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Delivering sustainability within profitable farming systems – is it possible?

A method to predict impacts of NVZ and Water Framework legislation on UK vegetable and arable farming

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Summary

A method is introduced to predict the scale effects of environmental legislation on major UK conventional and organic crop rotations. The paper attempts to extract the key crops and vegetable crop rotations (both conventional and organic farming) in all different UK regions. It highlights the conventional and organic concentration of UK field scale vegetable cropping. With this information representative crop rotations for different regions and soil types can be created and used e.g. in a recently developed integrated plant-soil-environment-economics model (EU-Rotate_N). This model is designed as a decision support system to optimise rotations on various decision-making levels. The levels considered are: farm or rotational level, catchment, regional and national level. By comparing different farming systems their strength and weaknesses in delivering environmental and economic sustainability can be assessed on various scales.

Key words: Vegetables, rotation design, regional distribution, nitrogen leaching, NVZ, water framework, modelling, scale effects

Introduction

Many arable and field scale vegetables crops in the UK are produced in intensive rotations, which rely heavily on large inputs of nitrogen from fertiliser or organic sources to maintain the yield and quality. Field vegetable crops use nitrogen inefficiently and often leave large residues of nitrogen in the soil after harvest. This can cause damage to soil, water and aerial environments. The environmental impacts may be reduced without loss of yield or quality by improved design of rotations and by more closely matching nitrogen supply to the demands of individual crops. At a larger scale, to develop policy decisions on codes of good agricultural practice to develop environmental protective measures like NVZ or water framework legislation, more detailed knowledge is required. Rotations and management practises vary among the different regions of the UK. In addition, an understanding of the distribution of conventional and organic management practises is required to improve the assessment of impacts. The impact of any change of management practise in individual crops largely depends, among other effects, on the area of the crop grown, the region, the rotation, the soil and the weather conditions. Within a recent research project EU-Rotate (2003) this questions are tackled by developing a model based decision support system to optimise nitrogen use in conventional and organic crop rotations.

Vegetable and arable crops in the UK

The analysis of statistical data supplied by Defra (Defra 2005) shows that UK vegetable production in terms of area, volume and financial output has been constant during the last 20 years. However, there have been larger changes in other arable cropping areas notably a reduction of barley and sugar beet and an increase of oilseed rape and peas and beans (data not shown). At present, there are 124,000 ha of vegetables grown in the open and there is a slight down-trend (slope) of 2%, or an average annual loss of about 3400 ha (Table 1). Potato production has decreased more clearly from 200,000 ha in 1984 to about 150,000 ha in 2004.

UK field scale vegetable crop areas

Trend analysis (assuming a 20-year linear trend) shows, that brassica crops had the highest reduction in area (-4%) while roots and onions were -1%, leguminous vegetables -2% and other vegetables -3%. Only the areas of parsnips, dry bulb onion, calabrese (broccoli) and asparagus increased. Larger reductions in areas of spring, summer and autumn cabbage, Brussels sprouts and runner and dwarf beans were recorded.

Table 1. *10-year and 20-year trends in UK vegetable production areas for all major vegetable crops. Source: Defra statistics*

	2004	**10 years**		**20 years**	
Roots and Onions	ha	Slope	% av	Slope	% av
Beetroot	1666	-78	-4%	-71	-4%
Carrots	9833	-432	-4%	-336	-3%
Parsnips	3060	-10	0%	25	1%
Turnips and Swedes	2683	-194	-5%	-104	-3%
Onions dry bulb	9063	71	1%	98	1%
Onions green	2128	-53	-3%	-4	0%
Total Roots and Onions	**28433**	**-696**	**-2%**	**-391**	**-1%**
Brassicas					
Brussels sprouts	4278	-281	-5%	-428	-8%
Cabbage, spring	2101	-184	-7%	-245	-9%
Cabbage, Summer and Autumn	2181	-155	-7%	-184	-9%
Cabbage, Winter	3825	-175	-3%	-236	-5%
Cauliflower	9947	-805	-6%	-458	-4%
Calabrese	8716	141	2%	275	4%
Total Brassicas	**31048**	**-1458**	**-4%**	**-1276**	**-4%**
Legumes					
Beans broad	2151	-6	0%	-74	-3%
Beans runner and dwarf	2470	-215	-8%	-332	-12%
Peas green for market	907	-28	-3%	-80	-8%
Peas green for processing	31455	-799	-2%	-712	-2%
Peas harvested dry	12685	-820	-6%	-101	-1%
Total Legumes	**49668**	**-1868**	**-3%**	**-1300**	**-2%**
Others					
Asparagus	788	9	1%	15	2%
Celery	623	-1	0%	-25	-4%
Leeks	1813	-119	-5%	-56	-2%
Lettuce	5224	-177	-3%	-77	-1%
Rhubarb	323	-26	-6%	-24	-5%
Watercress	60	0	0%	-3	-4%
Others	5547	-192	-3%	-259	-4%
Total Others	**14377**	**-505**	**-3%**	**-428**	**-3%**
TOTAL FIELD VEGETABLES	**123527**	**-4528**	**-3%**	**-3395**	**-2%**

