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Halving Mineral Nitrogen in European Agriculture: Insights from Multi-Scale Land-Use Models

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Abstract

Mineral nitrogen in agriculture has increased greatly food supply and allowed the historical population growth of the past century. Its intensive use is nevertheless the source of numerous environmental issues and remains a major challenge for policy-makers. In this paper, we explore the effects of a public policy aiming at halving mineral nitrogen use over European agriculture. We investigate the impacts in terms of agricultural production, prices, land use change and the resulting consequences for ecosystems and biodiversity. We present a modeling framework that links a set of models covering agronomic, economic, land-based, and biodiversity processes. We propose a comprehensive analysis of the underlying mechanism at play. At the EU level and regarding the results only from agronomic and supply-side models, reducing nitrogen implies lower crop yields, lower profits, and less agricultural land. However, following the results from global scale economic models that take into account market feedbacks, the policy implies an increase in food prices and the substitution of nitrogen input for land. Land allocation is then modified at the global level as the result of a "leakage" of the European scale nitrogen policy.

Keywords: agriculture, land use, nitrogen pollution, trade, environment.

JEL Classification: Q11, Q12, Q15, Q18, Q52, Q53, Q54

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1 Introduction

Transforming atmospheric nitrogen (N) into its reactive forms and using it as fertilizer has been one of the major technological advances of the XXth century allowing agriculture to feed the growing global population (Erisman et al., 2008). This has come major consequences since nitrogen is at the origin of one of the most critical environmental challenges of the XXIst century (OCDE, 2018). Indeed, according to Rockström et al. (2009) at least three of the planetary boundaries have already been crossed: climate change, biodiversity loss, and nitrogen use. Moreover, based on current trends, freshwater use and land use change are rapidly moving towards their boundary levels. Agriculture and land use changes are behind many of these environmental threats (Foley et al., 2011). Environmental impacts of agriculture include those caused by land use changes (conversion from forest and other natural areas to croplands and pastures) and those caused by intensification (mainly use of fertilizers and pesticides). For example, intensive use of nitrogen fertilizers in agriculture is responsible of global and local environmental issues, mainly GHG emissions, air quality degradation, and eutrophication of watersheds.

Europe has benefited economically to a large extent from the increase in nitrogen use in agriculture as it is one of the world's largest and most productive suppliers of food and fibre (Erisman et al., 2008). For example, 33% of the world's sustainable nitrogen budget is used to produce meat for people in the EU which represent only 7% of the world's population. The consequences of nitrogen losses in Europe are on the average more pronounced than in the rest of the world (Erisman et al., 2011). During the last decade the EU Common Agricultural Policy (CAP) has been reformed to reduce overproduction, reduce environmental impacts and improve rural development. However, policies tackling the nitrogen problem are deemed insufficient and too fragmented (Sutton et al., 2011). The purpose of this paper is to evaluate the impacts of a reduction of 50% of mineral nitrogen fertilizers use in Europe agriculture? We are interested here by local and global economic impacts in terms of production, prices, and welfare as well as agronomic impacts in terms of yield and impacts on ecosystem services (biodiversity, carbon and, water quality and water cycle changes).

Sutton et al. (2011) evaluate at €70–€320 billion per year the environmental cost in Europe associated with atmospheric and water pollution impacting ecosystems and human health. According to their evaluation, losses outweigh the direct N-related benefits in agriculture. In order to address this issue, in 2018, the UN started funding on a "nitrogen equivalent of the International Panel on Climate Change". International collaboration on the topic is indeed crucial for numerous reasons among which the competition on world food markets and the possible "leakages" resulting from adjustments such as direct and indirect land use changes (Searchinger et al., 2008).

The land use sector plays a critical role in three major social issues: food security (Verburg et al., 2013), the preservation of biodiversity and ecosystem services (Foley, 2005), and climate change mitigation through land-based carbon storage and management of other greenhouse gases emissions (Lal, 2004). A major challenge is to understand, measure and quantify the interactions and trade-offs between the production needed to meet a demand for food, bioenergy production and the preservation of biodiversity and ecosystem services in the context of global change. Understanding these complex interactions is crucial to designing the public policy that could avoid unwanted and unforeseen effects. Indeed, at the global level, biophysical, demographic and environmental drivers, as well as public policies, induce price changes that are major determinants of land use changes. Interrelated markets involve domino and leakage effects (e.g., incentives to use local rapeseed oil for energy in Europe may contribute to tropical deforestation through increased consumption of palm oil in the food industry). A paradox is that policies that have local environmental benefits (e.g., extensification of agricultural techniques) might have indirect effects on land use that reverberate across markets and countries through global price effects (i.e., "leakage").

Our study builds on a range of economic and biophysical models to analyze the impacts of halving mineral nitrogen use in EU agriculture on land use change and assess the ecological, agricultural, climatic and economic consequences. This multiscale framework is structured around agronomic models (STICS and

