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Development of a model based decision support system to optimise nitrogen use in horticultural crop rotations across Europe

EU-ROTATE_N

Quality of Life and Management of Living Resources

Key Action 5

CONTENTS

1. SUMMARY

A new model has been written and tested which enables the assessment of the economic and environmental performance of crop rotations in either conventional or organic cropping for a wide range of crops and growing conditions in Europe. The model though originally based on the N_ABLE model has been completely rewritten and contains new routines to simulate root development, the mineralisation and release of N from soil organic matter and crop residues, the effect of freezing conditions, and water movement. New routines have also been added to estimate the effects of sub-optimal rates of N and spacing on the marketable outputs and gross margins. Model performance was tested against experimental results and broadly simulated the patterns of growth N response and N losses. The model provides a mechanism for comparing the relative effects of differing cropping and fertilisation practices on yield gross margin and losses of nitrogen through leaching. The running of a number of scenarios has demonstrated that nitrogen management in field vegetable rotations can be improved in Europe by following at least Good Agricultural Practice but the model also provides the potential for suggesting improvements which have a minimal effect on gross margin whilst reducing nitrogen losses.

Key Words gross margin, leaching, marketable yield, field vegetables, nitrogen, crop rotations

2. INTRODUCTION

The production of healthy wholesome vegetables with minimal impact on the environment is becoming increasingly important. Agricultural practices have been developed over many centuries but during the last century there were several leaps in technology, with the developments of chemical pesticides and fertilisers. These have seen production levels increase dramatically, but not without problems associated with contaminants found in the wrong place; in the harvested produce, drainage waters, soil or air.

With around 750,000 t of nitrogen applied to tilled crops in England and Wales it is important to optimise fertiliser nitrogen applied to crops nitrogen requirement. Vegetables, particularly brassicas, receive large quantities of fertiliser nitrogen, for example 36 % of the area of Brussels sprout crops in England and Wales received more than 250 kg/ha N (British Survey of Fertiliser Practice). Demyttenaere et al. (1990) showed that growing field vegetable crops can lead to large amounts of potentially leachable nitrate being left after harvest. In addition the value of the produce far outweighs the cost of applying fertiliser.

The temptation to overfertilise is therefore high, leading to greater risks of nitrate pollution. Increasing health and environmental concerns about high nitrate levels in produce and drinking water from such intensive land use now demands effective systems for fertiliser recommendation

Systems based on one rate of fertiliser for all crops may be provide satisfactory yields for crops (Neeteson *et al.*, 1987), but may give rise to nitrate leaching and could increase the risk of variable quality produce. An improvement is to use simple tables such as provided by MAFF (2000) for UK use, with previous cropping history being taken account of as a nitrogen index. However in high residue situations where large quantities of manure have been applied (Shepherd, 1993), or in intensive Brassica rotations (Rahn *et al.* ,1993) timely measurements of soil mineral nitrogen allow more balanced fertiliser predictions to be made.

Neeteson and Carlton (2001) reviewed the multiple pathways by which nitrogen applied to field vegetable crops could pollute the environment. It is possible that excessive amounts of nitrate in produce can also be harmful to health (Boink and Speijers, 1999) but there is still much debate (L'Hirondel and L'Hirondel, 2002). As a result of these perceived problems a myriad of EU directives and regulations have come into existence to regulate the use of fertilisers..

The application of fertiliser should no longer be made on an 'ad hoc' basis, but demonstrate benefits with minimal impact on the environment or safety of the harvested product. Supermarkets increasingly demand that produce sold has been grown in accordance with environmentally sound practices. Models, incorporated in decision support systems, provide a vehicle to transfer better practice to the industry.

Decision support systems for fertiliser application such as the 'KNS' system (Lorenz *et al.*, 1989) provide a comprehensive system of fertiliser advice but does rely on the ability to make more than one measurement of soil mineral N in order to take account the release of nitrogen from crop residues, and the loss of nitrogen due to leaching. The 'KNS' system also assumes that irrigation will support the availability of late applications of nitrogen fertiliser. Another system is provided by computer 'expert' systems such as 'N Expert' which makes more allowance for the release of nitrogen from crop residues and soil organic matter (Fink and Scharpf 1993).

Over the years a variety of decision support systems, N Expert (Fink M, and Scharpf HC. and WELL_N (Rahn et al 1996) have been available to support fertiliser advice for field vegetable production in Germany and the UK respectively. WELL_N was based on routines in the N_ABLE model (Greenwood, 2001).

The N_ABLE model, however, only operates with single season crops and Rahn et al 1992, 1998 have demonstrated that crops can be more effectively fertilised if N fertiliser is managed over whole crop rotations.

Achievements

A flexible model-based nitrogen management and rotation planning system suitable for use throughout Europe was developed.
The new decision support system, EU-Rotate_N has adopted a totally new approach by:

- basing nitrogen recommendations on nitrogen cycling over the whole rotation in order to optimise nitrogen use
- spanning a wider range of vegetable crops, including those grown in the field in Southern Europe such as aubergine, tomato, peppers and artichoke
- considering alternative methods of N fertiliser application and other cultural practices, including irrigation.
- encompassing additional climatic regions, including hot/dry conditions in Mediterranean counties and cold/wet conditions in northern European countries where soils freeze to depth in winter.
- allowing the planning of crop rotations with sequencing of crops with deep root systems tthat mine nitrogen from the soil that might otherwise be lost by leaching.

To test its potential as a tool for developing improved agricultural practice, the new decision support system has been used to run using a series of scenarios for selectied cropping systems in different parts of Europe. This demonstration showed how the benefits of existing environmental protection measures can be quantified and help users to identify other robust methods for increasing N use efficiency, taking account of local variations in soil and weather.

This model decision support system is the first system to allow users to 'Think globally and act locally' - allowing testing of strategies for Good Agricultural Practice at Europe wide and local farm level.

2. MATERIALS AND METHODS

2.1 Model Development

There were six main areas of work that were carried out to extend and update the functionality of the existing N_ABLE model. The most important was to extend its use to simulate rotations rather than single crops.

2.1.1 The simulation of water movement

The present N_Able model was developed for temperate non-irrigated conditions. However, in the drier and hotter environments of Southern Europe, irrigation is a common practice together with ridging for furrow or drip irrigated crops. To include these conditions in the model, it has been necessary to distinguish between irrigation systems and where appropriate to divide the soil into wetted and un-wetted zones. A model to mimic the lateral water movement from the zones of higher water potential (not frozen or wet) to those of lower one (frozen or dry) has been introduced. These sub-models are parameterised using locally available experimental data and the scientific press. The performance of the new sub-models has been assessed by comparison with independent data and with outputs of more complex models. This allowed us to simulate the influence of spatial variability of water distribution in the soil on the dynamics of soil mineral N.

2.1.2 The simulation of N cycling in soils.

The existing sub-model dealing with Net N mineralisation from soil organic matter is not suited to extrapolation across climates and soil types. A new sub-model has been developed based on long-term trials in different soil types and climatic regions across Europe. It uses data for a wide ranges of soil properties (e.g. clay content 3 – 35 %, soil organic matter 0.3 – 3.8 % -measured as carbon content), climate conditions and management systems (no fertilizer, mineral fertilizer, different manuring). The new sub-model is based on the assumption that soil organic matter can be divided into two main pools: the stable pool, biologically inert due to its interaction with fine-grained soil particles; the pool representing degradable organic matter, the decay of which is determined by soil conditions (temperature, moisture, aeration) by means of another model. This model calculates “effective mineralisation time” depending on soil and climate conditions and it has already been widely parameterised with data from several countries. The new sub-model was based on the assumption that soil organic matter can be divided into three main pools. The first pool is biologically inert due to its interaction with fine-grained soil particles. The second and the third pool represent degradable organic matter, the decay of which will be determined by soil conditions (temperature, moisture, aeration). The second and the third pool are characterised by different decay rates, which represent different chemical properties of organic material located in these pools. The representation of the N-mineralisation process in the model has been in this way extended to both cold and hot temperature environments. This approach is particularly suited to the aims of this project, as the sub-model will only require input data that are easily obtained by farmers. A key stage in this process has been the validation with experimental data provided by all the participants.

Organic manures

A sub-model has been developed to quantify the relevant processes of N dynamics related to the use of organic nitrogen sources. Such processes include infiltration during application, ammonia volatilization, denitrification, leaching of organic nitrogen, mineralisation and leaching potential of inorganic nitrogen after incorporation. This sub-model is based on a theory describing the short-term effect of slurry and farmyard manure application on nitrogen losses and nitrogen availability to the plant. It also describes the long-term influence of manures on organic N content of the soil and thus on N mineralisation. Ammonia volatilization has been specifically addressed by using a recent model to evaluate the effect of different management strategies for manure spreading and incorporation.

2.1.3 Simulating the effects of snow and frost.

The existing model was developed for temperate conditions with few prolonged periods of sub-zero temperature. Such conditions do not prevail in most parts of Northern and Central Europe. In addition, water movement in soil is at present described as a simple downward and upward displacement process. In the new model algorithms have been developed to account for the effects of soil freezing on soil water flows in winter, and the effects of water storage in snow cover and its subsequent fate on thawing and for nitrate dynamics. This research takes account of existing mechanistic models, which describe such processes and have been extensively used in Scandinavia and Northern Europe. Such models are too complex to be used directly by growers and policy makers, because they use a large number of parameters and require input data not easily available. However, the principles involved have been translated into equations to be incorporated into the N response model.

2.1.4 Simulation of root growth.

To describe root growth, the N-Able model uses simple relationships based on limited experimental data. It has been necessary to incorporate new quantitative descriptions from recently published work on root growth, especially the spatial spread of the root systems to deeper soil layers and from the crop rows to the inter-row. A refined and updated description of the complex interactions between crop N concentration, root growth, soil N availability and N uptake has been incorporated in the model. This has been partially based on results from experiments on the interaction between root growth and residues of available N left unused in the soil and from experiments on the basic relationships between roots and soil N depletion. Important data for the parameterisation of the model has been provided in detailed studies investigating the N uptake by vegetable crops in relation to spatial patterns of root growth at various soil depths. Tests have been made to ensure that the root growth model can also be applied to dry conditions and to situations where crops are grown under drip irrigation.

2.1.5 The range of crops simulated by the model.

Cash crops

Simulation of crop response to N supply requires a number of crop-related parameters. The model requires input data that are available in existing literature or that which can be gathered from simple field experiments. These parameters include: plant critical N concentration, N recovery, N-uptake rates, potential dry mass production and shoot to root allometric ratios. The values for these parameters have been gathered from international, local and grey literature, in order to extend the use of the model to a greater variety of crops growing in a wide range of climatic conditions across Europe. When not available from existing data, specifically targeted observational and experimental work has been conducted to obtain these values. This has been limited to measurements of weather, soil and crop parameters at representative field trials sited on commercial farms. Soil and plant sampling has been made at key-stages in the crop life cycle to produce the necessary information on the effect of different levels of N-supply on N uptake and on the yield and quality of produce.

Fertility building crops

A desk study has been conducted to collect information on the accumulation and release of nitrogen in grass-clover leys and on the fate of N from ploughed out grassland. Research carried out locally has also been re-examined to identify the main factors affecting the release of N. When necessary, some limited sampling of existing fertility building crops has been undertaken on farm sites in all participant countries.

2.1.6 Economic modelling

The main objective of the economic modelling was to quantitatively assess the effect of varying levels of N supply on marketable yield and farm economics for vegetable crops in all participant countries, in both conventional and organic systems. The existing model is driven by changes in total dry-matter yield. Therefore, the link between total dry-matter yield and marketable yield for differing levels of N supply needed to be determined. This information is required to simulate the marketable yield, which is then used as an input into the gross margin calculation of this crop.

The method used was a collection of empirical, field-experiment data on the effects of varying N supply on marketable yields. The data were collected from all participant countries using previous experiments, published and un-published literature. The results of this data collection are stored as parameters in the EU-Rotate model's croptable and documented in the "Report detailing the effects of varying levels of N supply on crops yields, crop quality and farm gate value" (DL15).
For these parameters, two different sets of algorithms were written to calculate response curves between marketable yield and N supply. The link between N supply and the proportion of total dry-matter versus marketable yield was determined for each major vegetable crop in each participating country using either the 'direct conversion' or the 'single plant' approach (for details see model description 3.1.10). The 'direct conversion' approach is the default used by the model. The 'single plant' approach is used when the marketable product is a single part of a plant, e.g. a cabbage head - but not Brussels sprouts (among those 'single plant' crops are cabbages, cauliflower, carrot, parsnip, leek, onion, head-lettuces, melons…).

With the marketable yield modelled, the calculation of crop gross margin (GM) requires information on crop prices and various variable costs for different market channels, production systems and countries. Those were collected from published and un-published data as well as from personal inquires on farms. For the model inputs only two types of variable cost were considered: variable costs independent of marketable yield per ha (seed and transplants costs, fertiliser costs excluding N fertiliser, fleece, irrigation, crop protection, weed control.) and variable costs depending on the marketable yield. They are recorded per tonne marketed and multiplied by the marketable yield (packaging and drying, transport, harvest casual labour and market commission…). The variable costs of inorganic and organic fertilisers were calculated using the physical data generated by the model. The final model output 'rotational gross margin' (rGM), is calculated as the cumulative gross margin of all crops in the rotation (including the negative gross margins of any cover crops) divided by the number of years simulated. rGM is used as proxy for farm economics.

2.2 Model Integration

The process of model integration was carried out initially by developing a Java framework into which the fortran sub-routines could be wrapped in C . A database system was selected which would potentially allow the interchange of different modules and automatically allow the development of a graphical user interface (GUI) for users to input data. This process was followed for a three year period but it was not without problems. Whilst the sub routines were being developed to accommodate irrigation practices and better simulation of rooting the soils layers needed to be split into more discrete elements than was originally envisaged which required several changes in the design of the model framework. Whilst progress was made on the development of the framework it was to slow to allow the release of the model in time for the testing of the case study scenarios. With the assistance of Tessella a sub-contractor an integrated version of the model was released which contained the TRIGGERS that would allow the comparison of management systems on nitrogen losses and economic productivity of a series of case study rotations.

2.3 Validation Experiments.

Experiments were carried out at a number of locations across Europe to provide data to validate the completed model. Brief details are presented below. Fuller details are presented in the Annex for the 24 and 36 month periodic reports.

2.3.1 England

The purpose of these trials was to provide data to validate the model under organic conditions, specifically to test the simulations of fertility building crops and organic manures.

Work was conducted at a site known as Hunts Mill, one of the fields belonging to HRI Wellesbourne in the English Midlands. The soil is a sandy loam with low organic matter content. Conversion to organic management techniques (using stockless vegetable and arable rotations) began in 1995 and the site has been the focus of a series UK Ministry of Agriculture (MAFF, later DEFRA) projects. Legumes are the principal way of adding nitrogen to the system. Green waste compost is applied but it is mainly intended as a source of P and K since the nitrogen it contains is in a very unavailable form.

The replicated trials conducted as part of EU-Rotate_N were laid out in two areas on which differing fertility building strategies had previously been imposed:

Area 1 *(a rotation with a high proportion of time devoted to fertility building)*
2000, spring barley (undersown); 2001, grass clover ley; 2002, grass clover ley.

Area 6 *(a rotation with shorter fertility building crops)*

2000, potatoes; 2001, carrots; 2002, spring barley (undersown with overwintered white clover).

The choice of crops was complicated by limits imposed by organic regulations and practical considerations so that cultivations could be timed to fit in with the rest of the site. It was obviously impossible to impose a range of nitrogen availability (such as could be done with fertiliser applications) but the effects of FYM were tested in accordance with the UK *Code of Good Agricultural Practice (Reference)* .

Potatoes were grown across the whole of the trials in 2003 (with or without farm yard manure applications) and followed by one of five different vegetables in 2004 (carrots, beetroot, French beans, calabrese or leeks). In 2005 spring barley was grown as a final crop.

Crop yields were measured by harvest of sub plots. Occasional measurements of crop growth during the growing season were also made. The soil was periodically measured for mineral nitrogen to a depth of 60cm (stones and the hardness of the soil made sampling to any greater depth almost impossible).

2.3.2 Spain

During the first half of 2005 some field experiments were performed to obtain experimental data on crop response to N (from soil and fertiliser) and on nitrate leaching, to be used for model testing.

Experiments were conducted on three plots belonging to cooperating farmers in an important vegetable growing area North of Valencia.

In two plots romanesco was planted as the last crop of a rotation that had previously included lettuce and onion. One plot (A) was irrigated using the traditional furrow irrigation method, whereas the other plot (B) had drip irrigation. In another plot (C), an artichoke crop experiment was grown over a two year growth cycle. Nitrogen was applied at different available N levels (Mineral N and Fertiliser N).

Soil mineral N and crop uptake were measured on a regular basis during the growing season.

2.3.3 Norway

The purpose of the trials has been to provide data on aspects of vegetable crop responses to N and N turnover in the field, which may be used for model testing at a later stage of the project.

Two identical trials have been run, one on a loam soil (Kise) in inland eastern Norway and one on coarse sand (Landvik) in coastal southern Norway. The conditions were wetter and somewhat milder in both years at the coastal site Landvik than at the inland site Kise. Four vegetable crops were grown in 2003, each with three levels of N fertilizer input, and two contrasting vegetable crops were grown on the same plots in 2004.

Trials in 2003: Four crops with different N requirements and rooting depth were grown, each with three randomised replicates (carrot, onion, broccoli and lettuce). The latter two crops were double-cropped, with alternative sequences (lettuce before broccoli and broccoli before lettuce). Carrots and broccoli are assumed to be deep-rooting crops, whilst onions and lettuce have shallow roots.

Three levels of N fertilizer were compared, applied as randomised spilt-plot treatments within each replicate block, thus giving 36 plots per trial:

- High N: The level used by many growers, somewhat in excess of recommendations
- Low N: 33% lower than the above, probably slightly below the optimum level
- Zero N: No fertilizer N

In 2004 two crops were grown (white cabbage, deep-rooted, and onions, shallow-rooted). The crops were grown in 9 m bands across the replicates blocks from the previous year, and with three levels of fertilizer N (high, low and zero N). The fertilizer plots were arranged as spilt-plots at right-angles to the plots used in 2003. This made it possible to assess residual effects of the previous year's fertilizer. Each trial thus had in all 216 plots in 2004.

Plant FW DM and N concentration were measured regularly. Total and Saleable yield, product quality and N content of saleable produce and residues was made at each harvest. N-min was measured in the spring at harvest and late autumn. The final soil sampling was performed in the spring of 2005.

2.3.4 Germany

A major two-year monitoring program was carried by BOLAP establishing a working relationship with 14 vegetable growers in the Palatinate region (South-West Germany), which allowed the monitoring of 19 different crop rotations. IGZ itself also performed own investigations on crop rotations, focusing on the effect of cereal crops in vegetable rotations.

The Palatinate region in South-West Germany covers the area from the banks of the Rhine in the East to the rising mountains of the Palatinate Forest in the West. The Palatinate is one of the economically most important and at the same time one of the most diverse field vegetable production areas in Germany. Fourteen vegetable fields have been monitored from April 2003 until the end of 2004 taking soil samples on a fortnightly basis where possible to determine mineral N content. In 2004, the selected sites were sampled with less intensity. The main reason for this was the cultivation of mainly non-vegetable crops as cereals, maize, sugar beets and fertility building crops. On four sites early potatoes were grown, while the fields of farm 1 and 6 were fallow. Only on five sites vegetables have been cultivated. Several sets of vegetables have only been realised on farm 2. The high proportion of non-vegetable crops lead to a less critical mineral N status in the soil. This was also due to an advantageous rainfall distribution during the vegetation period.

2.3.5 Denmark

The main purpose of the trials at DIAS in Denmark was to obtain a dataset specifically suited for testing the ability of the EU-Rotate_N model to simulate 1) pre-crop effects and 2) vegetable root growth and 3) the significance of root growth for the ability of different vegetable crops to utilize pre-crop N effects.

In the first year (2003), cauliflower was grown at two different planting times, and at five different N levels. Higher N fertilization naturally leads to larger N residues left in the soil. With early harvest the N residues are likely to be leached deep into the soil or totally lost before the next growing season, whereas with a later harvest, more of the N residues likely to be retained in the soil and to be found closer to the soil surface. Thus in this way we tried to create a set of very different pre-crop effects of cauliflower. The effect of the different N rates on cauliflower yield, quality, dry matter production, N uptake, root growth and N residues left in the soil were measured. Root growth was studied with the minirhizotron method, allowing repeated measurements of root development of the crop. The amount of N residues left in the soil was studied by analysis of inorganic N in soil samples. The minirhizotron studies and the soil samples were both performed down to a soil depth of 250 cm. In the second year (2004), N carry over from the cauliflowers were again studied by soil sampling in the spring. Thereafter, lettuce, sweet corn and white cabbage were planted to study the utilization of the N left over from the cauliflower. These three crops were expected to have very different rooting depths. They were all grown at either 0 N fertilization or optimal N fertilization, and their root growth, N uptake, and soil N depletion studied in the same way as with the cauliflower in 2003. Soil sampling was repeated in selected plots in the very late autumn of 2004, and in early spring 2005 to study also pre-crop effects of the crops grown in 2004 and possible second year effects from the cauliflower grown in 2003.

2.3.6 Italy

An experiment has been conducted with four two-yearly rotations of four vegetable crops, each grown at three nitrogen levels and two times per year (spring-summer vs autumn-winter seasons) until completion of four cropping cycles. The crops included broccoli, cabbage, spinach, lettuce and fennel. Broccoli did not prove sufficiently suitable for the experiment in the first crop series and was thereafter substituted with cabbage, which was used from the second to the fourth series. The rotations were planned to provide combinations of alternating rooting depths and nitrogen requirements and different crop-season combinations.. The nitrogen fertilizer levels were: zero, average farmer's best, and 130% farmer's best.

A split-plot field layout was used, with the rotations in main plots and the N rates in subplots, with two replicates in adjacent blocks. For practical reason, given the limited time span of rotations, N fertilization treatments were repeated on the same subplots for each crop series, though this fact could widen somewhat with time the range of N available to crops. Observations included overground crop biomass, N concentration and marketable yield, soil mineral N and water content, root depth and meteoclimatic variables. The experiment started in November 2003 and was completed by July 2005.

2.4 Model Validation

The first version of the fortran model was released to participants at the end of 2005. In the early stages of validation checks were made on the rigour of the programming and errors often needed to be rectified. The process of finding one error often led to others being unearthed. All the initial validation was completed by April 2006. An agenda was set for modifications that needed to be made to the model before its release to carry out the testing of the case studies.

Validation in the early stages basically checked that the model operated and closeness of fit was largely assessed by graphing modelled and observed data. As the process of validation advanced and the performance of the model improved some participants of the project carried out a more formal analysis of the simulation quality..

