

Identifying areas with low vs. high trade-offs of fertilization reduction for soil carbon storage and crop production in Europe, under the Farm to Fork strategy

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- High nitrogen losses negatively affect the environment
- A 20 % reduction in fertilization rates is part of the EU's Farm to Fork strategy
- A modelling framework and a recently developed index allowed us to quantify effects of reduced mineral nitrogen fertilization at the European scale
- Reducing fertilization decreases nitrogen losses but could impair crop yields and soil organic carbon storage
- Areas with high and low risk of trade-offs were identified at the European level

INTRODUCTION

The Farm to Fork (F2F) strategy is a central element of the European Green Deal. One important aim of this strategy is to reduce nutrient losses by 50 %, by 2030, as these are associated with air, soil and water pollution, loss of biodiversity and greenhouse gas emissions. According to the strategy, the achievement of this target will require a reduction of fertilizer use by at least 20 % by 2030 ([Farm to Fork](#)). While it is evident that such a reduction will reduce environmental impacts such as the emission of the potent greenhouse gas nitrous oxide (N₂O) and leaching of nitrate (NO₃), trade-offs may occur. Most importantly the production function of soil (i.e. agricultural production/yields) and Soil Organic Carbon (SOC) storage - another essential soil function - could be negatively affected. The main goal of the project SIMPLE (*Scenario modelling for assessing impacts of policy changes and socio-economic effects on ecosystem services of soils*) was to develop a tool to quantify the effect of reduced nitrogen (N) fertilization on cropland at the European scale and quantify potential trade-offs on yields and SOC storage using the SOMMIT index, developed in the EJP SOIL SOMMIT project.

DESCRIPTION OF THE ISSUE

To quantify the effect of the F2F strategy on multiple ecosystem services of soils, complex biogeochemical model would be necessary. Such models require huge amounts of input data and have a high computational demand. In SIMPLE we use an alternative approach by setting up a modelling framework that combines two models of lower complexity (RothC and MITERRA-Europe) with approximations of yield responses based on long-term experiments.

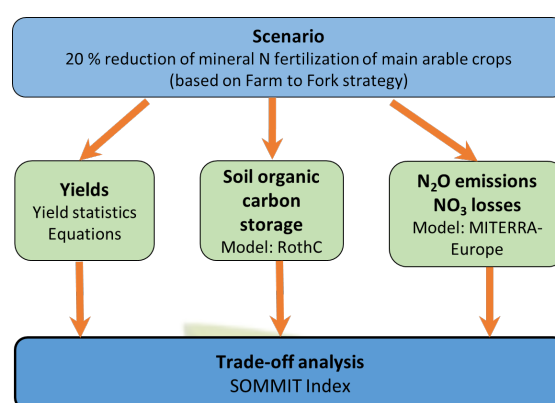


Figure 1: Modelling framework of the SIMPLE project

KEY MESSAGES FOR POLICY MAKERS

Recommendation One: Careful evaluation of site-specific conditions before reducing nitrogen fertilization.

Trade-offs between reducing N fertilization (and the associated reduced pollution) and declines in crop yields and SOC storage vary among crops and geographical regions. Policies should therefore be tailored to the conditions of each region.

Recommendation Two: Focus on area for which minor trade-offs were identified
Regions where trade-offs between reducing N pollution, crop yield and SOC storage are small, or indicators are even improved, should be prioritized for implementation.

Recommendation Three: Use SOMMIT index to identify priority regions
The SOMMIT index is a flexible tool able to normalize different agricultural and environmental indicators into one single number (<https://github.com/kofm/sommit-dashboard>).

METHODOLOGY

To quantify the effect of the F2F strategy on multiple ecosystem services of soils we linked different models, that have already been applied at the European scale, to a modelling framework (Fig. 1). We made use of the N flow model MITERRA-Europe (Velthof et al. 2009, Lesschen et al. 2011, Velthof et al. 2014) and the Soil Organic Carbon model RothC (Coleman & Jenkinson, 1996). To estimate yield responses, we used yield-fertilizer response functions from earlier studies (Hijbeek et al. 2017, van Grinsven et al. 2022) and combined these with yield statistics and information on fertilization recommendations gathered from various European countries (Madenoglu et al. 2024).

The main aim of SIMPLE was to quantify the effect of a 20 % reduction in mineral N fertilization on crop yields, SOC storage, N_2O emissions and NO_3 losses. We focused on mineral N fertilization as this is the main fertilizer used in Europe and evaluated effects on six important crops: wheat,

barley, maize, rapeseed, potato and sugar beet.

The responses to a 20 % decrease in N fertilization of each trade-off component (yield, SOC, N_2O , NO_3) were aggregated into a single number ranging between 0 and 1 (i.e., the SOMMIT index, Calone et al. 2024). A very low value means “very bad” (0–0.2) and a very high value (0.8–1.0) means “very good” (Fig. 2). The index was calculated for each crop type and NUTS2 region separately (Fig. 3).

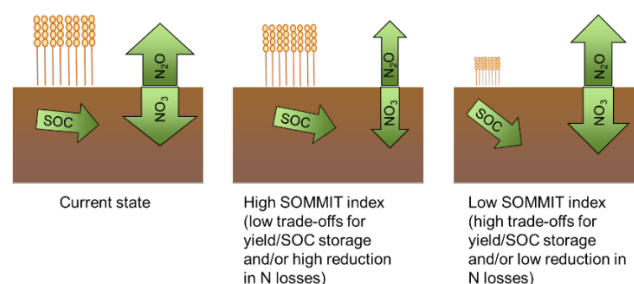


Figure 2: The SOMMIT index aggregates changes in yields, SOC stocks, N_2O emissions and NO_3 leaching in response to a 20 % reduction in mineral N fertilization into one number. Values range between zero and one with high numbers reflecting good results (central panel) and low numbers indicating poor results (right panel).