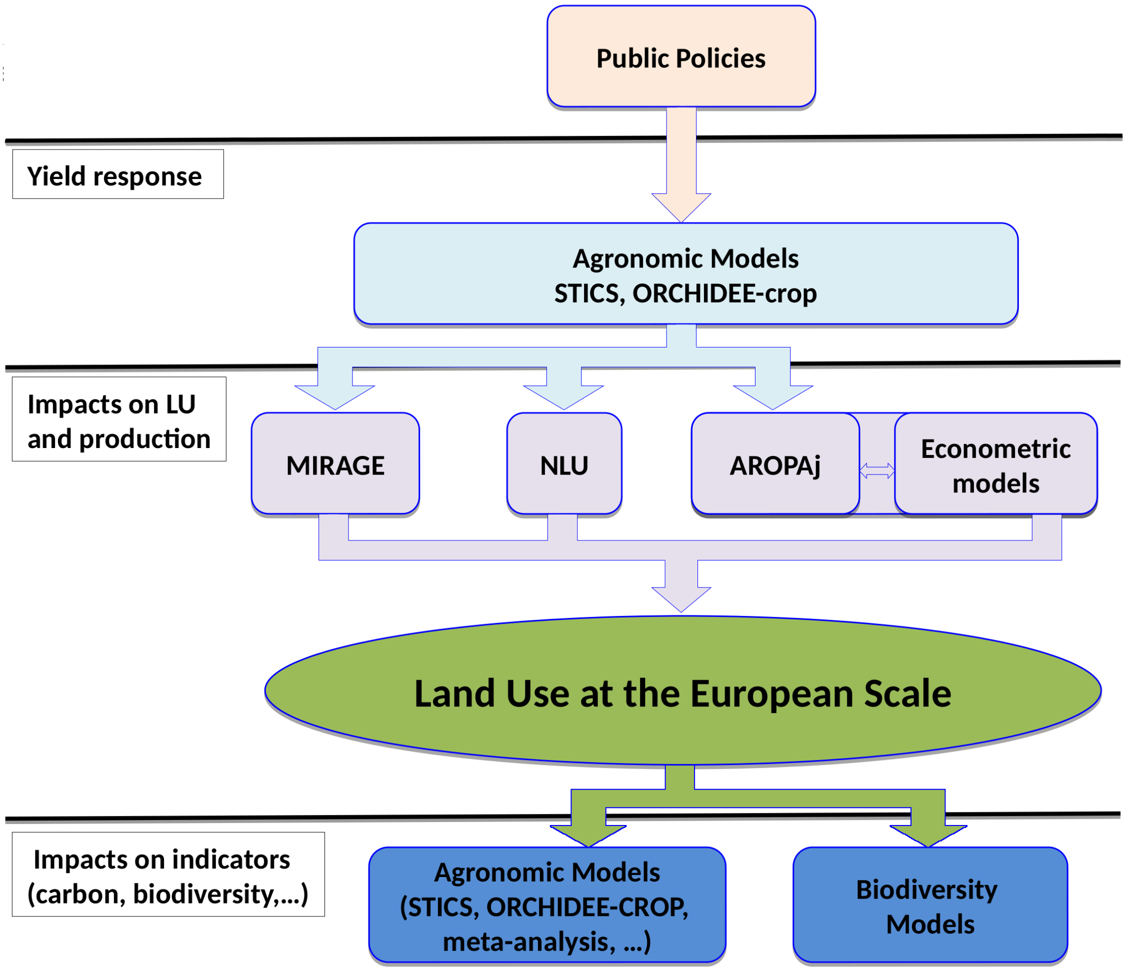


Figure 1: Models and interactions

ORCHIDEE-CROP), economic models (econometric land use model, AROPAj, NLU, MIRAGE) and biodiversity models (PREDICT). These models differ in their methodologies, the scale of interest and resolution, but they are very complementary and are all relevant for a comprehensive analysis of the impacts of halving mineral nitrogen in Europe in terms of land use change and leakage.

2 Data and models

2.1 Description of models

The models mobilized in our study and the interactions between them are summarized in figure 1. A short description of each model is provided in table 1.

Table 1: Description of models

Economic models	**Econometric models**	**AROPAJ**	**NLU**	**MIRAGE**
Scale	France/UE	UE	World	World
Resolution	Corine land Cover grids	versions UE15/100regions/1000GTand versions with UE27/130regions/1800GT + disaggregation	12 regions of the world. 60 land classes per region	Countries: possibility of aggregation of regions very flexible, according to GTAP classification (i.e. from 2 to 140 regions, 57 sectors, with a practical constraints of, say, that the product of both does not exceed 600)
Tools	Discrete choice models, land use share models, spatial econometric models	Mixed Linear Programming + forcing STICS ("yield(water,nitrogen)" in progress version UE27	partial equilibrium model of land-use.	General equilibrium model, trade oriented. The land use version is now quite old (based on 2004 data) and would require a large investment for an update/new version
Input data	agricultural rents (€/ha), forest rents(€/ha), population density(hab/ha), land quality (text, WHC,...) , elevation, slope, climate variables	FADN, IPCC (GHG), CLC+LUCAS+DMS+ESB (STICS and spatialisation), individual prices (FADN / reparametrized / exogenous)	biomass demand for food and bioenergy products population forest area price of chemical inputs carbon price	Social accounting matrices (in the model) and for policy simulations changes in taxes, subsidies, or productivity. SAMs rely on GTAP 9 data. External data for simulations include Cepii scenarios (population, long term productivity growth and consistency with GDP projections). Possibility of IPCC scenarios theoretically possible but our version has not developed this compatibility (a lot of work has been done with GTAP but would need a heavy investment to check what can be transferred to MIRAGE in practice)
Output data	Prediction of land use (agri, forest, pasture, urban) under different scenarios	marketed and on-farm crops prod, crops, grasslands and fodders areas (+/-15 land uses), perennial crops (bioenergy), GHG, livestock (more disaggregated for bovine), mineral and organic fertil, water demand / irrig (in progress / version UE27), ...	food price land rent crop yields cropland area pasture area international trade of agricultural products CO2 and nonCO2 emissions	world prices ; domestic prices; domestic production, consumption; exports ; imports (up to 57 sectors); land use changes (limited); sectoral GDP, taxe; tariff revenues; welfare, welfare decomposition (allocative efficiency; changes in terms of trade, etc.) With some extra inputs, it would be possible to develop land use and GHG emission data that has been compiled for GTAP, but this would be a heavy investment. Data mostly in "volume", i.e. a bizarre CGE concept where values are expressed relative to a good or services whose price is a numeraire. Hence possible to express everything in dollars but at a particular exchange rate.
Simulated scenarios	Climate scenarios, policy scenarios,	CAP, tax schemes (on N pollutants, on GHG emissions, ...), incentives (specific / energy crops), ...	Diet scenario Climate scenarios (impact or mitigation) Bioenergy scenario	The model was primarily designed to simulate trade policy changes; it can be used for simulations of domestic policy (agricultural support; climate policies; biofuels; productivity shocks such as organic or more extensive agriculture or energy policy changes). Policy shocks must nevertheless be quite large so as to get meaningful general equilibrium effects. The main advantage of MIRAGE in the global architecture of the project is certainly the ability to account for indirect land use changes through changes in the world price vector and supply/demand responses in each country (hence induced land use changes)

2.1.1 STICS model

STICS is a generic crop model at the plot level covering some twenty annual and permanent crops. The model has been used in international projects of intercomparison as AgMIP and MACSUR. STICS models the functioning of a plant cover and soil system. It accounts for weather data and has a daily time step to simulate crop growth. The model has several modules dedicated to ecophysiological processes, yield, root growth, water, and nitrogen balances and transfers, etc. For a full description (Brisson et al., 2009, 2003).

Main data inputs necessary to the model are climate (weather) variables, information on agricultural practices such as sowing dates, fertilizer types and rates, and irrigation schedule as well as the initial state and characteristics of soils in terms of water and nutrient content. On the other end of the model, the outputs are crop yields and quality of the harvest, and environmental indicators such as nitrate leaching, N2O emissions, etc. Outputs from STICS are employed in the agricultural supply-side model AROPAj (see below for details). We have conducted simulations in order to estimate and calibrate dose-response functions of yields with respect to the input of nitrogen and irrigation water (Humblot et al., 2017). The dose-response functions are fitted on points representing STICS simulations at different levels of nitrogen and water input. Nitrogen varies from 0 to 600 kg/ha/year and irrigation is covering values from 0% to 100% of the water needs of plants. Irrigation is only allowed for some AROPAj agents for which we know that they are currently irrigating. For the potential yields comparison, in STICS, we prescribe the N-fertilizer at 600 kgN/ha/year and irrigation at 100% (when applicable).