2.4.1 Example of statistical tests used to evaluate the performance of the model in Germany

Goodness of fit criteria

A number of criteria were chosen to evaluate statistically how well the model predictions fit the observed values. The following denotations apply:

n = number of experiments
P_i = predicted values
O_i = observed values
$\bar{O}$ = observed mean

Mean bias error

The mean bias error (MBE, Addiscott and Whitmore, 1987) gives information on any systematic over- or under-prediction of the model. Since it is based on the simple difference between observed and predicted values, the index can be expressed in the unit of the investigated values.

$$MBE = \sum_{i=1}^{n} \frac{(P_i - O_i)}{n} \quad (1)$$

Mean absolute error

The mean absolute error (MAE) is here given in contrast to the root mean square error (RMSE). Due to its quadratic nature RSME is very sensitive to outliers and furthermore dependent on $n^{0.5}$. In contrast, MAE averages the absolute, unaltered values and is thus more robust against unequally distributed error populations (Willmott and Matsuura, 2005).

$$MAE = \sum_{i=1}^{n} \frac{|P_i - O_i|}{n} \qquad (2)$$

Modeling efficiency

The calculation of the modeling efficiency (EF) follows Nash and Sutcliffe (1970) as

$$EF = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2} \qquad (3).$$

It is defined as the fraction of the variance of the observed values that can be explained by the model. Negative values indicate that the model predicts the observed value less precisely than the mean of the observed values. Nevertheless, in this case the model estimate can still contain more valuable information than the mean of the observed values.

Index of agreement

The Index of Agreement (IoA) was introduced by Willmott (1981). The dimensionless index varies between 0 (no agreement) and 1 (perfect agreement) and can be understood as the mean squared error, standardized by the variability of predicted and observed values about the observed mean.

$$IoA = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} \left(|P_i - \overline{O}| + |O_i - \overline{O}| \right)^2} \qquad (4)$$

2.5 Development of the scenario runs

The model allows the testing of the effects of many management strategies on the productivity and losses of nitrogen over crop rotations without the need for costly and time consuming field experiments. In a short period of time a complete crop rotation of several years duration can be investigated to identify overall losses of nitrogen, ‘leaky’ points, and overall economic productivity as expressed by the rotational gross margin. The user can assess both the environmental and economic benefits of different crop rotations and the most beneficial management strategies can be identified.

2.5.1 Scaling

The EU-Rotate_N model is designed to simulate a specific rotation on the field scale, so evaluations on larger scales have to be scaled up. This can be achieved by running every single vegetable field that makes up the respective target area and aggregating the results. Unfortunately the data required to do this is not always available. What is more likely to be available in many countries is average data on annual vegetable production by area and crops on a regional and national level and local expertise on the type of farms and typical crop rotations.

Scaling up from field level to regional or even national levels could be done using this approach and local production statistics. Given good local expertise and data a reasonable description of European field vegetable production can be assured.

This approach needed the construction of “model farms”. These model farms are virtual farms, containing up to three fields with different crop rotations. They form the key unit to bridge the gap between the data requirements of the simulation model and the aim of the project. A representation of a region can be constructed from several model farms, each of which represents a typical type of farm that can be found in the region. These model farms will form a best possible representative to a group of similar farms. In the simulation model, the number of farms in a region can be reduced from several hundred to less than ten.

Only the most important regions within an individual country will be described with the help of these model farms. This means, not only the most productive regions but also regions that produce niche products important for the local market. Based on statistical data for these regions a key was being developed that ensured the best possible scaling of results from single crop rotation simulations to the respective national level. An example of the results of this scaling up are shown for Baden Wurttemberg in Germany see 3.4.4.

2.5.2 Management strategies

A whole range of management strategies has been tested by the participants of the project. As a common approach, the first strategy for each country is always a comparison between two management strategies: Good Agricultural Practice (GAP) and Traditional or Typical Farmer’s Practice (TFP). GAP is defined in most European countries by law or other binding regulations, but differences do occur. In some countries GAP is not applied at a national level, but contains regional deviations. The GAP regulations commonly include rules for timing and amount of fertiliser applications as well as regulations for the management of soil and plant residues Approaches can be different from country to country: e.g. Denmark includes a sophisticated system which uses a farm nutrient balance to govern the use of fertilisers; Germany has included obligatory soil mineral N measurement in springtime to calculate fertiliser demand. GAP in Spain, which is implemented on a regional level, considers N in the irrigation water for calculation of fertiliser applications. GAP can also include more extensive regulations, which consider soil compaction, biological diversity, soil erosion protection and soil organic matter preservation, but these items are not considered in the model. TFP describes a management strategy that is based on the economic success of the crop. Environmental aspects do not play an important role, only if the gross margin is not affected. The comparison of these two management strategies has given detailed information the effectiveness of GAP implementation in different countries and on what potential there is to reduce N losses from agricultural systems. It gives, furthermore, an idea of the economic consequences of GAP implementation for the farmers.

Other management strategies have been included by individual participants to test the effects of particular factors important locally. They can involve special crop rotations, which may include varying percentages of catch crops, or for different environmental factors, which may become relevant, when local decisions affect the structure of field vegetable production in a region. Tools that have been discussed on national level for future improvement of GAP regulations can be tested in this framework and also the effect of changing general production approaches (conventional ↔ organic) can be investigated.

2.5.3 Assessment of the results

Discussions were held to decide on the most appropriate way of interpreting the output from the EU-Rotate_N model. The first step was to decide on the output data needed for this assessment. Key outputs included:-

- inputs of N from the air, inorganic and organic fertilisers
- outputs of N removed from the field as marketable crop.
- nitrogen losses to the air and to water.
- N mineralised from soil organic matter and cycling from recently incorporated crop residues.
- overall N balance
- marketable yield
- economic output

Macros within Microsoft Excel were developed which could read the data output from the model and provide a consistent output. The results of the simulations from the EU-Rotate_N model were then evaluated by local experts. The conclusions of these assessments led to the production of a final report and two shorter reports highlighting the main conclusions at farm and policy level.

3 RESULTS

3.1 The Integrated Model - description of the model sub-routines.

Where the model sub-routines are based on existing models or existing published algorithms these are referenced to the original source. Where new sub routines have been added which are based on new science such as the root routines these are described in more detail.

3.1.1 Model structure and timestep

The model consists of a number of subroutines to simulate the growth both below and above ground, nitrogen mineralisation from the soil and crop residues, subsequent N uptake and balance between supply and demand to regulate growth. These will all be regulated by weather factors such as rainfall, temperature and radiation. Routines simulate the flow of water and nitrogen into the plant, subsequent evaportranspiration or leaching.

The sub-routines operate daily in the following order, utilising data from soil properties, residues, fertiliser and weather data where appropriate.

1. The soil N mineralization: calculates soil N mineralization in the top 30cm soil depth from soil organic matter, crops residues and organic and includes the inputs from inorganic N fertilisers;

2. The potential maximum increment in shoot dry weight: calculated on the assumption of no restriction from N-deficiency and water stress;

3. The potential maximum N-uptake: calculated from the product of potential maximum dry weight and the critical %N for a crop of that size;

4. The root distribution: calculates the rooting depth and width, and root length distribution in the root zone;

5. The actual N uptake: calculates the amount of N that the roots can take from the root zone;

6. The actual %N in the plant: calculated from the N uptake, the amount of N in the plant on the previous day, and the dry weight of the plant calculated for the previous day;

7. The snow dynamics and frost depth: calculates the snow depth, depths of frost and of any thawed layer above the frost layer, actual infiltration water for winter climate;

8. The surface runoff: calculates the surface runoff caused by heavy rain;

9. The potential transpiration and evaporation rate: calculated from the reference transpiration and a crop coefficient varying with crop development.

10. The water drainage and redistribution: calculates soil water distribution in the entire soil domain from infiltration and soil properties;

11. The water removal: calculates the amounts of water that the roots can extract from the root zone and via evaporation;

12. The actual shoot dry weight increment: calculated from its current dry weight, the calculated %N and reduction in transpiration.

13. At harvest the amount of marketable crop and its gross margin is calculated using the Economics module.

Modules 1-12 are daily routines. Whether modules 7 & 8 are called is dependent on the information in the input file. During growth modules 1-12 are called on a daily basis, while modules 1, 7-11 are called when the model simulates fallow crops. At harvest module 13 is also called.

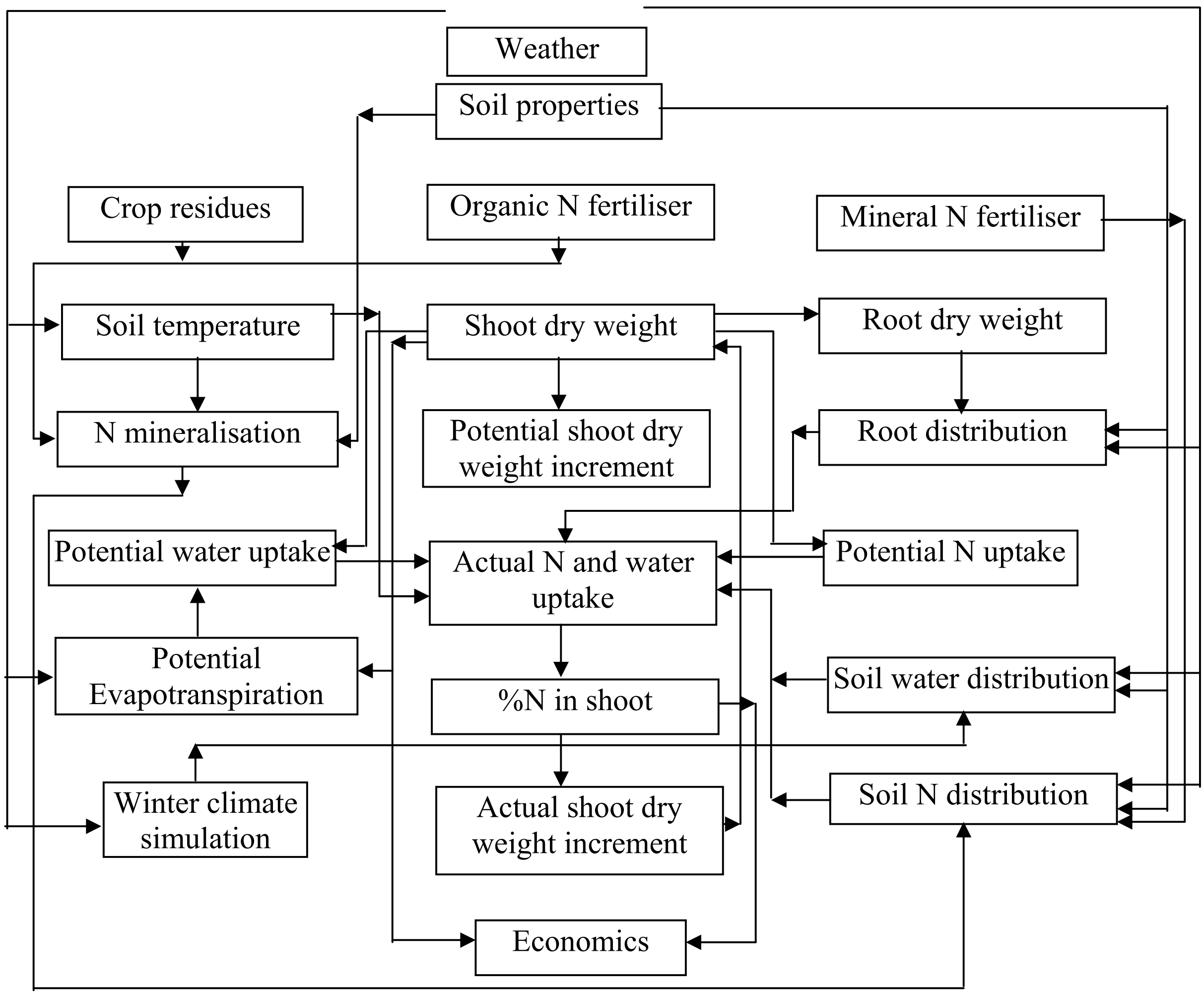


Figure 3.1 – showing the organisation of the main model sub_modules

3.1.2 Description of the soil

In the model the soil is divided into 40 5 cm thick vertical layers. After planting these layers are split horizontally into 5cm wide cells. The number of horizontal cells depends on row width. As soon as the crop is harvested OR when the residues are incorporated the horizontal elements are merged into one unit until the next crop is planted. The description of the soil in this way allows for more accurate simulation of root growth than was possible in the original N_ABLE model. While the crop is growing all the processes described below are all simulated at the cell level.

The properties of the soil layers are provided by the user of the model and include the water content at permanent wilting point, field capacity and at the saturated level. These control water availability to the plant and allow calculation of drainage. Mineralisation and losses of nitrogen by denitrification is adjusted for water content. Other inputs include pH which allows for the simulation of N losses where urea fertilisers are used. The amount of organic matter levels affects the supply of N from mineralisation. Clay and sand contents are used to calculate urea solution and hydrolysis, ammonia volatilisation from top layer, decay rate coefficients, and denitrification.

3.1.3 The water module

The water module has different parts that calculates the following:

- Crop evapotranspiration (soil evaporation and transpiration)
- Effective water infiltration (applied water minus runoff)
- Drainage
- Water redistribution in soil

Crop evapotranspiration is calculated using basically the FAO approach (Allen et al., 1998). The main parameters that enter in these calculations are those related to the evaporative demand of the atmosphere, summarized by the reference evapotranspiration (ETo,) and a crop coefficient that varies with crop development.

The effects of water stress on plant growth are considered assuming that the reduction in dry matter accumulation due to water deficit is proportional to the transpiration reduction (Hanks, 1983; Shani and Dudley, 2001).

Water infiltration and redistribution in soil follows a capacitance approach, similar to the one in the N_ABLE model but that has been modified using a drainage coefficient that allows the water transfer between layers above field capacity to be done progressively (in more than one day) and more or less rapidly depending on soil type (Ritchie, 1998). Drainage at any depth is given as the water downward flow of the cell elements at this depth. The module also accounts for upward/downward capillary flow by adopting a soil water normalised diffusion approach (Rose, 1968 and Ritchie, 1998). The main parameters that define the hydraulic soil properties such as the water content at field capacity and wilting point, are input by the user for the different soil layers, although default values depending on soil texture are available.

Runoff is calculated using the approach by the U.S. National Resource Conservation Service (NRCS, formerly the Soil Conservation Service) based on studies of small (< 800 ha) agricultural watersheds across the United States.

3.1.4 Mineralisation Module

Nitrogen (N) release from soil organic matter and from different kinds of N containing materials added to the soil for fertilising is calculated in a module that hosts the following routines:

- N mineralisation from both soil bound and freshly added organic matter
- N volatilisation from added manures and slurries
- Hydrolysis of urea and volatilisation of NH_3

The concept of N mineralisation from organic matter is based on the routines used in the DAISY model (Hansen et al., 1990). Three pairs of conceptual pools (soil organic matter, soil microbial biomass added organic matter), each representing a rapidly decomposable and a slowly decomposable class of N containing organic substances, respectively, describe C dynamics in the soil. Decomposition rate coefficients are temperature and moisture dependent and reflect the environmental conditions of the simulated site. Decay and maintenance rates of soil microbial biomass are additionally influenced by soil clay content. Efficiency parameters determine the loss of CO_2 during the single turn-over processes. N release as NH_4^+ is a consequence of C lost as CO_2 from the system that maintains fixed C to N ratios in the different pools. Processes of nitrification and denitrification are implemented to complete the turn-over model.

Residues of crops simulated with the crop growth model enter the mineralisation routine with a dynamic C to N ratio, which reflects the growth conditions of the crop during season with respect to N supply. The variable C to N ratio is assigned to the rapidly decomposing part of the material, while the remaining part is considered to decompose slowly, having a fixed C to N ratio. Decomposition rate coefficients of both pools are also fixed (Abrahamsen, 2000). C to N ratios and partitioning coefficients for crop residues are derived from stepwise chemical digestion experiments (Jensen et al. 2005). Manure and slurry properties are taken from DAISY parameterisations (Abrahamsen, 2000).

N volatilisation from soil applied manures and slurries are described using an empirical relation implemented in the ALFAM model (Søgaard et al., 2002). A soil pH dependency factor was introduced by fitting data from He et al. (1999) to Michaelis-Menten kinetics and subsequently normalising the relation between pH and volatilisation half life time to pH 7.0.

Hydrolysis of and gaseous N loss from applied urea fertiliser is calculated based on routines of the AMOVOL model (Sadeghi et al., 1988), taking into account the temperature dependent equilibrium between ammonium ions, solved and gaseous ammonia as well as the effect of soil organic matter, soil temperature and soil water potential on the hydrolysis process itself. An atmospheric resistance parameter finally governs the loss of gaseous ammonia from the top soil.

3.1.5 Snow and Frost Module

Routines have been developed that allow the calculation of snow depth and density, water storage in snow and water melting from the snow pack, using daily input of air temperature.
The original snow model was developed at the University of Helsinki by Vehviläinen & Lohvansuu (1991) for calculating water equivalent, but modified by Tuomo Karvonen (see internet reference) to calculate snow depth, which is important for determining soil freezing and thawing. We have further modified this model and have calibrated it by iterative simulation using a 10-year dataset from Norway, as described by Riley and Bonesmo (2005). The approach has later been validated with independent data.

The chosen soil frost model is based on two approaches, one for freezing and one for thawing. The approach for soil freezing was proposed by Olsen and Haugen (1997), at the Norwegian University of Life Sciences, Ås, assuming uniform thermal properties throughout the profile. Values for the latter properties are taken from the Swedish SOIL model (Jansson, 1991). The model requires input of surface temperature as modified by the snow pack. The approach used for thawing is that in the ECOMAG model developed at the University of Oslo (Molitov et al., 1999). We have validated both freezing and thawing processes for Norwegian conditions.

The snow and frost calculation procedures, including all parameters used, are described in detail in a programming note (Riley, 2004a). This note also describes how these processes interact with water infiltration and associated processes such as leaching. In brief, it is assumed that infiltration ceases when soil freezes. During snowmelt and soil thaw, an amount of water equal to the difference between field capacity and total porosity is stored for later infiltration, whilst the remainder passes to surface runoff. An example of the interaction of frost with runoff appeared in an article in the second project newsletter (Riley, 1994b).

3.1.6 Root Module

The root model calculation consists of three main parts: 1) first the physical extension of the root system , 2) then the total root length of the crop , and 3) finally the distribution of the root system depending on depth and distance from the crop row.

The depth development of the root system is calculated from the accumulated temperature sum from crop planting. After a lag period (ddglag) the rooting depth increases linearly with temperature sum. The length of the lag period and the rate of rooting depth development are controlled with crop specific parameter values. A crop specific base temperature (Tmin) for calculation of root growth is also used, and Tmax is then set to Tmin+20 °C. This approach to simulation of crop rooting depth is based on a number of studies showing good linear relationships between accumulated temperature sum and rooting depth (Kristensen & Thorup-Kristensen, 2004; Thorup-Kristensen, 2001; Thorup-Kristensen, 2006; Thorup-Kristensen, 1998; Thorup-Kristensen & Van den Boogaard, 1998; Thorup-Kristensen & Van den Boogaard, 1999; Kage et al., 2000).

$$rz=zstart+((cumuT-ddglag)*Krz) \quad (1)$$

Horizontal root extension is calculated in the same way, but for each soil layer the calculation starts when the roots reach this layer rather than when the crop is planted. In this way horizontal root growth starts progressively later at larger depths.

$$rx=xstart+((cumuT-ddglag)*Krx) \quad (2)$$

Crop root length is then calculated as a function of 1) crop biomass, 2) crop growth stage, and 3) the parameter value of root class “Rtclss”. The root biomass is calculated as a function of aboveground crop biomass, a fraction which declines with crop size, but increases with Rtclss ($1<2<3$), to allow for crops with different root/shoot ratios. Total root length is then calculated from the simulated root biomass and a fixed specific root length which is used for all crops.

Root length is distributed spatially into a 2D array of soil units. Root models in crop/soil simulation models are mostly 1D; i.e. root density varies only with depth. However, most vegetable crops are grown as row crops, and the 2D approach was used to be able to simulate the effects of the row crop structure on crop rooting and uptake of water and nitrogen. Root distribution is calculated to a maximum depth of 2 m, and to a max width of half crop row distance. The soil units used in this array are 0.05 by 0.05 m.

The root length declines by a logarithmic function from the topsoil downwards, as originally proposed by Gerwitz and Page (1974), and from the crop row to the interrow soil. However, contrary to Gerwitz and Page (1974) we include a value for rooting depth, under which root density declines fast to zero. In the modified forms of the Gerwitz and Page equation used in other models, a rooting depth has also been included, but in these approaches the root density at maximum rooting depth has been constant, meaning that subsoil root density will always be low, and variation in root length will practically only be found in the topsoil. With our approach we allow higher root densities in the subsoil, but compared to the original equation from Gerwitz and Page (1974) our setup allows relatively high root density at the simulated rooting depth without leading to significant root density also in layers below that. In our approach the steepness of the logarithmic decline is controlled by one parameter for the vertical distribution (az) and another parameter for the horizontal distribution (ax).

rootlength(i,j)=(lz(i)*exp(-ax*x)) (3)

Ideally, the model should have been a 3D model, to simulate also the effect of plant distance within the crop row. At the early growth stages where root width is less that plant to plant distance within the row, an arbitrary function is used to reduce N uptake capacity accordingly.

3.1.7 N uptake

N uptake is calculated as a function of crop N demand on a specific day and the potential root N uptake on the same day. The simulated crop N demand is received from the crop growth part of the model. The potential supply from the soil is calculated as a function of the root length in each soil unit, the content of ammonium-N and nitrate-N in each soil unit and the value kN read from the Croptable, to control root N uptake efficiency. Diffusion terms are not included in the simulation, as with N uptake this is not assumed to be significant over the relevant time spans for the simulations. N in the form of nitrate is highly mobile in the soil, and diffusion processes will only limit uptake on the very short term even at low root density. Here the equation for potential ammonium-N uptake is shown; this calculation is made for each soil unit and summed for the whole soil volume. The value of k1 determines the minimum amount of ammonium-N which can be left in the soil:

Npotnh4=((rootlength*kN*(nnh4-k1))/ (k2+nnh4) (4)

A minimum level of N left in the soil is included for both ammonium-N and nitrate-N, as experimental data show, that even though crops with high N demand compared to the soil N supply may reduce soil N to very low levels, some soil N is always measured in the soil analyses, especially in the topsoil layers (e.g. Thorup-Kristensen, 2001, 2006). A function is then used to balance actual N uptake according to crop N demand and potential root N uptake. When crop N demand and potential root N uptake are close to each other, the simulated N uptake will be below either value, but at very high or low N supply relative to demand, the uptake will be fully controlled by crop N demand and potential root N supply respectively.

Nup=Ndemand*(1-exp(-1*(Npot/Ndemand))) (5)

Often, the calculated actual N uptake will be lower than the potential root N supply. When this is the case, the actual depletion of soil N will be reduced proportionally from the potential value in all soil units. Lastly, a specific calculation is made of N taken up from below 0.9 m in the soil. This is made as N leaching loss and other N balance figures are shown mainly from the 0-0.9 m soil layer in much of the model output, and it is therefore necessary also to have an output showing how much N is taken up from below this zone.

