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Using the EU-Rotate_N model to forecast the effects of nitrate legislation on the economic output and environmental benefits in crop rotations.

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Abstract

The production of fresh vegetables within Europe relies on intensive rotations, supported by large inputs of nitrogen from fertiliser and organic sources which is required to maintain the yield and quality of produce demanded by the multiple retailers and their customers. Most field vegetable crops use nitrogen inefficiently and often leave large residues of nitrogen (either as unused fertiliser or crop debris) in the soil after harvest, which can potentially cause damage to soil, water and aerial environments. Funding from the EU Commission has enabled the development of a new computer model, EU-Rotate_N, which can be used to investigate the fate of nitrogen supplied to rotations of field vegetable crops.

EU-Rotate_N was used to examine the effects of applying existing codes of Good Agricultural Practice (GAP) on the economic and environmental performance of several case study rotations in Europe. In some cases, following GAP, led to significant reductions in N losses without affecting the farmer's gross margin but in others reduced gross margin without reducing N losses significantly. This paper will briefly describe the development of the model and will present the results of several case studies to show the effects of applying GAP on the performance of horticultural rotations.

Introduction

Large amounts of nitrogen are applied to intensively cultivated land where field vegetables are grown. Demyttenaere et al. (1990) and Goulding (2000) showed that growing field vegetable crops can lead to large amounts of potentially leachable nitrate being left in the soil after harvest. Since the value of the produce is high in comparison to the cost of additional fertiliser the temptation to overfertilise is 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 of fertiliser recommendation.

Neeteson and Carlton (2001) reviewed the multiple pathways by which nitrogen applied to field vegetable crops could pollute the environment. A myriad of EU directives and national regulations are now in place, which seek to regulate the use of fertilisers. Many of these were identified by an EU concerted action, the NUMALEC project (De Clercq et al., 2001).

Supermarkets are demanding that the produce they sell has been grown according to environmentally sound practices and have introduced assurance schemes as a result. Model based decision support systems can be valuable tools for consultants and farmers to help meeting these increasingly tight standards and the regulations mentioned earlier.

Over the years a variety of decision support systems, N Expert (Fink and Scharpf, 1993) and WELL_N (Rahn et al., 1996) have been released 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 on 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.

A new model, EU-Rotate_N, was developed with EU funding, as a tool for testing the effects of different fertiliser and rotational practices on losses of nitrogen to the environment and gross margin returns across Europe. This paper will illustrate how the benefits of codes of Good Agricultural Practice can be quantified against existing farm practice taking account of local variations in soil and climate.

Materials and Methods

The Model

EU-Rotate_N is a new computer model developed over the last four years by a consortium of European researchers. It is a decision support system for soil-plant interactions based on the use of nitrogen in crop rotations. Up to 30 years of cropping can be simulated in organically and conventionally managed rotations. The model can automatically recommend fertiliser application rates according to various mineral N target level systems. Additional features allow the analysis and comparison of environmental and economic considerations which will extend the use of its results beyond farmers and growers to consultants and policymakers. The model is written in FORTRAN and runs through Microsoft's DOS emulator. Inputs into the model are via text files and outputs take the same format. The model allows the experienced researcher great flexibility since all inputs can be modified to suit local conditions, equally default values for all the main inputs allows the casual user to overview the model's abilities. The model, complete with instructions and example files is available on the project website at www.warwick.ac.uk/go/eurotaten.

The treatment of soil was based on 2 dimensional 5*5 cm units rather than single 5 cm layers as in the original N_ABLE model, to allow for more effective simulation of a range of different irrigation practices. Routines for water use were updated to bring them into line with the FAO approach (Allen et al., 1998). Routines were added to simulate the effects of water stress on plant growth. The mineralisation routine was based on the DAISY model (Hansen et al., 1990). The model now simulates the effects of snow and frost (Riley and Bonesmo, 2005). N uptake is better modelled as it's now based on a more explicit description of root distribution (Kristensen & Thorup-Kristensen, 2006). The relationships for critical N concentration are broadly based on the work of Greenwood (2001). New algorithms simulate the growth and release of nitrogen from fertility building crops. A new sub routine has been added which estimates the economic return of the rotation and which takes into account the market channel, size of produce and the spacing of crop in the field. The model has been tested under a wide range of environmental conditions in northern and southern Europe. The results of the validations are available on the EU-Rotate_N website.

