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Dynamic economic modelling of crop rotations with farm management practices under future pest pressure

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ABSTRACT

Agricultural practice is facing multiple challenges under volatile commodity markets, inevitable climate change, mounting pest pressure and various other environment-related constraints. The objective of this research is to present a dynamic optimization model of crop rotations and farm management and show its suitability for economic analysis over a 30 year time period. In this model, we include management practices such as fertilization, fungicide treatment and liming, and apply it in a region in Southwestern Finland. Results show that (i) growing pest pressure favours the cultivation of wheat-oats and wheat-oilseeds combinations, while (ii) market prices largely determine the crops in the rotation plan and the specific management practices adopted. The flexibility of our model can also be utilized in evaluating the value of other management options such as new cultivars under different projections of future climate and market conditions.

1. Introduction

Future projected climate trends in relation to agricultural production in northern Europe may play out in two ways: the northward movement of crop suitability zones may in principle increase crop production potentials in Northern Europe (Easterling et al., 2007; IPCC, 2014), while at the same time likely increase in frequency and severity of adverse agroclimatic events might also lead to more frequent low-yielding seasons and higher yield variability (Rötter et al., 2011, 2013; Trnka et al., 2014). Pest and disease pressure are gradually increasing from their relatively low level compared to central and southern Europe due to climate change (Hakala et al., 2011).

In Finland, some of the predicted impacts of climate change on the future yield of Finnish cereal crops for the 21st century include sustaining or slightly increasing yield potential in most climate change scenarios and soil types (Rötter et al., 2013, Höglind et al., 2013). However, in some climate change scenarios and soil types, potential yields are estimated to decrease due, for instance, to an increased frequency of drought. Furthermore, a slightly widening gap between potential yields and actual observed average farmer's yields since the 1980s has been witnessed in many Finnish regions (Peltonen-Sainio et al., 2015, Palosuo et al., 2013, 2015. This widening gap, the so called "yield gap" (van Ittersum et al., 2013), is greatly affected by socio-economic factors influencing farm level management actions. After Finland joined the EU in 1995, Finnish farmers have gradually not only faced challenges on the production side, but also increasingly uncertain markets mostly driven by global demand and a complex interaction among agriculture, food and energy markets (Godfray et al., 2010, Huchet-Bourdon and Korinek, 2011). Peltonen-Sainio et al. (2015) found that low real prices of crops (e.g. a price drop in Finland due to EU integration in 1995) and discouraging and restrictive policies (e.g. those imposed on fertilization in an agri-environmental scheme) may lead to a cost minimization strategy. As a result, farmers are not motivated to improve crop management to narrow the yield gap at farm level (See Fig. 1), which eventually may hamper farmers' economic optimum in the long-run.

Crop rotation is a typical crop management practice in designing cropping systems that ensure long-term yield stability and maintain soil fertility (Maynard et al., 1997; Vereijken, 1997; Stoate et al., 2001; Hennessy, 2006; Dury et al., 2011). Crop rotation has regained attention due to the observed problems resulting from short rotations and monocropping, such as increasing disease pressure, declining soil quality and increasing environmental degradation (Baldwin, 2006; Bennett et al., 2012). In addition, rotation choices in comparison to monocropping could possibly reduce the intensive usage of pesticides and synthetic fertilizers, and mitigate greenhouse gas emissions (Lal et al., 1999; Wu et al., 2004; Meyer-Aurich et al., 2006; Cai et al., 2012).

Crop rotation can also be applied together with other management practices such as fungicide treatment and liming. Liming practices have been found to be important and necessary in Finland where

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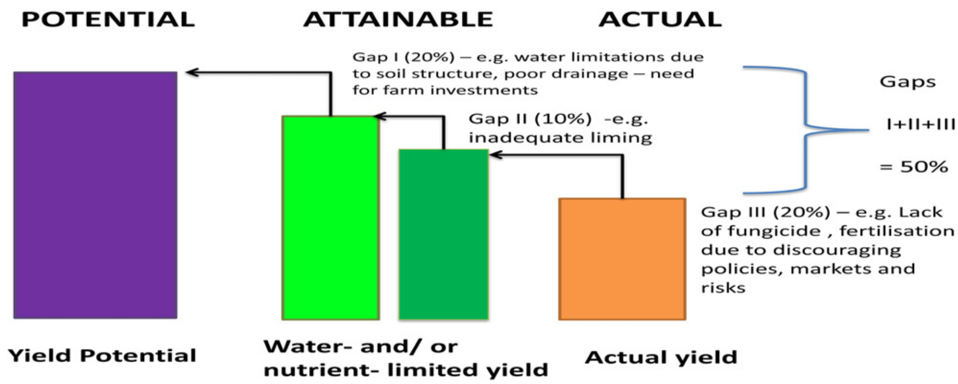