3.1.8 Crop growth and critical N

Each day the increment in plant dry matter is calculated from:

$$\Delta W = \frac{K_2 G_N G_T G_W W}{K_1 + W} \quad (6)$$

where W is the cumulative dry weight, K_2 is calculated as described below. K_1 = 1 t ha^{-1}. G_T is the effective day degree for the day divided by the average day degree throughout the entire growing period, where the effective day degree is the average temperature for the day less a base temperature, with the limitation that if the average temperature exceeds 20^0C then it is set equal to 20^0 C. G_N and G_W are the growth coefficients dependent on crop %N and water supply. K_2 is calculated from the integral of the above equation with G_N G_W and G_T set equal to 1. The equation is then

$$K_2 = \frac{K_1 \ln W_{\max} + W_{\max} - K_1 \ln W_P - W_P}{T_h - T_P} \quad (7)$$

where W_P is the dry weight at planting. T_h is the time of final harvest and T_p is the time of drilling or planting in days from Jan 1st.

We use a unified equation to define critical %N for different crops, i.e.

$$\%N_{Crit} = a(1 + be^{-0.26W}) \quad (8)$$

where $\%N_{crit}$ is the critical %N, and a and b are the coefficients, varying from crops (see the crop table of the model).

Luxury N consumption is permitted to take place. It is calculated as follows:

$$\%N_{\max} = R_{lux} \%N_{crit} \quad (9)$$

where $\%N_{max}$ is the maximum possible crop %N, and R_{lux} (≥1) is the coefficient for luxury N consumption (see the crop table).

For each day a growth coefficient G_N is calculated as:

$$G_N = \min(\frac{\%N}{\%N_{crit}}, 1.0) \qquad (10)$$

where %N is the actual %N in the dry matter of the whole plant (excluding fibrous roots)

Similarly, a growth coefficient G_W is calculated as:

$$G_W = \frac{TR_{act}}{TR} \qquad (11)$$

where TR and TR_{act} are the actual and potential transpiration rates.

3.1.9 Fertility Building Crops

As it is difficult to specify an appropriate target yield for a fertility building crop an alternative approach is used. The user specifies Good, Medium or Bad growth rather than a numerical value and the actual numbers for each crop are read from the crop table. The increment in plant dry matter on each day is calculated from:

$$\Delta W = \min(GG_N G_T W, \Delta W_{type}) \qquad (12)$$

where W is the cumulative dry weight, G and ΔW_{type} is set to one of thee possible values (good, medium, bad) to define the growth rate and the dry weight increment, G_N and G_T are the growth coefficients dependent on the crop %N and day degree. The calculation of the growth coefficient G_N is the same as that for a cash crop.

The growth coefficient G_T is calculated:

$$G_T = \begin{cases} 1.0 & if\ day\ degree > 10.0 \\ \dfrac{day\ degree - base\ temperature}{10.0 - base\ temperature} & base\ temperature \le day\ degree \le 10.0 \\ 0 & day\ degree < base\ temperature \end{cases}$$

(13)

Another crop parameter specifies the percentage of biomass which is retuned to the upper layer of the soil each day; it is then mineralised as a crop residue. This is particularly significant for longer term leys. The user can specify dates at which the crop is mown – on these occasions 50% of the biomass is added to the soil.

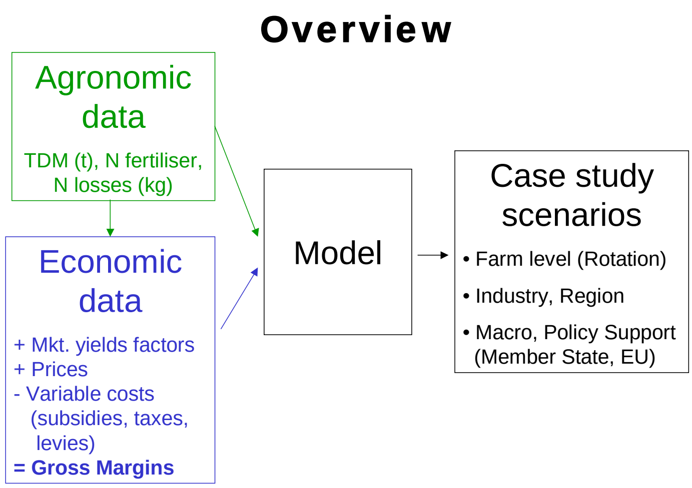
Most fertility building crops are legumes and nitrogen fixation is the main source of nitrogen in organic cropping systems. A crop parameter specifies N fixation or not (this also applies to cash crops). The growth of N fixing crops is not limited by nitrogen in the soil as any more that they need is taken from the air.

Annual crops are killed after an appropriate period if time (specified in the Crop Table) regardless of the 'harvest date' set by the user. Crops are also killed if the temperature drops below a specified value.

Modelling of the growth of undersown crops begins at the harvest of the overstory with an appropriate dry matter and nitrogen content as specified in the Crop Table; the user can choose between Good, Medium and Bad performance as an understory to give different starting conditions.

3.1.10 Economics Module

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. 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 was 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.



Simplified model overview and link to economic data

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 un-marketable if below or above the specifications. Considering these, two strategies were developed - one more empirical the other more theoretical.

(1) For the empirical conversion ”Direct 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 considering the effects of both sub- and supra-optimal supply of N. 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.

”Direct conversion” is a direct conversion of total dry matter (TDM) into marketable yield (MKTY) with one factor R, sourced from empirical data.

$$MKTY = TDM \; x \; R \, f(N_{av}) \qquad (14)$$

- With:
  - R the ratio of marketable yield to total dry matter for optimum nitrogen supply and spacing
  - Nav the available nitrogen (N)

The ratio R is individual for each crop and depends on the available N supply used for each crop. The formula for R is a linear or polynomial relationship of available nitrogen (Nav).

$$R = r_0 + r_1 \; x \; N_{av} + r_2 \; x \; N_{av}^2 + r_3 \; x \; N_{av}^2 + r_4 \; x \; N_{av}^2 \qquad (15)$$

The terms r0, r1 and r2 are empirically gained for individual crops. For a simple constant relationship: r1 = 0 and r2 = 0. For a linear relationship: r2 = 0. Otherwise, the relationship is non-linear. For some crops, more polynoms may be needed because of different behaviour in sub- and supra-optimum conditions and therefore r3, r4 …rx are added.

(2) 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.

$$\text{av. single plant fresh weight} = \text{TDM} \; x \; \text{HI} \; x \; \text{plant population}^{-1} \; x \; \%\text{dm}^{-1} \quad (16)$$

A normal distribution with a given coefficient of variation is used to simulate the %-gradeout, then the marketable yield in tonnes is calculated. For each crop, a default model choice (approach 1 or 2) is stored in the crop table, but the experienced user can change this.

Prices, variable costs and gross margin calculation

With the marketable yield modelled, the calculation of the crop gross margin (GM) uses the standard equation:

$$\text{GM} = \text{MKTY} \; x \; \text{Price} - \text{VC}_{\text{ind}} - \text{VC}_{\text{dep}} - \text{VC}_{\text{N fert}} \quad (17)$$

The variable costs independent (VC_{ind}) of marketable yield are recorded per hectare and consist of seed and transplants costs, fertiliser costs excluding N fertiliser, fleece, irrigation, crop protection, weed control. Variable costs depending (VC_{dep}) on the marketable yield are recorded per tonne marketed and multiplied by MKTY. They consist of packaging and drying, transport, harvest casual labour and market commission. The variable costs of inorganic and organic fertilisers ($VC_{N\ fert}$) are calculated using the physical data generated by the model. The triggered amount of fertiliser and number of applications are multiplied by the cost of fertiliser and the cost per application as specified in the input file. Subsidies are not considered in the gross margin calculation. Rotational gross margin is cumulative gross margin of all crops in the rotation (including the negative gross margin of cover crops) divided by the number of years simulated.

For the calculations, own figures or standardised figures stored in a separate economic data file can be used. In this database, the countries Norway, Denmark, Germany, UK, Italy and Spain are considered. 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.

3.2 Results of the trials and validation (Based on WP4 report)

All participant countries performed monitoring trials during the project period to provide suitable datasets against which to compare important features of the EU-rotate_N model. Results from these trials have been used in the appraisal of consecutive model versions since early 2005, and this report summarizes conclusions from evaluations of model versions 10 or later, performed since August 2006. A brief summary of each country's experience is given, followed by some comments on the fitness for purpose of the individual modules. Evaluation of the model's user interface is discussed elsewhere.

3.2.1 England

Simulations were made for nine organic rotations following both long-term (high fertility) and short-term (low fertility) grass/clover leys. In each case, four of the rotations included the use of manure (FYM). Potatoes were grown in all cases after the ley, followed by one of five different vegetable crops, and finally spring barley in all cases.

The main focus of these evaluations was to assess the model's effectiveness in simulating growth and N contribution of fertility-building crops. Although development of the model has been completed, much work remains to refine the parameters used, particularly those in the Crop and Residue tables.

<u>Simulations of fertility building crops</u>
For assessing dry matter accumulation the target yield concept used for cash crops was considered unsuitable for fertility crops. Instead, growth rates are specified in the input file ('Good', 'Medium' or 'Bad'), and the Crop table contains values for daily increase in biomass for each growth rate category. The effect of the growth rates is modified by a daily litter loss parameter, expressed as a percentage of biomass. Measurements in a short-term winter cover crop (grazing rye) suggest that the model underestimates the potential for winter growth, but this may be easily improved by changing the parameters. The general principles used give satisfactory results. Rye biomass after sowing at four different dates in the autumn was simulated logically, with later sowing giving less biomass and greater nitrate leaching. Long-term leys were also simulated reasonably well; as expected the starting conditions have a big effect on the first few months of growth but in subsequent years they are unimportant.

The model simulates clearly the gradual fall in plant biomass over winter periods and sudden drops as a result of mowing.
Crop death is simulated in various ways. Perennial crops continue growing until the specified harvest date is reached. Growth of frost sensitive crops is terminated when a specified minimum temperature is reached. Growth of annual crops is terminated after a

specified number of days. These functions all work as expected. Although they could be made more sophisticated this may not be necessary.

Nitrogen fixation is assumed to allow the relevant crops to obtain as much nitrogen as they need from the atmosphere to maintain their critical N concentration, whilst fertilizer applications reduce fixation, as do high levels of mineral N resulting form mineralization of crop residues. This approach works, but a number of improvements are possible. Crops that do not fix all of the N they need (e.g. leys with a low proportion of clover or when suboptimal rhizobia strains are present) could be simulated by setting the degree of N obtainable by fixation on a scale from 0 to 100%. An anomaly of the model is that it gives high fixation on the first day of growth and on the days of mowing. This does not reflect reality, but it may be unimportant for the cumulative total. The fixation by a long-term crop is closely linked to the rate of mineralization of litter and mowing residues, for which problems with modeling were found. This resulted in excessively high levels of fixation.

Nitrogen concentration in plant DM is governed by two parameters (PNIF and B0) used to calculate the critical N concentration. The model assumes actual N to equal critical N in nitrogen fixing crops, so that these crops will never (in the model) be short of nitrogen. This did not seem to be appropriate for long-term fertility building crops which have fluctuating biomass over several years. For these crops B0 was set to 0; this meant that critical (and actual) N were constant for the whole period of growth and equivalent to whichever PNIF value was used.

Mineralization of fertility building crops was not simulated satisfactorily for long-term crops because the litter loss biomass did not decompose and built up instead in the AOM soil pools. This resulted in a shortage of mineral N for the crop and thus huge amount of fixation. Even after incorporation, negligible mineralization of the ley could be seen, and the extra amount of N fixed was in no way reflected, as it should be, in the performance of the following cash crops.

The effects of changing some parameter values on simulated mineralization of fertility crops focused on the proportion of plant residues entering the slow and fast decomposing pools.

<u>Simulation of organic cash crops</u>

Simulation of dry matter growth and marketable yield for potatoes and vegetables were performed. Using a 13t/ha dry matter target for potatoes, production was greatly over estimated (by 60% when using MEDIUM ley growth). Reducing the target dry matter yield to 9t/ha improved the overall accuracy of the simulations (to on average 114% of measured values). However, this gave poorer simulation of the relative differences between the four potato crops. The pattern of simulated marketable yields closely followed that of total dry matter.

Simulated DM yields of the five different vegetables grown as the second cash crop were always too high, particularly in the case of the crops following the short ley. This was in some cases be explained by external factors such as the incidence of disease. The simulated effects of ley length were smaller than those seen in practice. Soil analyses showed no differences in organic matter or nutrients between the leys, but long leys may well have brought subtle physical, chemical or biological changes that improved crop yields in ways that are not considered by the model.

Yields of the third cash crop, spring barley, were in all cases over-estimated, especially those in the short ley rotation. Reducing target yields improved the simulation after the long ley but in the short ley rotation yields were still over-estimated by on average 75%. Patterns of soil mineral N (both measured and simulated) were very similar for all five vegetable crops. MEDIUM ley simulations gave a good match between simulated and measured values, with lower levels of mineral N after the short ley than after the long ley. An underestimation was seen two months after incorporation of the ley and also at other times in the treatments without FYM application. Whilst the simulations showed a clear difference in soil mineral N between long and short leys, comparable to measured values, it is unclear why these were not reflected in the yields of the cash crops.

Soil Mineral nitrogen

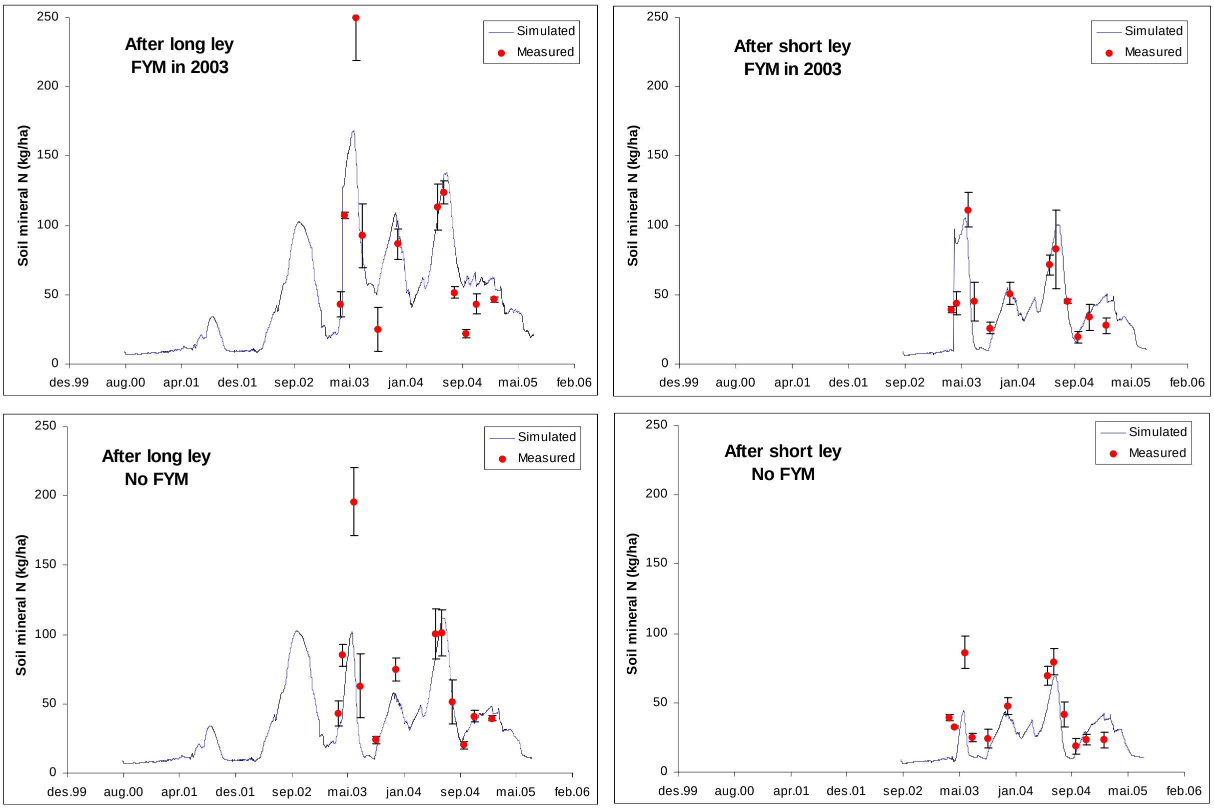


Figure 3.3. *Comparisons of simulated (lines) and measured (dots) soil mineral N (0-60 cm) in organic crop rotations monitored in England (potatoes in 2003, carrots in 2004 and spring barley in 2005) after a long ley (left) and a short ley (right), with (above) and without (below) the*

use of farmyard manure (FYM) in 2003. Error bars are +/- standard deviation. Simulated values agree well with measured valued in most cases, confirming the ability of the model to predict the release of nitrogen from both ley residues and farmyard manure

Conclusion

The new routines introduced to the model to deal with fertility building crops are broadly satisfactory. More work is needed to justify the parameters of some of the crops.

3.2.2 Spain

IVIA has tested the several model versions available during the year to validate the main model routines, with a special emphasis on the performance of the water module. Datasets coming from the field experiments, including furrow and drip irrigated rotations, were used in the validations.

Simulations were made for three cases in an important vegetable growing area in Valencia. Case 1 was a drip irrigated onion-romanesco rotation in which inorganic nitrogen was applied by fertigation. Case 2 was a lettuce-onion-romanesco rotation, irrigated by furrow irrigation and case 3 was artichokes grown during two consecutive seasons, also using furrow irrigation.

Several levels of nitrogen fertilizer were applied in all three cases and crop growth was measured several times within each growing season. Focus was placed on water balance, drainage, leaching, soil mineral N, crop DM and marketable yield and N concentration and uptake.

Prediction of soil moisture content

Soil moisture was well simulated in the 0-30 and 30-60 cm layers but overestimated at greater depth (60-90 cm); this was attributed to differences between estimated and real values for field capacity. Drainage was simulated in agreement with independent estimates and local experience. Soil mineral nitrogen was systematically underestimated by the model in Cases 1 and 3, suggesting that simulated mineralization was too low, but showed quite agreement in Case 2. This pattern was also found in the simulated leaching which was lower than expected in Cases 1 and 3, and as expected in Case 2.

Yields and Nitrogen Uptake

Total dry matter yields were underestimated for both crops in Case 1 and for two out of three crops in Case 2; the incorrect simulation of soil mineral nitrogen and in some cases (e.g. onion and romanesco) incorrect critical N curves were thought to account for this. Prediction of artichoke dry matter was in agreement with the observed values.

Marketable yields were underestimated in cases where simulated dry matter was low. However, the simulated ratio of marketable yield to total dry matter was nevertheless reasonable. In most cases the direct conversion approach gave better results than the single-plant approach.

Nitrogen uptakes were overestimated in some cases (e.g. onions and artichokes at high nitrogen levels) and underestimated in others (e.g. lettuce and romanesco, in both cases due to wrong critical nitrogen curves). In the case of onions, the simulated nitrogen concentrations were higher than those measured, due to the critical nitrogen curve being too high.

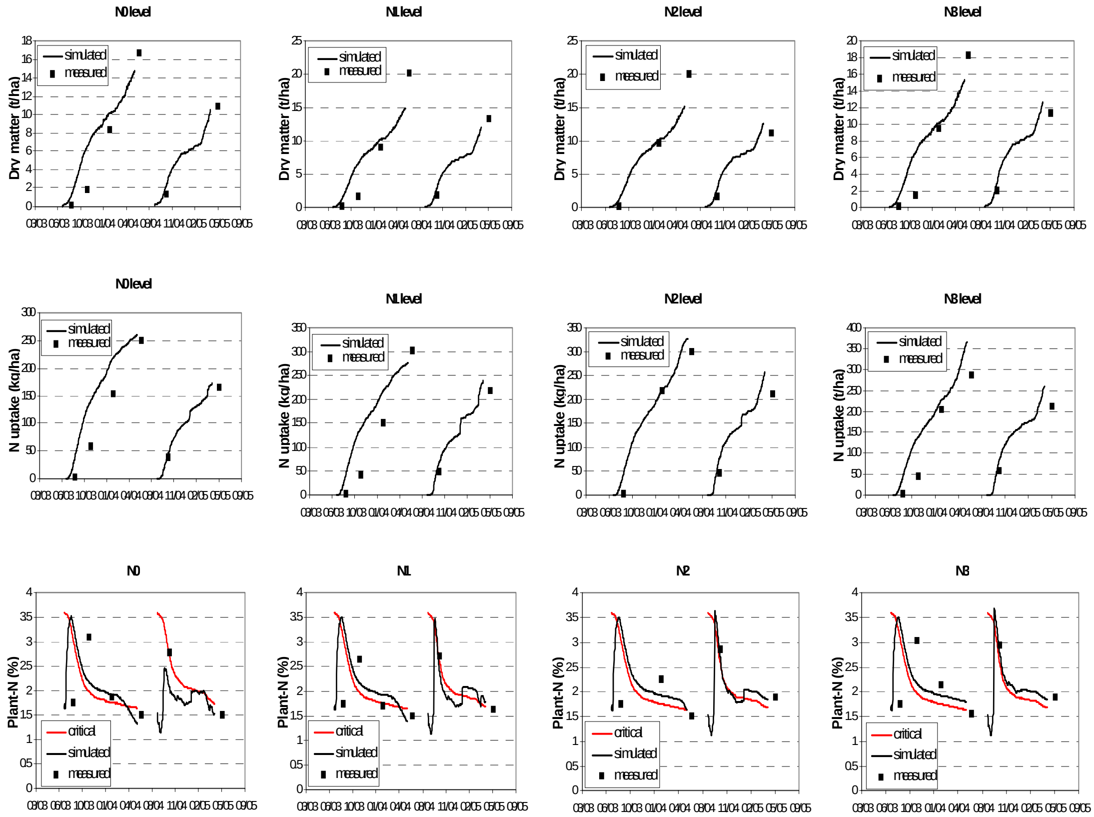


Figure 3.4 Simulated and observed DM, N uptake and plant N concentration in the four N treatments for the two artichoke growing periods.

Data from the lettuce experiment showed total N values obtained were much higher than expected, if the critical N curve used in the crop parameter file was correct (our cultivar was Romaine lettuce, and not butterhead lettuce that is in the crop file, however). So, the analytical procedures used for N plant analysis were tested. For this, we compared the results for total N obtained by using standard Kjeldahl (does not include NO_3^-N) plus the nitrate N determined by a nitrate electrode, with a total N analysis performed with an elemental N analyser (Dumas combustion method). Results showed a good agreement between both procedures, confirming that our analytical work was good and that it would be necessary to modify the critical N curve parameters (or the luxury consumption coefficient) for Romaine lettuce.