Case Studies - Norway

Cases were selected where early vegetable crops were planted within 6 year rotations with spring cereals as break crops. They were selected in contrasting regions of Norway to illustrate the effects of rainfall on nitrate requirement. The cases were based on two choices of N management and represent the east and south coastal regions where early field vegetables are grown. To allow comparisons between the two areas, the water holding capacities of the sandy loam and sandy soils in each of the regions have been set equivalent to each other.

Surveys of current grower practices revealed that levels of applied N fertilizer to vegetables often exceed the 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 two scenarios are compared:

- ‘Current recommendations’ (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’)

Case Studies - Spain

Vegetable growing in Spain is considerably more intense than in Norway with up to three crops a year in rotation. To illustrate the performance of the model, an intensive rotation is simulated with lettuce, water melon, and cabbage in year 1, escarole, bell pepper, and broccoli in year 2, and melon in year 3. The rotation is grown in the Alicante province and is drip irrigated. Two cases are compared: (1) where fertiliser is applied to meet crop requirement but does not take N in the soil or in the irrigation water into account and (2) where Good Agricultural Practice is followed which does take these two sources of N into account. The soil mineral N target values used following the Valencian Good Agricultural Practice (Generalitat Valencia, 2000) were 150, 180, 270, 150, 150, 300, and 180 kg N/ha for the 7 crops in the three year rotation, to 60 cm depth, except for lettuce and escarole which were to 30 cm.

Results and Discussions

Norway

Table 1 shows the simulation results for the southern and eastern coastal regions of Norway. The main loss of nitrogen was from leaching as losses to air were not predicted. Which ever rate of N fertiliser has been applied the amounts leached were always greater in the southern coastal region, especially on the lighter sandy soil with up to 130kg/ha per year being lost, averaged over the whole rotation. The productivity of the crops, as assessed by gross margin, on the sands in the southern region was considerably lower than the sands in the eastern area; the crops grown on the heavier textured soils were more productive.

Survey results revealed that growers often applied up to 36% more N than recommended as good practice. Where this occurred in eastern Norway, rotation AN, the amounts leached increased by 60% while gross margin was increased by only 2%. Similarly in AS, leaching increased by 36% but there was still no great benefit in gross margin. In BN, whilst only 27% more N was applied, leaching losses were increased by over 40% and gross margin fell

as the increase cost of fertiliser was not matched by an increase in yield. Rotation BS showed proportionally less increase in N losses but from a higher starting point. Gross margin was lifted but only by 7%. When the second cropping rotation was simulated on sand, as opposed to sandy loam, there was in the eastern region (CN) an increase in leaching associated with the extra N fertiliser applied, but the gross margin was not significantly increased. In the southern region (rotation CS), whilst leaching increased by 19%, the gross margin increased by 14%, suggesting that grower N rates may be justified there. The predicted average nitrate concentrations in drainage water were much lower in the wetter southern coastal region. With better management practices nitrate concentrations were nearer the 50 mg/litre EU limit for drinking water.

The results demonstrate that the growers are wasting resources by using their higher rates of N in 5 out of the 6 cases tested. This suggests that, in the wetter southern coastal region economic benefits could be achieved by applying higher rates of fertiliser to the lighter sandy soils than currently recommended, but that care should be taken to design rotations and/or application strategies that minimise the risks of nitrogen losses.

Table 1. Key annual N-flows (kg/ha) and gross margins (Euro) simulated for various early vegetable crops grown in 6-year rotations with spring cereals in coastal regions of Eastern and Southern Norway, with A: Currently recommended N fertilizer rates, and B: Assumed grower N fertilizer rates.