Material and Methods

Based on the available 20-years statistical data of the UK an attempt was made to find a balance between a maximum detail in terms of regions and crop rotations, while still maintaining a reasonable number of different rotations.

(1) Therefore, in a first step, the main regions of vegetable cropping where identified, based on published Defra statistics.

(2) In a second step, the main crops within each region were ranked and a threshold of crop importance in terms of area was defined for each region. This was based on un-published data from Defra statistics, which were specifically sourced from the York statistics office to give a full regional breakdown. As this data include conventional and organic cropping areas Defra statistics was approached again to source organic area census. However, because of confidentiality issues, a breakdown in region and crops is not possible and therefore only a regional breakdown for all organic vegetable crops is shown.

(3) In a third step, typical rotations for both conventional and organic rotations were extracted to represent the statistical distribution of the crops in all major areas. This was done with the help of an expert panel of horticultural consultants and researchers. The expert panel also discussed a series of scenarios to reduce the nitrogen leaching from horticulture and agriculture in the UK.

(4) In a further step, these rotations were used to predict the impacts of environmental legislation in terms of cropping practice, rotational design and overall land use. This was done with a beta-version of the model EU-Rotate_N (data not shown). More details on this model in development and its different modules is given by Schmutz *et. al.* (2006). A final version of the model is expected to be available in 2007 (see website www.hri.ac.uk/eurotate for further details).

Results

Defining main vegetable regions in the UK

The following rules were adopted to exclude minor crops from the regional analysis: a regional important crop needs to represent more then 5% of the vegetable cropping area in this region and it has to be grown on more then 250 ha in this area. Using these rules, the following eight regions (Table 2) with major field scale vegetable areas within the UK were identified.

Table 2. *Regional breakdown of vegetable cropping in the eight most important vegetable producing regions of the UK (excluding potatoes and leguminous vegetables) and percentage each region of UK total. Source: Defra statistics and HDRA data*

Nr.	Region	Abbreviation	% UK area
1.	East Midlands	(EM)	32%
2.	Eastern England	(EA)	25%
3.	South East	(SE)	8%
4.	Scotland	(Scot)	9%
5.	North West	(NW)	7%
6.	West Midlands	(WM)	6%
7.	South West	(SW)	5%
8.	Yorkshire & Humber	(YO)	4%
			Total 96%

The North East of England, Wales and Northern Ireland represent to small an area to be representative for UK field scale vegetable production. For Wales however, this is only true for conventional production, not organic (see below). Together the eight areas represent 96% of the UK conventional and organic vegetable cropping area.

Table 3. *Regional breakdown of vegetable cropping area (ha) and percentage in the eight most important vegetable producing regions of the UK (excluding potatoes and leguminous vegetables). Source: Defra statistics and HDRA data. Abbreviations see table 2.*

EM			**ha**	**%**
	Calabrese		**5287**	**21**
	Cauliflower	Summer	**4846**	**19**
	Brussel sprouts		**2175**	**9**
	Carrots		**1954**	**8**
	Cauliflower	Winter	**1777**	**7**
	Dry bulb onions		**1433**	**6**
	Cabbage	White	**1421**	**6**
	Cabbage	Autumn	**1096**	**4**
	Cabbage	Summer	**758**	**3**
	Cabbage	Spring	**686**	**3**
	Total key crops		**21433**	**86**

EA			**ha**	**%**
	Dry bulb onions		**5466**	**28**
	Carrots		**3579**	**19**
	Parsnips		**1718**	**9**
	Lettuce	Iceberg	**1255**	**7**
	Field herbs		*1387*	*7*
	Lettuce	*other*	*569*	*3*
	Leeks		*451*	*2*
	Beetroot (red)		*447*	*2*
	Sweetcorn		*428*	*2*
	Calabrese		*400*	*2*
	Total key crops		**12018**	**62**