Conclusions

It is considered that the current EU-Rotate_N model simulation of the soil water dynamics is “fit for purpose” under Spanish conditions. The water module provided satisfactory results of simulated soil moisture as well as reasonable amounts of water draining below the root depth, according to rainfall and irrigation practices. However, some aspects of this module still need further work. Some results indicate that calculated runoff might overestimate actual runoff in some situations such as in drip irrigated systems and for essentially flat land surfaces. In these cases, it is desirable to switch off the runoff submodule. In some situations, the model overestimates the soil water content in deeper clay soils; this feature is also found in other capacitate models. As the model is developed further it would be interesting to use a more deterministic approach of soil water movement in different soil layers. The inclusion of a water stress factor provided general reasonable effects in crop growth, although it is clear that more work needs to be done to determine the stress weighting factor parameter for individual crops and environments.

3.2.3 Norway

Simulations were made both of selected rotations from the two monitoring studies performed in the project period and for a number of other situations on the basis of earlier field trials. The present trials were performed on loam and sandy soils under inland and coastal climatic conditions, respectively, and included 5 vegetable crops grown at 3 N fertilizer levels. The previous field trials were performed with at the inland site with a variety of vegetable crops and N fertilizer levels.

The main focus of the evaluations was on crop DM production, marketable yields, N uptakes and soil mineral N. The plausibility of other aspects, such as evapotranspiration, winter climate, drainage, mineralization, leaching and crop sensitivity to water stress were also assessed in some cases.

Water balance and potential evaportranspiration.
Water balance was compared over 10 years of measured drainage from a cereal-potato field. Winter surface runoff was simulated to be about 30% of the total. No directly comparable data for loam soil were available, but in a study on clay soil about 40% was found. Simulated drainage was deemed most realistic when the model was run with ‘summer’ surface runoff in the ‘off’ mode (i.e. with no surface runoff except in periods with snow/frost).

Potential evapotranspiration simulated by the model was slightly higher than that measured locally from open water. However, as the latter values are known to be slightly below those calculated by the Penman standard equation, it was concluded that the method used by the model is equally (or more) satisfactory.

Yields and N uptake

Total DM yields were well simulated in many cases. The fact that simulated yields equalled the targets at high N levels of supply was to be expected. Of greater interest is whether the model predicted yield reductions due to N deficiency in the correct way. In many cases the yield reductions were in fact predicted fairly well. One exception was for carrots, for which the model failed to predict a decline, probably due to the very low critical N curve used. An alternative N curve was proposed. An opposite tendency was seen in several cases with onion, and an alternative N curve may be necessary for this crop also. The effect of water stress on potato DM production was simulated quite well in a trial with different irrigation intensities.

Marketable yields were predicted with moderate and varying success. Fairly good agreement was seen with the direct conversion method for carrots and onions and for other crops in some cases. Experience both in the evaluation of trials and in the simulation of scenarios in WP5 suggested that the method and crop table settings for marketable yield must be chosen with care. This relates in particular to plant densities, min/max product weights etc.

N uptakes were consistently overestimated in both monitoring trials and, with few exceptions, in all of the previous field trials. The overestimation was often, but not exclusively, greatest at high levels of N input. In many cases almost all of the applied N appeared to be taken up by the crop. This is in clear contrast to the situation that has previously been reported by many workers. There are several possible reasons that may account for the present overestimations (leaf senescence, N uptake in roots, unaccounted for immobilisation and/or losses, excessively high mineralization etc). In some cases the measured data may also be at fault. However, taking into account the similar experience found by earlier modellers, the present evaluations do suggest the need to include more processes/parameters in the model.

Soil mineral nitrogen mineralisation and leaching.

Soil mineral nitrogen was simulated in a logical manner with respect to uptake and expected mineralization patterns. The match with measured data in the monitoring trials was rather variable, but mostly within the correct range. There was however a clear tendency for the model to underestimate Nmin at levels below 50 kg/ha, and to overestimate it at high levels. The latter was seen particularly in rotations with double-cropping of lettuce and broccoli, possibly suggesting too rapid mineralization of crop residues. In several of the older trials there was an indication that Nmin simulated at harvest was lower than the measured values.

Mineralization was not measured directly, but the contribution from soil organic matter was assessed in minilysimeters. Levels simulated under carrots and onions were similar to the minilysimeter values for the loam soil, but were higher for the sandy soil. Climatic conditions were however not comparable in the latter case. Much higher levels were simulated when residues of lettuce and broccoli were present. Whilst this is logical, the mineralization of these residues may have been simulated too rapidly

Leaching could only be assessed subjectively, but the model was clearly able to portray the differences in leaching level and timing that were to be expected between sites due to their contrasting soils and climates.

Conclusions

The overall conclusion is that the model can, with careful selection of input parameters, simulate soil nitrogen dynamics and crop growth in a reasonably accurate manner. The model encompasses all the most important processes that are relevant in a wide variety of situations. The most demanding aspect of the model use is to ensure the correct selection of parameters that govern water balance and N mineralization, as these are fundamental to both leaching and crop growth. With respect to crop growth, a major determinant is the critical N curve, which appears to give good simulation of crop responses to N in many cases, but needs modification for some crops. The simulation of crop N uptake requires further study.

3.2.4 Germany

As part of the validation process, simulations were performed for 19 rotations on 14 growers' fields in south-west Germany that had been monitored over a two year period. Frequent sampling provided data on soil mineral nitrogen (Nmin) and soil moisture, as well as total crop dry matter, nitrogen uptake and marketable yield. A wide range of crops was represented. All crops were grown with a single (non-limiting) level of nitrogen fertilizer, reflecting actual user practice. In addition, simulations were performed for 8 rotations similarly monitored at two research stations in eastern Germany, 4 on sand and 4 on clay soils.

Results

The main focus was on soil mineral nitrogen, soil moisture, dry matter yield and plant nitrogen concentrations. A range of model assessment statistics was used to evaluate model error (RMSE and MAE), model bias (MBE), model efficiency (EF) and index of agreement (d). Section 2.4.1 shows the basis for this evaluation.

Table 3.1: *Statistical evaluation of model performance – all data.*

	Soil mineral N	Soil water	Dry matter yield	N concentration
	kg N ha^{-1}	*kg kg^{-1}*	*t ha^{-1}*	*%*

n	*no unit*	2383	771	89	85
RMSE	*unit*	62.72	0.07	2.02	1.07
MAE	*unit*	42.38	0.05	0.97	0.81
MBE	*unit*	-9.87	0.00	-0.75	-0.16
EF	*no unit*	-0.14	0.51	0.79	0.47
d	*no unit*	0.71	0.87	0.95	0.82

Taking all measured data into account for evaluation of the model performance, the single reasons for model failure at specific tasks loose their explanatory power. The different indices thus tell the following story: Dry matter yield and plant tissue N concentration simulation were satisfactory. Since the target approach used for crop growth modelling is used, a result at this level of quality was expected. It shows, however, that the soil N and water simulation allowed the crops to grow as it was observed in the field.
Soil water simulation is not so much dependent on crop growth simulation, although the water uptake from the soil by the plant can play a role in a shorter section of the season. The simulation performance with an EF of 0.51 is not a bad result. However, soil hydrology models are known to act more precisely than this. In this part of the model there is further potential for improvement. The simulation of soil mineral N has shown in few occasions that the translocation of mineral N in the soil profile may be simulated too slowly. This is seen as one reason for the unsatisfactory result in soil mineral N simulation. Other reasons are due to unsatisfactory initialisation of the model and bad reporting of the observed data.
All in all, the Index of Agreement (d) attests the model to be able to explain three quarters of the variation in the observed data for all four categories, which is an acceptable result, which could be improved if more time was available.

Conclusions

The model in its current state has been evaluated as being fit-for-purpose in terms of demonstrating certain management effects. With the algorithms used it is very much possible to show differences in soil mineral N dynamics which follow the use of different rotations, including cover crops, catch crops or a different sequence of cash crops of varying rooting depth. Also differences in fertilising and irrigation strategies can be worked out with the help of the model and used to derive recommendations for the use of fertiliser and irrigation.
As evaluated on the basis of the data presented here, the model turns out not to be appropriate for very accurate prediction of soil nitrogen dynamics but the level of accuracy achieved with the model is satisfactory for serving its current aims. On top of this, its educational power and its unique features make the EU-Rotate_N simulation model a valuable tool in fertiliser advisory service.

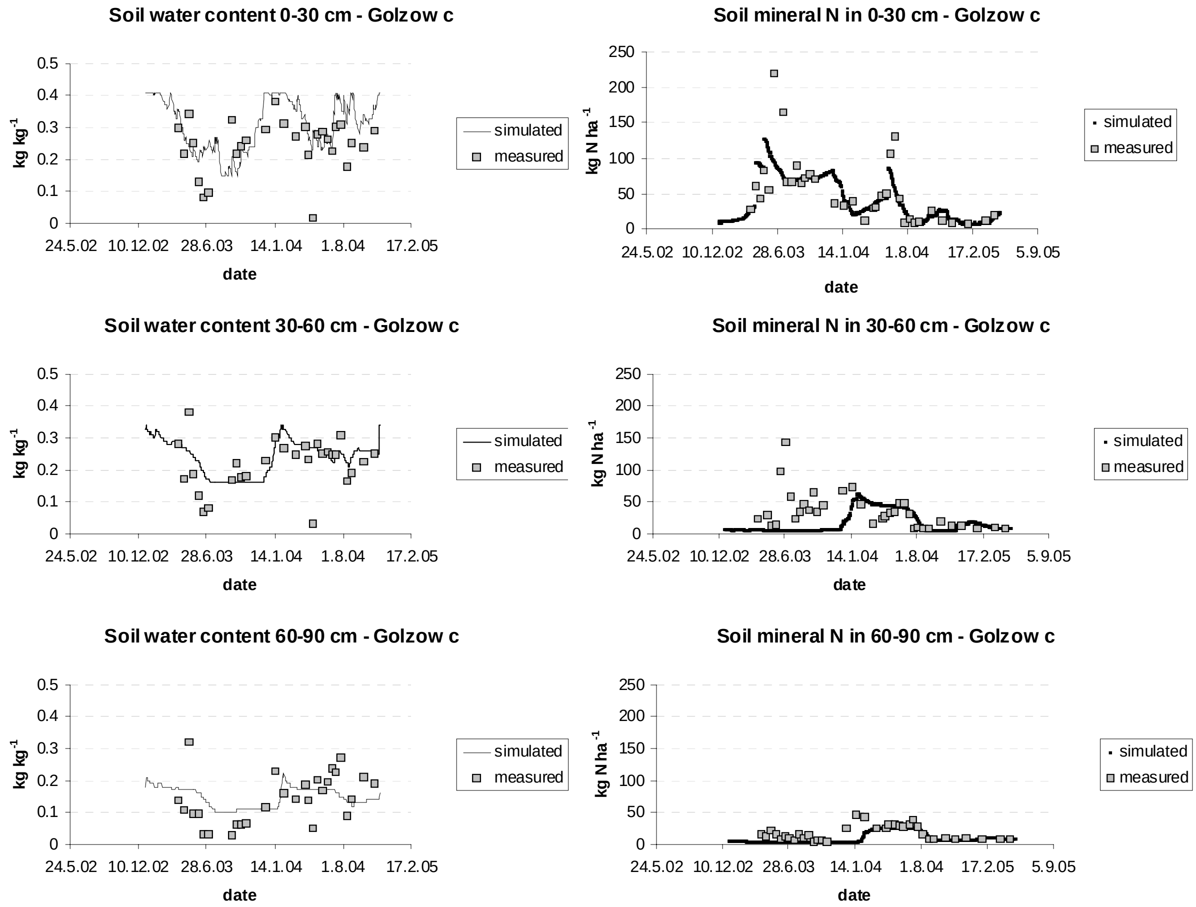


Figure 3.5 *. A representative example of simulated versus measured soil moisture content (left) and simulated versus measured soil mineral N (right) at three depth intervals in one of the fields monitored over two years in Germany. The figure shows good agreement for moisture, especially in the upper soil layer. The agreement for mineral N was also fairly close, though mismatch at intermediate depth may be due incorrect initialization of model parameters.*

3.2.5 Denmark

The main focus of the validation process was to evaluate the model's ability to simulate carry-over effects of nitrogen from one cropping season to the next. The experiment made to obtain data for model validation has also given new information on various subjects. The results show the effect of N fertilizer level and harvest time on N carry-over and availability in the next season, and even into the second succeeding season. It has supplied new data on the effect of N fertilization on crop root growth where little data have previously been available. Further, it has provided results showing that the ability of the deeper parts of the root system to deplete the soil of available N interacts with the total N supply to the crop, whether this comes from fertilizer or from pre-crop effects. To our knowledge, no data has been published on such effects, though data from some previous experiments indicate that there may be important interactions.

Yields and N uptake

The model simulated dry matter accumulation at harvest well when nitrogen supply was non-limiting, a result of the target yield approach. However, under nitrogen limiting conditions dry matter yields were poorly estimated. In cauliflower and lettuce crops simulated dry matter yields were too low, whilst simulated N% in dry matter was higher than measured, suggesting that the critical nitrogen curves over-estimated nitrogen demand. A slight tendency for the opposite effect was seen in cabbage.

All simulated marketable yields were clearly higher than the measured values, with overestimations from ca. 20% in nitrogen-limited lettuce to 130% in lettuce with high nitrogen supply. In the case of cauliflower and cabbage, comparable overestimations were in the range of 30% to 60%. The reason for this discrepancy is not clear. However, the harvest index (HI) and the %dry matter upon which the approach is based, are difficult to predict precisely. The overestimation in cabbage was due to simulated HI being too high, whereas in lettuce the effect was due to simulated %dry matter being too low. The fact that different parameters were responsible in different cases, suggests that there is no single problem with this part of the model. A much larger amount of experimental data is required for testing the routine in all crops.

Total nitrogen uptake of crops was poorly simulated with uptakes of fertilizer nitrogen by cauliflower, lettuce and cabbage being 35%, 38% and 52%, respectively, compared to measured values of 28%, 24% and 32%, respectively. The problem was not due to excessive soil N_{min} depletion, but rather that the simulated amount of nitrogen available was too high. This was apparently caused by the too rapid and complete mineralization of cauliflower residue nitrogen.

Soil nitrogen (N min) and N carry over

The simulated downwards movement of N_{min} left in the soil was too fast. This appeared to be due to underestimation of evaporation from bare soil surfaces. Another finding was that simulated mineralization of N from the soil organic matter was too low, whereas that from N rich crop residues appeared too fast, compared to typical experimental results.

The model was able to simulate the pattern of response of nitrogen carry-over correctly, i.e. more carry-over after late cauliflower than after early cauliflower, and better use of the carry-over effect when a deep rooted main crop (white cabbage) was grown compared to when a shallow rooted main crop (crisp head lettuce) was grown. However, too rapid nitrogen leaching and mineralization of nitrogen from crop residues meant that nitrogen was lost too fast, reducing the ability of the model to simulate nitrogen carry-over from one year to the next.

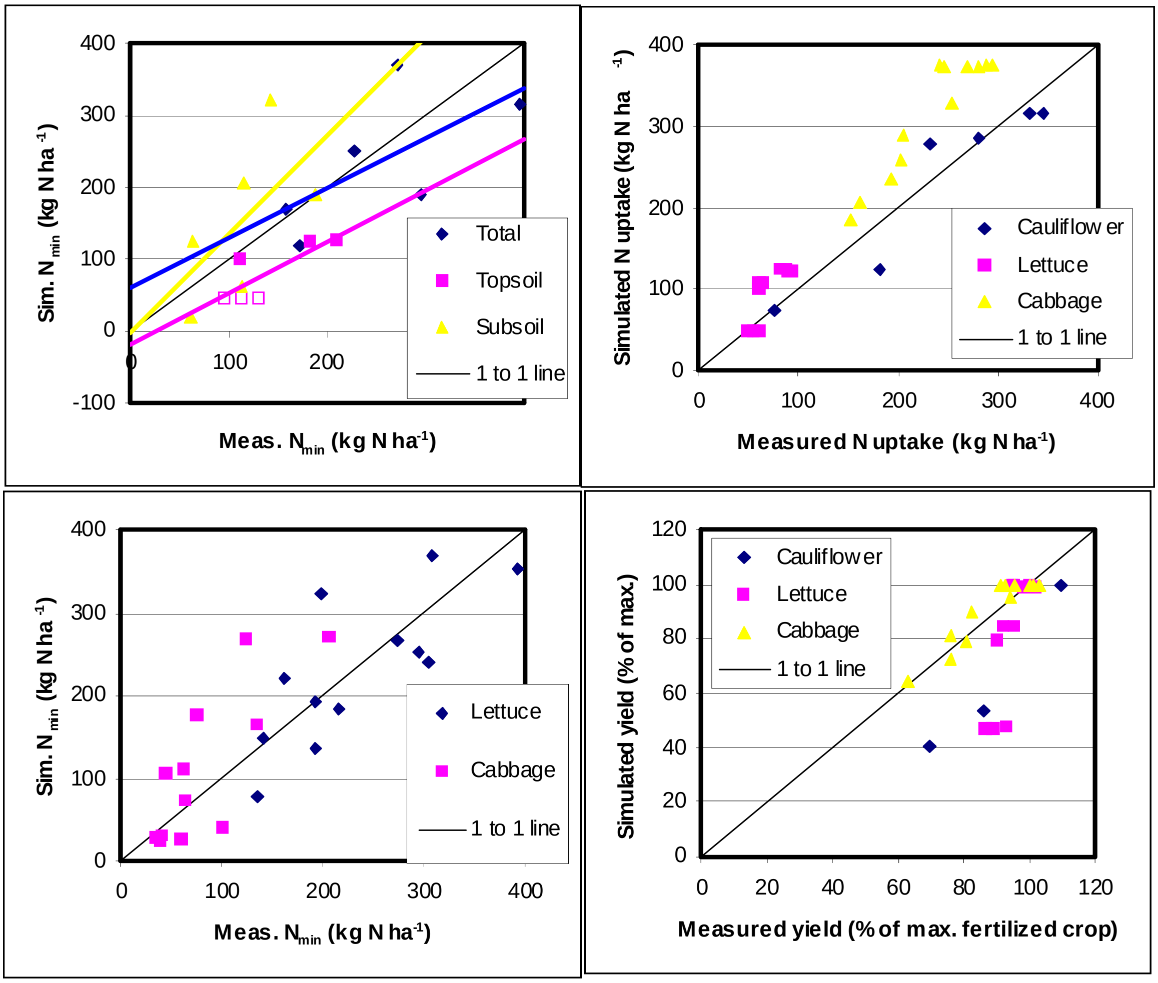


Figure 3.6 Simulated vs. measured N carry-over, N uptake, soil mineral N and yield reduction due to N limitation in some of the crops grown in the monitoring trial performed in Denmark.

Above left: N carry-over estimated as N_{min} in May 2004 after the cauliflower crops grown in 2003 (data split between N_{min} found at depths of 0-1 m and 1-2 m). The total carry-over was modeled fairly well, but it was overestimated in the upper layer and underestimated at depth
Above right: N uptake by cauliflower in 2003 and lettuce and cabbage in 2004. Reasonable agreement found for lettuce and cauliflower, but a degree of overestimation for cabbage.
Below left: Remaining soil N_{min} (0 to 2 m) at harvest of lettuce and cabbage in 2004. The model predictions showed no clear bias, but the overall match was somewhat variable.
*Below right:*Yield reduction due to N limitation in cauliflower grown in 2003 and lettuce and cabbage grown in 2004. In cauliflower and lettuce the yield reduction is clearly too severe, whereas in cabbage there is a good match between simulated and measured values.

Conclusions

The model, on a general level, is able to reproduce the pattern of response in yield, crop nitrogen uptake and soil nitrogen. This indicates that the basic principles of the model work as intended. However, the quantitative precision of the simulated estimates is low.

Though there are some examples of fine accordance between measured and simulated data, there are many where the simulated values are quite far from the measured data. Thus, before the model will be useful for simulations, where it is important to get quantitatively precise data, several of the processes simulated with the model needs to be adjusted more carefully. In particular, more work is required in the following areas: Water movement (too slow percolation was found using measured evaporation values, and too rapid percolation was found using modeled values); Mineralization (too rapid and complete mineralization of crop residues was found); Parameter values in Crop Table (these require more verification, in particular the values for critical nitrogen curves, root growth parameters, for both of which limited data are available for many crops.

3.2.6 Italy

Several validation tests were conducted on successive versions of the model up to the final version, with simulations for two-yearly rotations of four vegetable crops (broccoli/cabbage, lettuce, fennel, spinach), each at three nitrogen application rates (none, recommended and 30% above). Observed responses included: total dry matter, marketable yield, residues, crop nitrogen content and uptake, soil mineral nitrogen and soil moisture. Evaluations were made overall (with samplings in the growing season) and at final harvest by statistical graphics and summaries.

Overall predictions

Overall predictions were good for dry matter, nitrogen uptake and most levels of marketable yield. Low values of the agreement indices for soil nitrogen reflect the failure of the model to predict the higher tail of the observed distribution.

Table 3.2 *Statistical tests for overall model fit for the monitoring trials in Italy: normalized mean squared error (NMSE), mean absolute error (MAE), mean bias error (MBE), index of agreement (d) and modeling efficiency (EF)*

Response variable	NMSE	MAE	MBE	d	EF
Total dry matter yield	0.07	0.36	-0.06	0.97	0.90
N uptake in plants	0.11	17.01	3.16	0.95	0.80
Marketable yield (single plant)	0.11	11.10	-2.62	0.90	0.66
Crop residues (direct conversion)	0.21	0.68	0.37	0.90	0.36
Crop N	0.07	0.84	0.38	0.78	0.23
Marketable yield (direct conv.)	0.31	17.99	-9.34	0.80	0.22
Soil mineral N	1.29	37.26	-29.71	0.64	0.20
Crop residues (single plant)	0.80	0.74	-0.41	0.59	0.11
Soil moisture	0.08	0.06	0.01	0.74	-0.83

Soil Moisture Content

Soil moisture was systematically over predicted in the first autumn cycle for all crops except fennel, for which the reverse is true, slightly under predicted in the first spring cycle and somewhat over predicted in the second autumn cycle, except for cabbage. In the second spring cycle the model gave a narrower range of values than the experimental estimates. This trend is typical of an amplified relationship, with under prediction for low observed values (spring-summer) and over prediction for high observed values (autumn-winter). A sensitivity analysis with selected values of the drainage coefficient has shown this pattern to be a result of using a value lower than the default (about half of it), set with the aim of correcting (successfully) the average negative bias obtained with the default value.