2.1.2 ORCHIDEE-CROP

ORCHIDEE-CROP is a process-based agro-land surface model which integrates vegetation phenology (including generic crop phenology), carbon allocation, litter decomposition, soil carbon dynamics, harvest module and a very simple parameterization of nitrogen fertilization (more details can be found in Wu et al., 2016). The model simulates biophysical and biogeochemical interactions of croplands as well as plant productivity and harvest yield. ORCHIDEE-CROP also simulates the specific carbon allocation to grain prior to harvest, seasonal dynamics of leaf area index (LAI) and the timing and amount of grain filling that determines yield. LAI is a key variable that impacts surface albedo, roughness, water, energy, and carbon fluxes. The winter wheat, maize, and rice are three crop varieties currently tested in this version of the model. Additionally, the vegetation is divided into 12 more plant functional types (PFTs), including bare soil, 10 natural PFTs (e.g., evergreen and deciduous trees, C3 and C4 grass) and the other crops modeled as C3 supergrass. More vegetation types can be simulated using a new PFT external definition module. Several PFTs can coexist within the same grid cell (also referred to as mosaic vegetation), which can have any size but generally given by spatial resolution of climate forcing data. All PFTs that co-exist within a grid cell share the same climate but different carbon, energy, and water dynamics, due to their specific parameterizations. The off-line simulation of ORCHIDEE-CROP needs meteorological forcing, which can be from the observations or the general circulation models for the required simulation years of interest.

2.1.3 AROPAj

AROPAj (Jayet et al., 2018) is an agricultural supply-side model of the European Union. It is build on data from the Farm Accountancy Data Network (FADN) and models agricultural offer by (group of) farmers, representative at the FADN region al level (similar to the EU NUTS2 level). Each agent of the model is maximizing its gross margin which is the difference between revenues from production sales and variable costs (such as nitrogen input costs). The mathematical programming structure of the model is solving this maximization problem while respecting a number of constraints associated with physical processes and the EU Common Agricultural Policy (CAP).

One of the strengths of supply-side models is the fine description of the production processes at the farm level. Indeed, by introducing nitrogen-water dose-response functions derived from STICS simulations (see above), the input level choice by farmers is endogenous. This way, we can estimate the impact of reducing nitrogen input via an input taxation policy or just by limiting the amount of nitrogen when defining the mathematical problem solved by AROPAj.

Another aspect of the AROPAj that is important for our work, is the dual (shadow) value of agricultural land. This value is associated with the total area constraint of the model: farmers allocate their land to different crops but they cannot exceed the total area at their disposition. The dual value associated with this constraint is a measure of the additional benefit to farmers if there is one addition hectare of land. In microeconomic terms, this corresponds to the marginal profit of the production factor land. For this reason, land shadow price is important to us when we econometrically model land use (for more details on the econometric land use model, see below).

2.1.4 NLU

The NLU model is a partial equilibrium model in which the agricultural sector is divided into 12 regions of the world, inter-connected with each other by international trade. It provides a simple representation of the main processes of agricultural intensification for crop and livestock production: the substitution between i) land and fertilizer for the crop sector and ii) grass, food crops, residues and fodder for the livestock sector. It does so by minimizing the total production cost under a supply-use equilibrium on food and bioenergy markets. A detailed description can be found in Souty et al. (2012) or in Brunelle et al. (2015).

Intensification process in the crop sector is modelled with a non-linear response of yield to fertilizer inputs. The asymptote of this function corresponds to the potential crop yield given by the vegetation model LPJmL (Bondeau et al., 2007). The yield-fertilizer relationship is calibrated on the N, P, K fertilizer consumption values calculated with FAOSTAT data. Nutrients are represented as complementary inputs without any substitution possibilities between them. Parameters of the yield-fertilizer relationship (minimum yield and slope at the origin) are calibrated so as to minimize the error between modeled and observed crop yields over the 1961-2006 period. NLU integrates a nitrogen balance based on Zhang et al. (2015) which represents the different sources and outputs of nitrogen in the cropping system.

2.1.5 MIRAGE

MIRAGE-e (Fontagné et al., 2013) is a multi-sector multi-region computable general equilibrium developed by CEPII in Paris. It is primarily designed to assess the impact of trade policies and interactions between trade and climate change. As a result, in the current version of the model, the agricultural sector does not deserve a particular attention, while older versions allowed for simulations of domestic agricultural policy (agricultural support; climate policies; biofuels; productivity shocks such as organic or more extensive agriculture or energy policy changes), thanks to collaborations with INRA UMR Economie Publique. In particular, land and fertilizers are not direct substitutes, meaning that the effect of the tax on fertilizers translates in less land cultivated.

The main advantage of MIRAGE in the global architecture of the project is certainly its ability to account for indirect land use changes through changes in the world price vector and supply/demand displacements in each country in response to the initial policy shock. To take full advantage of this feature within our project, the representation of the agricultural sector is being improved, allowing for substitution between land and other inputs, to represent intensification. This mechanism is going to be calibrated on dose-response functions based on STICS simulations. Land use and expansion will also be better represented, in each agro-ecological zone of the regions considered in the model.

2.1.6 Econometric land use models

Most econometric land use models are explicative models, seeking to generate realistic dynamics of land-use change based on a detailed and faithful representation of the possible drivers of the changes. These models are more explicitly targeting decision-support, providing for example simulations of the impact of public policies (pasture subsidy, deforestation tax) or climate change scenarios. The econometric land use models used in this paper explain land use by land rents and pedo-climatic variables for the following classes: Agriculture, Forest, Pasture, Urban. They also provide land use simulations under different climate/policy/economic scenarios (Chakir and Parent, 2009; Chakir and Le Gallo, 2013; Ay et al., 2017; Chakir and Lungarska, 2017). The novelty of the econometric models used here is that they explicitly model the spatial dimension of land use by estimating spatial models and taking into account spatial autocorrelation.