Rotation name	Eastern Norway, coastal region (ann. temp. 6.4 °C rainfall 877 mm)			Southern Norway, coastal region (ann. temp. 7.8 °C rainfall 1483 mm)		
	Sa. loam	Sa. loam	Sand	Sa. loam	Sa. loam	Sand
	AN	BN	CN	AS	BS	CS
Non-cereal crops included in 6-year rotation with cereals	early pot. early car. sum. onion early car.	sum. cabb. early. pot. early cauli. early pot.	sum. cabb. early. pot. early cauli. early pot.	early pot. early car. sum. onion early car.	sum. cabb. early. pot. early cauli. early pot.	sum. cabb. early. pot. early cauli. early pot.
A: Results simulated with currently recommended N fertilizer rates						
Total N fertilizer	110	144	144	110	142	144
Net N mineralisation	56	70	66	59	71	65
Total N uptake	124	151	145	109	133	118
Marketable N offtake	91	112	107	82	99	90
Leaching below 90cm	53	71	79	77	99	109
¹ % Time leaching >0.1	7.8	8.0	9.1	14.1	15.4	16.1
² Drainage below 90 cm (mm)	256	235	274	762	749	799
Average Nitrate concentration mg/litre	92	133	127	45	58	60
Gr. margin (eur./ha)	4033	2450	2383	3850	2200	1717
B: Results simulated with assumed grower N fertilizer rates						
Total N fertilizer	150	183	183	150	183	183
Total N uptake	132	161	160	125	153	143
Marketable N offtake	98	119	118	94	114	107
Leaching below 90cm	85	100	105	105	123	130
¹ % Time leaching >0.1	9.9	9.5	9.5	14.4	15.8	16.2
Average Nitrate ¹ concentration mg/litre	147	188	169	61	73	72

Gr. margin (euro/ha)	4117	2433	2433	3933	2350	1967
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(All data are means of all six years in the rotation, calculated for the period 2000-2005)

¹ Proportion of the rotation expressed as a % when leached nitrogen was greater than 0.1 kg/ha/day.

² Drainage same for both A+B case studies

Spain

Table 2 shows the overall N balance and gross margin for an intensive rotation following either traditional or GAP. Where GAP was followed the amount of fertiliser applied was reduced by 40%, the amounts of N applied in the irrigation water fell by 16% and the amount of N leached was reduced by over 60%. Nitrate concentration in drainage water also fell but the concentration of N was still predicted to be above the EU 50 mg/litre limit. Losses of N to air also are reduced by 40%. Gross margin was reduced but only marginally so.

Table 2. Key annual N-flows (kg/ha) and gross margins (Euro) simulated for Traditional and GAP for intensive field vegetable rotation over 3 years in Alicante province in Spain.

	Traditional	Good Practice	% Difference
Total N fertilizer	480	284	-41
N in irrigation water	55	46	-16
Total N uptake	383	377	-2
Marketable N offtake	259	254	2
Leaching below 90cm	230	87	-62
Gaseous loss	132	77	-40
¹ % Time leaching >0.1	267	210	-21
Drainage below 90 cm (mm)	383	253	-66
Average Nitrate concentration mg/litre	265	152	-57
Gr. margin (euro/ha/year)	8100	7533	-7

¹ Proportion of the rotation expressed as a % when leached nitrogen was greater than 0.1 kg/ha/day.

Discussion

These diverse case studies demonstrate how the simulation model can be used as a tool to illustrate the effects of different management strategies on rotational productivity and nitrogen losses. It is clear that in many circumstances that following Codes of Good Agricultural Practice, which include assessments of available N in the soil, can reduce the amounts of applied fertiliser in most cases, thereby reducing N losses, particularly by leaching. The simulations in southern Norway illustrate that following Good Agricultural Practice can reduce gross margins which could affect the sustainability of production. However the model could be further used to refine the management practices to minimise N leaching. These practices could be tested in the field and demonstrated to farmers. Even then it may not be sustainable to allow any excess nitrate leaching which might pollute groundwater and cause eutrophication. Further evidence from the project demonstrated that N losses are smaller from more extensive organic rotations but will these be able to provide sufficient yield when grown on a large scale? If we stop growing locally because of diffuse pollution what are the social costs of closing industries down? What are costs of transporting

produce from further away? Does moving the areas of production to less sensitive areas actually reduce N pollution from horticulture or just move it elsewhere?

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