Yields and N uptake

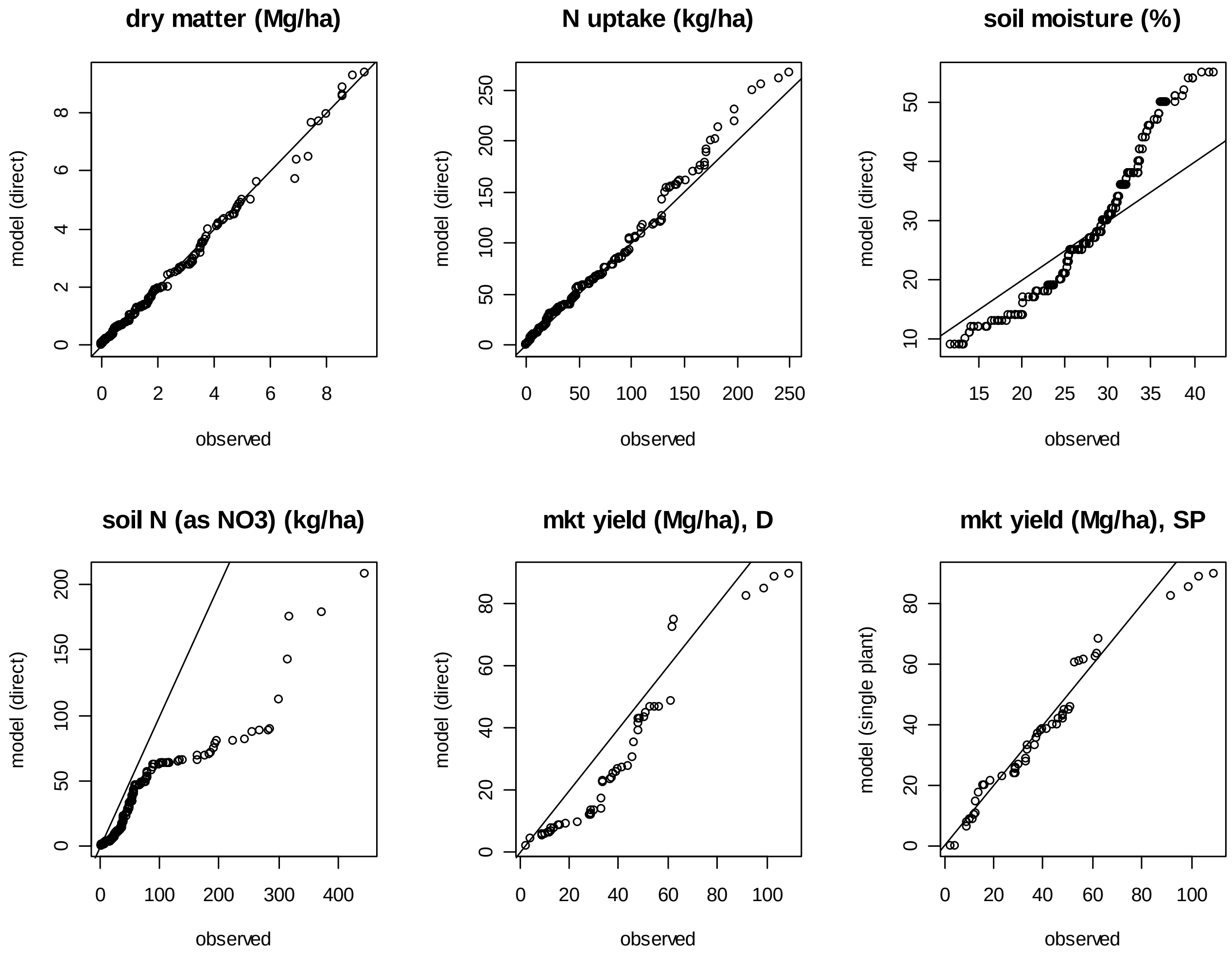
Total DM yield was well simulated apart from over prediction at the zero nitrogen level in the first and second cycle for fennel, in the second and third for cabbage and in the fourth for lettuce and spinach.

Marketable yield predictions with the single plant method were very good for broccoli, cabbage and spinach across seasons and nitrogen levels. For lettuce the model over predicted at the zero nitrogen level in the third and fourth cycle. Predictions for fennel were good with the direct method at positive nitrogen rates and also at the zero nitrogen level in the third and fourth cycle, while the single plant method under predicted in all cases.

Nitrogen uptake was predicted well in all cases for spinach and lettuce, as well as for broccoli at positive nitrogen rates, and less well for cabbage on nitrogen fertilized plots in the third and fourth cycle and on zero nitrogen plots in the third cycle. Fennel showed a mixed picture, with cases of good fit (late cycles at the zero nitrogen rate, autumn crop at the highest nitrogen rate) and cases of bias, positive in the first cycle, mainly negative in further cycles.

Crop residue predictions were good with both methods in all cases for broccoli, spinach, cabbage and lettuce. For fennel, on the contrary, both methods over predicted at the zero nitrogen level, but the single plant method over predicted and the direct method under predicted at higher nitrogen rates. So, the overall low quality of model simulations found for this response is uniquely due to the fennel crop.

Figure 3.7 *Quantile-quantile plots of observed and model-simulated values for crop dry matter, N uptake, soil moisture, soil nitrate-N and marketable yield (D: direct method; SP: single plant method) in monitoring trials in Italy. The plots show good agreement for dry matter, fair agreement for N uptake and marketable yield, contrasting bias at low and high levels of soil moisture and serious underestimation at higher levels of soil mineral N.*



<u>Soil mineral N</u>

Model predictions for soil nitrogen as NO_3-N were similar to- or slightly below the observed for all crops at the zero nitrogen rate and for nearly all at the recommended nitrogen rate, with the only exception of spinach in the first spring cycle, showing a negative bias. Four instances of high negative bias occurred at the highest nitrogen rate, namely for lettuce in both spring cycles, spinach in the first spring and cabbage in the second autumn. So, the overall bad fit indices for this response are mainly due to inadequate predictions for a small number of the nitrogen fertilized plots.

The high organic matter content of the experimental soil may have allowed for high rates of mineralization not adequately predicted by the model. This was evident at the end of summer 2004, particularly for species unable to use high amounts of available nitrogen in spring-summer cultivation (lettuce and spinach). Under prediction of soil mineral nitrogen at this stage certainly distorted the nitrogen leaching simulation for the following season. However, sensitivity analyses for the impact of soil organic matter have not been conducted, because measurements of nitrogen mineralization were unavailable. In addition, there was insufficient time for altering the input file parameters in order to enhance prediction accuracy.

Conclusions

The model appears fairly accurate for comparing the outcome of vegetable rotations, as a decision support tool for finding more economically and environmentally sustainable options. The performance with Italian validation data was robust in several respects, considering the diversity from the model training data. It seems plausible that predictions for specific production systems could be further improved by fine-tuning the parameters in the input files. Because of expert knowledge and training needed to run crop management simulations and policy scenarios, effective use will be likely in the horticultural experiment and advisory service environments.

3.3 Fitness of Purpose of Model and strategy for its use to run case studies

3.3.1 Fitness of purpose of individual modules

The model has a novel two-dimensional **soil water balance** module that allows calculation of water use and water movement both vertically and horizontally. Thus it is suited for situations such as wide-row crops and trickle- and furrow-irrigation, as well as conventional conditions.
Potential evaporation, calculated from latitude, altitude and readily-available weather data, is probably adequate for most situations, but may be substituted with other values if desired. The routine for actual evapotranspiration assumes crop coefficients based on lengths, in numbers of days, of individual growth phases. These sometimes require modification by the user to suit local conditions. A simpler solution is desirable, based, for example, on day-degrees instead of time. The module also requires the user to make two somewhat arbitrary choices, both of which have been shown to have a marked effect on water movement (surface runoff ON/OFF, and drainage rate from 0.0 to 1.0). Evaluations in northern Europe have suggested that default values result in too little water movement. More testing and better guidelines are therefore required for a range of soils and environments. Underestimation of evaporation from bare soil has also been indicated in Danish simulations, but the reason for this is not yet established.

The **root growth** module is a highly innovative feature of the model, representing a ‘state of the art’ portrayal of two-dimensional root growth that may be adjusted for all crops. Coefficients for many of the major crops are well-documented, whilst for some less common ones they are based on assumptions that may need more verification. The model includes a possibility for the user to stipulate a maximum rooting depth below which roots cannot penetrate. Though in some cases there may be clear reasons for so-doing (shallow bedrock, high water-table etc.), the user very often has no way of justifying a limitation to rooting depth. Often no such limitation exists. However, a means of taking account of such factors as suboptimal soil structure (low macroporosity, high penetration resistance etc.) would be a clear improvement to the model, although this was outside the scope of this project. A thorough sensitivity test of simulated root growth and associated N uptake has been performed.

The **snow/frost depth** module, though relatively simple, appears to give an adequate description of winter conditions where applicable (ie. northern and/or continental climates). The interaction of frozen soil with surface runoff in freeze/thaw periods gives a reasonable representation of reality. Though in fact part of this 'winter runoff' may in fact take place by bypass flow in soil macropores, the effect on leaching during winter is thought to be similar.

The module for **soil nitrogen dynamics** is based largely on the established DAISY model, and encompasses all important N processes and flows. Evaluations show that these are simulated in a logical manner, but there has been uncertainty about parameter values in some cases. Mineralisation in an organically-amended soil in southern Europe was underestimated, whilst that of soils with a high content of recalcitrant organic matter, as in northern Europe, may be over-estimated. A simple means is required of adjusting the model to such variations.
Excessively rapid mineralisation of plant residues has also been indicated in some cases, suggesting that more work is needed to parametrise and/or document this aspect.

The **crop growth** module is based on user-supplied targets expressed as total DM. This concept worked well in evaluations, as data for total DM was in all cases available. In actual practice, a basic weakness is that most users are only able to state their target in terms of product fresh-weight. This means that target total DM must be estimated indirectly, by means of a separate routine that is at present not included in the model (e.g. the R-target spreadsheet developed at HDRA for FW/DM conversion). Whilst the target DM values limits potential growth, actual growth is limited by N availability in relation to crop-specific critical N% curves. The latter are well-documented for major crops, but for many vegetable crops they are based on rather few observations. Evaluations have revealed examples of cases where the assumed critical N curves are too low (e.g. carrots) or too high (e.g. onion, cauliflower). This has a significant effect on simulated fertilizer responses, leaching and gross margins. The option to include the effect of **water stress** on growth was a late addition to the model, but appears to function as intended. More testing is required for a range of crops.

The module that calculates **marketable yield** and amounts of **crop residues** from total DM, includes alternative means of calculation ('direct conversion' or 'single plant'). The approach is flexible but highly empirical. Whilst default values are given for all crops, experience with these in evaluations so far has been rather inconsistent, suggesting that considerably more experimental data is required, as well as clearer guidelines on how to select the method of calculation.

The routines for **fertility-building crops** are broadly satisfactory. However, more work is required to refine the crop growth and residue parameters used for various crops and to test the new parameters under a wider range of conditions. Specific problems with regard to mineralization of long-term crops were found, and a new approach may be needed to model this. It is particularly important for these problems to be addressed if the model is to be used under organic conditions where long-term fertility building crops are the main source of N.

The **economics** has not been evaluated specifically, though users have had experience of its use in connection with WP5. The concept of gross-margins is well established in farm management and is thus a useful addition to the model. An essential requirement for the future is that the economics input data must be kept up to date with respect to costs and prices.

Various triggers included in the model (**irrigation strategy, fertilization by Nmin**) were not relevant for the evaluation studies, but have been used with success in WP5. The option for **N optimization** was found by several users to grossly underestimate N fertilizer requirements. The reasons for this are unclear and more work is needed on this topic.

3.3.2 Use of EU-Rotate_N to run Case studies

Whilst the model did not always provide perfect accuracy for every measured value it provided a tool for comparing the relative effects of differing rotational strategies for nitrogen use. Experience using the model during the validation stage did highlight a number of areas where care needed to be used in running the model.

- It was suggested that the value of the drainage coefficient would be set to 1 and runoff would be switched off.
- Initial testing was required to test the release of N from soil organic matter. Should the rate of mineralization be less or more than expected the value of the Soil organic matter in the input file would be adjusted.
- The target yield levels of crops should be carefully chosen – as any errors in the yield expectation had a marked effect on crop N uptake. If crops are unirrigated then the total yield expected should be included or the adjustment for water stress needs to be switched on. In organic rotations some allowance for the drymatter accumulation in weeds should also be taken into account.
- Checks need to be made to ensure that marketable yields are in the expected range.

3.4 Results of Scenario Runs

3.4.1 United Kingdom

This section compiles the results from model runs with organic and conventional rotations. The results draw on earlier work namely the "Report on a set of conventional & organic management strategies to test in the main vegetable regions of the United Kingdom" and the rotational partial budgeting technique outlined in the "Report on simulated N losses and economics of UK conventional & organic management strategies." The data and methods used are described in the recently published paper "A method to predict impacts of NVZ and Water Framework legislation on UK vegetable and arable farming" (Schmutz et. al. 2006).

Methods

The organic rotations were run with standard management data. They represent current organic practises in the described UK regions and are drawn from commercial farms. The target dry matter yield was increased (by 10%), due to the fact that organic systems have higher weed populations in the field, which also take up nitrogen.

The conventional rotations were run with standard management data. They also represent current conventional practises and fertilizers are applied as recommended by the Defra publication RB209. The described UK regions were drawn from commercial practices as extracted by an expert panel.

Organic field scale horticulture

For the organic rotations it can be concluded that the average annual leaching (below 90 cm) found in the UK is predicted within the range of 13 – 88 kg N /ha and year. The weighted annual average figure for the UK with median weather is 39 kg/ha/yr with the 25 and 75% rainfall percentiles giving a range of 24 – 45 kg N/ha/yr. Figure 3.8 demonstrates that there is no apparent relationship of rotational gross margin with leaching. The most profitable rotations in the main vegetable production area at the English East coast had also the lowest leaching.

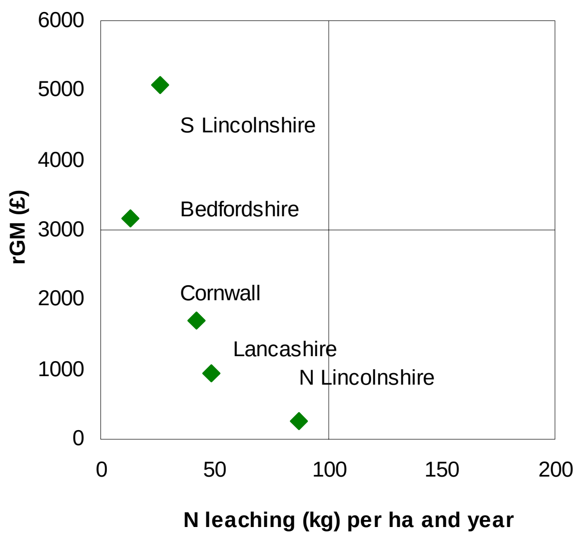


Figure 3.8*: Rotational gross margins (rGM) in £ per ha and year for key UK organic rotations plotted against N leaching (N system loss water, below 90 cm in kg/ha/year).*

Overall leaching losses in organic systems are 48% of conventional data. As the model runs demonstrate a certain amount of N (1-8 kg N/ha/year) can be taken up from below 90 cm and therefore are reduced from the "N leaching below 90 cm" figure and called "N system loss to water" or simply overall N leaching. The magnitude of this uptake below 90 cm is very low compared to the annual conventional mineral N fertiliser input of 158 kg N/ha/yr and can be considered as agronomically insignificant in conventional farming. In organic systems however, any recovery from below 90 cm with deep rooting crops and cover crops is a welcome addition to the N balance. In fact breeding programmes for deep rooting crops with higher N efficiency are in place. Modelling this uptake shows that the magnitude of this effect is low, however not zero.

The simulation runs also show a considerable amount of gaseous losses. The model does not differentiate between the form of N (N_2, N_2O or NO_x) being lost and the possible impact on climate change, this requires further research. However, for organic systems any loss is important especially when it is higher than N fixed from the air as simulated for most organic. The existing EU and national regulations in organic agriculture are restricting the use of N to the equivalent of 170 kg/ha/year from livestock or other permitted organic fertiliser. This measure proves to ensure that total N inputs (from organic fertilisers) are low in organic farming compared to conventional farming: 18 kg N/ha/yr versus 158 kg N/ha/yr in conventional. Consequently, the lowest annual leaching was simulated for well-balanced organic rotations on fertile soils with low rainfall (South Lincolnshire, Bedfordshire); well-balanced meaning in the use of cover crops where possible and a reduced use of imported farm yard manure.

Given the high profitability of this farming system it can be considered as an alternative to conventional land use in vulnerable river catchments. When the current share of the organic vegetable land use in the UK of 6.1% (Schmutz et. al 2006) will be increased to 20% a considerable contribution of to reduction of unwanted losses from UK intensive horticultural land use can be expected. However, these are only projections from today's land use and management practices, nobody can actually predict the complex interactions of scale effects when organic production increases it critical mass and conventional production becomes "greener". As discussed earlier, high leaching was also simulated for organic rotations, mainly in the high rainfall areas of the UK West coast and where grass/clover leys were ploughed in. In Cornwall high leaching after a 3-year grass/clover ley even occurs with a nutrient demanding winter cauliflower planted as early as 15-July.

<u>Conventional field scale horticulture</u>

For the conventional rotations it can be concluded that the annual leaching predicted for different UK regions and rotations is within the range of 54 – 130 kg N /ha and year. The weighted annual average figure for the UK with median weather is 81 kg N/ha/yr. The 25- and 75- rainfall percentiles give a range of 50 – 93 kg N/ha/yr for the predicted UK annual average leaching for conventional horticulture under current conventional GAP (good agricultural practice). Figure 3.9 demonstrates there is a large variation of rotational gross margins and N leaching in the different regions. Rotations that are more profitable do not necessarily incur higher leaching.

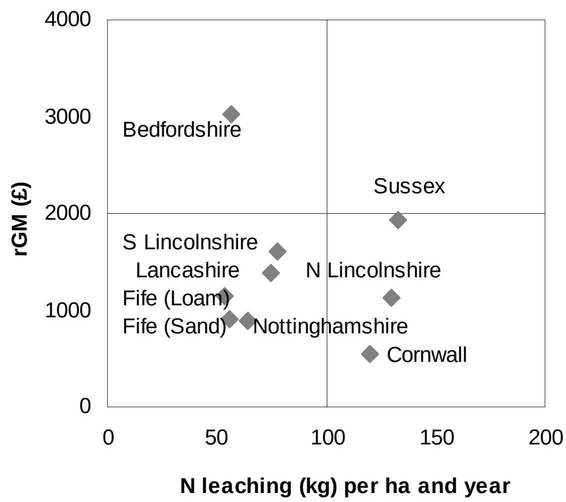


***Figure 3.9**: Rotational gross margins (rGM) in £ per ha and year for key UK conventional rotations plotted against N leaching (N system loss water, below 90 cm in kg/ha/year).*

The most interesting result in the conventional scenarios is the large effect the assumed traditional farming practice ("GAP+30%" = 30% higher fertiliser use then recommended by RB209) would have on the leaching losses. If UK conventional growers would use on average 30% higher fertiliser rates then recommended by GAP, the weighted annual average UK figure (with median weather) would be 117 kg N/ha/yr, well above the current range even with more extreme weather. The simulations predict no financial gains for using higher fertiliser rates. On the contrary, reducing the GAP N fertiliser applications by 30% ("GAP-30%") predicts not only large reductions in N leaching (from 81 to 49 kg/ha/year), but overall very little negative financial impact except in the more intensive vegetable rotations where gross margins were reduced.

At present, there is no monetary incentive to reduce leaching. On the basis of the simulated data if every kg N lost above a certain threshold of e.g. 50 kg N/ha/year had a "polluter-pay" levy of £1/kg N, this would immediately make the "GAP-30%" scenario the most profitable. At the GAP baseline with 81 kg N/ha/year average leaching, this levy is £31/ha/year or £2.3m per year for the industry. This would be an incentive to avoid leaching and reward good environmental management practice; the total UK tonnage of N leached would be cut in half with all the environmental benefits.
However, such a system, based on unwanted N outputs rather then N inputs, is only realistic if leaching above a certain threshold can be modelled (or measured) within acceptable error margins, given variable weather and soil conditions.

Farm level conclusions.

At farm level, it is important to visualise the results, show where nitrate leaching occurs in a rotation and test different management strategies. In organic farming, changes can be made to the sequence of crops in a rotation, to maintain longer or shorter fertility building phases, to try different fertility crops (leguminous or non-leguminous) and to adjust the timing and amount of organic manures. All of these scenarios can be evaluated in the model including an estimation of costings and gross margins and the effects, both environmentally and economically, can be assessed. The same is true in conventional farming, since all organic management strategies are also available to conventional farmers. In addition, the timing and amount of mineral fertilizer can be predicted more precisely compared to the current GAP RB209 tabulated figures.

Simulations with mineral N fertilizer at 30% below GAP showed little reduction in rotational gross margins on average, but the performance of some of the higher valued vegetable crops was reduced though the environmental benefits of the lower rates were large. Routine use of cover or “N-trapping crops” after incorporation of summer crop residues, minimising fallow periods and improved timing of cropping are other important recommendations at the farm level. Farmers and growers regard improved timing of field operations as one of the most important issues, however this remains challenging given weather, labour, machinery and marketing (continuous delivery) constraints

Policy Level conclusions.

Organic production - Given the higher profitability of the organic system and its lower average N leaching it can be considered as an alternative to conventional land use. This is especially true for vulnerable river catchments where the N loads in the groundwater are high. If the current share of the organic vegetable land use in the UK of 6% could be increased to 20%, a considerable contribution to the reduction of N losses form UK horticulture can be expected. However, these are projections form today’s land use and management practices, it is difficult to predict the complex interactions of scale effects when organic production increases its critical mass and produces higher yields and simultaneously conventional production adopts some “organic” management practices without compromising on yield and gross margin.

Conventional production - Comparing the magnitude of effects an increase of organic land use to 20% would have a smaller effect on N leaching losses in the UK then large changes in conventional GAP. Therefore, the main policy recommendation is to follow GAP in all horticultural rotations and update the regulations by fine-tuning them. With cross compliance regulations growers can be asked to submit their management practice, which then can be used to run models to identify leaky strategies.
Reducing the N inputs below GAP (“GAP-30%”) would reduce the modelled N leaching considerably, however would also reduce gross margins in some rotations. If lower N losses are necessary then currently achieved by GAP (EU Water Framework Directive or other policy pressures), a system of compensation or levy might be required to avoid reduced gross margins in horticultural rotations.

Model runs also show that over fertilisation ("GAP+30%") should be avoided. It not only incurs high N losses, is it is also predicted to be less profitable then GAP under current conditions.

3.4.2 Spain

The main objective is the comparison of the effects of common grower nitrogen fertilisation practices (Traditional Farmer Practices or TFP) with the recommendations given in the Valencian Good Agricultural Practices Code (GAP), with the use of the N target level method and, finally, with the optimisation carried out by EU-Rotate_N v1.5.