2.2 Data comparisons

2.2.1 Yield data

ORCHIDEE-crop The potential yield for wheat and maize over Europe is simulated using ORCHIDEE-CROP model corresponding to the 2007-2012 climate conditions. 3 hourly observed meteorological datasets are used to force the model. Full irrigation is turn on to make sure the crops do not have water stress to simulate potential yields. 100% crops are covered on a 0.5° × 0.5° grid all over Europe (25% share of each crop types-wheat, maize, rice, and other crops). Potential yields of wheat and maize simulated in ORCHIDEE-CROP are compared with other model results in figure 2. On average the ORCHIDEE-CROP potential wheat yields (5.3 tons/ha, median value) are at lower side when compared with other models (STICS: 8.5 tons/ha, LPJmL: 7.8 ton/ha, GAEZ: 6 ton/ha). The spatial variability in the wheat yields (i.e. between 25th and 75th percentile) is very small in ORCHIDEE-CROP. This is likely due to the biases in the meteorological forcing ERA-Interim used to force the model. We find a least spatial variability in climate in this forcing when compared to CRU-NCEP and GWSP3 meteorological forcing datasets, which is reflecting through least spatial variability in yields.

In LPJmL the potential wheat yields in southern Europe are higher compared to central Europe whereas STICS simulated yields over Spain are smaller than over central Europe (Fig.3). GAEZ simulates highest yields over Central Europe (e.g. France, Belgium etc.) and lowest over southern and northern Europe (figure 3). Similar behaviour is also observed for maize crop yields in all the models. For maize also ORCHIDEE-CROP simulated yields are at lower side compared to other models (figure 4). In fact, the potential yields in this model are lower than actual yields reported (Schauberger et al., 2018; Hossard et al., 2016). Our comparison reveals substantial differences in the magnitude of simulated yields in each model across Europe, which highlights the larger uncertainty in estimating wheat and maize crop yields.

STICS Yields in STICS are simulated for different levels of water and nitrogen input. On the basis of these simulations, dose-response functions are fitted following Humblot et al. (2017). Because of the lack of geographical information on farmers, we are testing a set of parameters concerning soils characteristics, crop varieties, and sowing dates. We then choose the "best" dose-response function with respect to economic data provided by the FADN on observed yields, input and output prices. For each economic agent (our representative farmer), we have a set of dose-response functions for the crops they are growing.

LPJmL To represent biophysical constraints affecting cultivation, yield in each region of the Nexus Land-Use is parameterized on potential crop yields and calibrated on actual crop yields. Both values are calculated by the LPJmL vegetation mode which simulates biophysical and biogeochemical processes impacting the productivity of the most important crops worldwide using a concept of crop functional types (CFTs). (Bondeau et al., 2007). LPJmL describes crop production with 11 CFTs on a 0.5° × 0.5° grid representing most of the cereals (4 CFT), oil seed crops (4 CFT), pulses, sugar beet and cassava with irrigated and rainfed variants.

Climatic potential yields are computed by LPJmL for each of the 11 CFTs with irrigated and rainfed variants, at each grid point of global land area, by setting management intensity parameters in LPJmL (leaf area index, harvest index and a scaling factor between leaf-level photosynthesis and stand-level photosynthe-

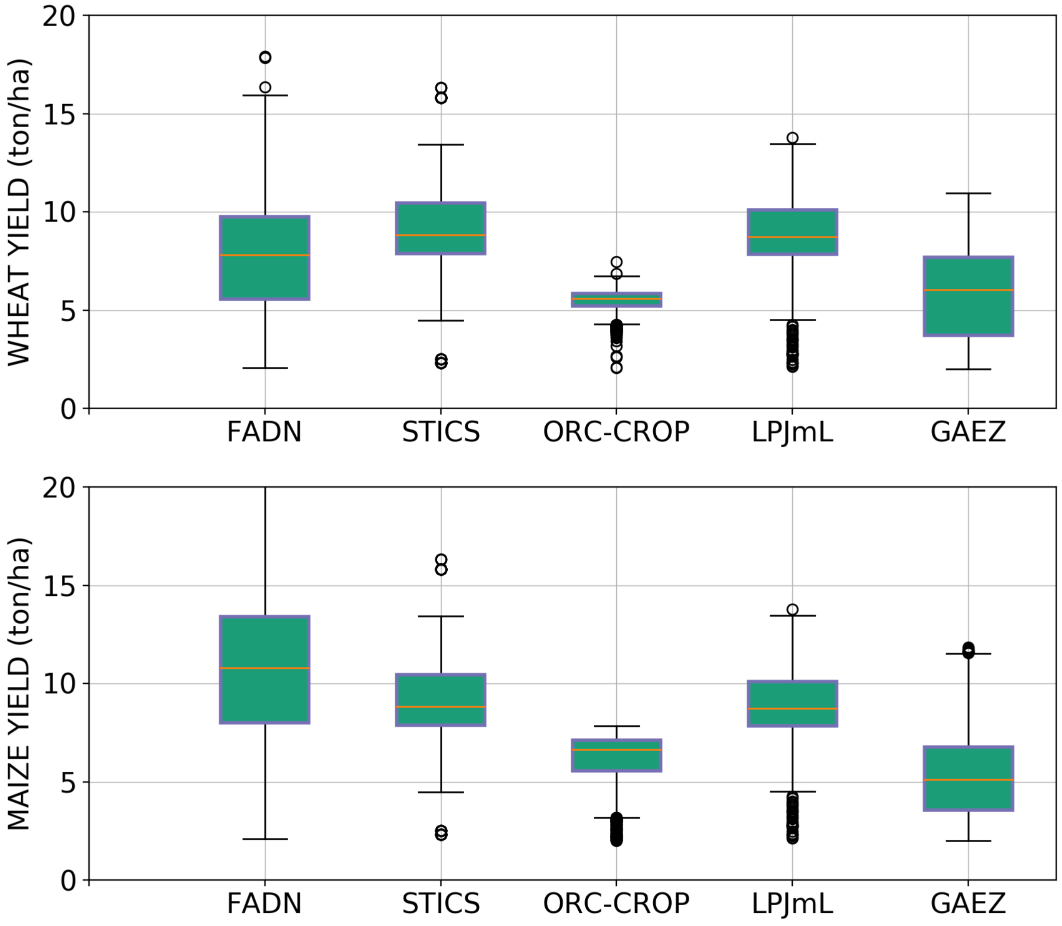


Figure 2: Comparisons of different model simulated spatial variability of potential wheat yields (tons/ha) across Europe. The bottom and top of the box are the 25th and 75th percentiles, and the horizontal line within each box is the 50th percentile (the median). The whiskers (straight lines) indicate the maximum and minimum yields across Europe. The circles above or below the straight lines are the outliers.

