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Production of cereals in northern marginal areas: An integrated assessment of climate change impacts at the farm level

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ABSTRACT

Crop production in northern regions is projected to benefit from longer growing seasons brought on by future climate change. However, production also faces multiple challenges due to more frequent and intense extreme weather phenomena, and uncertain future prices of agricultural inputs and outputs. Extensive studies have been conducted to investigate the impacts of climate change on cereals yield change, but integrated assessments that also consider the management and economy of cereal farms have been rare so far. In this study, the effects of climate change-driven crop productivity change on farm level land use dynamics, input use, production management and farm income were considered from the point of view of dynamic decision making of a rational risk-averse farmer. We assessed whether a farmer can gain from improved crop yields when using adapted cultivars and managing the farm accordingly. We incorporated crop yield estimates from a process-based large area crop model (MCWLA) run with two climate scenarios into a dynamic economic model of farm management and crop rotation (DEMCROP) to investigate future input use, land use with crop rotation, economic gross margins and greenhouse gas emissions. A time span of 30 years was considered. The model accounts for the yield responses to fertilisation, crop protection, liming of field parcels, and yield losses due to monoculture. The approach resulted in a novel and necessary analysis of farm management, production and income implications of climate change adaptation under different climate and socio-economic scenarios. We analysed the effects of different climate and price scenarios at a typical cereal farm in the North Savo region, which is currently a marginal area for crop production in Finland due to its harsh climate. Crop modelling results suggest a 19–27% increase of spring cereal yields and 11–19% increase of winter wheat yields from the current level until 2042–2070. According to our economic farm level simulations, these yield increases would incentivise farmers towards more intense input use resulting in additional increase of yields by 3–8% at current prices. More land is allocated to barley and wheat, less to set-aside and oat. The economic gross margin would increase significantly from the current low levels. Greenhouse gas emissions from farms were estimated to increase with increasing production, but emissions per quantity produced (measured as feed energy units) would decrease. There is potential for sustainable intensification (SI) of crop production in the region.

1. Introduction

Climate change patterns and impacts have been witnessed and predicted to vary geographically across regions (IPCC, 2014). For northern Europe, a prolonged growing season (Ruosteenoja et al., 2016) and increased crop yields under projected climate change have been estimated (Bindi and Olesen, 2011; Höglind et al., 2013; Rötter et al., 2012) although the range in climate projections also allows for negative yield effects (Rötter et al., 2012). Recent literature suggests that in northern regions, such as in Finland, where agriculture is limited by short growing seasons, crop cultivars that are better suited to longer growing seasons are likely to provide increase in yield potential (Rötter et al., 2013; Tao et al., 2015; Palosuo et al., 2015). Especially, yields of cereal crops such as wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) may increase by 20–30% in some individual regions, such as North Savo region in central Finland, where e.g. cereals crop yields are currently below the national average in Finland (Tao et al., 2015). In fact the region is currently a marginal area for cereals production in Finland due to unfavourable climatic conditions. Yields of grass species like Timothy (*Phleum pratense*) may also increase remarkably in North

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Savo region, even 10–15% (Höglind et al., 2013). These yield changes, if they come about, may have significant effects on production structure and land use in the region. Expansion of production in the currently marginal production areas may have significant societal and environmental consequences.

Development of agricultural production, however, is highly dependent on global markets, prices of agricultural inputs and outputs, as well as on agricultural policy that affect farmers actions via aids and regulations (Lehtonen, 2015; Mittenzwei et al., 2017). Farmers' use of fertilisers, pesticides, liming for soil improvement and drainage largely affect crop yield levels produced. However, sufficiently high market prices of agricultural commodities are required to cover the costs of such farm management practices. Input prices as well as crop prices in Europe are dependent on the realisation of global food demand and price developments. Any attempts to improve crop yields may be jeopardised by increasing prices of agricultural inputs or decreasing crop prices. In fact, price volatility as a remarkable source of uncertainty may significantly inhibit agricultural investments and the use of agricultural inputs (FAO et al., 2011). Hence, it is important to take account of the uncertainty of future mean price levels in our analysis of yield change driven impacts on future agricultural crop management and production.

Impacts of climate change on agricultural production in Europe have been studied in various countries by using bio-physical research results of crop yield changes in different climate scenarios as inputs for economic models of agriculture (Blanco et al., 2017; Dono et al., 2016; Mittenzwei et al., 2017; Özkan et al., 2017; Schönhart et al., 2016; Zessner et al., 2017; Zimmermann et al., 2017). Although these studies consider crop yield changes in a wider market, biophysical or policy context, they provide little explicit results or reasoning on farm level adjustments, e.g. use of different inputs, yield effects, production and overall management, due to changed crop yields. There are few, if any, studies that focus on farm level management changes, including change in the use of several inputs related to climate change driven crop yield changes. This however is important in northern Europe where crop yields and the use of yield determining inputs, such as fertilisation, fungicide use and liming, have been low and even decreasing due to low expectations related to crop prices, yields and policy incentives (Lehtonen et al., 2016a; Myyrä et al., 2005; Peltonen-Sainio et al., 2015). However if low yield potential and/or price expectations are changed that may trigger increased use of some yield determining inputs, and a further change in crop yields and farm income, depending to realised prices and yields. Dono et al. (2016) comprehensively studied farm level effects of climate change for some farm types in Italy focusing on water availability, temperature and related stochastic aspects of climate change. Studies of e.g. Mittenzwei et al. (2017), Özkan et al. (2017), Schönhart et al. (2016) and Zessner et al. (2017), can be considered as positive examples as well since they report some aspects of changed farm management, either land use patterns or the use of agricultural inputs, in addition to crop yield changes.