Methods

Several model farms were defined in the Valencian Community (VC) representing the main vegetable areas in terms of crops grown, type of soils, irrigation practices and climatic conditions. The model farms included up to fifteen different crops representatives of the three provinces of the VC (Castelló, València and Alacant), and reaching 90 % of the vegetable production of the area (29,000 ha). The main crops with the range of N input levels for TFP and GAP are shown in table 3.3. Available soil and climatic databases were used to match the input model requirements. Pedotransfer functions (Saxton et al., 1986) were used to estimate soil missing data. An average meteorological year for each location was used in the simulations. In the VC GAP recommendations, the mineral N in the soil at planting time, and the N applied with the irrigation water are considered so that the total amount of N fertilizer to apply varies depending on these values. Economical input data were obtained from GVA (2005) and Albiac and Tapia (2004). The fertilizer optimisation according to the EU-Rotate_N model was done for the traditional irrigated crop rotations. This optimisation was accomplished by iteration increasing fertilisation in 10 kg N/ha steps until 95% of maximum yield is achieved. The fertilization based in N target levels, which is the basis of the N_{min} system, takes into consideration the mineral soil N available in a given soil depth (depending on the crop) for a particular fertilization event to calculate, if required, the amount of N to be applied. All simulations were done using the version 1.5 of the EU-Rotate_N simulation model.

Results

The results show that by adopting the GAP it is possible to achieve a 30-50% reduction in the use of N fertilizer in several areas of the VC with minimum impact on the farm gross margin (table 3.4). This scenario has important environmental benefits: a 30-60% decrease in the NO_3-N leached to the groundwater and a 20-50% reduction of the N loss by volatilisation, depending on the crop rotation, vegetable area and current farmer practices. This means that, on average, leaching losses would be reduced by about 90 kg N/ha/year, and that the agricultural N pollution of the atmosphere would be reduced by about 40 kg N/ha annually. A comparison of 4 different scenarios is presented in table 3.5 for a traditional crop rotation in the horticultural area of the Valencia province: TFP, GAP, inorganic N-fertilizer optimisation done with EU-Rotate_N v1.5, and the application of the N_{min} system. The table shows that any scenario different than TFP would reduce the amounts of N input to the fields while yield would be only barely affected. The great variability in the N fertilization resulting from one approach to another, is the reflection of the different ways in which the soil and plant N dynamics are considered in these approaches. The model N optimisation also indicates that fertilization according to the GAP and the N target levels might be potentially reduced before any significant decrease in yield is produced.

***Table 3.3**. Main vegetable crops grown in the Valencian Community (VC), surface area and different values of N fertilizer used in the simulations: traditional farmer practice (TFP) and recommendations given in the VC code of Good Agriculture Practices (GAP) for surface and drip irrigation systems.*

CROP	Surface (ha)	TFP N-fert applied (N, kg/ha)	GAP: N target levels (kg/ha) for surface irrigation	GAP: N target levels (kg/ha) for drip irrigation
Artichoke	4638	110-300	250-300	200-240
Cauliflower/broccoli	4065	250-350	-	-
Watermelon	2996	180-300	200-250	160-200
Lettuce	2722	150-200	150-220	120-175
potato	1918	300 - 350	250-300	200-240
Melon	1866	180-300	200-250	160-200
onion	1826	200 - 300	200-250	160-200
Tomato	1601	200-300	200-250	160-200
Escarole	828	150-200	-	-
Pepper	658	180-200	-	-
Cabbage	586	250-350	-	-

***Table 3.4.** Comparison of the cumulative values of N related parameters and gross margin in two drip irrigated (rotations 1 and 2) and one furrow irrigated (rotation 3) crop rotations, with the N levels of the assumed traditional farmer practices (TFP) and those corresponding to the assumed good agricultural practices (GAP). Vegetables grown in crop rotation 1: artichoke, lettuce, broccoli and melon; crop rotation 2: lettuce, watermelon, cabbage, escarole, pepper, broccoli and melon; crop rotation 3: potato, watermelon, onion, cauliflower and watermelon.*

Crop rotation 1	**TFP**	**GAP**	**Units**	**Difference %**
Inorganic N fertilizer	723	486	kg N/ha	-32.8
N irrigation	110	93	kg N/ha	-15.5
N mineralised	336	331	kg N/ha	-1.5
N uptake	843	767	kg N/ha	-9
N leached (90cm)	291	193	kg N/ha	-33.7
N Gaseous loss	241	187	kg N/ha	-22.4
Days leaching (>0.1)	478	334	days	-30.1
Gross Margin	48100	46900	Eu/ha	-2.5
Crop rotation 2	**TFP**	**GAP**	**Units**	**Difference %**
Inorganic N-fertilizer	1440	833	kg N/ha	-42.1

N irrigation	166	139	kg N/ha	-16.3
N mineralised	486	481	kg N/ha	-1
N uptake	1210	1180	kg N/ha	-2.5
N leached (90cm)	712	303	kg N/ha	-57.4
N Gaseous loss	387	247	kg N/ha	-36.2
Days leaching (>0.1)	815	501	days	-38.5
Gross Margin	89100	84100	Eu/ha	-5.6
Crop rotation 3	**TFP**	**GAP**	**Units**	**Difference %**
Inorganic N-fertilizer	1530	729	kg N/ha	-52.3
N irrigation	124	124	kg N/ha	0
N mineralised	583	568	kg N/ha	-2.5
N uptake	933	909	kg N/ha	-2.6
N leached (90cm)	788	400	kg N/ha	-49.2
N Gaseous loss	335	159	kg N/ha	-52.5
Days leaching (>0.1)	517	503	days	-2.7
Gross Margin	33600	32800	Eu/ha	-2.7

***Table 3.5** Dry matter (t/ha), marketable yield (t/ha) and mineral N applied as fertilizer (kg/ha) according to the assumed traditional farmer pratices (TFP), the good agricultural practices (GAP), the optimisation done by Eurotate_N mode and the target N values of the N min system.*

	TFP			**GAP**		
Crop sequence	**Dry Matter**	**Yield**	**Nmin-Fert**	**Dry Matter**	**Yield**	**Nmin-Fert**
Potato	9	16	325	9	17	206
Watermelon	9.3	106	300	8.8	101	141
Cauliflower	7.5	29	300	7.1	32	166
Onion	8.8	60	300	8.1	57	160
Watermelon	9.5	108	300	8.8	100	56
	EUrotate optimisation			**N min system**		
Crop sequence	**Dry Matter**	**Yield**	**Nmin-Fert**	**Dry Matter**	**Yield**	**Nmin-Fert**
Potato	8.6	18	50	8.6	18	66
Watermelon	9.1	104	190	9.3	106	231
Cauliflower	7.2	31	100	7.9	28	485
Onion	8.7	60	160	7.4	52	54
Watermelon	-	-	-	9.5	109	258

Farm level conclusions

It is common practice across the Valencian Community to use more fertilizer than recommended. Simply reducing applications of mineral N fertilizer would result in significant cost savings, thereby increasing the gross margin with almost no impact on yield. In addition, the implementation of GAP provides an additional quality label to counter consumers concerns regarding the nitrate content in fresh vegetables. This “label” could potentially increase the price of the products in the market. In conclusion, a simple reduction of between 30-50% in applications of nitrogen fertilizer could result in increased income for farmers, less environmental pollution and better consumer perception regarding quality.

Policy makers conclusions
The adoption of the GAP by farmers has shown important environmental benefits in relation with N losses to groundwater and to the atmosphere. In contrast, the increasing concern of the European Union about food security and, specifically, about the effects of nitrate from vegetables on human health, demands that the intensive N fertilizer vegetable crops are treated with a more reasonable fertilisation. To achieve this, policy makers in Spain should stimulate the adoption of the GAP at a field level, with restrictive fertilization and traceability related policies and also, promoting the consumption of products coming from those farms where the GAP are implemented. It is important to extend recommended or reference N levels to other vegetables, where N recommendation levels are not yet available. Therefore, research at a field level must be promoted to obtain the reference values for more vegetable crops and also, in order to investigate whether or not the present recommended rates in the GAP code are still too high under certain conditions of soil, climate, irrigation system and agronomical practices.

The simulated scenarios also showed the importance of an adequate irrigation management for N use optimisation. In this sense, changing from traditional irrigation systems (furrow and surface irrigation) to frequent irrigation such drip irrigation systems, would allow a more accurate irrigation scheduling and a higher water and nutrient application efficiency. Policies encouraging and promoting the adoption of advanced irrigation technology are, therefore, of great importance for the optimisation of N fertilisation in the vegetable areas of the Valencian Community.

3.4.3 Norway

Work in 2006 involved performing the simulations of typical vegetable rotations for Norwegian conditions, using recommended and assumed current practice levels of N fertilizer use. Simulations were performed for about 15 rotations, distributed among the four main vegetable growing districts in the country.

Methods
Scenarios have been run for situations that are likely to affect nitrogen use efficiency and consequently give rise to varying risks of leaching losses, such as location, rotation length and nitrogen fertilizer intensity.

Most farmers have restricted access to alternative areas with suitable soil for growing vegetables, which results in short crop rotations. This may increase leaching risks, as many vegetable crops receive high N inputs and most leave significant amounts of crop residue on the field, from which N may be lost during the winter period.

The vegetable-growing districts of Norway differ with respect to both the water-holding capacity of their soils and the risk of leaching associated with their winter climate. Though neither of these factors may be governed in practice, information on their relative effects on N use efficiency may be of interest to policy-makers concerned with encouraging environmentally sound production methods.

Surveys of current grower practice have revealed that levels of N fertilizer to vegetables often exceed norms set by the Norwegian Institute for Agricultural and Environmental Research. The reasons for this include a desire to safeguard against deficiencies as well as a tendency to overestimate the expected/target yield level (to which current recommendations are linked). Growers make little use of N-min measurements, as small field size and limited time in spring combine to make this impracticable and costly. The modelling approach is an effective way of taking into account previous leaching losses and N mineralization from crop residues. The following three scenarios are compared:

- 'Current recommendations' (current norms set according to yield level, based mainly on http://www.bioforsk.no/dok/senter/ost/ape/gjodslingshandbok/veksttabeller.html#gronnsaker).
- ' Current grower practice' (based on survey if available, otherwise on 'best guesses')

The current location of vegetable production in Norway is dominantly in three main districts:

East (inland area north of Oslo): 24% of the total vegetable area is located here, mostly on deeper, more retentive soils (loams and sandy silts). The average vegetable area per farm is about 5 ha here, and they are mostly grown in long rotations as the total area per farm is far normally not a limiting factor. Some growers also rent land. The most common rotations include cereals and often potatoes. The precipitation in this area is around 600 mm/yr and the winter climate is fairly stable, with long periods of frost and snow. This, together with the deeper soils and longer rotations in the area, probably reduces the risk of leaching during the winter period. However, late soil warming in spring limits the growing of early vegetables.

East (coastal area south of Oslo): 48% of the total vegetable area is located here, mostly on light, shallow soils (sands and silty sand). The average vegetable area per farm is about 5 ha here also, but they are mostly grown in short rotations as the total area per farm is limited. The precipitation in this area is around 850 mm/yr and the winter climate is variable. There has been a tendency in recent years to concentrate vegetable production in this area, mainly for economic reasons connected with ease of transport to processing factories etc.

South/South-West (coastal areas): 17% of the total vegetable area is located here, mostly on light, shallow soils (sands and silty sand). The average vegetable area per farm is <3 ha, and they are grown in short rotations as the total area per farm is limited. Mostly early vegetables are grown here. The precipitation in this area is around 1350 mm/yr and the winter climate is mild, with high associated risks of leaching. A summary of vegetable growing shows:

- Vegetable growing in Norway is concentrated in eastern, southern and southwestern Norway. Climatic conditions differ between these regions, with cold winters and short, relatively dry growing seasons in the east, as opposed to generally milder and wetter in the south and southwest. Soil types vary, with loams in the northern part of eastern Norway, and sandy loams or sands in other regions. Vegetable rotation intensity is lowest in the east (north of Oslo), due to higher land availability. Early vegetable crops are grown mostly in the regions south of Oslo, and often in short rotations, due to limited land availability.
- A total of 15 vegetable crop rotations were used in the scenarios, chosen to represent different intensities of production with crops that have contrasting N requirements. A cereal-potato rotation was included for calibration purposes and for comparison. The scenarios for each region included only those rotations that are feasible in each case. Simulations were performed at both recommended and current grower fertilizer rates. Details of rotations, cropping dates and fertilizer application are given in Appendices.
- For the inland eastern region north of Oslo, rotations with up to 50% vegetables were selected. Annual leaching from a cereal-potato rotation was about 35 kg/ha, which is close to values measured in the region. Inclusion of cabbage or onions in the 6-year rotation increased this by about 25%, whilst inclusion of swedes reduced it. Carrots were also found to give low leaching. Growing both cabbage and onion gave >50% more leaching and the inclusion of cauliflower as well almost doubled it. The percentage difference in leaching between soils with contrasting moisture retentivity was similar in rotations with no vegetables as in rotations with 50% vegetables.
- For the coastal eastern region south of Oslo, simulations were performed for similar with 50% vegetables, but in this case both main-season and early-season crops were compared. Despite lower soil organic matter, both the annual leaching was about 10-20% higher here than in the inland region. Early-season crops involved lower N fertilizer use, but gave about the same amount of leaching as main-season crops, probably due to lower harvest indexes and/or longer periods with bare soil. The inclusion of peas instead of one of the other vegetables reduced leaching somewhat.
- More intensive vegetable rotations, with vegetables in 4 out of 6 years, gave higher amounts of leaching both in the eastern region and in southerly regions.

For both rotations simulated, the leaching was about 40% lower in the eastern region than further south, due to the milder, wetter climate in the latter regions. About 5-10% more leaching was simulated from a sandy soil than from a sandy loam in all regions. The highest leaching was associated with the growing of early brassica crops. The simulated levels agree with measurements made in stream water in southern Norway.

- Simulations performed with assumed grower levels of N fertilizer, as opposed to the recommended rates, resulted in all cases in considerably more leaching. In the eastern region, there was almost no change in the calculated gross margins, except in rotations with onions. However, the model has been shown before to over-predict responses to N shortage in this crop. In the southerly regions, on the other hand, higher gross margins were simulated in most cases with grower N levels.
- Three alternative indices of leaching risk were calculated for each simulation case, by relating leaching to either the amount of N fertilizer, the N offtake or the gross margin. In relation to N fertilizer use and N offtake, leaching risk increased them frequency of vegetables in the rotation, but the same was not true in relation to gross margins. This has implications in relation to possible taxation of environmental costs of production.

Farm level conclusions

In conclusion, at farm level the simulations suggest that farmers gain little in terms of gross margins by using higher than the recommended N fertilizer rates in the main vegetable-growing regions of eastern Norway. In more southerly regions, on the other hand, the recommended rates may be too low in some cases, at least when applied in the traditional way, with a relatively large dose in early season. In fact, local advisers in these regions are known to recommend higher fertilizer rates. This finding confirms the need for alternative practices, such as the use of slow-release N fertilizer, which is currently receiving attention in southern Norway. The use of autumn-sown, deep-rooting catch crops is another alternative that should be used more in these regions.

In the inland region, on the other hand, the use of catch crops is limited by the time available for crop establishment and the high risk of frost kill. Here, cropping sequence is an important factor in relation to optimising the N uptake by crops following those with large N residues. These simulations suggest that the growing of swedes or carrots after cabbage or cauliflower is a means of reducing N leaching from vegetable rotations. The simulations showed that it takes a relatively long time before leaching occurs under the relatively dry inland conditions, so that the use of soil N monitoring on vegetable fields may be justified. So far, this has not been practiced by vegetable growers in Norway, due to small field size, high soil variability and the short time available for sampling in spring.

Policy level conclusions

At policy level, the simulations clearly show the difference in leaching level between regions with different climate, between soils with contrasting moisture retention and between rotational types. In practice, however the location and type of cropping is determined by crop requirements in terms of climate suitability and by economic factors such as proximity to processing industry than by environmental considerations. It is an unfortunate but largely unavoidable fact that vegetable production in Norway is located in high-risk areas.

3.4.4 Germany – Baden-Wurttemberg

Vegetable production in Baden-Wurttemberg covers 9900 hectares and includes 2475 farms and includes a wide variety of vegetables. Eight crops account for 66% of the vegetables grown: lamb's lettuce 11%, white cabbage 10%, head lettuce 10%, onion 10%, carrot 9%, cucumber for pickling 6%, French bean 5% and cauliflower 5%. Vegetables in this region are often grown in rotations with cereals or other agricultural cash crops and field swapping with neighbours is also practiced, but not that frequent. Some farms produce for the local market in intensive or extensive crop rotations.

Traditional farmers practice

Traditional farmers practice (TFP) represents the experience-based approach to fertilizer recommendations where the farmer has gained experience over the years and uses that to formulate their own fertilizer rates. This farmer probably has no knowledge of the mineral N content of his soil and reacts simply by monitoring the performance of his crop. Within the model this strategy is simulated by applying the crop specific target value of the official Baden-Wurttemberg fertilizer recommendation without consideration of the soil mineral N content. A reduction of 20% of the target value is applied to take into account the farmer's experience with soil organic matter mineralization.

TFP suggests that farmers use on average 516 kg N fertilizer in their rotations (over a three year period). This would result in 399 kg N ha^{-1} leached below 90 cm and a gaseous loss of 20 kg N ha^{-1} per rotation. To counter this, 33 kg N ha^{-1} would be recovered from below 90 cm by crop roots during a rotation. Mean annual gross margin for all rotations was calculated as 3749 € a^{-1}. Assuming that all farmers produce their vegetables according to traditional practice and fertilise amounts of N corresponding to the crop's respective target value minus 20%, the average N loss per year via leaching and gaseous phase would sum up to 1473 t N a^{-1} for the region of Baden-Wurttemberg. This corresponds to a hectare loss of 95 kg N ha^{-1} a^{-1}.

Good Agricultural Practice

In Germany, Good Agricultural Practice (GAP) is followed when fertilisation follows current state-of-art knowledge and technology which means adhering to the official fertilizer recommendations. The simplest technique for determining the crop fertilizer demand is based on a crop specific target value and the soil mineral N status in spring (Wehrmann and Scharpf, 1979) and takes into account that crop available N during the season is made up of both fertilised N and mineral N already present in the rooted volume of the soil. This method has been a large step towards ecologically and economically sound fertilising strategies, since available soil N can take considerable values already at the time of sowing or planting of the crop. However, this method involves additional effort and costs for the farmer which may explain why it is not practised all over the country.

Fertilizer rates according to Good Agricultural Practice would lead to an average application of 283 kg N in the simulated rotations over a three year period. As a result leaching below 90 cm would amount to 220 kg N ha^{-1} and gaseous losses 11 kg N ha^{-1} per rotation. Recovery from below 90 cm by crop roots was calculated as 26 kg N ha^{-1} during a rotation. Mean annual gross margin for all rotations under GAP scheme was calculated as 3768 € a^{-1}. Providing that all farmers produce their vegetables according to GAP and apply N corresponding to the crop's respective target value minus the amount of mineral N available in the soil before sowing or planting, the average N loss per year via leaching and gaseous phase would sum up to 672 t N a^{-1} for the region of Baden-Wurttemberg. This corresponds to a hectare loss of 43 kg N ha^{-1} a^{-1}.

Model derived fertiliser recommendations (MOD)

An even more advanced method for the derivation of fertilizer recommendations is the use of a mechanistic model for the dynamic simulation of the water and N cycle in crop and soil. All relevant processes that affect the turn-over and translocation of N in the system are considered. Crop N demand can be calculated by simulating the growth of the respective crop and its N uptake during its lifetime. N and water deficiency give a feed-back to crop growth and would lead to lesser growth than under optimal conditions. An iteration process, beginning with no fertilizer application and proceeding with increasing applications enables the determination of the optimal fertilizer application for unlimited crop growth.

When this approach is used and GAP is followed the average fertilizer use is 91 kg N in the model farm rotations. This would result in 62 kg N ha^{-1} leaching below 90 cm and 11 kg N ha^{-1} being loss in a gaseous form. Recovery from below 90 cm by crop roots was calculated as 25 kg N ha^{-1} during a rotation. Mean annual gross margin for all rotations was calculated as 3890 € a^{-1}. Providing that all farmers produce their vegetables according to the recommendations of the simulation model, the average N loss per year via leaching and gaseous phase would sum up to 165 t N a^{-1} for the region of Baden-Wurttemberg. This corresponds to a hectare loss of only 11 kg N ha^{-1} a^{-1}.

Scenario comparisons

The conclusions from scenario simulations suggest that the use of nitrogen fertilizer could be reduced which would result in a reduction in leaching. Though, problems with simulating the movement of water and N in the soil may have over-estimated the reductions , the high reductions possible suggest that this approach is worth persevering with. In comparison to the GAP standard in Germany (Nmin-method) the use of the EU-Rotate_N simulation model offers the following improvements:

- Mineralization of crop residues and their potential contribution to the nutrition of the succeeding crop is considered

- Site properties as climate, soil texture, soil organic matter content and soil reaction and their impact on the site specific N supply are considered
- Crop properties as rooting depth, rooting density, specific coefficients for evapotranspiration calculation and their impact on soil water dynamics are considered
- Crop N supply from depth below 90cm is considered (particularly important for fertilizer recommendations in rotations with deep rooted cash and cover crops)
- Climate and tissue quality effects on added organic matter (crop residues, organic fertilizers) are considered

Where soils are rich in organic matter and crop residues with high N contents are incorporated these improvements promise a better way of adjusting fertilizer applications compared with experience or GAP. However, trusting such a precise calculation of crop fertilizer demand also means bearing a risk of failure. Since fertilizer recommendation are based on ‘average’ weather data for a season, if the weather turns out to be abnormally warm or cold, recommendations could be too low. A cold year would lead to less mineralization and thus lower N supply to the crop while a warm year would lead to higher mineralization, which is prone to leaching, and may be translocated out of the reach of crop roots. In non-irrigated conditions unexpectedly high or low precipitation amounts could spoil the recommendation given by the model.

Farm level conclusions

At farm level, the comparison of fertilizer strategies shows the benefit of the Nmin system for the farmer. The adjusted fertilizer rates, are on average, less than half of the traditional ones which results in reduced variable costs. Yield levels remain the same while N losses per year and hectare are significantly reduced. Using the Nmin system does result in extra costs for sampling and analysing the soil, however, the savings in fertilizer costs covers these expenses, provided that low-cost local advisory service and laboratories are available. Using the simulation model does not incur extra costs, however, the use of the model in its present form is restricted to trained personnel as access to good data is required for sensible recommendations. The model can also be used as an educational tool in addition to its primary function. Advisors can show the farmer effects of hypothetical case studies on-screen and underline sensible strategies that otherwise would be hard to communicate. Simple what-if scenarios such as the positioning of certain crops in the rotation, the use of alternative catch crops or the reduction or timing of fertilizer applications can be demonstrated. In some cases, we suggest that educational use of the model might be more valuable and effective than use for generating fertilizer recommendations.

Policy level conclusions

At policy level at a regional scale there is particular interest on the environmental aspects of the vegetable production. The implementation of the Nmin system has had a clear effect on the environmental impact of field vegetable production according to the case study. With the help of scaling procedures like the one presented in this study, farm level demonstrations can also be calculated for larger-scale areas and support policy-makers in finding effective methods of assessing nitrogen use by region.

