Research proposal: **Assessing the potential of alternative agricultural land use to reduce reactive N emissions and water demand**

**Research background**

Climate change and the shortage of freshwater resources are important threats for the sustainable development of the human population. Global atmospheric concentration of carbon dioxide (CO2) is currently exceeding 420 ppm, the highest ever recorded (Pieter and Ralph, 2022), and agricultural soils emit large amounts of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), accounting for 13% of the total emissions. CH4 and N2O are important GHGs from agricultural sources, N2O and methane CH4 emissions and contributed 25%–30% of total N2O emissions and 40%–50% of total CH4 emissions during the 2000s (Tian et al., 2014). Along with climate change, population growth and the impact of human activities, nearly 5 billion people live in a situation where water security may be at risk and water scarcity is increasing (Rodell et al., 2018).

Farmers are increasing N fertiliser use to increase or sustain crop yields, but there are regions with low returns to N fertilizer application and some regions with stable low yields (Basso et al., 2019). This depends to a large extent on the soil and weather and relative position on the landscape (Kravchenko et al., 2005). The mismatch between fertiliser application and yields reduce the economic benefits of farming while also exacerbating regional environmental problems (Gu et al., 2023) such as reactive nitrogen losses and high agricultural water consumption. The loss of scarce resources and negative impacts on the environment, can be mitigated by changing the type of land use in low-yielding areas, converting low-yielding arable land to pasture and promoting sustainable agricultural production while maintaining economic and environmental benefits (Zhang et al., 2022).

The conversion of agricultural land use has significant impacts on water-carbon cycle processes in agroecosystems (Sun et al., 2017). Changes in land use can alter ecosystem structure (i.e., species composition and biomass) and function (i.e., biodiversity, energy balance, and carbon and nitrogen water cycle) (Felipe-Lucia et al., 2020). Converting croplands to pasture can improve soil quality, prevent soil erosion, increase soil aeration and moisture retention, and provide fodder for the livestock industry, thus improving economic efficiency (Silburn et al., 2007). Pasture with diverse species require less nitrogen fertiliser than cereal crops when the pasture include N2 fixing legumes(Ledgard and Steele, 1992). Furthermore, pastures can play a positive role in soil and water conservation, and carbon storage (Teague et al., 2016; Wang et al., 2011), maintaining soil ecosystem health. Land use type can also affect land productivity, which can ultimately impact food security (Yawson et al., 2017). Thus, quantifying the response mechanisms of water demand, greenhouse gas emissions, and yields under changes in agricultural land use types is critical to assess the sustainability of agricultural landscape development.

Since 1850, land use changes such as deforestation, agricultural expansion, and urbanisation have resulted in carbon emissions of approximately 180 billion tons, representing 25-30% of total anthropogenic carbon emissions worldwide (Mishra et al., 2022). The IPCC Tier 1 and 2 approach to quantify GHG emissions due to land use change uses emission factors and focus on emissions throughout the change process(IPCC, 2023). This method of estimating emission from LUC using emission factors overlooks the specific response of regional soils and crops, and multiple factors that directly influence emissions and water demand, due to a changing environment. In contrast, biogeochemical models, such as DNDC (Li et al., 1992), are not only useful for integrating large-scale observations and analysing ecological processes but also for the dynamic analysis of changes induced by multiple concurrent factors. The DNDC models are used worldwide to assess greenhouse gas emissions from agroecosystems (Tang et al., 2021; Wang et al., 2021; Zhao Zhang et al., 2022), and can be rapidly parameterised to simulate farmland and grassland ecosystems processes.

To be able to manage landscapes more efficiently and to reduce emissions especially those from reactive N, there is a need to understand temporal and spatial dynamics and the relative importance of crop and plant type, and of other variables that can be managed such as fertilisation types and rates or livestock grazing regimes. This research aims at specifically exploring the potential to reduce N2O emissions and improve water use efficiency by managing landscape diversity and the type and timing of management practices intensive agricultural systems of northern Europe. This research will provide scientific evidence for the efficient and sustainable management of regional agricultural land with the objective of reducing total water demand and improving environmental sustainability.

**Goals**

1. To quantify GHG emissions from agricultural land with different crops, pastures and yield potential in current and alternative agricultural systems, using the DNDC model.
2. To assess the effects of changes in greenhouse gas emissions and crop water requirements resulting from the conversion of stable low yielding agricultural land to pasture.



Fig.1 The Evaluation process of this research include: Step1: to build a simulation database; Step 2: To parameterise the model; Step3: To simulate N and other GHG emissions and water demand according to changes in land use scenarios.

**Research approach**

To achieve the goals set up above, this study will focus on the following steps:

1. Build a GIS-based database: Gather data on the current crop production system, including the cropping practices and fertiliser inputs, soil characteristics, and weather data.

2. Model validation and parameterisation: Collect experimental data on greenhouse gas emission fluxes and related soil parameters from the literature. Then the DNDC model output is point validated and the validation results will be used to further calibrate the model and design scenarios. Using regional yield simulation results, the crop parameters of the model will be compared against yield statistics to form a set of simulation parameters adapted to in each study region. Key parameters such as maximum biomass during crop growth, C/N ratio of roots and stems will be parametrically calibrated for the regional model simulations.

