# Endogenising yield development through management and crop rotation decisions in dynamic farm level modelling

H. Lehtonen, X. Liu and T. Purola[1]

***Abstract* - Crop rotation may gain more importance in the context of climate change while monocropping is expected to become increasingly problematic. This is, among others, because of increasing plant protection challenges due to warmer climate, which is also expected to result in more frequent droughts, heavy rainfall and waterlogging in northern latitudes. Such changes require improved soil structure and water retention, also aided by crop rotations. Our objective is to build and apply a dynamic economic optimization model of farm level crop rotation on many field parcels over 30-40 years. The model takes into account various adaptation management methods such as fungicide treatment, soil improvements such as liming, and nitrogen fertilization, simultaneously with dynamic crop rotation choices.**

## INTRODUCTION

Agriculture is challenged by increasingly volatile commodity markets, inevitable climate change and gradually tightening environmental constrains. While some positive impacts may be anticipated for Northern Europe, increasing climatic variability with higher frequency of extreme events, pest pressure and continuous changes in the regional and global market may present significant challenges for farmers and agricultural production in Nordic countries (Hakala et al., 2011).

Crop rotation could maintain the soil productivity, reduce disease risk and pest damage, and thus mitigate yield risks (Maynard et al., 1997; Hennessy, 2006). In addition, rotation choices in comparison to monocropping could decrease the intensive usage of synthetic chemicals inputs and mitigate the greenhouse gas emission (Lal et al., 1999; Wu et. al. 2004). When plant disease pressure is mitigated by sufficiently diverse crop rotations, chemical crop protection practices such as fungicide treatment is more effective than under monocropping practices. While fungicide treatment is traditionally rare in Finland it is, however, likely needed in future climate of higher temperature sum at northern latitudes. Also other management practices such liming, due to the acid soils in Finland, are important means of maintaining and improving crop yields. However, these management practices and investments do not realize if crop prices and agricultural policies are discouraging for farmers and for their efforts of developing the production. The lack of such investments and management practices lead to already existing yield gaps, i.e. difference between potential, attainable and realised yields. Hence there is a need for economic analysis of adaptation to climate change to produce insight how some adaptations options to be decided at the short (1 year), medium (2-10 years) and long run (over 10 years) may realize at a reasonable cost and how they pay off for farmers, food sector and society, under different market and policy conditions

The aim of this paper is to evaluate farm level adaptation in two regions in Finland, under alternative market and disease pressure scenarios, using a dynamic optimisation model.

## METHODS

We simulate land use and crop rotation patterns for the next 30 years. The main objective in such a modeling is to endogenise the yield gap through explicit modeling of the key management practices and investments in a long-term model. The model takes into account various adaptation management methods such as fungicide treatment, soil improvements such as liming, and nitrogen fertilization, simultaneously with dynamic crop rotation choices. However, these management options imply costs. Hence both input and output price developments are important for the realization of the adaptation options. The adaptation is also affected by agricultural and agri-environmental policies already influencing farmers' efforts in developing production.

The model is tested and validated in terms of how well the observed management practices can be reproduced by the model. However this kind of comparison of the model outcomes to the realized aggregate level management practices indicated by the aggregate use of individual inputs is not without problems due to the large variety of farm types in reality while only few typical farm types can be modelled with a large scale non-linear dynamic optimization model including many dimensions of management practices and a 30 year long time span.

Risk behavior is one important part of the model, implemented through mean-variance specification. Despite the relatively simple representation of the risk behavior (through mean-variance approach) we are able to show its significance and the role of risk

[1] Heikki Lehtonen, Xing Liu and Tuomo Purola are from MTT Agrifood Research Finland, Economic Research, Helsinki, Finland (heikki.lehtonen@mtt.fi).