3.4.5 Denmark

In Denmark, vegetable production is generally spread across the country with just a few intensive areas. We chose to work with the two main soil and climate regions in Denmark representing the greatest area of vegetable production: conditions of western Denmark (WD) with high precipitation and sandy soils leading to intensive leaching loss, and of eastern Denmark (ED) with lower precipitation and sandy loam soils and thus less intensive leaching. The fact that the Danish vegetable production is scattered around the country means that it occurs in areas and rotations with many cereal and other less intensive crops. This offers a special set of possibilities for using catch crops and other crops to reduce leaching loss from vegetable production, and for optimizing rotations.

Table 3.6. *Rotations tested in Danish scenario simulations*

Rotation type	Crop rotation
Ext: Five-year relatively extensive vegetable rotation with vegetables in only two out of five years. The rotation includes white cabbage and winter wheat as deep rooted species.	barley – winter wheat – white cabbage – barley+ryegrass – cauliflower
Int: Five-year intensive vegetable rotation with vegetables in four out of five years. In two of the years two lettuce crops are grown, and no deep rooted crops are included in the rotation.	barley+ryegrass – lettuce/lettuce – lettuce/lettuce – onion – onion

In Denmark, nitrogen fertilization is strongly regulated by law. The basic principle is that farmers are allowed to use only 90% of optimal N supply for their crops. Quotas are calculated on a field basis, but granted at a farm basis. This allows vegetable farmers to "redistribute fertilizer N" among their crops, and add more N to the high value vegetable crops in their rotations and less to cereals, in an attempt to optimize their income. Another aspect of Danish N regulations is that farmers must grow autumn catch crops on typically 10% of their area to reduce leaching losses.

The Danish scenarios simulations are directed towards testing the effect of the current Danish legislation. Focus was given to the use and optimization of catch crops, as by now the research base and general experience with catch crops in Denmark is considerable, and economic analysis has shown catch crops to be a cost effective way to reduce N leaching loss.

Aims and objectives

The aim was to test the robustness of the current Danish N regulations and its effect on farm economics and nitrogen losses to the environment. A second aim was see if current regulations could be improved, mainly through improved utilization and management of catch crops.

Results

Before interpreting the outcome of the simulations, a word of caution: Model work contains uncertainties, and smaller differences should not be interpreted as significant. No attempt was made to fine tune economic estimates in these Danish simulations, and economic output should only be used to illustrate trends between the scenarios, not to predict real economic output of the strategies tested.

The results show N utilization and gross margin (GM) to be higher on sandy loam soils (ED) than on sandy soils with high leaching losses (see tables 1.3.6 and 1.3.7). They also show the intensive rotation with more vegetable crops to a higher GM per hectare than the more extensive rotation. Both of these trends are in agreement with expected system performance.

Table 3.7. *Summary information the Danish intensive vegetable rotation. Except in S2 and S3 the all scenarios were fertilized according to GAP regulations. In S4 N was redistributed towards the high value vegetable crops, in the others it was added as recommended for each field.*

	S1 GAP	S2 GAP+ 10% N	S3 GAP+ 40% N	S4 N di-rected to vegetabl e.	S5 No catch crop	S6 Deep rooted catch crop
WD: Sandy soil						
Marketable N upt. (kg N/ha/year)	122	126	133	111	123	121
Net N leaching (kg N/ha/year)	162	179	261	174	164	163
GM vs. N leaching (EURO/kg N lost)	88	82	60	84	89	87
Gross margin (EURO/ha/year)	14256	14678	15660	14616	14596	14181
ED: Sandy loam soil						
Marketable N upt. (kg N/ha/year)	136	137	139	125	137	136
Net N leaching (kg N/ha/year)	185	205	290	197	187	181
GM vs. N leaching (EURO/kg N lost)	89	81	59	84	89	90
Gross margin (EURO/ha/year)	16410	16580	15660	17130	16580	16520

The clearest result of the simulations is found in the effect of fertilizer level. Though the GM is slightly increased by going above GAP N levels, this occurs at the cost of clearly increased N leaching losses. Redirecting the farm N quota towards vegetable crops tended to increase GM slightly with little effect on N leaching losses. Thus it does not seem to be a problem that farmers use this flexibility in the regulations, rather than applying N exactly the calculated rates.

***Table 3.8**. Summary information the Danish extensive vegetable rotation. Except in S2 and S3 the all scenarios were fertilized according to GAP regulations. In S4 N was redistributed towards the high value vegetable crops, in the others it was added as recommended for each field.*

	S1 GAP	S2 GAP +10 % N	S3 GAP +40 % N	S4 N directed to vege-tables	S5 No catc h crop	S9 Best catch crop sce-nario
WD: Sandy soil						
Marketable N upt. (kg N/ha/year)	145	150	161	137	142	148
Net N leaching (kg N/ha/year)	92	107	145	101	98	79
GM vs. N leaching (EURO/kg N lost)	31	28	22	32	28	38
Gross margin (EURO/ha/year)	2852	2996	3190	3232	2744	3002
ED: Sandy loam soil						
Marketable N upt. (kg N/ha/year)	157	160	170	158	155	160
Net N leaching (kg N/ha/year)	115	132	171	113	122	101
GM vs. N leaching (EURO/kg N lost)	30	27	21	32	28	35
Gross margin (EURO/ha/year)	3450	3564	3591	3616	3416	3535

The effects of catch crops were good but somewhat variable. Catch crops clearly reduce leaching loss, but the effect on crop yields and GM varies. In the extensive rotation catch crops could be used with good effects on economy as well as the environment. This rotation allowed many possibilities for improving catch crop use further. The intensive rotation left few possibilities for optimizing catch crop use, leading to slight decrease in GM and limited environmental effect. But even in the intensive rotation catch crops were a relatively cost efficient way of reducing leaching loss.

The results obtained in the Int rotation show that further improvement in catch crop practices could be needed here, or the rotations should maybe be changed somewhat to allow better use of catch crops.

Farm level conclusions

The results indicate that it makes good sense for farmers to redirect their N quota towards the vegetable crops. It is worth accepting a limited yield reduction in cereal crops if it reduces the risk of any yield loss in the economically more important vegetable crops.

The results indicate that it could be valuable for farmers to grow catch crops, when in general they have too little N for their main crops. Growing catch crops on a larger area than required by regulations may be valuable to them. The catch crops can help them reduce N losses, and direct the N towards their main crops instead. However, catch crops should not just be grown as easily and cheaply as possible, but the catch crop management should be optimized by selection of species, placement in the rotation and incorporation time, to achieve the good effects.

In some rotations as in the intensive rotation of these simulations, it can be difficult to grow catch crops in an optimal way, and some economic losses can occur. Under these conditions farmers should consider to change their rotations to allow a better use of catch crop, to make the catch crops they must grow (due to the regulations) an advantage rather than a problem for them. Under Danish conditions this will often be possible, as it will almost always be possible to include more land in the vegetable production and then maintain the farm vegetable production by producing in less intensive rotations on a larger total area of land.

Policy level conclusions

The results indicate that the current regulation of N fertilization in vegetable systems in general makes good sense. The N quotas may be a bit too strict for high value crops as vegetables, as even though they can normally be fertilized optimally within the current restrictions, the cost in the situations when this is not the case may be considerable. Allowing farmers to redirect fertilizer N from cereal crops to vegetable crops within their rotations allow them to reduce this risk, and the negative environmental effects of this seem to be very small.

The results also show catch crops to be an efficient way of reducing N leaching losses, and in accordance with previous analysis, catch crops do this at a relatively low cost compared to most other measures. Forcing farmers to grown more catch crops than the current regulations is one option to reduce N leaching losses from vegetable rotations. However, in some rotations including further catch crops may be difficult or very expensive as it may reduce the possibilities of growing the vegetables the farmers want to grow. It could also be very difficult to optimize catch crop management through strict regulations. Thus if more catch crops are to be grown, it might be better to work with incentives (subsidies for growing catch crops or penalties for not doing so), and then let farmers find out how to optimize this on their own farms.

3.4.6 Italy

Many regions contribute to vegetable production in Italy, but the most important are, in decreasing order: Puglia, Campania, Sicilia, Emilia-Romagna, Lazio and Veneto. The main crops are by far tomato and potato, followed in decreasing order by artichoke, lettuce, pepper, zucchine, common bean. In the last two decades potato, artichoke, bean and pepper importance has decreased in favour of tomato, melon, radicchio, lettuce and carrots, with rising vegetable outputs in Trentino, Liguria and Marche, but otherways the regional and crop distribution has remained remarkably stable.

Rotations of vegetables with different crop types (e.g. cereals, fodder crops, etc.) are more likely practiced in the horticultural areas of Emilia-Romagna and Puglia, due to larger than average farm sizes. In Campania, Sicilia and other Southern regions, the favourable climatic conditions for vegetable growing tend to be more intensively exploited, since even large farms growing vegetables tend to specialise in vegetable rotations. In this case intercrops, where used, are represented mainly by maize in Campania and by durum wheat in Puglia.

Irrigation is common everywhere for vegetable crops and the relevant resource in Southern regions is groundwater, with high salinity becoming a problem of many coastal areas aquifers.

Climate, soils, crop sequences, irrigation and fertilization practices allow for substantial risk of N leaching in at least some part of the year in any of the various contexts. Factors of direct impact of N fertilization are amount by crop, application forms and timing, previous crop residues, irrigation methods and rainfall seasonal concentration.

Management strategies

In Italy recommendations have been devised at various levels of detail, depending on crop and agricultural system, and made binding in order to qualify for subsidies from regional authorities. Recommendations for fertilizer use take into account a range of indicators for soil, irrigation, actual and previous crop, presumed or target yield level, etc. These recommendations can be regarded as a code for good agricultural practices (GAP). However, Italian farmers have a liberal approach to N fertilizer use, which results in them generally exceeding recommended rates. From interviews with representative farmers and fertilizer sellers considerable information on the farmer's preferred management strategy is available.

The EU-Rotate_N model has been used to evaluate on different soil types (heavy vs light) the effects of rotations and N fertilisation practices on N losses in the environment, biomass production and economic returns. The chosen environment is a coastal plain of the Campania region (Italy), with a mild climate and dry summers. TFP has been compared with the regional version of good agricultural practices (GAP) and with a model recommendation (KNS), using two fertilizer types (ammonium nitrate vs exclusively nitric) on rotations of four crops: cabbage, lettuce, fennel and spinach. Responses of interest have been compared as time profiles and yearly averages.
The KNS trigger was enabled from transplanting to ten days before harvesting and disabled for one day after each N application. Allowed fertilizer applications were in the range 30-100 kg/ha. Rotations were run twice, starting at the Julian day 250 (first week of September), but only the two years of the second cycle have been considered for results. Between successive crops fallow cultivation and natural weeds were allowed.

The soil was occupied by crops for about 50% of the year (slightly less by the rotation starting with cabbage and slightly more by the rotation starting with lettuce) and for a quarter of the year each by natural weeds (in winter) and fallow (in summer) following soil incorporation of crop residues after harvesting. Simulations results showed considerable effects of rotation, crop timing, soil type and N input management on both economic returns and N leaching and volatilization. N losses appeared to be a severe problem mainly for the light soil type, where N dynamic is more intense. Regardless of soil type, N leaching was shown to be significantly mitigated by TFP with optimal matches of crop type and season, which also increased returns, while GAP proved only marginally better in reducing N leaching, but at the price of halving returns. As N leaching as a proportion of available N peaked in winter, it can be expected that winter cover crops, feasible in a mild climate, might be very useful to reduce the environmental impact of nitrogen from fertilizers.

Typical farmer practice vs GAP

TFP applied about 100 kg/ha of N per year more than the amount recommended by GAP, though exceeding maximum GAP ceilings only for cabbage and lettuce. Mineralization added about 150 kg/ha of N per year more in the loam than in the clay soil, thanks to a 3.5% organic matter content of the former, where mineralised N is around 100 kg/ha of N per year. Up to three applications were used for both strategies. N uptake by plants came out similar for soil types, while N leaching reached the maximum for the loam soil and whole nitrate N fertilizer. GAP, the clay soil and ammonia reduced N leaching, although forms with ammonia show a tendency to increase gaseous losses, so that total N losses were not modified by the N fertilizer form.

About 80% of available N came from fertilisation in the clay soil, compared to an average of 60% for the loam soil, where mineralization supplied the remaining two fifths. The wasted fraction of N, through leaching and gaseous losses, peak during winter months before the spring crop, much more for the loam than the clay soil, with no difference between farmer strategy and GAP, which in this case resulted even less efficient in reducing N losses.

GAP dry matter production did not vary with crop sequence, but TFP could take advantage of the rotation with season-sensitive crops in the most suitable season (cabbage and fennel as spring crops), with considerable increase of biomass and some reduction of N losses. At comparable dry matter outputs, N losses were higher in the loam soil, where the relatively high organic matter content, rather extreme for this type of soil, enhanced N dynamic through the high mineralization rate. In this situation GAP appeared not effective in reducing N losses, which even exceed N inputs. On both soil types, in fact, GAP allowed a limited reduction of N losses in comparison with TFP, probably because of too low target yields.

The yearly N balance given by the simulation showed higher N uptake for TFP and the rotation starting with lettuce, apart from substantial more leaching on the loam and slightly higher gas losses on the clay soil. Up to 100 kg/ha of N are not accounted for by the considered N flows. Despite very different N losses, economic returns were similar for soil types. The TFP achieved higher returns, enhanced by the crop sequence with better season-crop matches (cabbage and fennel as spring crops, while lettuce and spinach appeared less affected by seasonality). This increased efficiency imply also a reduction of N leaching. On the contrary, GAP target yield recommendations prevented taking advantage of the more favourable season and resulted in uniformly high leaching and low returns with both rotations. For comparable returns N leaching was substantially higher on the lighter soil, both for GAP and TFP.

Typical farmer practice vs KNS model trigger

The KNS trigger improved dry matter growth slightly and yields but at the price of much higher N inputs, causing higher N losses in comparison with the TFP, by keeping substantial amounts of N in the soil in the leaky season. In particular, KNS triggered inputs were excessive in the first phase of the crop cycle. So, for comparable dry matter outputs and N uptake, the KNS trigger showed higher N losses, particularly in the rotation with better crop-season matches, where better crop growth in spring triggered an excessive model response in terms of N inputs.

Farm level conclusions

As a scenario tool the model allows the typical farmer to select a profitable and environmentally cautious behaviour, evaluating alternative crop sequences and N fertilisation practices. Our simulation, for example, showed that growing crops preferably in the season where they can reach full growth potential reduces significantly N leaching without sacrificing economic returns. It also highlights the higher risk of N leaching in light soils and winter seasons in the Mediterranean climate and the need for winter cover crops to mitigate the problem. Moreover, comparisons in terms of returns are very useful for weighting GAP advantages and disadvantages for the farmer.

Policy level conclusions

The GAP strategy did not fare well in our scenario runs, possibly because reference yields seem too low for allowed nitrogen rates. Anyway, GAP appears inadequate as the only measure for reducing nitrogen leaching in the more leaky situations of the Mediterranean environment (light soils and winter months). Guidelines for rotation planning and N application timing, preferably supported by the possibility of estimating N flows in the cropping system, as given by the EU-Rotate_N model, could be a very useful complement to GAP recommendations. Allowing for the need of some expertise for proper use, at least in the actual stage of its development, the model could be made accessible to farmers, if not used directly by them, through public and professional support services, where such expertise could be promoted.

4 DISCUSSION

4.1 Process of model integration

The advantages and disadvantages of what we did within this piece of work are important conclusions from the research. In many respects at the outset we were far too ambitious in our aims and the science led us in directions that could not easily be followed in the programming. At the outset the original intention was to only make minor changes to the original fortran code of the N_ABLE model. However it soon became apparent that this approach was too simple and would not allow the model to be usefully extended. In order to properly simulate the input of water from irrigation and to simulate the development of roots the soils needed to be split into smaller elements. As this was not envisaged when the original framework was designed it had to be largely re-designed to cope with the change.

The framework itself was to be very flexible but this was to lead to difficulties in wrapping the fortran parts of the model. Much code was required to identify the inputs and outputs of each module. These had to be strictly defined leading to limited later flexibility within the individual modules of the model without the need for reprogramming the shell. It was also envisaged that the inputs and outputs of the individual modules would automatically generate the graphical interface between the user and the model. This would however also need a large amount of editing to suit all potential users of the model as they would often not want to be concerned with all the data requirements at the sub model level – another programming overhead. All these steps became increasingly time consuming as the underlying fortran model evolved. In hindsight the model framework approach should only have been adopted using a mature model.

Whilst the development of the model framework did not work out as originally expected an integrated model was still produced which provided a model EU-Rotate_N with considerably extended capabilities compared with the original N_ABLE model.

4.2 The wider context: - the use of models to simulate economic and environmental effects.

One of the specific advantages of the EU-Rotate_N decision support system is the possibility to evaluate N losses from the simulated production system in the light of economic consequences to the farmer. It provides a unique platform for testing the effect of codes of good agricultural practice on crop, environmental and economic output of horticultural crop rotations and allowing the identification of leaky points and beneficial practices which can reduce their environmental impact..

Other evaluations of the economic and environmental impact (in terms of N leaching) of farmer's decisions or political measures range from very simple approaches based on yield and N leaching assessment with the help of non-feedback functions (Hasler, 1998) to quite advanced approaches using dynamic soil-crop-atmosphere models. The EPIC model includes an economic subroutine to determine net farm revenues. It is widely accepted in the USA and was used in combination with different approaches for specific problems at different scales: catchment level (Lakshminarayan et al., 1995), farm level

(Hughes et al., 1995; Teague et al., 1995; Kelly et al., 1996), and field level (Johnson et al., 1991; Rejesus and Hornbaker, 1999).

In Europe, other models were used for this purpose: Vatn et al. (1999) linked the SOIL-SOILN (Johnsson et al., 1987; Jansson, 1991) model to an agent-based approach for economic farm revenues and presented the ECECMOD framework (Vaten et al 2002). The FASSET framework was recently introduced (Berntsen et al., 2003), being able to calculate a number of economic and ecological indicators for livestock and cash crop farms for simultaneous analysis. Turpin et al. (2005) used a framework of different deterministic catchment models and alternative approaches for cost assessment of Best Management Practices (BMPs) in European watersheds. In the approach used by Rossing et al. (1997) the rule-based decision simulator for on-farm work processes OTELO (Attonaty et al., 1993) was included in the field-level framework for crop management.

In Italy the CropSyst model has been successfully linked with GIS data to investigate the production and environmental effects of a whole range of alternative criteria (Donatelli; et al 1998, Fares, 2003 Morari et al 2004). In the Mincio River Basin (NE Italy) criteria such as irrigation and nitrogen fertiliser efficiency have been tested allowing crop yields to be improved with 50% reductions in irrigation and nitrogen requirement.

The STICS scaling approach has been also used in France to assess GAP effectiveness over a seven-year period showing that such a practice did reduce nitrate leaching, but not yet at a satisfactory level (Schnebelen et al, 2004).

Policy impact investigations using combinations of agricultural sector models and nutrient leaching models can only be applied at national level (Lehtonen et al., 2007) and watershed level (Faeth et al., 1991; Schou et al., 2000; Ribaudo et al., 2001). At these scales trade-off between yield and gross margin can often not be realised (Turpin et al., 2005; Lehtonen et al., 2007), although also at field level this functional link may be neglected (Johnson et al., 1991).

Modelling of nitrogen cycling has historically focussed more on conventional than on specifically organic systems. Conventional farming occupies the majority of the land area (so providing a good market for a commercialised model) and optimisation of fertiliser applications offers a clear opportunity for assistance with decisions to be taken by the farmer. Although the same processes occur in both types of farming a model has to perform better to predict the flows of nitrogen under organic conditions as any shortcomings are not hidden by applications of artificial fertilisers.

The main role for models in organic systems is to help with rotation planning (although the application of permitted fertilisers and manures must also be optimised). A very simple approach was used to do this by ORGPLAN (Padel, 2002). This is basically a tool for predicting nutrient and financial budgets using a database of information. It is not very flexible. The FBC model (Cuttle, 2006) operates in a computer spreadsheet. The fertility building (ley) phase of the rotation is not actually modelled but appropriate starting conditions (length of ley, proportion of clover, cut for silage or cut and mulched etc) for the cash cropping phase are drawn from a database. This avoids many of the difficulties associated with the EU-Rotate_N approach of handling the recycling of N as a result of litter loss and mowing residues. However, it is also less able to deal with more complex rotations with several short term fertility building crops (common on field vegetable production). Both ORGPLAN and the FBC model were developed specifically for organic farming under UK conditions.

A more sophisticated approach has been used in the NDICEA model (Koopmans and Bokhorst, 2002; van der Burgt et al., 2006 (www.ndicea.nl). It was developed for use under Dutch conditions although meteorological and soil databases allow it to be used in other countries. This model does allow a more complex rotation to be built up but it does not include any of the economic aspects of EU-Rotate_N.

The EU-Rotate_N model with its ability to simulate field level scenarios in both organic and conventional rotations with dynamic feedback of gross margin to calculated dry matter yield makes it capabilities equivalent to EPIC and the ECECMOD and FASSET frameworks. However, focussing on crop rotations including vegetable crops EU-Rotate_N occupies an important niche. The only contender here is the NDICEA decision support system, mentioned earlier which is, however, unable to simulate reductions in yield due to lack of water or N.

Statistical aggregation procedures, such as the model farm approach we have used allows EU-Rotate_N to operate on larger spatial scales, making it a unique tool for impact assessment of horticulture to the environment on the regional or supra-regional level without loosing its ability to simulate the effects of differing fertilisation strategies.

4.3 Further work possible

Now that the EU-Rotate_N framework is in existence there are many areas where its performance and functionality can be enhanced. Section 3.1.1 listed some of the limitations that need to be taken into account when running the model. National programmes of research are able to fund some of the developments required. In many cases the performance of the model can be improved by paramaterising it more closely to the conditions and environment where it will be used. Some of the steps being taken by the project partners to these ends are shown in section 6.

Water routines

The implementation of a soil profile geometry that accounts for ridges would be a useful improvement of the model, since vegetables in Spain and other Southern European countries are often grown in ridges. This feature would provide better accuracy in simulations under Spanish conditions.

Some improvements could be made to the crop coefficients used for estimating potential evaporation, by adjusting the default length of individual growth phases using local information. Different approaches are required for a better prediction of water losses from bare soil and water movement into deeper soil layers.

Soil nitrogen dynamics

The module for soil nitrogen dynamics is based largely on the established DAISY model, and encompasses all important N processes and flows. Evaluations show that these are simulated in a logical manner, but there has been uncertainty about parameter values in some cases. Mineralisation in an organically-amended soil in southern Europe was underestimated, whilst that of soils with a high content of recalcitrant organic matter, as in northern Europe, may be over-estimated. A simple means is required of adjusting the model to such variations. Excessively rapid mineralisation of plant residues has also been indicated in some cases, suggesting that more work is needed to parametrise and/or document this aspect. The accumulation of soil organic matter from the growing of fertility building crops also needs to be improved.