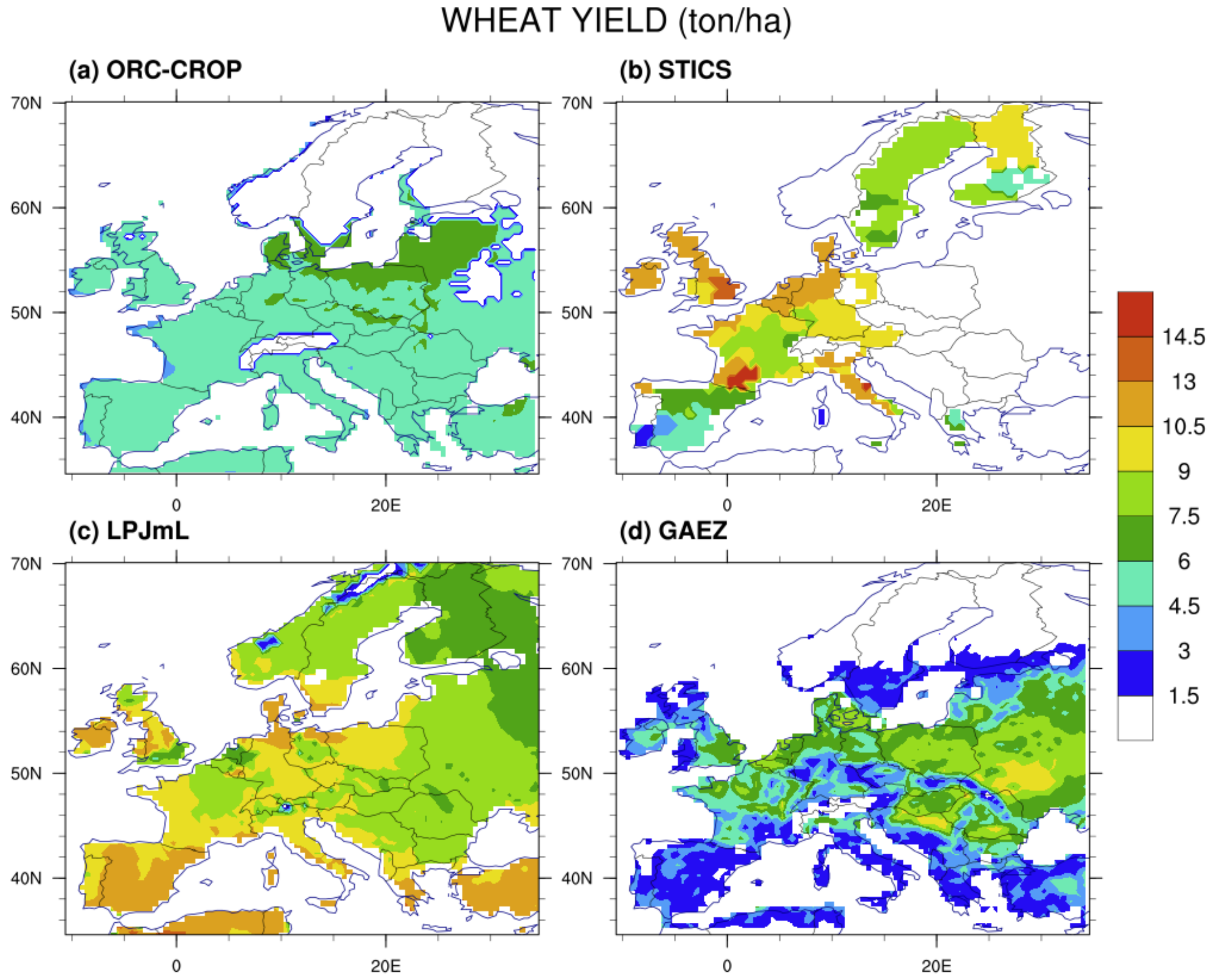


Figure 3: Simulated potential wheat yields (ton/ha) for the present day climate conditions in ORCHIDEE-CROP, STICS, LPJmL and GAEZ models.