SE	**Cauliflower**	Winter	**938**	**14**
	Lettuce	Iceberg	**753**	**11**
	Sweetcorn		**622**	**9**
	Lettuce	other	**594**	**9**
	Cabbage	Spring	**474**	**7**
	Cauliflower	Summer	**400**	**6**
	Babyleaf vegetables		**371**	**6**
	Salad onions		**305**	**5**
	Field herbs		*294*	*4*
	Other veg ex legumes		*217*	*3*
	Total key crops		**4458**	**68**

Scot	**Carrots**		**1662**	**24**
	Swedes & Turnip		**1570**	**23**
	Calabrese		**1230**	**18**
	Brussel sprouts		**430**	**6**
	Beans		*643*	*9*
	Other green veg		*439*	*6*
	Cauliflower		*285*	*4*
	Cabbage		*213*	*3*
	Leeks		*177*	*3*
	Lettuce		*162*	*2*
	Total key crops		**4892**	**72**

NW	**Carrots**		**1213**	**22**
	Brussel sprouts		**697**	**13**
	Lettuce	Iceberg	**565**	**10**
	Cauliflower	Summer	**460**	**8**
	Leeks		**364**	**7**
	Lettuce	other	**328**	**6**
	Calabrese		*261*	*5*
	Cabbage	*Spring*	*239*	*4*
	Celery		*235*	*4*
	Total key crops		**3627**	**66**

WM	**Salad onions**		**1458**	**32**
	Dry bulb onions		**478**	**11**
	Lettuce	other	**355**	**8**
	Calabrese		**252**	**6**
	Leeks		*206*	*5*
	Brussel sprouts		*195*	*4*
	Field herbs		*195*	*4*
	Other brassicas		*182*	*4*
	Parsnips		*157*	*3*
	Total key crops		**2544**	**56**

SW	**Cauliflower**	Winter	**1341**	**33**
	Cabbage	Spring	**492**	**12**
	Cauliflower	Summer	**268**	**7**
	Swedes		**258**	**6**
	Other veg ex legumes		*241*	*6*
	Calabrese		*174*	*4*
	Lettuce	*other*	*146*	*4*
	Field herbs		*124*	*3*
	Cabbage	*Summer*	*119*	*3*
	Total key crops		**2359**	**59**

YO	**Carrots**		**994**	**30**
	Beetroot (red)		**661**	**20**
	Brussel sprouts		*190*	*6*
	Cabbage	*Autumn*	*143*	*4*
	Calabrese		*141*	*4*
	Rhubarb		*125*	*4*
	Swedes		*112*	*3*
	Cauliflower	*Summer*	*109*	*3*
	Dry bulb onions		*102*	*3*
	Total key crops		**1655**	**50**

Extracting a UK regional breakdown of vegetable cropping

In Table 3, the regional breakdown (conventional and organic areas together) is presented with all crops listed (leguminous vegetables are excluded). The total area (ha) of the region is presented (25,039 ha in the example of the East Midlands) and the main crops (>5% or >250 ha) with their representation of the area (86% are represented with all different cabbage types included). The smallest area considered is Yorkshire & Humberside. It represents only 4% of the UK vegetable area with only two crops considered relevant after adopting the selection rules: carrots and beetroot.

Available UK regional breakdown of organic vegetables cropping

The data available are less detailed for organic field scale vegetables. Under Defra confidentiality rules a crop with less then 5 data records in a region, cannot be disclosed. Table 4 shows the regional breakdown organic vegetable production (Source Defra 2005 & HDRA). The East Midlands and Eastern England regions are also the main organic vegetable production areas; they are followed by the South West and Wales. In terms of organic vegetable holding records, the South West and Wales represent 22% and 15%. The breakdown excludes potatoes and leguminous vegetables and only crops with more than five data records are used in the producer and area count. This represents 71% of the producers and 61% of the area. According to this figures the total organic field scale vegetable area was 4,600 ha in 2004. This is 6.3 % of the total area used for field scale vegetables (73,000 ha, excluding potatoes and leguminous vegetables).

Table 4. *Organic regional breakdown of i) no of producers, ii) area and iii) average hectare of vegetable cropping in the eight most important vegetable producing regions of the UK (excluding potatoes and leguminous vegetables). Source: Defra statistics and HDRA data. (Abbreviations of English regions see table 2)*

