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Combining models to estimate the impacts of future climate scenarios on feed supply, greenhouse gas emissions and economic performance on dairy farms in Norway

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ABSTRACT

There is a scientific consensus that the future climate change will affect grass and crop dry matter (DM) yields. Such yield changes may entail alterations to farm management practices to fulfill the feed requirements and reduce the farm greenhouse gas (GHG) emissions from dairy farms. While a large number of studies have focused on the impacts of projected climate change on a single farm output (e.g. GHG emissions or economic performance), several attempts have been made to combine bio-economic systems models with GHG accounting frameworks. In this study, we aimed to determine the physical impacts of future climate scenarios on grass and wheat DM yields, and demonstrate the effects such changes in future feed supply may have on farm GHG emissions and decision-making processes. For this purpose, we combined four models: BASGRA and CSM-CERES-Wheat models for simulating forage grass DM and wheat DM grain yields respectively; HolosNor for estimating the farm GHG emissions; and JORDMOD for calculating the impacts of changes in the climate and management on land use and farm economics. Four locations, with varying climate and soil conditions were included in the study: south-east Norway, south-west Norway, central Norway and northern Norway. Simulations were carried out for baseline (1961–1990) and future (2046–2065) climate conditions (projections based on two global climate models and the Special Report on Emissions Scenarios (SRES) A1B GHG emission scenario), and for production conditions with and without a milk quota. The GHG emissions intensities (kilogram carbon dioxide equivalent: kgCO_2e emissions per kg fat and protein corrected milk: FPCM) varied between 0.8 kg and 1.23 kg CO_2e (kg FPCM)$^{-1}$, with the lowest and highest emissions found in central Norway and south-east Norway, respectively. Emission intensities were generally lower under future compared to baseline conditions due mainly to higher future milk yields and to some extent to higher crop yields. The median seasonal above-ground timothy grass yield varied between 11,000 kg and 16,000 kg DM ha^{-1} and was higher in all projected future climate conditions than in the baseline. The spring wheat grain DM yields simulated for the same weather conditions within each climate projection varied between 2200 kg and 6800 kg DM ha^{-1}. Similarly, the farm profitability as expressed by total national land rents varied between 1900 million Norwegian krone (NOK) for median yields under baseline climate conditions up to 3900 million NOK for median yield under future projected climate conditions.

1. Introduction

The projected change in climate during the 21st century is expected to affect grass and crop dry matter (DM) production, causing changes in forage and grain feed supply throughout the world (Morley, 1978; Olesen et al., 2011). Such changes may, in turn, alter the effects of agricultural production on the environment through emissions of greenhouse gases (GHG), necessitating changes in farm management practices and land use (Cederberg and Mattson, 2000). In Norway, agriculture contributes 8.5% of the national GHG emissions (The Norwegian Environment Agency, 2014), of which livestock and feed production accounts for 90% (Grønlund and Harstad, 2014). The contribution from the livestock to climate change occurs mainly in the form of methane (CH_4) and nitrous oxide (N_2O) emissions (FAO, 2010).

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Greenhouse gas emissions on dairy farms can be reduced by adapting alternative feeding strategies. Such changes in management may result in varying levels of costs and benefits, which eventually determine if the activity is implemented on the farm (Özkan et al., 2016).

The projected climate in Norway until the mid-21st century entails increased air temperature and an increased number of rainy days in all seasons across the whole country (Hansen-Bauer et al., 2015). Climate change can impact livestock production through its effects on availability of resources such as water and feed as well as farm profitability and the need for new management practices and environmental policies (Krol et al., 2006). Therefore, it would be useful to evaluate bio-geophysical and economic aspects of GHG emissions from livestock sector under plausible climate conditions in an interdisciplinary study (Özkan et al., 2016). In this study, we aimed to determine the physical impacts of future climate scenarios on grass and wheat DM yields, and how such changes in future feed supply affect farm GHG emissions and decision-making processes. For this purpose, we combined four models: BASGRA (Höglind et al., 2016) and CSM-CERES-Wheat (Ritchie et al., 1998) for simulating forage grass DM and wheat DM grain yields respectively; HolosNor (Bonesmo et al., 2013) for estimating the farm GHG emissions; and JORDMOD (Bullock et al., 2016) for calculating the impacts of change on land use and farm economics. These models have previously been used individually to address specific challenges within their system boundaries. For example, BASGRA was recently used to simulate the impacts of climate change on timothy grass productivity, harvest security and yields in northern Europe and Norway (Persson and Höglind, 2014). Similarly, CSM-CERES was used to simulate the impacts of climate change on wheat yields in Norway (Persson and Kværnø, 2016) and in other main wheat production locations under current climate conditions (e.g. Persson et al., 2010; Thorp et al., 2010; Xiong et al., 2008). HolosNor has been used to estimate the GHG emissions associated with current dairy production in Norway (Bonesmo et al., 2013), and to compare the impacts of the climate and feed base (Hutchings et al., 2017), and impaired animal health on GHG emissions (Özkan Gülzari et al., 2017). JORDMOD model was previously used by Brunstad et al. (2005a) to evaluate the relationship between public goods, and by Bullock et al. (2016) to determine the trade-offs between conflicting public goods. In this study, the grass and wheat grain DM yields simulated by BASGRA and CSM-CERES models were processed and combined with farm and herd data in HolosNor to assess the GHG emissions under current and future climate and production conditions at farm level. The same grass and wheat grain DM yields were also used in JORDMOD together with data from HolosNor on feed intake, milk yield and GHG emissions to further evaluate the impacts of these production conditions on land use, economics and GHG emissions at national level.

