Environmental and economic modelling of organic, stockless, horticultural crop rotations

Ulrich Schmutz[1], Francis Rayns[1], Chris Firth[1], Anton Rosenfeld[1], Kristian Thorup-Kristensen[2], Kefeng Zhang[3] and Clive Rahn[3]

***Abstract* – Selected results from the ongoing "EU-Rotate_N" research project are presented. This EU 5th-framework project is developing a model-based decision support system to optimise nitrogen use in horticultural crop rotations across Europe. This paper introduces the economic and the fertility-building crops sub-models, and shows data from model validation and first model runs on an organic farm in central England. Preliminary results show that the model has the potential to be a powerful support tool for farmers and advisors, making decisions on rotational planning. The economic, agronomic and environmental consequences of different rotational designs can be projected and assessed in detail.[1]**

INTRODUCTION

EU-Rotate_N is a 4-year, EU funded, research project, which is developing a model-based decision support system to optimise nitrogen use in horticultural crop rotations across Europe. The EU-Rotate_N project builds on an existing soil- and plant nitrogen model (N-ABLE). To enhance its power various sub-models and more field scale vegetable and arable crops including fertility-building crops from all European climates have been added. Further information on the project, including annual reports, project newsletters and internal scientific reports are found at www.hri.ac.uk/eurotate, or are available from the authors. As a decision support tool, the model aims at different decision-making levels. One is the farmer and advisor level making decisions on crop management and rotational planning. This level is evaluated further in this paper. The other levels are regional (e.g. catchment), national and EU (policy makers). For those more scientific inputs in terms of statistical data, GIS analysis and additional programming are needed.

THE SUB-MODELS OF EU-ROTATE_N

Among the new-programmed sub-models are a root model, a water movement & irrigation model, a soil mineralisation model, a snow & frost model and an economic sub-model. EU-Rotate_N also looks at the rotational level and not only specific crops to understand the agronomic, environmental and economic interactions of rotational strategies.

THE ECONOMIC SUB-MODEL

At present soil- and plant models rarely contain economic components, because natural and social sciences often use different approaches to modelling. In the EU-Rotate_N model we did not attempt building a separate economic model, rather integrated the economics into a sub-model, so that EU-Rotate_N can run with or without the economic part (Schmutz et. al. 2004). The main entry into the economic model is the total dry matter (TDM), which includes roots, and all above ground dry matter (figure 1). TDM is an output of the current agronomic model. This parameter however, does not give an indication of the above ground dry matter or fresh matter, nor is there an indication of size or shape of the marketable vegetable parts. Therefore, one of the challenges is finding appropriate algorithms to calculate a marketable yield, which is a major input in any farm economic model. This gives also a figure for the dry matter removed, and the remaining residues (post-harvest) are used as an input for the mineralisation sub-model.

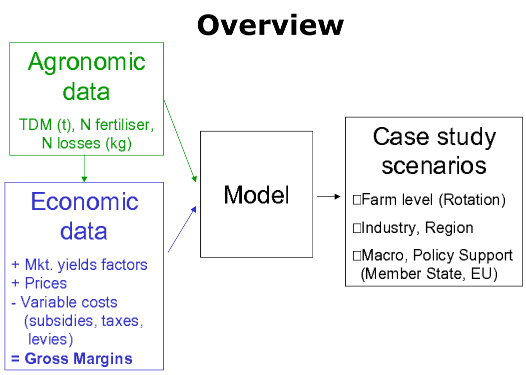

Figure 1. Simplified model overview

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[1]Authors are with HDRA (Henry Doubleday Research Association), Ryton Organic Gardens, Coventry CV8 3LG, UK (England), USchmutz@HDRA.org.uk, [2]Kristian Thorup-Kristensen, DIAS Horticulture Research Centre Aarslev, Denmark, [3]Clive Rahn, University of Warwick HRI, Wellesbourne, Warwick, UK (England)

Conversion of total dry matter in marketable yield

Marketable yields are not fixed: the percentage of total yield marketable depends on "soft" or social factors. Among those are market channels, production systems (organic or conventional), eating cultures (e.g. some countries prefer small, other large vegetables, a full-flavoured taste in one may be considered bitter in another). Only a few "hard" figures can be used such as the EU trade classifications, which makes certain vegetables unmarketable if below or above the specifications.