Producers			**Area (ha)**			**Av. ha**	
SW	188	22%	EM	556	19%	EM	6.3
Wales	132	15%	EA	450	16%	YO	4.6
SE	126	15%	SW	429	15%	EA	4.2
EA	108	12%	Wales	372	13%	NW	3.8
EM	89	10%	SE	307	11%	WM	3.6
WM	77	9%	WM	274	10%	Wales	2.8
YO	55	6%	YO	253	9%	SE	2.4
Scotland	35	4%	NW	118	4%	SW	2.3
NW	31	4%	Scotland	78	3%	Scotland	2.2
N. Ireland	17	2%	N. Ireland	15	1%	NE	1.5
NE	7	1%	NE	10	0%	N. Ireland	0.9
All	**865**	**100%**	**Sum (ha)**	**2862**	**100%**	**Av. ha**	**3.3**

Typical conventional and organic field scale vegetable rotations in the main UK regions

Using an expert panel, typical rotations for the different regions were combined with the statistical knowledge of the crops. The results are shown on in following table 5. The rotations reflect current practice in all major regions with field vegetable production in the UK. The rotations are not specified for a particular farm or farm size because this is often irrelevant: e.g. with carrots and potatoes more than half of the crop is contract-farmed on other farmers' land and rotations. Using the area information of each rotation, depending on the crops predominance in a region, the data can be scaled up to regional and national level. Using the 20- year linear trends for different crops, projections of future impacts are possible.

Table 5. *Typical conventional field vegetable rotations for different regions and soils of the UK (Abbreviations of regions see table 2, WW winter wheat, SB spring barley, OSR oilseed rape, G/C grass/clover ley). Source: HDRA data.*

Region	Soil	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
EM	silt	Broccoli	Cabbage 2x	Caulif.			
EM	silt	Broccoli	Onions	Brussel S.			
EM	silt	Caulif.	Caulif.	Potato	Onions	WW	
EM	silt clay	Brassica	WW	Sugar beet	Potato		
EM	silt clay	Brassica	WW	Peas (Vining)	Potato		
EM	sand	Carrot 2x	WW	Potato	WW	WW	
EM	sand	Leeks	WW	Sugar beet	Set aside		
EM	sand	Onions	WW	Sugar beet	WW		
EM	sand	Carrot	Potato	Set aside	Leeks	SB	
EA	peat	Lettuce 2x	Lettuce 2x	Celery	WW		
EA	s. loam	Carrot	WW	Sugar beet	WW		
EA	s. loam	Carrot	WW	WW	OSR		
EA	s. loam	Carrot 2x	WW	Potato	Set aside	WW	OSR
EA	sand	Onions	WW	Potato	Set aside		
SE	loam	Babyleaf 3x	Potato	Babyleaf 3x			
SE	loam	Early Potato	Caulif. (ow)				
SE	loam	Early Potato	Caulif. (ow)	Lettuce 2x			
SE	s. loam	Sweetcorn	Sweetcorn	Squash	WW		
SE	s. loam	Babyleaf 3x	Babyleaf 3x	WW			
SE	clay loam	Celery	Lettuce 2x	Lettuce 2x	WW		
SE	clay loam	Lettuce 2x	Lettuce 2x	WW	WW	Peas	
SE	sand	Salad onion 2x	WW	Lettuce 2x	WW		
SE	sand	Brassica	WW	Potato	WW		
SE	sand	Lettuce 2x	WW	Potato	WW		
Scot	s. loam	Caulif.	WW	Potato	WW	Broccoli	WW
Scot	s. loam	Brussel S.	Broccoli	WW			
Scot	s. loam	Brussel S.	WW	Potato	WW	SB	
Scot	s. loam	Peas (Vining)	WW	Potato	WW	OSR	WW
Scot	sand	Carrot (ow)	Phacelia	WW	Potato	WW	SB
Scot	sand	Carrot (ow)	Phacelia	WW	Broccoli	WW	Potato
Scot	sand	Carrot	WW	SB	Grass	Grass	
Scot	sand	Swedes	Grass	SB	Set aside		
NW	peat	Lettuce 2x	Lettuce 2x	Celery	WW		
NW	s. loam	Brassica	Potato	Carrot	WW	WW	
NW	s. loam	Brassica	Potato	Leeks	WW		
NW	s. loam	Caulif.	Caulif.	WW	WW	WW	
NW	sand	Leeks	Grass	Grass			
WM	silt	Brassica	Lettuce	Leeks			
WM	s.loam	Runner beans					
WM	s.loam	Salad onion 2x	WW	Sugar beet	WW		
SW	s. loam	Early Potato	Brassica				
SW	s. loam	Early Potato	Caulif. (ow)	Grass			
SW	clay	Swedes	SB	Grass	Grass		
YO	peat	Beetroot	WW	Potato	WW	WW	
YO	sand	Carrot	Potato	WW	WW	WW	