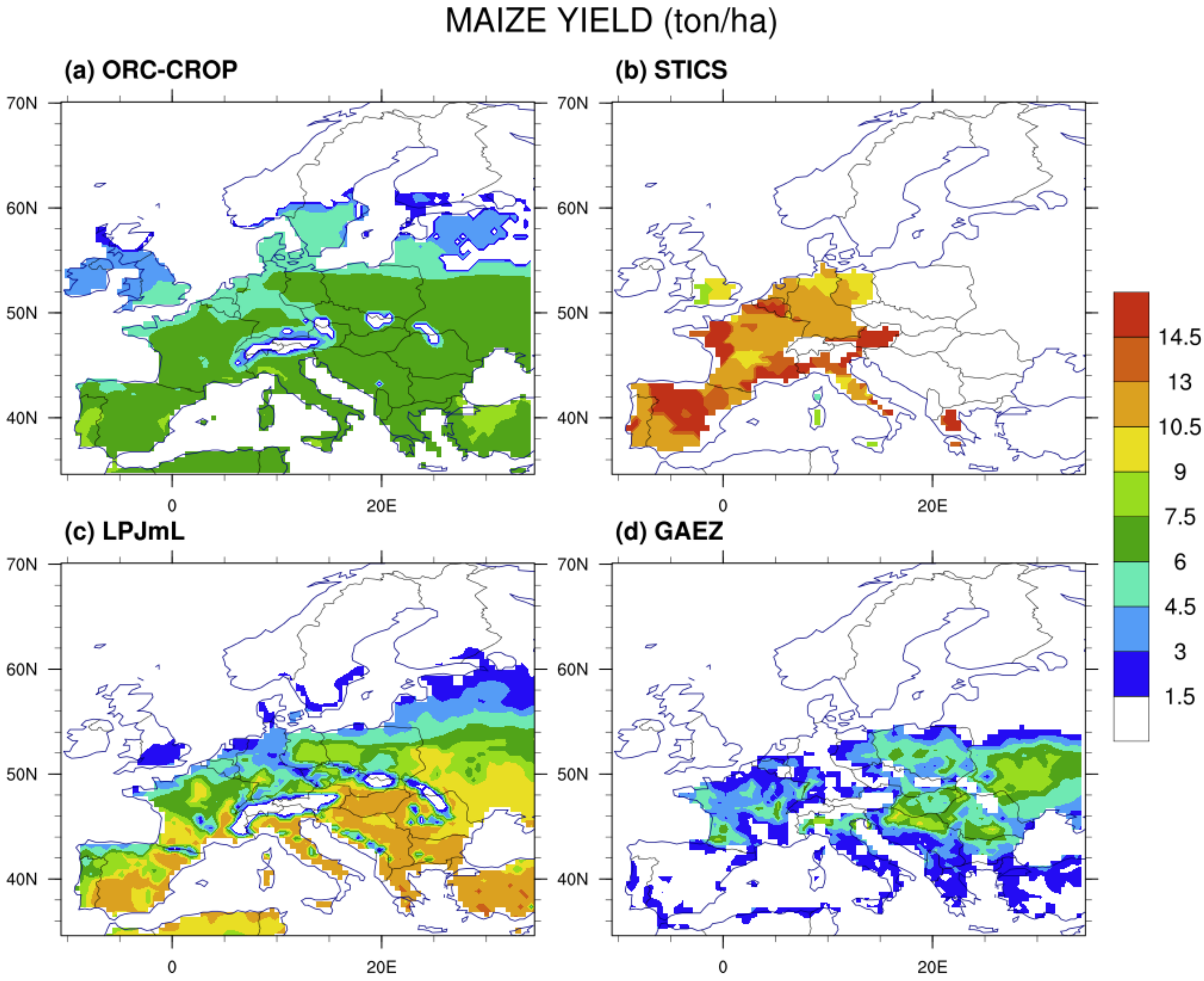


Figure 4: Simulated potential maize yields (ton/ha) for the present day climate conditions in ORCHIDEE-CROP, STICS, LPJmL and GAEZ models.

sis) such that crop yield is maximized locally. Climatic potential yields are taken as a mean of five LPJmL simulation years between 1999 and 2003 in order to minimize the climatic bias due to interannual variability.

2.2.2 Land use data

FADN provides us a representative sample of farming activities at the scale of the FADN region (close to the EU NUTS 2 level). Further information on land use/cover is obtained from the CORINE Land Cover database. We derive the share of crops and pastures, forests, and urban land uses at the scale of the EU NUTS 3 region. The rules applied for this aggregation are summarized in table 2.

Land Cover class	CLC value	LU class
1 Artificial Surfaces	1, ..., 11	Urban
2 Agricultural Areas	12, ..., 22	Agriculture
3.1 Forests	23, ..., 25	Forest
3.2 Shrub and/or herbaceous vegetation associations	26, ..., 29	Other
3.3 Open spaces with little or no vegetation	30, ..., 34	Other
4 Wetlands	35, ..., 39	Other
5 Water bodies	40, ..., 44	Other

Table 2: Extract from the CLC classification and the corresponding LU aggregation

2.2.3 Economic Data

AROPAj The source of economic data for the AROPAj model is the FADN database. This is an annual survey of EU farmer's income build on accountancy information from a sample. FADN data is the sole microeconomic database harmonized at the scale of the EU. Data is a representative of three dimensions: region, economic size, and type of farming. The sample covers 80,000 holdings which are representative of a population of about 5 million farms (or 90% of the total utilized arable land and agricultural production in the EU). FADN is subject to a strict privacy policy and data cannot be exploited/published when it concerns less than 15 individuals. No geographical location for the sampled farms is provided.

MIRAGE The MIRAGE version we employ is to build on GTAP 9.2. This release of the GTAP database, features 2011 as the last reference year. The geographic decomposition is 140 regions of the world economy for 57 GTAP sectors. Data on land come from the GTAP 9 Land Use and Land Cover Data Base. This satellite database builds global land cover and land use databases 2011, based on publicly available geospatial maps (circa 2000/01 at 5-minute grid resolution). These are then aggregated for each AEZ-region and updated to the base year using national level output price, land use and land cover information from FAOSTAT (2016).

2.3 How to simulate -50% of N in each model?

2.3.1 STICS model

The dose-response functions derived from STICS simulations are allowing us to estimate the yields for different levels of N input. In this sense, the -50% of N is by design implemented when the simulation protocol for STICS was defined.

2.3.2 ORCHIDEE-CROP

There is a simplified function to reproduce empirically the effect of nitrogen addition on crop growth, based on the facts (i) i.e. increase in soil nitrogen availability increases photosynthesis due to nitrogen addition, (ii) the experimental phenomenon that the productivity of crops increases along a nitrogen addition gradient, but with a limit after which the productivity will not increase. This response function is introduced in ORCHIDEE-CROP which has a direct additive impact on the photosynthetic parameter (known as the maximum rate of Rubisco carboxylase activity). The 50% reduction in nitrogen fertilizer input in the response function changes the crop productivity and the LAI, which consequently impacts on crop phenology, carbon allocation, yields, water fluxes, and the turbulent fluxes exchanged with the atmosphere (Wu et al., 2016; Chang et al., 2015).

2.3.3 AROPAj

There are two ways to simulate the -50% of N scenario in AROPAj. The first consists of running a benchmark simulation and then imposing a 50% reduction in N to all farmers as a technical limitation to their activity. The second one and the one we are focusing on is to increase the price of the N input to a level that total N use in EU agriculture is halved. Economic agents of AROPAj have different options for adapting their activity with respect to the new input prices. Since the choice of N input is endogenous thanks to the dose-response functions derived from STICS, they can simply reduce the level of input (adaptation on the intensive margin). They can also switch from one crop, more N intensive, to another one that requires less input (adapting production on the extensive margin).

2.3.4 NLU

The -50% of N is simulated in NLU through the yield-fertilizer substitution. By artificially increasing the fertiliser price, we orient farmer's behaviour towards land-intensive practices rather than N intensive ones. We use a stepwise procedure to select the fertilizer price level consistent with the -50% of N. As there is no possibility of substitution between nutrient, the reduction in N implies a reduction of the same amount in P and K. The -50% of N is assumed to take place in 2050. We consider a default scenario in which the exogenous drivers (e.g., population, energy prices, technological change) follow the trends prescribed by the Shared Socioeconomic Pathway 2 (SSP2).

In our simulations with NLU, we explore 3 additional scenarios: i) Improved nitrogen use efficiency (NUE, denoted "ImpNUE"); ii) reduced consumption of animal products (denoted "LessAnimProd"); and iii) a combination of the two. Let us note that the NUE improvement and the reduced consumption of animal products are exogenously applied without any costs associated with them.

2.3.5 MIRAGE

Our current assumptions when simulating the halving of nitrogen use in Europe are the following. We consider nitrogen to represent 25% of the use of by crop sectors. We thus aim at decreasing it by around 12% for cereals, fiber crops, oilseeds, other crops, sugar and vegetables, and fruits. The policy is implemented by increasing by 20 pp of the tax on chemical inputs which produces a decrease of 11%. We simulate a one-shot tax increase in 2019.

