CO_2-eq.), and Denmark (1.7 Mt CO_2-eq.).

Figure 1: Mitigated GHG emissions (million tonnes CO_2 eq.) for technologies scenarios compared to the reference



Source: Thünen Institute/Jörg Rieger (2024).

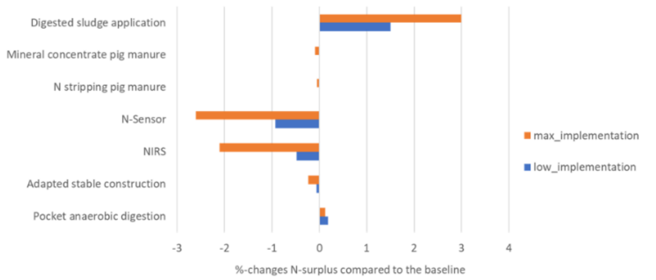
The extensive adoption of “NIRS” showed lower emission mitigation potential, resulting in a reduction of 3.2 million tonnes of CO_2-eq. (0.8 %) primarily attributable to the effective mitigation of N_2O emissions. Likewise, the “N-Sensor” technology, when implemented to its maximum capacity, exhibits the potential to curtail agricultural GHG emissions by 1.9 million tonnes of CO_2 equivalents, corresponding to a 0.4 % decrease in total EU agriculture emissions. For the “application of digested sludge”, the GHG emissions are reduced by 1.5 Mt of CO_2-eq., a 0.3 % decrease in total emissions. However, this is mainly due to the sequestration of carbon in soil organic matter while N_2O emissions increase.

In terms of the nutrient-related environmental impacts of the modelled technologies, we analyse their influence on mineral fertilizer utilization, manure application, N-surplus, and N-leaching. Compared to other technologies, the “N-Sensor” shows the highest potential for reducing N-surplus, achieving a 2.6 % reduction in the EU at maximum implementation share, followed by NIRS with a potential reduction of 2.1 % compared to the baseline in 2030 (Figure 2).

For the solution “Digested sludge application”, the mineral N fertilizer use is reduced by almost 1 %. However, the nitrogen fertilizer replacement factor is only 50 %, which means that not all nitrogen is directly available for plant uptake and the total N input is increased, which results in a higher N-surplus. Improving the N availability of the digested sludge, or reducing the total N inputs is required to prevent an increase in N emissions.

The “N-Sensor” has exhibited the most significant impact on mineral fertilizer use, resulting in a reduction across the EU ranging from 0.1 to 0.3 Mt, equivalent to a 1 % to 3 % decrease.

Figure 2: %-changes in N-surplus for the EU ranging from an increase of the initial implementation by 10 % to the maximum implementation share



Source: Thünen Institute/Jörg Rieger (2024).

This result is not surprising as this technology directly enhances mineral fertilizer use efficiency, distinguishing it from most other modelled technologies. The application of digested sludge emerged as the second-best-performing technology achieving a 0.1 Mt reduction, corresponding to a 1 % decline.

Precision farming coping with heterogeneous qualities of organic fertilizers in the whole chain (“NIRS”) shows the highest direct effect on decreasing manure use ranging from -0.1 to -0.4 Mt, equivalent to a 1.9 % to 7.4 % decrease resulting from the higher manure use efficiency via this technology. Technologies associated with pig manure processing, such as “N stripping pig manure” and “Mineral concentrate pig manure”, contribute to a reduction in manure use in agriculture.

Conclusion

Technologies can play a prominent role in European efforts to close nutrient cycles and reduce GHG emissions. All technologies analyzed in Nutri2Cycle contribute to a net reduction in agricultural greenhouse gas emissions within the European Union. Our findings highlight farm-scale anaerobic digestion as the most beneficial technology, potentially reducing EU agricultural GHG emissions by up to 18.8 million tonnes of CO_2 equivalents. Technologies such as precision farming and manure treatments exhibit relatively lower emission reduction potential. Additionally, the evaluated technologies varied in their impacts on mineral fertilizer utilization, manure application, and nitrogen surplus. This emphasizes the complexities and regional variations inherent in achieving sustainability goals within EU agriculture. Further interdisciplinary research and projects, as well as adequate policy instruments and support mechanisms, are needed to foster the implementation of these technologies.

Further Information

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