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Combined analysis of climate, technological and price changes on future arable farming systems in Europe

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A B S T R A C T

In this study, we compare the relative importance of climate change to technological, management, price and policy changes on European arable farming systems. This required linking four models: the SIMPLACE crop growth modelling framework to calculate future yields under climate change for arable crops; the CAPRI model to estimate impacts on global agricultural markets, specifically product prices; the bio-economic farm model FSSIM to calculate the future changes in cropping patterns and farm net income at the farm and regional level; and the environmental model INTEGRATOR to calculate nitrogen (N) uptake and losses to air and water. First, the four linked models were applied to analyse the effect of climate change only or a most likely baseline (i.e. B1) scenario for 2050 as well as for two alternative scenarios with, respectively, strong (i.e. A1-b1) and weak economic growth (B2) for five regions/countries across Europe (i.e. Denmark, Flevoland, Midi Pyrenées, Zachodniopomorski and Andalucia). These analyses were repeated but assuming in addition to climate change impacts, also the effects of changes in technology and management on crop yields, the effects of changes in prices and policies in 2050, and the effects of all factors together. The outcomes show that the effects of climate change to 2050 result in higher farm net incomes in the Northern and Northern–Central EU regions, in practically unchanged farm net incomes in the Central and Central–Southern EU regions, and in much lower farm net incomes in Southern EU regions compared to those in the base year. Climate change in combination with improved technology and farm management and/or with price changes towards 2050 results in a higher to much higher farm net incomes. Increases in farm net income for the B1 and A1-b1 scenarios are moderately stronger than those for the B2 scenario, due to the smaller increases in product prices and/or yields for the B2 scenario. Farm labour demand slightly to moderately increases towards 2050 as related to changes in cropping patterns. Changes in N_2O emissions and N leaching compared to the base year are mainly caused by changes in total N inputs from the applied fertilizers and animal manure, which in turn are influenced by changes in crop yields and cropping patterns, whereas NH_3 emissions are mainly determined by assumed improvements in manure application techniques. N emissions and N leaching strongly increase in Denmark and Zachodniopomorski, slightly decrease to moderately increase in Flevoland and Midi-Pyrenées, and strongly decrease in Andalucia, except for NH_3 emissions which zero to moderately decrease in Flevoland and Denmark.

1. Introduction

Conditions for farming over Europe are changing, driven by a multitude of interrelated factors such as a higher integration of EU agriculture in global markets, on-going technological developments (Ewert et al., 2006), climate change (Parry et al., 1999, 2004; Porter et al., 2014) and growing global demand for feed, food, fibre and bio-based energy. Understanding the risks, as well as the opportunities for EU farming evolving from these partially long-term changes (cf. Reidsma et al., 2015; Wolf et al., 2012 for The Netherlands) can support a rational redesign of the Common Agricultural Policy or others policies impacting EU agriculture. For example, climate change will induce more frequent extreme weather events (Field et al., 2012) and the reduction of water availability in many locations. Both may result in lower yields and/or lower yield quality, and require adaptation measures at farm level which can be supported by an appropriate policy environment. Socio-economic conditions will also change over time dependent on drivers such as degree of globalization and will affect the future crop prices and consequently cropping patterns and intensity, and finally the

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sustainability and environmental impacts of future farming systems. While recent studies have examined future European crop yields and production under climate change (Donatelli et al., 2012), they have not considered how changing technology in combination with climate change will impact crop yields, nor were the macro- (EU) and micro- (farm) economic impacts and environmental impacts evaluated. Integrated approaches that are able to model the interactions between future macro- and micro-economic impacts appear to be essential to derive information on impacts of future changes in climate and other drivers on the sustainability and the environmental impacts of future farming systems (van Ittersum et al., 2008).

While, the demand for integrated studies of climate risk impacts on farming systems is clear (Robertson et al., 2013; Ewert et al., in press), few examples of such studies exist (for exceptions, see Fischer et al., 2005; Lehtonen et al., 2010; Nelson et al., 2014). In addition to the various conceptual and methodological challenges associated with linking disciplinary models (Ewert et al., 2009, 2011a, 2011b, in press), integrated assessment studies are particularly challenging due to their cross-scale nature: climate, policy and price drivers generally occur at large scales, whereas management decisions are typically made at farm and local levels (Patt et al., 2010).

Our aim in this study is to generate policy relevant information about how EU farming is likely to evolve in response to climate, technological and market changes to 2050. Based on important indicators at farm level we have identified problems, threats and opportunities for current and future EU farming systems. We have linked four existing models (i.e. SIMPLACE, CAPRI, FSSIM and INTEGRATOR). The linked models constitute an impact assessment (IA) tool that captures impacts of these future changes on various economic and environment aspects of EU farms. A meeting with various stakeholders from DG Agriculture and Rural development (http://ec.europa.eu/dgs/agriculture/index_en.htm) initiated this Agri-test case, and framed the subsequent study. The resulting aim of the test case was to assess the impacts of future climatic and other (technological, socio-economic and policy) changes on (i) agronomic, (ii) socio-economic, and (iii) environmental indicators of different farming systems in the EU. The main focus was on five regions: Denmark, as a whole; Flevoland, The Netherlands; Midi Pyrenées, France; Zachodniopomorski, Poland and Andalucia, Spain. With these regions, a wide cross-section of the variation in farming and environmental conditions across the EU is covered. These regions range from cool to warm climates in the sequence of Denmark, Zachodniopomorski, Flevoland, Midi Pyrenées and Andalucia and from extensive (with rather long rotations and low input levels) to intensive arable cropping systems in the sequence of Zachodniopomorski, Andalucia, Denmark, Midi Pyrenées and Flevoland.