2.3.6 Econometric land use models

The econometric models include land rents and pedoclimatic variables as input and provide the distribution of land use for agriculture/forest/urban under different scenarios: climate change, public policy, price shocks. We use the agricultural land rents (approximated by the land shadow price) from AROPAj. This land rent is modified by the introduction of the policy scenario and we can evaluate the resulting land use effect.

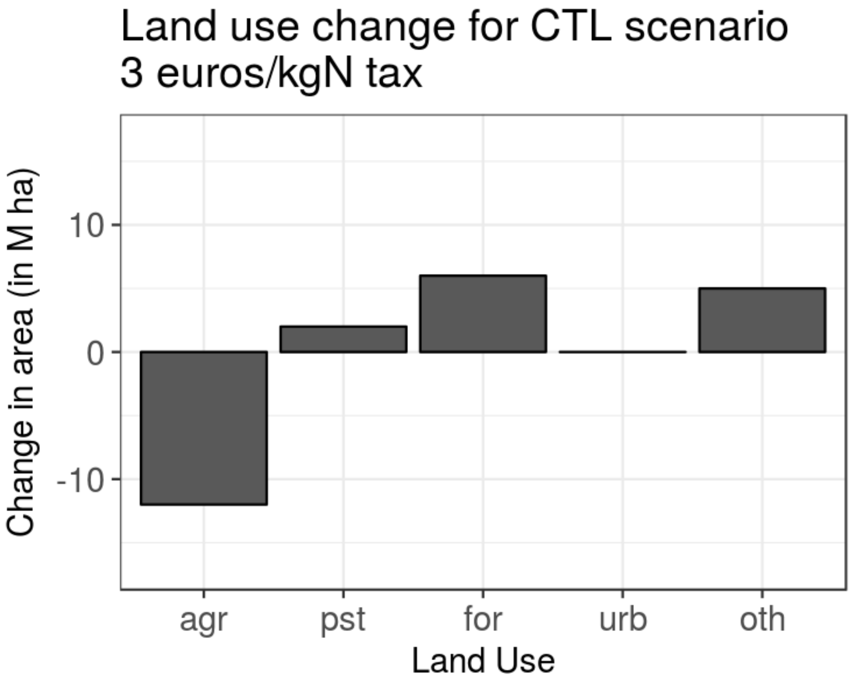


Figure 5: Land use change in EU 15 following the application of a €3 tax per kgN.

3 Scenario simulations results

3.1 Land use changes

3.1.1 AROPAj and econometric land use models

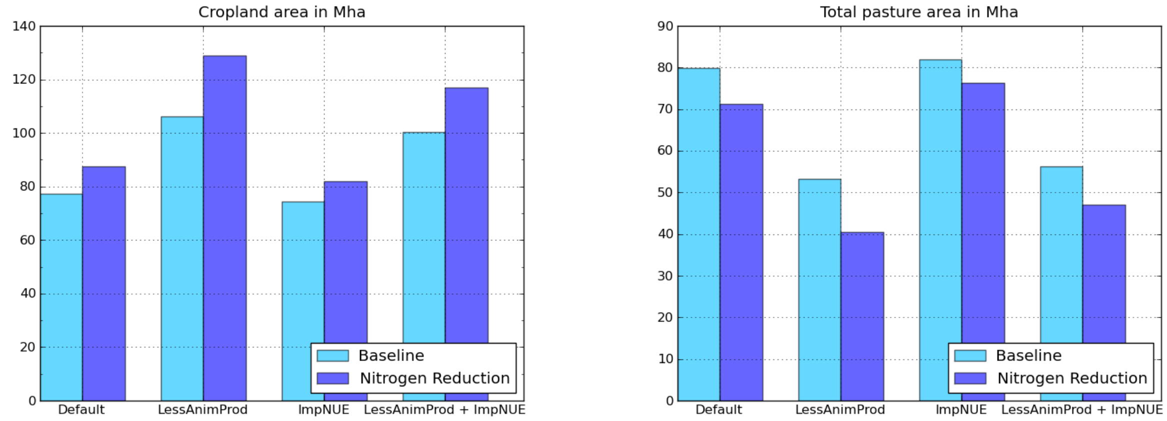
When taxing N input, farmers' profit is decreasing. In order to achieve a This effect is captured by AROPAj and sent forward to the econometric land use model through the lower values of the land shadow price. It is thus less interesting for landowners to allocate their land to agriculture. The results of the reallocation of land is presented in figure 5. The total area that we are modeling is about 130 million hectares. Crop land (agr) is reduced while pastures (pst) and forests (for) increase. Some lands are abandoned (oth) and there is a negligible effect on urban land use. AROPAj is a supply-side model. Its results are valid only if price feedbacks from global markets are limited.

3.1.2 NLU

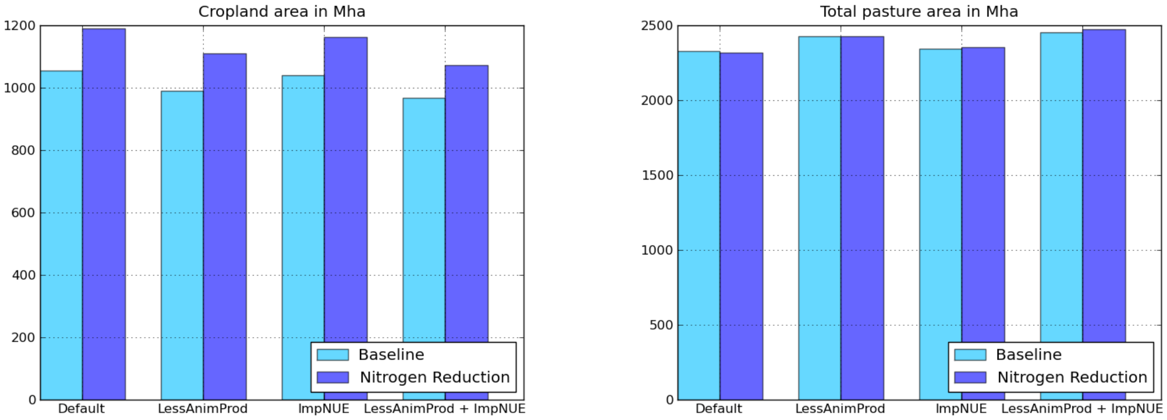
The results in terms of land use are presented in figure 6. NLU takes into account the substitution between land and fertilizer and we can see an expansion of cropland at the expense of pastures (especially in Europe). In the default scenario, the cropland area increase by nearly 10%. The effect is more pronounced for Europe with a more plant-based diet. Improvement in NUE slightly mitigate the increased need in cropland area especially at European scale.