aversion coefficients for the land use patterns of the model, in comparison of the land use types of specific farm types in 2 regions of Finland. We present both risk-neutral and risk-averse models that integrate agronomic criteria and historical farm-level observed data in Finnish two regions to generate baseline crop rotation choices for these two regions. We first implement risk neutral model to a typical cereal producing region Varsinais-Suomi (Southwest Finland) and risk-averse model to a typical dairy dominated region Pohjois-Savo (Northern Savo in middle/ eastern part of Finland). The simulated results further compare with the observed land use in two regions to show the robustness of the models. We set up 6 scenario concerning both price and disease pressure. Two disease pressure scenarios have been defined based on research projects in cooperation between agricultural economists and crop scientists in MTT. Increasing length of initially short growing seasons at northern latitudes result in a significant relative increase in pest and disease pressure. Here the disease pressure increases from (current) low to high disease pressure scenarios by a factor of 2.

S1: High-disease-pressure vs. High-price expectation
S2: High-disease-pressure vs. Current-price exp.
S3: High-disease-pressure vs. Low-price exp.
S4: Low-disease-pressure vs. High-price exp.
S5: Low-disease-pressure vs. Current-price exp.
S6: Low-disease-pressure vs. Low-price exp.

| Crops | High-price €/kg +30% of Current-price | Current expected -price €/kg (~5 year average) | Low-price €/kg -30% of Current-price |
|---|---|---|---|
| **Spring wheat** | 0.224 | 0.172 | 0.120 |
| **Winter wheat** | 0.224 | 0.172 | 0.120 |
| **Barley** | 0.208 | 0.160 | 0.112 |
| **Oats** | 0.187 | 0.144 | 0.101 |
| **Oilseed** | 0.481 | 0.370 | 0.259 |
| **Set aside / grassland** | - | - | - |
| **NMF (nature management field, incentivised)** | - | - | - |

## Parameter and data set

We implemented the model to a typical average sized cereal producing farm in Varsinais-Suomi (Southwest of Finland) and North Savo regions. Crop yields are the 16-year-average-yields between 1995 till 2011 extracted from farm-level data by Statistics Finland. Variable costs and subsidies of the crops are from a dynamic regional sector model of Finnish agriculture (DREMFIA)(Lehtonen, 2001).

## Results

Our results show responsiveness of crop yields to disease pressure and prices. High prices trigger adaptations through liming and fungicide use. The yield of barley is retained in scenario S1. Barley yields are more responsive to prices than the yields of other crops since fungicide treatment is currently defined for barley only. Oilseed is a good break crop for cereals, but it is cultivated less due to its lower gross margin compared to wheat, and high yield penalty on successive cultivation on the same field parcel over years.

**Table 1.** Main model outcomes over a 30 year time span for South West Finland. Average yields (in parenthesis) are based on official statistics.

| | | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| **Avg. Yields** | S.wheat (3557) | 3347(-6.4%) | 3351(-6.3%) | 3224(-9.8%) | 3520(-1.6%) | 3503(-2.0%) | 3429(-4.1%) |
| | W.wheat(3794) | 3485(-7.3%) | 3451(-8.2%) | 3412(-9.2%) | 3681(-2.1%) | 3678(-2.2%) | 3654(-2.8%) |
| | Barley (3550) | 3591(+0.3%) | 3274(-8.5%) | 3214(-10.2%) | - | - | - |
| | Oilseed (1393) | 1549(+11.2%) | 1539(+10.5%) | 1505(+8.0%) | 1562(+12.1%) | 1555(+11.6%) | 1535(+10.2%) |
| **Average profit, 1000 €** | | 117 | 82 | 55 | 133 | 95 | 63 |
| **Fungicide, Nr. of applications** | | 102 | 0 | 0 | 0 | 0 | 0 |
| **Average pH** | | 6.73 | 6.68 | 6.43 | 6.73 | 6.70 | 6.40 |

## Conclusion

Our study indicates that farm level agricultural systems benefit from crop specific adaptations and crop rotations to manage increasing disease pressure in the future. Nevertheless, output and input prices play also a key role in providing incentive for farmers to utilize adaptation management such as fungicide treatment and liming. Yield reductions due to higher disease pressure can be mitigated, or even eliminated, by combining crop rotation with other management practices, despite increasing plant disease pressure.

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