3. Model the current system: Use the DNDC model to simulate the greenhouse gas emissions and water requirements of the current crop and pasture production using the data collected.

4. Model alternative systems: Model the greenhouse gas emissions and water requirements of alternative systems (Conversion of crops to pasture in stable low-yielding areas) using the DNDC model, based on data collected on these systems.

5. Compare the results of modelling of different agricultural land use patterns: compare the greenhouse gas emissions and water requirements under the current agricultural land use pattern and under the conversion of low-yielding areas to pasture cultivation, and analyse the resource, environmental effects under different scenarios.

**Methodology**

**1. Building the database**

(a) Delineate the minimum simulation area (county or raster) with consistent parameters in the minimum simulation area and collect the following parameters for each simulation area:

Table 1 Input parameters required for regional simulation with the DNDC model

|  |  |
| --- | --- |
| **Items** | **Parameters** |
| **Climate** | Temperature, precipitation, rainfall N concentration, CO2 concentration |
| **Soil** | SOC, soil texture, pH, bulk density |
| **Crop parameters** | Acreage, maximum yield, thermal degree days, water demand,  growing degree days |
| **Management** | Planting date, harvest date, fertilizer application rate, film mulch, manure amendment, tillage, residue incorporation |
| **Crop map** | Planting area |

(b) The kind and diversity of data required for the study requires harmonisation of the scale of the data due to different sources. Interpolation of some of the data may be required to match each data type, depending on the actual difference in accuracy, spatial and temporal resolution.

**2. Parameterising the DNDC model**

First, the selected points will be validated and then accuracy tested. This will involve calibrating the model parameters using data on measured yield, soil carbon and nitrogen changes, and greenhouse gas emissions from the literature to match the actual conditions of the study area. Secondly, the model will be parameterised. In DNDC, there are several key crop parameters, which include maximum yield, growing cumulative temperature. The model is parameterised using yield as a validation object to validate the model on a regional scale and obtain suitable crop parameters. Thirdly, the simulation of greenhouse gas emissions and water demand will be carried out using the matched parameters. Finally, we will design scenarios of agricultural land change to analyse the response mechanisms of agricultural greenhouse gases and water demand to changes in land types.

Table 2 Output parameters required for regional simulation with DNDC

|  |  |
| --- | --- |
| **Items** | **Parameters** |
| Physical properties of soil | Soil temperature profile, Soil humidity, pH, Eh, ET |
| Chemical properties of soil | SOC，Soil N，DOC，NO3- andNH4+ |
| Plant growth | Daily plant growth，biomass in roots, stems, leaves and grains, Nitrogen uptake, water uptake |
| Gas | Daily emission fluxes of CO2, CH4, N2O, NO, N2 and NH3 |

Considering the differences between grassland plants and crop cultivation, each grassland type can be simulated as a "plant species" in the DNDC simulation process because the same type of grass has relatively similar physiological characteristics.

**3. Future Scenarios**

The following scenarios outline a potential future for agricultural land, in which stable, low-yielding areas are replaced with natural grassland, specifically mixed grassland with a substantial cover of legume species. In contrast to grasses, legumes do not necessitate nitrogen fertiliser inputs, and can improve the overall grassland productivity and resilience to climate extremes. Moreover, legumes facilitate nitrogen fixation into the soil and promote higher use N use efficiency from exhausting residual fertiliser on the fields when transitioning to the new land-use type. Scenarios will test the hypothesis that: *“including pure and mixed grasslands compared to the situation of a landscape dominated by cereal crops (e.g. maize), and including grazing livestock promotes a tighter N use efficiency, lowering GHG emissions and reducing overall water demand”.* Table 3 illustrates the differences between the future scenarios and the aforementioned land use scenario.

Table 3 Differences between the future land use scenario and the current agricultural system

|  |  |  |
| --- | --- | --- |
|  | Current system | Future Scenarios |
| Plant type | Maize | High-yield maize & grasslands with legumes |
| Nitrogen input | Three times | None |
| Harvest | Annual Harvest | Recurrent cutting  Annual harvest for crops |
| Area | Maize-growing regions of the Midwest, USA (Basso et al., 2019) | Replace stable low yield areas with mixed grasslands. |

**4. GHG emissions intensity**

The CO2 equivalents of soil N2O and CH4 emissions were estimated by multiplying the annual emissions in crop fields by the global warming potential values over a 100-year time horizon, which are 265 kgCO2-eq/kg for N2O and 28 kg CO2-eq/kg for CH4 (IPCC, 2014), respectively.

**Expected outputs**

This research will deliver a novel implementation of the DNDC model to test hypothesis of integration of alternative land-uses in landscapes that currently emit large amount of GHG and reactive N. The novel findings will be included in a scientific paper to be submitted to a peer-reviewed journal. The parameterization of the DNDC model will be useful to explore similar questions in other landscapes that emit large loads of nutrients and GHG, and that have high water demand.

**Time Plan**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Task | 2023 | | | 2024 | | | | | | | | | | |
| 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Data collection and preprocessing |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| DNDC model validation and parameterization |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Model the current system |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Model the alternative systems |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Analysis the results |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Visualize the results |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Write a scientific paper |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Fig. 2 Gantt chart of the research proposal

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