However there is a tendency of direct incorporation of crop yield changes, predicted by bio-physical models, into economic models, with little consideration of changed use of inputs and resulting responses. Such papers (e.g. Blanco et al., 2017; Nelson et al., 2014) may have other merits, however, if focusing on e.g. market feedbacks, global trade flows and price effects of climate change in large scales. Nevertheless, analysing changes in the use of multiple inputs simultaneously is important because they may have important responses on crop yields and farm economy. Such farm level analysis, with related dynamic aspects of responses and farm level decision making, are important and could be accounted for when analysing impacts of climate change in larger scales and dimension. For example environmental effects of agriculture are likely to be dependent on the use of inputs, land use changes and crop yields (Huttunen et al., 2015; Schönhart et al., 2016). Even though many extensive studies have been conducted to investigate the impacts of climate change on cereals yield change, as mentioned above, the integrated assessment of the impacts of climate change driven crop yield changes on management of cereals farms and their economy has been rare so far.

Agricultural production and its sustainable development in northern Europe - with potential benefits due to climate changes as well, not only negative consequences - is considered necessary due to sustainability concerns (Tilman et al., 2011) and expected large scale challenges on agricultural production in southern Europe (Dono et al., 2016) and elsewhere where climate change is expected to bring difficult negative consequences in a large scale (IPCC, 2014). Reaching higher crop yields with more effective use of inputs (better yield responses) seems to be a core issue of sustainable intensification (SI) (Tilman et al., 2011). Developing more adapted cultivars for future climate conditions is considered a major adaptation option in northern Europe (Peltonen-Sainio et al., 2009; Rötter et al., 2013).

In this study, we focus on dynamic farm management and implications of climate change on production, farm income, and include estimated effects on greenhouse gas emissions as well, in the context of northern Europe. Our objective is to find answers to the following research questions: What are the effects of crop productivity change on farm level land use, input use, production and farm income? What are the effects of improved crop yields to farm's profitability? How do the effects vary with different future price levels? What are the differences between spring and winter cereals in future climate conditions? Do higher crop yields lead to reduced GHG emissions per farm or per unit produced? To this end, we focus our analysis on adaptation to climate change by using new, more adapted crop cultivars and study the implications of their usage to production and farm management of cereals farms in the North Savo region. The yields of cereals crops are currently below the national average in the North Savo region. However the predicted increase in the cereals yields are relatively high, assuming more productive cereals cultivars (Tao et al., 2015). Our aim is to analyse the extent to which the productivity and profitability of the cereals farms in the region may improve due to more adapted cultivars to future climate. We bring the crop yield benefits of adapted cultivars, predicted by bio-physical crop modelling, into a dynamic decision making of a rational risk-averse farmer. We use an economic modelling approach that considers the yield potential of adapted cultivars, but also accounts for the yield responses of changed fertilisation, crop protection, liming of field parcels, and crop rotation, with yield losses due to monoculture, over a 30 year time period. Thus we analyse management, crop yield and income implications of more adapted cultivar under dynamic, economically rational decision making.

2. Materials and methods

2.1. Pilot region: North Savo, Finland

North Savo is a province in central part of Finland (Fig. 1) with 4.6% of total population in Finland and 6.4% of agricultural land area of Finland. Average size of cereals farms in this region is approximately 50 ha. 32% of farm family income at cereals farms in the region comes from agriculture (Lehtonen et al., 2016a).

Dairy farms (10% out of whole Finland, average size appr. 35 cows and 50 ha) along with other cattle husbandry and cereal farms are the major agricultural production lines in this region (Lehtonen et al., 2016a). Consequently, a large share of farmland is occupied by specialised livestock farms and cereal farms. Yields of cereals are 20–39% lower than in the southern Finland. According to FADN data (Luke, 2017a), the average gross margin per hectare on all cereals farms in Finland was 234 €/ha 2010–2012, whereas the average gross margin per hectare at North Savo cereals farms was 198 €/ha 2010–2012, i.e. 17% less than the whole country average (data does not allow to compare the gross margins for the whole 2000–2015 period). At present, North Savo can be considered a marginal area for cereals production, producing mainly feed cereals for local dairy and beef