3.1.3 MIRAGE

[Work in progress]



Europe



Rest of the world

Figure 6: Land use impacts of N policy for Europe and the rest of the world.

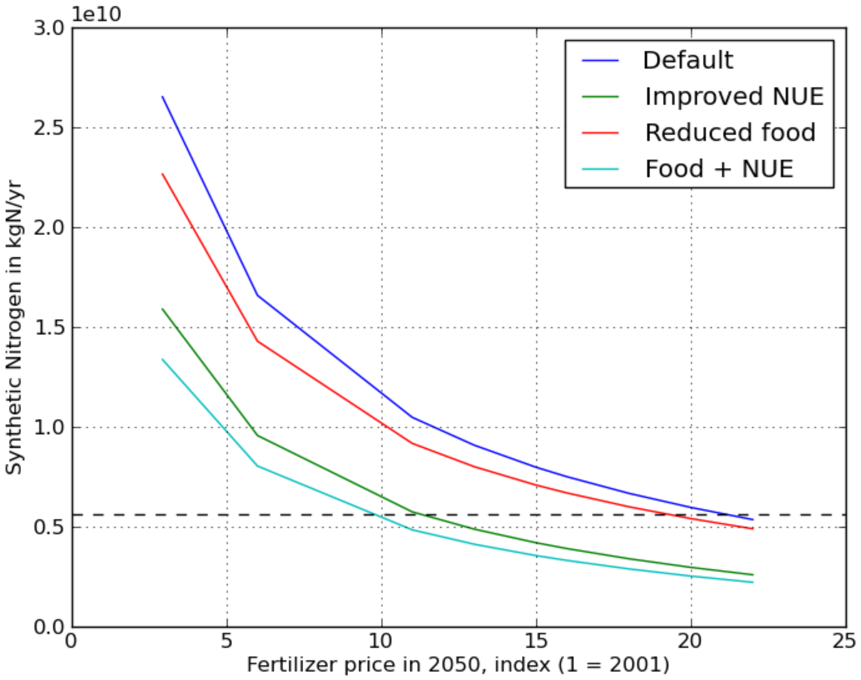


Figure 7: Scenarios explored by NLU. The objective of halving mineral nitrogen use is given by the dashed horizontal line.

3.2 Price variations

3.2.1 NLU

Figure 7 presents the different levels of mineral nitrogen use in agriculture associated with the prices of the input. A -50% reduction in N requires large increase in fertilizer price: around 10 times the baseline level with an improved NUE, and around 20 times without. A reduction in animal products does not significantly reduce the breakeven price of fertilizer to meet the -50% objective. As a result, the N reduction policy leads to large increase in food price, but this result is difficult to interpret as it follows from the way we implemented the policy (tax on fertilizer) and we didn't do any assumption on how the revenue generated by the tax would be employed.

3.2.2 MIRAGE

[Work in progress]

3.3 Production

[Work in progress]

3.4 Trade

3.4.1 NLU

The N reduction policy has important impacts on European trade. In the default scenario, the European trade balance expressed in petakilocalories deteriorates sharply (see figure 8), with a nearly doubling of the deficit in 2050. The impact of the N reduction is sharper with more plant-based diets as it reduces to zero

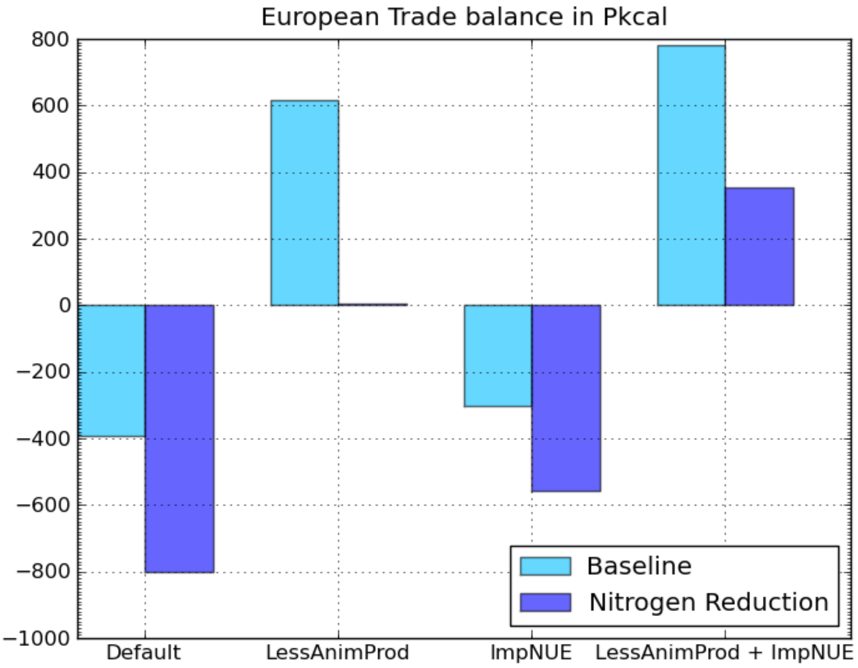


Figure 8: European trade balance in 2050 expressed in petakilocalories (Pkcal) in the four scenarios studied.

the large trade surplus experienced by Europe in this case. The NUE improvement does not improve the situation much with a comparable relative deterioration of the trade balance to the default scenario.

3.5 Ecological impacts : biodiversity, carbon

[Work in progress]

4 Discussion and conclusion

The objective of this paper was to propose a comprehensive analysis of the mechanisms underlying a public policy aimed at halving the mineral nitrogen use in European agriculture. We investigated the impacts of such a policy from an agronomic, economic, land-based and biodiversity perspectives. In order to do so, we consider a multi-scale framework based on a set of models: i) STICS crop model; ii) ORCHIDEE-crop agro-land surface model; iii) global scale partial equilibrium agricultural model Nexus-Land Use (NLU); iv) global scale general equilibrium model MIRAGE; and v) European agricultural supply-side model AROPAj; combined with iv) a spatial econometric land use model at the UE level. The results from these models provided us with insights on the effects of the policy in terms of agricultural production, prices, land use change and the resulting consequences for ecosystems and biodiversity.

At the EU level and regarding the results only from agronomic and supply-side models, reducing nitrogen imply lower crop yields, lower profits and less agricultural land. When we consider global scale economic models which take into account market feedbacks, the policy implies an increase in food prices and the substitution of nitrogen input for land. Land allocation is then modified at the global level as the result of a "leakage" of the European scale nitrogen policy. Some of these effects could be offset by increasing the nitrogen use efficiency or by reducing the demand for animal products.

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