2. Materials and methods

2.1. Locations

Climate, soil and farm management practices (e.g. cutting time and number of cuts per season for forage grasses, length of pasture period, and the use of concentrates and forage:concentrate ratio in the dairy cow diet) for four dairy farms representative of four production locations were included. The locations compared were south-east Norway (SEN), south-west Norway (SWN), central Norway (CN) and northern Norway (NN) (Fig. 1). Economic production analyses were performed at a national level based on the conditions in these locations.

2.2. Models used

Forage grass DM and spring wheat grain yields were simulated with BASGRA and CSM-CERES-Wheat model, respectively, and fed into HolosNor model to estimate the GHG emissions at farm level. Finally, JORDMOD was used to scale-up the farm-level results from HolosNor to evaluate the production of grains and milk, land rents, food production and imports of agricultural products, and the GHG emissions at national level. A brief description of the models and their applications in this study is provided below.

2.2.1. Grass and crop models (BASGRA and CSM-CERES-Wheat)

The BASGRA model was used to simulate the multiple annual harvest of above-ground tissue and the subsequent regrowth (Höglind et al., 2016). Spring wheat, a major feed concentrate component, was simulated with the CSM-CERES-Wheat model (Ritchie et al., 1998), in the Decision Support System for Agrotechnology Transfer (DSSAT) software v.4.5 (Hoogenboom et al., 2010). In these two process-driven models, growth development and yield of wheat and timothy grass, respectively are dynamically simulated as a function of weather, soil, management and crop genetics with a time step of one day. Growth is limited by sub-optimal soil water conditions in both models. In BASGRA, the soil is represented by one single layer with homogenous hydraulic properties, whereas the CSM-CERES-Wheat model in DSSAT includes multiple homogenous soil layers, of which the water content is affected by infiltration, evaporation and plant water uptake. The BASGRA assumes optimal nitrogen (N) status whereas CSM-CERES-Wheat includes functions for soil and plant N as affected by crop management, plant, soil and weather conditions. Plant N uptake is regulated by the ratio between the actual N concentration in the plant and the critical plant concentration for growth, and the availability of mineral soil N (Godwin and Singh, 1998; Jones et al., 2003).

2.2.1.1. Simulations of crop yield. The climate, soil and management practices used as input data for the grass and wheat simulations represented the locations in Fig. 1. The weather data used in the simulations represented the period 1961–1990, which were used as a baseline reference since is the latest full normal period, and projected future climate for the period 2046–2065 according to the Special Report on Emission Scenarios (SRES) GHG emissions scenario A1B (Nakicenovic et al., 2000). This scenario represents the intermediate future GHG emissions in the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (Pachauri and Reisinger, 2007).

Downscaled daily data on weather variables, including minimum and maximum air temperature, precipitation and solar radiation, for the farm locations and the two periods were stochastically generated by the Long Ashton Research Station Weather Generator (LARS-WG) (Semenov, 2010). For the period 2046–2065, four sets of 100 years of daily weather data were generated based on two Global Climate Models (GCM): BCM2.0 and HadCM3 as previously described by Persson and Höglind (2014). Soil input data including particle size distribution, organic carbon (C) and hydraulic characteristics were obtained from Bonesmo et al. (2013).

Timothy grass was simulated for all four geographic locations whereas spring wheat was simulated only for SEN and CN following the current regional production allocation of forage grass and cereal crops in Norway. We kept these geographic simulation settings for all scenarios since it is reasonable to argue that the rainfall patterns in western and northern Norway will continue to be adverse to spring cereal conditions also under projected future climate conditions. Weather inputs were obtained from LARS-WG calibrations against observed weather from Ås, Akershus County (59°40′N; 10°48′E; 89 m asl) for SEN, Sola, Rogaland County (58°53′N; 5°39′E) for SWN, Værnes, Nord-Trøndelag County (63°27′N; 10°55′E) for CN, and Tromsø, Troms County (69°39′N; 18°57′E) for NN.

Soil input represented one farm in Marker municipality, Østfold County (SEN), one farm in Time municipality Rogaland county (SWN), one farm in Trondheim municipality Sør-Trøndelag county (CN), and one farm in Tromsø municipality, Troms county (NN). The atmospheric carbon dioxide (CO_2) concentration was set to 350 ppm for the period 1961–1990, and 532 ppm for the period 2046–2065 according to the SRES A1B GHG emission scenario. In order to encompass most of the