Considering these, two strategies were developed - one more empirical the other more theoretical. For the empirical conversion our own research, published and un-published field research data were collected, where both total dry matter and marketable yields were measured across Europe. From this an algorithm was derived converting total dry matter into marketable yield at any given N supply level including sub-optimal and supra-optimal supply. A unified algorithm with different crop specific parameters is used for each annual vegetable with a single harvest. There are three main types of vegetable crops: some with a simple constant relationship at all available N levels, some with linear increasing or decreasing relationship depending on available N. Some are more complicated with a non-linear relationship. Other vegetable crops are perennial, like artichokes, or with multiple harvests and need different algorithms than annual, single harvest crops.

In a second approach, the single plant fresh weight is calculated. This is done using the harvest index to calculate the dry weight of the harvested parts. Then, with the dry matter content and the plant population, an average single plant fresh weight is produced. Assuming a normal distribution of plant fresh weights and a coefficient of variation of e.g. 20% a lower and upper limit of marketable plant fresh weight can be set (e.g., the EU trade specifications). With this information, an average fresh weight of marketable plants within these specifications is calculated. Using the plant population again, the marketable yield and the residues left post-harvest are calculated.

Prices, variable cost and gross margin database

The economic calculations of output, variable costs and gross margins are not done within the core model (figure 1). They are hosted in the model framework, because prices differ for each country, market channel and growing system. For the calculations, standardised figures stored in an economic database are used. The countries considered in the database are Norway, Denmark, Germany, UK, Italy and Spain. The market channels considered are pre-pack for supermarket, wholesale, direct marketing and processing. The growing systems considered are conventional and organic. The database holds about 300 crop entries of all relevant horticultural crops, including fertility-building crops, across Europe. The data are current prices and standardised variable cost data published in each country for conventional and organic farming systems (e.g. Lampkin et al., 2004; Nix, 2004; Agro Business Consultants Ltd., 2005). The level of data availability and the depth of detail vary among countries.

The Fertility-building Sub-model

For the growth of fertility crops, a daily target growth rate is used. This is different from the target yield approach used for vegetable and arable crops in the main model. Parameters for percentage daily dry matter increase and maximum daily growth are introduced for three different growth conditions. For N-fixing, fertility crops the programming allows no growth limitation by soil mineral nitrogen. The amount fixed daily is then the difference between total new plant N and available N in the soil. Other parameters control daily litter loss, senescence after a given period and frost impact if minimum temperatures reach a specific value. Mowing dates are specified by the user; at each date half the biomass is returned as a residue to the upper layer of the soil.

Species mixtures (e.g. grass-clover leys) are treated as single crops and at present, there is no distinction for different clover percentages in the ley. Undersown crops are split in two phases. During the undersown phase, the fertility understory is ignored and the target yield of the nurse crop (cereal or vegetable) is reduced as necessary. After harvest of the nurse crop the fertility crop is modelled as described above, however growth starts with a appropriate dry matter and nitrogen content (similar to transplants in the vegetable crop model), again set for three different growth conditions.

Some Validation Results

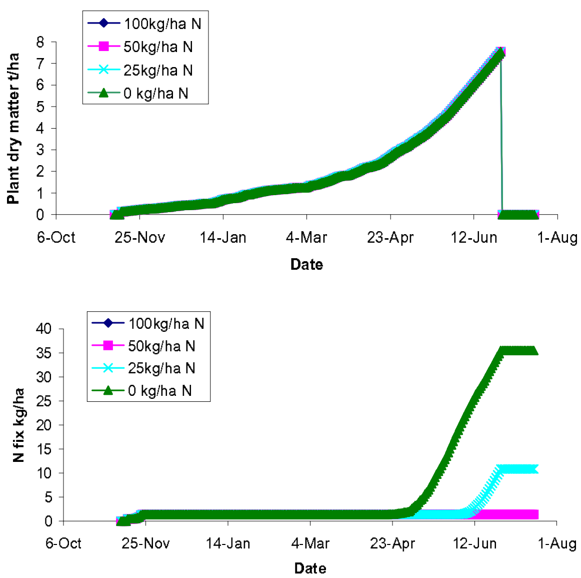

Figure 2. Modelling total plant dry matter growth (t/ha) and nitrogen fixation (kg/ha) of broad beans at four nitrogen fertiliser levels.