Fig. 1. Production situations and yield gaps in Finland (Source: modified from van Ittersum et al., 2013).

many soils are fairly acid (Myyrä et al., 2005). Since climate change will favour e.g. powdery mildew, fungicide treatment is expected to become more important in Finland with a future climate (Hakala et al., 2011). Suitable rotations together with other crop management practices can benefit the overall productivity and profitability of the farm, thus contributing to food security and rural development (Bergez et al., 2010). Carefully designing crop rotations and other farm management practices becomes even more important with future climate change than it is at present. An understanding of the agro-economics of rotation choices with other agro-management work can be very useful to crop growers, policy makers, environmental scientists and agricultural scientists.

Crop rotations have been intensively studied through different kinds of decision support tools (Dury et al., 2011). Some methods rank crop rotation decisions according to agronomic perspective such as ROTAT (Dogliotti et al., 2003), ROTOR (Bachinger and Zander, 2007) and CropRota (Schönhart et al., 2011); other models such as reported by El-Nazer and McCarl (1986) and Livingston et al. (2012) follow social-economic criteria. While the agronomic models clearly show the effects of crop rotation on crop yield, many have argued (Dury et al., 2011) that these normative and static approaches fail to address the dynamics of mechanisms involved in the processes of farmers' decision-making. In particular, these models rarely consider farmers' acreage decisions under the volatility of both crop yields and prices, and farmers' risk preferences are also neglected.

At a farm level, socio-economic models of crop rotation based on El-Nazer and McCarl (1986) and Livingston et al. (2012) are most popular. They focus on the role of risks as a cost to farmers and a very significant factor affecting farmer's management decisions and production output. The risks include yield and price uncertainty, but are also affected by the farmer's risk attitude (Heady, 1948, Leroy and Jacquin, 1991; Itoh et al., 2003, Sarker and Ray, 2009; Louhichi et al., 2010). Decisions on actual crop rotations and other farm level management practices have to be made for a time span of several (more than 2–3) years. Nuppenau and Höft (2009) attempted a dynamic optimization approach to crop rotation in order to increase awareness of the long-run effects of declining soil fertility that can be linked to the economic planning of crops and rotations from a farmer's perspective. They suggested that more practical and comprehensible dynamic models are needed at the farm level. A transition matrix was suggested as a temporal link between "yield potential and previous cropping pattern of the past". Nevertheless, the empirical application was not provided in that study.

According to van Wijk et al. (2014), integrated analyses at the farm level that combine the strengths of dynamic mathematical programming and decision models seem promising and well suited for complex climate change related issues. They could support a robust evaluation of climate change impacts and adaptive management options. Van Wijk et al. (2014) further found that only a few farm level models based on explicit dynamic optimisation were utilized in the context of food security and climate change. Such models should in future include a longer time span than just a few years.

Therefore, the aim of our research is to develop a dynamic economic model of crop rotations that allows us to incorporate management practices at farm level into a farmer's long-run economic decisions. As a case study, we apply our model to simulate land allocation, crop choices, yield response, management choices and fertilizer input choices across six scenarios in Varsinais-Suomi (a province in south-west Finland) for a period of 30 years (e.g. 2016–2045). Furthermore, we evaluate how increasing plant disease pressure is likely to affect crop production in this region. The contribution of our model is to show that crop rotation and crop-specific management choices such as fertilization, fungicide treatment and liming practices can be integrated into a single dynamic optimization model, in which the yield becomes largely endogenous and conditional on management decisions from current and earlier years.

The paper is designed as follows: we first explain the structure of the model, followed by a description of case study region and empirical data from this region. Then parameters of baseline disease pressure, parameters of liming and fungicide treatment and risk aversion are introduced. 6 scenarios are formulated based on 3 different levels of future crop prices and 2 disease pressure scenarios affecting yield losses from monocultural cultivation: low, median and high prices under a relatively low disease pressure scenario (baseline), and low, median and high crop prices under a higher disease pressure scenario affecting significantly crop yield losses. The farm level economic model is used in evaluating the crop rotation, land use and other farm management choices in the 6 different scenarios. Results are presented with an interpretation of their significance for farm management. Finally, we draw conclusions on the main results and the suitability of the modelling approach.

2. Materials and methods

2.1. Model

We utilize a dynamic optimisation framework, as it can accommodate truly dynamic inter-temporal decisions, without excluding short-term decisions affecting only one year. The optimisation framework is flexible to accommodate various technical data and response functions such as changed crop yield as a response to nitrogen fertilization, nutrient use efficiency of future cultivars, proven empirical impacts of liming (soil pH)