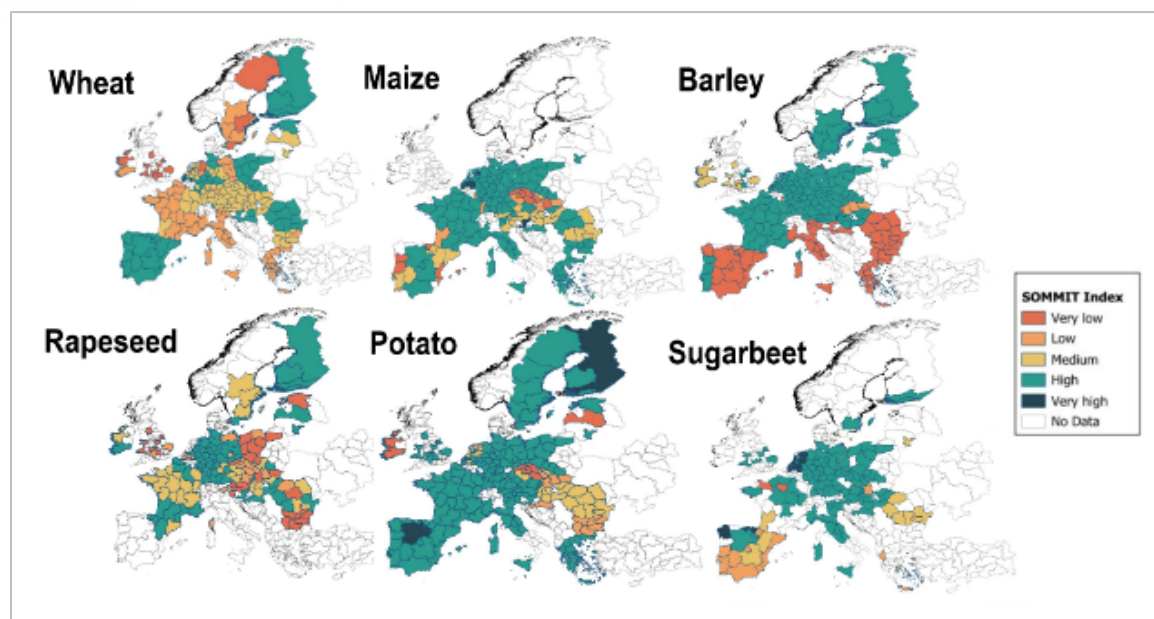


Figure 3: SOMMIT index for six important arable crops presented for each NUTS2 region. Target regions for a reduction in mineral N fertilization were identified based on a very high index (e.g., parts of Spain in the case of potato or parts of the Netherlands in the case of maize). Regions with high risks for yield reductions/and or high SOC losses or regions where N losses remain high despite reduced fertilization have a low index (e.g., large parts of Italy, Greece and Spain for barley).

BACKGROUND RESULTS: EFFECTS OF REDUCED N FERTILIZATION ON YIELDS, SOC AND N LOSSES

Averaged over all EU countries (including the UK), yields were reduced by 9–10 % in response to a 20 % reduction in mineral N fertilization (Madenoglu et al. 2024). For single countries and crops, yield reductions ranged between 1.8 % (maize in Portugal) and 21 % (rapeseed in many countries like Czechia and Germany).

Average SOC losses were 0.9 t per hectare of agricultural land over 30 years, mainly caused by wheat and rapeseed cultivation due to the large share in agricultural area in Europe and high yield reductions, respectively (Pape 2024). For Czechia (-2.2 t C ha^{-1}), the United Kingdom (-1.7 t C ha^{-1}) and Slovakia (-1.6 t C ha^{-1}) major losses were estimated, due to large shares of high-yielding crops in their agricultural areas.

On average N_2O emissions were 15 % or $0.13 \text{ t CO}_2\text{-eq ha}^{-1} \text{ year}^{-1}$ lower under reduced fertilization for the six crops (Lesschen et al. 2025).

Total N leaching and runoff were reduced by 24 % on average (Lesschen et al. 2025). For single countries, reductions varied between 8 % and 33 % compared to present conditions, depending on the share of mineral fertilizer use (relative to the total amount of organic and mineral N applied) and the current N surplus.

The average reduction in N_2O emissions ($0.13 \text{ t CO}_2\text{-eq ha}^{-1} \text{ year}^{-1}$) was slightly higher compared to the loss of SOC ($0.11 \text{ t CO}_2\text{-eq ha}^{-1} \text{ year}^{-1}$). From a climate mitigation point of view, the reduction in N_2O emissions is thus not offset by the loss of SOC, and as the C losses will decrease over time (because the system reaches a new steady state), the net climate benefit will increase.

Overall, 20 % reduced mineral N fertilization will therefore reduce N pollution in the EU, with net climate mitigation benefits, improvements of ground- and surface water quality, however at the expense of a slight decline in SOC storage. Effects of indirect land-use changes in response to reduced yields per ha were not considered in the study.



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