2. Methodology

2.1. Model descriptions

SIMPLACE (Scientific Impact assessment and Modelling PLatform for Advanced Crop and Ecosystem management) is a modelling framework in which various dynamic and process-based crop growth and development related model components can be combined at an appropriate level of process detail, as dictated by the specific application and the spatial and temporal scales considered (Gaiser et al., 2013). For this study, SIMPLACE included the LINTUL-5 (Wolf, 2012) crop growth and development model and the water balance model DNUNIR from the LINTUL-2 crop growth model (Spitters and Schapendonk, 1990; van Oijen and Leffelaar, 2008). This specific implementation of SIMPLACE considers the effects of climate including limited water supply as described in Spitters and Schapendonk (1990) and Farré et al. (2000), and of limited N supply as described by Shibu et al. (2010). A simple representation of the effects of increased atmospheric CO_2 concentration on biomass production is used by applying the relationship between atmospheric CO_2 and radiation use efficiency, as proposed by Stockle et al. (1992). The second effect of increased CO_2 considered is the reduction of crop transpiration (i.e. reduction by 10% for all crops when atmospheric CO_2 increases from 370 to 700 μmol CO_2/mol, as based on Ewert et al. (2002) and Kruijt et al. (2008)). The resulting combination of modules enables assessing the impacts of changes in CO_2, temperature, rainfall and crop management (sowing date, varietal characteristics, nitrogen fertilization) on crop yields. Model calibration was performed for units corresponding to the intersection of environmental zones and NUTS2 administrative zones to allow assessment for Europe at NUTS2 level in this study (Wolf et al., 2012; Angulo et al., 2013; Reidsma et al., 2015).

CAPRI (http://www.capri-model.org/dokuwiki/doku.php) is a comparative static partial equilibrium model for the agricultural sector, developed for policy impact assessment of the Common Agricultural Policy (CAP) and trade policies from global to regional and farm type scale (Britz et al., 2007; Britz and Witzke, 2012). CAPRI allows the assessment of economic consequences at the regional level across Europe, based on the linkage of its supply and global market module. The *supply module* covers the EU27, Norway, Western Balkans and Turkey, and represents all agricultural production activities and related output generation and input use at a regional or farm type level (Gocht and Britz, 2011) captured by the Economic Accounts for Agriculture, and depicts policy instruments under the CAP. In addition to outputs, including nutrients in manure, the model considers in detail variable costs for different production activities, captures the effects of labour and capital on farmers' decisions and comprises a land market which renders total agricultural land endogenous. Prices are exogenous in the supply module and are provided by the market module. The core of the *market module* consists of a spatial global multi-commodity model for about 50 primary and processed agricultural products, representing the world with approximately 80 country groups or blocks in 40 trading blocks. This module delivers the output prices used in the supply module and allows for market analysis at global, EU and national scale, including a welfare analysis.

FSSIM is a generic bio-economic farm model, developed to simultaneously quantify agricultural, environmental and economic responses of major arable farm types across the EU to new policies and agro-technologies (Janssen et al., 2010; Louhichi et al., 2010). FSSIM simulates farmers' decisions regarding land use and management at farm level in response to changes in policies, technology, yields and product prices. These decisions in turn affect cropping patterns and thereby farm gross income, total costs per farm, farm net income and per farm labour demand, which are the main outputs of FSSIM. FSSIM can assess optimal adaptation strategies to changes in climate and policies for different farm types. FSSIM is generally run for representative farm types in a region, and the results can be aggregated to the regional level.

INTEGRATOR is an environmental agricultural model which quantifies N and greenhouse gas emissions from housing and manure storage systems, agricultural soils, non-agricultural soils and surface waters at EU27 level (de Vries et al., 2011; Kros et al., 2011). For agricultural systems, the calculations of N (NH_3, NO_x, N_2O and N_2) emissions and N leaching to groundwater and runoff to surface water are based on an adapted version of the MITERRA-Europe model (Velthof et al., 2009). This adapted version in INTEGRATOR uses soil emission factors that vary with the N source (e.g. fertilizer and manure types, crop residues and mineralized soil organic N), manure application technique, soil type, land use and precipitation (Lesschen et al., 2011). Modelled losses of N from agricultural systems to groundwater and surface waters include: (i) leaching from stored manure to groundwater, (ii) surface runoff to surface waters, (iii) subsurface runoff to surface waters, and (iv) downward leaching to groundwater, as described in Kros et al. (2012). In this study, INTEGRATOR calculates total N leaching to both ground and surface waters, NH_3 emission and N_2O emission to the air from arable land, which N losses contribute, respectively, to eutrophication, decrease in biodiversity and greenhouse gas accumulation.