Crop growth

The crop growth module is based on user-supplied targets expressed as total DM. This concept worked well in evaluations, as data for total DM was in all cases available. However the possibility of including target marketable yields on a fresh wt basis will be essential if the model is to be used by the grower. Further data is also required to improve the conversion of the outputs of the model into marketable yield. Whilst the target DM values limits potential growth, actual growth is limited by N availability in relation to crop-specific critical N% curves. The latter are well-documented for major crops, though some adjusting for local conditions may still be required. Evaluations have revealed examples of cases where the assumed critical N curves are too low (e.g. carrots) or too high (e.g. onion, cauliflower). For many vegetable crops they are based on rather few observations so further work is needed to expand the range of crops with reliable critical N curves.

Triggers in the model

Various triggers included in the model (irrigation strategy, fertilization by Nmin) were not relevant for the evaluation studies, but have been used with success in WP5. The option for N optimization was found by several users to underestimate N fertilizer requirements so some further work to improve its function would be beneficial.

Additional utilities

EU-Rotate_N does not have linkages with Geographical Information Systems but it is hoped that they will be developed in the future.

5. CONCLUSIONS

5.1 Model Developed

A new model has been written and tested which enables the economic and environmental performance of crop rotations in either conventional or organic cropping for a wide range of crops and growing conditions in Europe. The model though originally based on the N_ABLE model has been completely rewritten and contains new routines to simulate root development, the mineralisation and release of N from soil organic matter and crop residues, the effect of freezing, and water movement. New routines have also been added to estimate the effects of sub-optimal rates of N and spacing on the marketable outputs and gross margins. Model performance was tested against experimental results and broadly simulated the patterns of growth N response and N losses. The model provides a mechanism for comparing the relative effects of differing cropping and fertilisation practices on yield gross margin and losses of nitrogen through leaching. The running of a number of scenarios has demonstrated that nitrogen management can be improved in Europe by following at least Good Agricultural Practice but does provide the potential for suggesting improvements which have a minimal effect on gross margin whilst reducing nitrogen losses.

5.2 Scenario Results Farm and Policy Level

The main conclusion from the case studies is that existing codes of Good Agricultural Practice (GAP) already contain sufficient information to reduce N leaching from field vegetable production. However, the actual amounts of N that can be saved by enforcing the legislation can only be guessed at, since no country has reliable data on how many farmers actually follow GAP and how many don’t. Typical farm practice (TFP) normally involves higher levels of N application but the amounts applied depend on the individual farmer’s level of education and their access to information.

It can be concluded that many countries could reduce their nitrate leaching by following existing GAP codes; however, there are some countries, notably Italy and parts of Norway, where TFP is preferred to GAP to ensure productivity of quality vegetable crops. Adopting the strict Danish regulation of limiting nitrogen purchases to 90% of the crop’s requirement can be done with little economic loss to farmers, providing it is allowed to target nitrogen at the more economically important crops such as vegetables whilst reducing the overall farm inputs of nitrogen. However, countries like Norway, with difficult climatic conditions, would see little advantage in enforcing board brush GAP legislation as this would limit the productivity of the industry in some regions.

The following steps are recommended at Farm Level ;-

- Encourage over-wintered crop covers to be established where there is a risk of nitrate leaching
- Design crop rotations to maximise efficient use of nitrogen

- Consider using deeper rooted crops in rotations to limit accumulations of N at depth in soil profile.
- Use decision support tools such as mineral N sampling to make better allowances for available N in the soil.
- Consider encouraging the development of user friendly versions of the EU_Rotate-N model to help refine fertilizer and rotation practice

The following steps are recommended at Policy level ;-

- Encourage crop cover to be established over the winter in leaky situations
- Improve training of farmers so that they are able to follow GAP and to know how to make allowances safely where GAP is less appropriate.
- Consider further use of EU_Rotate-N to refine fertilizer practice
- Consider dynamic (taking into account seasonal and yield variations) rather than static regulations.
- Improve training of Policy makers so that they allow some flexibility to farmers following GAP in special circumstances.
- Use EU-Rotate_N to investigate the effect of modifying rotational practices in vulnerable catchments on N losses.

6. EXPLOITATION AND DISSEMINATION OF RESULTS

6.1 Model Release

The model has been released to the wider community in 2007 and is available as a set of files which can be downloaded to the users computer from the internet. These files include documents describing the model, based on the text in this report. There is a user guide providing instructions on how to use the model, the contents pages are reproduced in section 6.1.1 of this report. There are also a series of simple example files for users to work through as they begin to work with the model. One file itemises issues that users need to be aware of when using the model. Before access is provided everyone downloading the model from the internet site has to agree to a series of simple terms and conditions. These are reproduced in 6.1.2.

6.1.1 Extract of the User guide.

The user guide is split into 7 main sections:

7 BATCH FILE TO RUN THE MODEL

The getting started section provides a simple overview of the easiest way to start running the model using the example files provided. An excel spreadsheet tool provides a system for providing graphical outputs of yield and losses of nitrogen through leaching over cropping rotations.

For more advanced users the next sections explain how more complex input files can be created with rotations up to 30 years in length. The various triggers which can be used to control the amounts of nitrogen fertilisation and irrigation are explained. There is also a section describing a whole range of output files some of which can be used for more searching investigations of the leaky points within rotations other provide diagnostic outputs such as: data on N content of the nitrogen pools in the soil, distribution of water and roots with depth.

Setting up and first runs of the model

The model can be downloaded from EU-ROTATE_N web site www.warwick.ac.uk/go/eurotaten as a single ZIP file which contains:- .

- a folder containing 4 example cases;
- an executable file *EU-ROTATE_N_1-6.exe*;
- This user Manuel
- a dynamically linked library *salflibc.dll* from Salford software;
- a crop parameter file *CropTable1-6.txt*;
- a crop residue parameter file *ResidueTable1-6.txt*;
- an organic fertiliser parameter file *OrganicFertilisers1-6.txt*;
- an inorganic fertiliser parameter file *MineralFertilisers1-6.txt*,
- a weather data file *Weather.met*
- A brief description of the model in *Model Description.doc*
- A list of Known issues that need to be taken account of when running the model in *Known Issues.doc*

To run the model all the files need to be placed in the **same directory**. Set up an area on your computer where you want the model files to run.

There are two ways of running the model.

In WINDOWS: double click *EU-ROTATE_N_1-6.exe*, a blank screen appears and type on it the name of the input file, i.e T*est.dia* followed by return, the screen disappears and the output files appear in the same directory.

In MS-DOS: type *EU-ROTATE_N_1-6* followed by return, on the next line type the name of the input file, i.e T*est.dia* followed by return, output files appear in the same directory.

For the simple example file, *Test.dia* the model should take only a short time but it may take several minutes for crops containing long rotations of crops.

6.1.2 Access agreement for the model.

ACCESS RIGHTS TO USE EU-Rotate_N

IMPORTANT – READ CAREFULLY BEFORE USING THE "EU-Rotate_N SOFTWARE". By using the EU-Rotate_N SOFTWARE you are agreeing to the following:

1. GRANT OF ACCESS

The University of Warwick (whose administration offices are at University House, Coventry CV4 8UW, UK) on behalf of the consortium grants access to EU-Rotate_N ("the Software").

This Agreement permits you to use and make copies of the Software programs solely for your own use.

The consortium appreciates any feedback from the users of the Software and wishes to encourage its widest use.

The composition of the consortium can be seen at www.warwick.ac.uk/go/eurotaten The consortium can be contacted via the above address or eurotaten@warwick.ac.uk

2. COPYRIGHT

This Software was developed with EU funding under project QLK5-2002-01100. 'Development of a model based system to optimize nitrogen use in horticultural crop rotations across Europe'.

The information contained within the Software in no way reflects the views of the European Commission or its services.

All users of the Software must acknowledge the EU-Rotate_N consortium in all references/publications.

3. OTHER RESTRICTIONS

This Software is available for use in educational research institutions and not for profit organisations. Should you wish to commercialise its use please consult with the consortium via eurotaten@warwick.ac.uk .

4. LIMITED WARRANTY

The EU-Rotate_N model is ***as is*** and the consortium does not warrant that this is fit for a particular purpose and the users should accept this as a condition for using it.

The consortium is not responsible for any consequential or inconsequential losses arising from its use.

6.2 Dissemination

There have been a range of dissemination activities during the fourth reporting period. The final newsletter launches the model which will be available as a CD or downloadable from the Warwick HRI website. The final newsletter is appended. The website also provides considerable background information about the model, its description, and its use. A whole series of papers have been published during the life of the project, particularly the fourth reporting period and these are itemised at the end of this report.
Further pier reviewed papers will be presented to launch the model in the scientific community during 2007 and 2008. These will be written by all participants.

6.3 Exploitation

This will be based on a partner by partner basis as each partner has differing exploitation requirements and differing access to funds to support it.

6.3.1 WHRI - UK

Part of the matching funding for the EU-Rotate_N project comes from a Defra project which aims to improve nitrogen use over rotations of horticultural crops. The model will be further validated using data from this source. It is hoped that further work can be carried out to support improvement of the parameters for the EU-Rotate_N mineralisation routine under UK conditions. Meetings will be held with Defra during the summer of 2007 to promote the use of the EU-Rotate_N model and its further development in other projects.
Additionally some of the data collected for the EU-Rotate_N project will be used in the process of revising the National Fertiliser Recommendations for England Wales and Northern Ireland.

HDRA and Warwick HRI are working on a new UK DEFRA funded project *Fertility management strategies in organic arable and vegetable production* (OF 0363) – See HDRA Section.

6.3.2 IVIA – Spain

A new demonstration project was approved by the Spanish INIA (Instituto Nacional de Investigaciones Agrarias) for years 2007-2008 in which the traditional fertiliser N application will be compared with the Nmin method, in several important vegetable crop rotations in the Valencian Community. Data obtained from this project will be used for further testing of the EU-Rotate_N model under Spanish conditions.

Also, a research proposal is being prepared in which several Spanish groups from different regions (Andalusia, Extremadura, La Rioja, Navarra, Catalunya, and Valencia) will test the performance of EU-Rotate_N for important vegetable crop rotations in their respective areas. Since many of these research groups have been collaborating in another research project during the 2005-2007 period on water and nitrogen management in vegetable crop rotations, data from these field experiments will also be used in the new project for EU-Rotate_N model testing. An improvement of many crop parameters for the most important vegetables grown on those regions is expected. All this testing work is considered to be necessary before the application of the model by the technical farmers' advisors.

A comparison between the EU-Rotate_N model with other models such as NLEAP (Nitrogen Leaching Economic Analysis Package) developed in the Agricultural Research Service of Colorado (USA) is also being prepared.

6.3.3 BIOFORSK - Norway.

Bioforsk have funding to follow up the project to see how the model can be used. It will be useful in creating/updating fertilizer recommendations for which they are responsible and also for evaluating various strategies such as the use of catch crops. It is planned to simulate various organic vegetable rotations that have been grown at Landvik in recent years. Bioforsk are applying for a project to assess the cost-benefit of measures to reduce N and P losses in which they hope to use the EU-Rotate_N model.

6.3.4 IGZ – Germany

IGZ are coordinating a national follow-up project, in which they will utilise the EU-Rotate model in two important vegetable growing areas in Germany. The German Fertilisation Ordinance was changed in 2006 so that vegetable growers are obliged by law to reduce nitrogen losses to a given threshold so many cases growers are required to adapt their fertilisation and rotation planning. It is envisaged that the model can be used to derive strategies which allow growers to comply with the new Fertilisation Ordinance. These strategies will be presented to growers and advisors in form of demonstration experiments in three German vegetable research stations.

The German Federal Ministry of Agriculture is interested to use the model as tool to assess the impacts of changes in legislation, such as the Fertilisation Ordinance, on the environment and on the profit of the German vegetable industry. The project runs from 1st of January 2007 to 31st of December, 2009. It has a total budget of 250,000 €, granted by the German Federal Ministry of Agriculture, and the Ministries of Agriculture of the Brandenburg and the Thüringen state.
A similar project is in preparation together with the Ministry of Agriculture of the Baden-Württemberg state and the local authorities for water protection in vegetable growing areas.

6.3.5 DIAS - Denmark

DIAS have three possible approaches for using and developing the EU-rotate model in the future:

1. **Root modeling for other models:** The root and N uptake part of the model was developed as an approach to improve root and N uptake modeling for soil-plant models in general, not only the EU-rotate model. DIAS are trying to arrange collaborative projects with other models, to implement the algorithms and ideas from the root and N uptake modeling from EU-rotate into other models.
2. **Scandinavian or Northern European implementation of the EU-rotate model:** The EU-Rotate_N model covers crops and conditions from all of Europe, however, sometimes its complexity makes it difficult to use in specific local conditions. If DIAS can obtain funding they will try to organise a Scandinavian or a broader North European project where that complexity is reduced to optimize model function, and also improve the user interface to make the model more suitable for use by farm advisors.
3. **Further development of the model and using the model for environmental audits:** Within the EU project Quality Low Input Food (QLIF), DIAS's task is to improve the modeling of organic vegetable rotations, and to use simulation models to make environmental audits of different approaches to organic field crop production. It has not been finally decided yet, which simulation model we are going to use in the QLIF work, but we expect the EU-rotate model to be used for at least some of this work. We have a similar task in a Danish project on organic vegetable production, and the choice of model made within the QLIF work, will determine which model we are going to use in the Danish project as well.

6.3.6 CRA - Italy

CRA-ISOR will concentrate on the following:

1. To promote the model as a decision support system for evaluating crop rotations and for use by interested agencies for reducing the environmental impact of nitrogen fertilization;
2. as a tool in research/extension for supplementing expensive observations in studies of nitrogen management in vegetable crops.

6.3.7 HDRA – UK

HDRA and Warwick HRI are working on a new UK DEFRA funded project *Fertility management strategies in organic arable and vegetable production* (OF 0363).

One objective of this is to determine the usefulness of recently developed computer models for assessing the nitrogen dynamics of organic rotations, specifically with regard to nitrate leaching. The EU-Rotate_N model will be a key part of this work. More validation will be done and comparisons made with two other models developed specifically for organic farming situations (the IGER FBC model and NDICEA).

Revisions will be made to the parameters used in EU-Rotate_N and areas requiring improvements to the programming will be highlighted. Further developments will be the subject of future funding applications.

6.4 list of Papers

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Carpintero J. M., Doltra J., Berbegall F. y Ramos C. 2007. Efecto de la fertilización nitrogenada sobre la lixiviación de nitrato y la producción en el cultivo de alcachofa. (To be presented at the XI Congreso Nacional de Ciencias Hortícolas, Albacete 24-27 Abril 2007)

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Doltra J, Carpintero JM, Berbegall F, Khayyo S., and Ramos C. 2007 Use of a crop model to study the response of artichoke to different levels of soil mineral nitrogen. Act. Hort. 730:257-264.

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Nendel, C. (2006): Ansätze zur Modellierung des Stickstoffhaushaltes in verschiedenen Simulationsmodellen (Invited speaker). Forschung und Perspektiven zur Abschätzung der N-Mineralisation in Ackerböden. Sächsische Landesanstalt für Landwirtschaft, 02.11.2006, Leipzig.

Nendel, C. (2007): EU-Rotate_N - Ein modellgestütztes Entscheidungshilfesystem für nachhaltigen N-Düngereinsatz im europäischen Freilandgemüsebau (invited speaker). Workshop on groundwater protection in Baden-Wurttemberg. April 2007, Heidelberg.

Nendel, C. and M. Fink (2006): A database of nitrogen fertilisation experiments with field vegetables. Proceedings of the Symposium of the International Society of Horticultural Science, 07 –10 June 2004, Perugia, Italy. Acta Horticulturae 700, 229-232.

Nendel, C. and H. Riley (2005): N mineralisation from horticultural soils in two different climate zones. In: C.J. Li, F.S. Zhang, A. Dobermann, P. Hinsinger, H. Lambers, X.L. Li, P. Marschner, L. Maene, S. McGrath, O. Oenema, S.B. Peng, Z. Rengel, Q.S. Shen, R. Welch, N. von Wirén, X.L. Yan, Y.G. Zhu (eds.): Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, Beijing, China, 1084-1085.

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Vågen, I.M., A.O. Skjelvåg and H. Bonesmo (2004). Growth analysis of broccoli in relation to fertilizer nitrogen application. Journal of Horticultural Science & Biotechnology, 79(4), 484-492

Meetings & workshops

Italy

Meeting: *Utilizzo del compost da frazione organica di rifiuti solidi urbani: attualità e prospettive* (Use of compost from the organic fraction of urban solid waste: current status and prospects). Naples, 30/11/2006

Meeting: *Itinerari innovativi dell'orticoltura di pieno campo nell'Italia meridionale* (Innovation paths of field vegetable cropping in South Italy). Menfi (Agrigento), 22-23/11/2005

First workshop of the project *Potenziare la competitività di orticole in aree meridionali* (Empowering vegetable crops competitivity in southern areas). Naples, 24/3/2006

Workshops and field days of the project *Colture alternative al tabacco* (Crops for substituting tobacco) in various places

Periodical field days of extension service technicians and farmers at the Instituto Sperimentale per l'Orticoltura at Pontecagnano (SA)

UK

Expert panel on rotational design of organic and conventional vegetable rotations in the UK regions. HDRA, Coventry July/2005

'Organic Day at Kirton' (an event to disseminate the results of various research projects to farmers in one of the key vegetable production areas of England). Talk on the potential value of the model for farmers and advisors. Kirton, July/2005

Open day: Organic vegetable variety open day. Talk on the farm-level use of the model to plan organic rotations. HDRA, Coventry November/2006

Sweden

Sweden (Nordic Countries). 2-day Seminar: Talks on "Organic farming - a measure to minimise risks for leaching" and "Optimising economics and N use – the economic module within the model EU-Rotate_N". Malmö, October/2005, www.improvednp.com

Germany.

EISfOM Conference: European Information Systems for Organic Markets. A position paper was published in the conference reader. Berlin April/2004, www.eisfom.org

7 POLICY RELATED BENEFITS

7.1 Community added value

The project was drawn from an earlier ENVEG concerted action which identified partners with the key skills needed to form this project consortium. The results of this research pool the expertise of several strands of European research for example making the most of the research that originally let to the development of the N_ABLE model in the UK. The project rebuilt the earlier model so that it could simulate N flows over crop rotations. In addition the effects of irrigations using expertise already present in Spain, the simulation of root development based on work carried out in Denmark. Additionally expertise came from Germany and Denmark on nitrogen mineralisation, the UK and Denmark had expertise on the fate of N in organic rotations.

This project has been able to add value to what was already done and pool the knowledge into a single decision support system which can be further developed. Inevitably during the process of this project new unknowns were identified. These can be answered in subsequent projects but now within the EU-Rotate_N model Framework.

Section 3.4 has shown how use of EU-Rotate_N as a tool to highlight practices which can be seen as leading to higher amounts of leaching., Increasing proportions of vegetable crops in crop rotations dids give rise to increased risk of N losses. The implementation of GAP on its own did not always lead to reductions in these losses but generally reduced the economic sustainability of the industry. The model did highlight where N management could be optimised sometimes by applying higher rates but with better management of rotations could reduce the environmental impact of field vegetable crops. In summary the need for a dynamic system taking into account seasonal variations rather than static regulation was identified.

7.2 Contribution to Community Social objectives

EU-Rotate_N provides a framework in which to test the effects of differing management strategies on the productivity of field vegetable in conventional and organic rotations. The results of the project have clearly indicated the benefits of certain practices in reducing nitrogen losses. It has highlighted the need for further development and use of the model to refine agricultural practices to take the most account of local circumstances.

7.2.1 Quality of life of the EU Citizen

The EU-Rotate_N can be used by scientists and consultants to provide better advice to growers on the amounts of nitrogen and the types of rotations that they should grow to minimise the effects of nitrate in water and produce. Additionally the model provides advice on how growers should manage their N resources in less extensive conventional or organic culture of field vegetables. I.e. so that tools such as increased crop spacing can be used to make more productive use of soil N.

7.2.2 Employment and level of skills

EU-Rotate_N will provide a tool for the practices of N management to be brought up to the same standard across the main field vegetable growing areas in Europe. It provides guidelines on managing N in those sensitive rural areas close to centres of population to allow continued production but with a better understanding of risks of N loss and how they can be reduced. This will help to maintain employment within those local industries

The model includes many of the crops grown by the new member states and in the climatic conditions that the model is designed. It is expected that all of the new members states will be able to benefit from the knowledge that we have incorporated into the model and also contribute to its further development.

7.2.3 Environment and natural resources

The use of EU-Rotate_N will help to optimise the application of N to crops that need it, will help to design rotations which make the best use of the available nitrogen. It has also shown that in certain circumstances reducing N input does not always reduce environmental impact but can reduce gross margins. This is useful as the emphasis on policy is to cut back but we have shown that there are limits to the reductions in N that can be made. Cutting back too far can reduce the productivity of field vegetable rotations without always delivering better use of natural resources. The results demonstrate that some there are disadvantages in static regulations that take little account of seasonal, or soil variation.

7.2.4 Opportunities for education and training – cohesion in the union.

Already many of the participants of the EU-Rotate_N consortium have identified the benefits of the model as a tool for teaching. The project has demonstrated the importance of considering the agronomy of rotations rather than just single crops. Such skills are often being lost in favour of studies and training improving the understanding of plants but only at the cellular level. During the process of model validation and scenario testing many important factors have been identified. Such as the importance and usefulness of deep rooted crops to mine nitrogen from deeper depth should it be lost after shallow rooted crops. It also clearly demonstrates that for high quality crops where single plant size needed for the crop to be marketable can still be produced with lower available nitrogen if crop spacing is increased. The model is suited for a wide range of tasks from the running of “what if” scenarios to testing the effects of new or existing practices on N leaching and economic output.

7.3 Economic development and scientific and technological prospects - Exploitation and dissemination plans

7.3.1 Contribution to growth

The EU-Rotate_N model section 3.4 of this report has already identified circumstances where the amounts of N fertiliser can be cut by following GAP. It has also shown where there is a limit to the simple proportional reductions in N application that can be imposed without loss of gross margin.. It has shown that where there is better knowledge of the underlying processes the local conditions can be managed more effectively to maintain gross margin with minimal detriment to the environment.

The implementation of static regulations on nitrogen use could be quite harmful to the sustainability of localised production. However EU-Rotate_N can be used to dynamically match the N supply from previous crops, chemical and inorganic fertilisers in the most efficient way for these localities. With the ever increasing pressure to reduce food miles and stop an increasing tide of food imports these centres of localised production continue to have a role providing local food, sustaining local employment and providing GDP.

7.3.2 Exploitation

Section 6 of this report shows the proposed exploitation by the partners of this project.

7.3.3 Dissemination

During the delivery of the project dissemination has been an important part of the work and 4 newsletters have been released. Section 6.4 lists a whole series of papers meetings and workshops participated in by participants in this project.
The final newsletter advertises the release of the model, which is now in the public domain as an executable module. It is available with a description, user guide and series of example files as a download from the website or on a CD.

7.3.4 Future Demonstration

Section 6.2 indicates in outline the plans of each individual group to disseminate their work in the future. Most projects will be funded nationally.

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