The model is now in its 3rd version and is simultaneously being validated in all participating countries. As and example validation data are shown for the growth of a N-fixating crop (broad beans, figure 2). The plant dry matter growth is not affected by N fertiliser level; from May onwards, missing nitrogen is fixed in the lower N fertiliser levels.

Another example (figure 3) shows how the model treats the plant dry matter growth of grass-clover ley with no and up to four mows (mulching) per year.

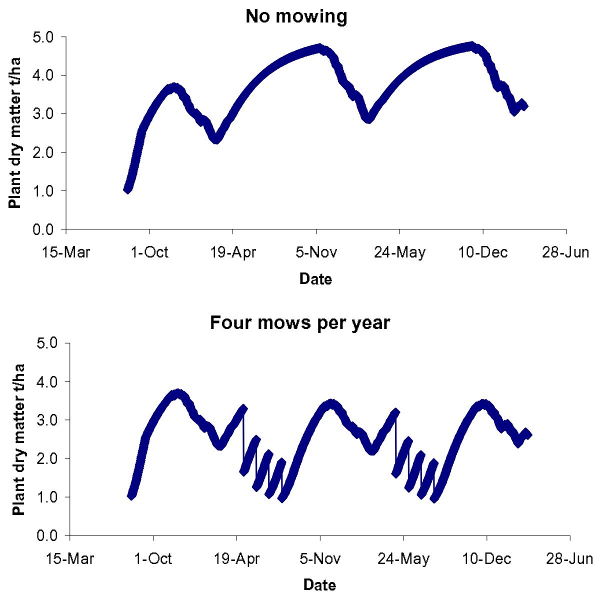

Figure 3. Modelling total plant dry matter growth (t/ha) of grass-clover ley with no and four mows per year.

The effect of three different chosen daily growth rates is shown in figure 4. The model produces considerable different plant dry matter for an overwinter grazing rye cover crop. Validation with the field experiments conducted within the EU-Rotate project will help finding appropriate growth rates for different climates and conditions.

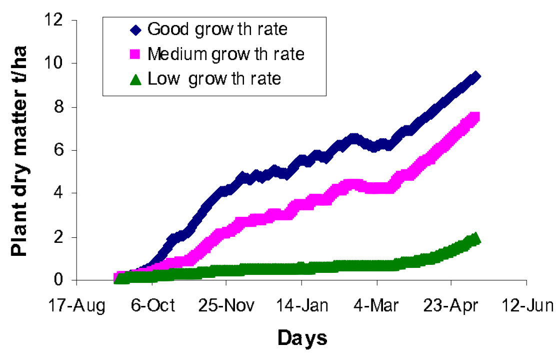

Figure 4. Modelling total plant dry matter growth (t/ha) under three different growth conditions.

FIRST MODEL RUNS

First model runs were done with two sample rotations derived form a commercial organic vegetable farm in England (figure 5). The farm is currently considering the change from a 4-year rotation to a 6-year rotation, mainly for pest control and marketing reasons, however without detailed information on the fertility management, farm economic and nitrogen leaching implications. This is a typical situation where a model-based planning tool can give valuable decision support to organic growers. Because of confidentiality considerations standardised economic data were used. This is held in the EU-Rotate_N model database and drawn from regularly published information (e.g. Nix, 2004 and Lampkin et al., 2004 for the UK).
Other physical data are as found in the field in 2006. The planned change in rotational design will increase the fertility area to 33%; it will also increase the cabbage and potato area and decrease the leek and sweetcorn cropping. The farm is on light sandy loam soil and uses also 25t/ha cattle manure and 0.9 t/ha of a commercial 5-1-10-fertiliser, with 5% N at 45 kg N/ha. This fertiliser is a by-product of GMO-free oilseed-rape processing and is permitted on this farm with derogation from the certification body. As a winter cover crop vetch or rye is used were possible. The annual grass-clover is cut and mulched twice.

Year	4-year	6-year
1	Grass-clover	Grass-clover
2	Cabbage/Pot.	Potatoes
3	Leek	Leek
4	Sweetcorn	Grass-clover
5	--	Cabbage
6	--	Sweetcorn
% per year		
Grass-clover	25%	33%
Cabbage	12.5%	17%
Potatoes	12.5%	17%
Leek	25%	17%
Sweetcorn	25%	17%

Figure 5. Current and planned rotation designs on a commercial organic vegetable farm in central England.

Year	4-year	6-year
1	-80	-80
2	7498	5827
3	4398	4398
4	8451	-80
5	--	9169
6	--	8451
Rotational Gross Margin	**5067**	**4614**

Figure 6. Annual crop gross margins (€/ha) and rotational gross margins (€/ha/yr) of the above rotations.

With the standardised figures used, the 4-year rotation is expected to produce a slightly higher rotational gross margin of 5067 Euro/ha per year (figure 6). This is mainly because less area is down in fertility building (25% instead of 33%). However, the question is: Is this really the case? Higher fertility could result in higher marketable yields, lower fertiliser costs and less leaching. In order to answer these questions the crops have to be "grown" on a daily basis within the model using the farm soil and weather data.
The two rotations shown (figure 7) were modelled using a standardised weather file. It was created using the average weather during the 6 year period and repeating the average weather annually. Preliminary results show that the two rotations differ in the NO_3 leached below 30, 60 and 90 cm. In year 5 and 6 of the 6-year rotation little additional leaching occurs (figure 7).

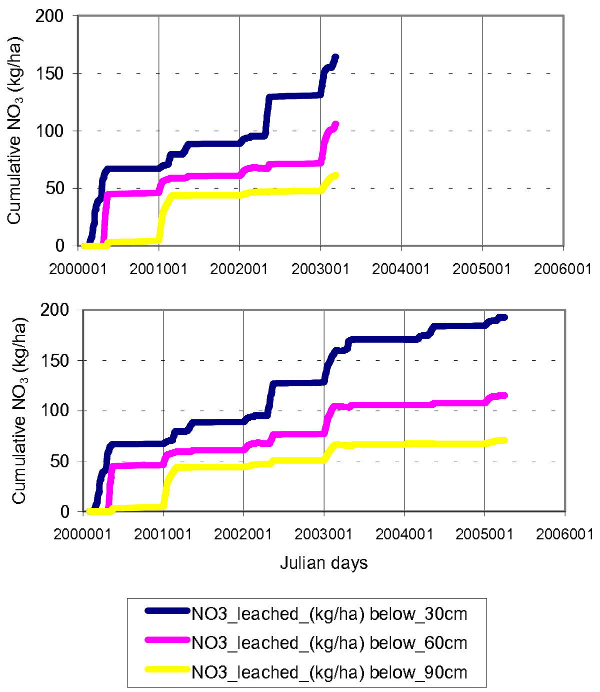

Figure 7. Model runs of a 4-year (top) and 6-year (bottom) rotation. The cumulative nitrate (NO3) leaching in kg/ha is shown below 30, 60 and 90 cm. The time axis is shown as Julian days (e.g. 1.1.2000 is 2000001). For crops grown in the different rotations see figure 5.

If in the second cycle of the 4-year rotation a similar leaching is assumed as in the first cycle, then the cumulative leaching of this rotation would amount to over 100 kg N/ha, while the 6-year rotation leached only 70 kg/ha, or 30% less over a 6 year period. This indicates that the 6-year rotation, although slightly less profitable, appears to uses nitrogen better and has the potential to produce higher marketable yields.
As already outlined, these are preliminary results showing the approach of the model. In this model runs no cover cropping and fertiliser additions were used. In a further step, the over winter crops rye and vetch can be added in the model run and thus optimise the nitrogen retained within 90 cm soil layer. The available fertilisers cattle manure and Dingleys can be used to fine-tune the rotations, and secure that the target yield can be reached.

Discussion & Conclusions

Research conducted so far shows the complexity of the modelling with is tried to achieve. At some point, a trade-off has to be made between preparing the model for all different climates, crops and cropping strategies and a understandable output for farmers and policy makers. Further validation and possibly cross validation with other similar models is certainly needed. In general, the model can be a useful decision support system, however considerable inputs in terms of data and expertise are required to run rotations on a farm level. Therefore, it is more likely to be used as an advisory tool. However, it is planned to make the model and all its documentation freely available on the internet for everyone to use and feedback - creating an interactive learning environment.

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