Table 6. *Typical organic field vegetable rotations. Source: HDRA data.*

Region	Soil	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
EM	silt	G/C	G/C	Potato	Caulif.	Beans	
EM	silt	G/C	G/C	Broccoli	Caulif.	Beans	
EM	sand	Grass	Grass	Pigs/Silage	Carrot	Lupines	SB
EM	sand	G/C	G/C	Potato	Carrot	WW	
EA	s. loam	G/C	Potato	Broccoli	Onions	WW	
EA	s. loam	G/C	Potato	Celery	Sweetcorn		
EA	s. loam	G/C	Brassica	Leeks	Beans		
EA	s. loam	G/C	Brassica	Sweetcorn	G/C	Potato	Leeks
EA	s. loam	G/C	Brassica	Beans	G/C	Potato	Celery
EA	sand	G/C	G/C	Potato	Carrot	WW	
EA	sand	G/C	G/C	Potato	Leeks	WW	
SE	s. loam	G/C	G/C	Lettuce 2x	WW	Lettuce 2x	
SE	clay loam	G/C	Lettuce 2x	WW			
SE	sand	G/C	G/C	Potato	Lettuce	WW	
Scot	s. loam	G/C	G/C	Brassica	Carrot	SB	
Scot	s. loam	G/C	G/C	Potato	Swedes	SB	
NW	peat	G/C	G/C	Lettuce	Brassica	Carrot	
NW	peat	G/C	G/C	Lettuce	Brassica	Celery	
NW	silt	G/C	G/C	Broccoli	Leeks		
NW	silt	Red Clover	Brassica	Lettuce	Carrot		
NW	silt	Red Clover	Celery	Lettuce	Parsnips		
NW	s. loam	G/C	G/C	G/C	Potato	Brassica	Carrot
WM	s. loam	G/C	G/C	G/C	Brassica	Leeks	Carrot
WM	s. loam	G/C	G/C	Brassica	Sweetcorn	Carrot	WW
WM	s. loam	Grass	Grass	Grass	Brassica	Carrot	Beans
SW	s. loam	G/C	G/C	G/C	Early Potato	Caulif. (ow)	
SW	s. loam	G/C	G/C	G/C	G/C	Early Potato	Caulif. (ow)
SW	clay	G/C	G/C	G/C	Caulif. (ow)	Early Potato	
YO	peat	G/C	G/C	Brassica	Carrot	Peas (Vining)	
YO	sand	G/C	G/C	Leeks	Carrot	WW	

Construction of scenarios – conventional farming

The statistical analysis shows that 58% of the UK vegetable production is in the dry, flat and fertile crescent around "The Wash" in the East Midlands and Eastern region. The soils vary from heavy clay, silt, loam, sandy loam and sand and the rotations reflect this. The following set of management strategies were discussed at an expert meeting:

- The current practice (status-quo) for the documented rotations (table 5 and 6). This includes "leaky" strategies.
- Best-practice (GAP) are the same rotations but with fertiliser applications restricted to those documented in UK GAP fertiliser recommendations (Defra RB209, 2000), current assured produce crop specific protocols (Assured Produce Ltd., 2006) and the NVZ regulations in place in many parts of vegetable growing in England and Scotland.
- Use of cover crops or "N-trapping crops" to trap N after a summer crop residues.
- Improved timing of cropping. This is one of the most important issues, however this may be difficult given weather, labour and machinery constraints.
- Predicting water framework legislation effects e.g. reducing the level of diffuse pollution in a river catchment (e.g. requirements to cut the background level of N pollution from agriculture/horticulture by 20%).

It was established that the general problem is not so much reducing the N input into the rotation, but minimising the losses or unwanted output. This strategy is already a key emphasis of organic production. Therefore, issues like maximum total and single N application rates or N budgets with penalty levies (MINAS in the Netherlands, Oenema *et al.*, 1998; Ondersteijn *et al.*, 2002) were not seen as the best farm level approach.

Construction of scenarios – organic farming

The statistical analysis shows that, similar to conventional production, the East Midlands and the Eastern region are the most important organic regions. However, in organics considerable production is also found in the West (South West and Wales) with high rainfall (>700 mm), hilly land and over-winter production. This could be a problem on free draining soils with poor fertility building management. One of the basic questions in organic farming is how to improve nitrogen use efficiency in organic rotations by avoiding any N losses from the system and defining best organic practice in conversion and established organic rotations. Leaky periods in conversion and post conversion crop rotations occur when grass-clover leys are ploughed in autumn and when high levels of manures are applied, exceeding the requirements of the crop. In addition, as organic farming is often found on poorer soils and less favourable areas, the effects of light sandy soils, high rainfall areas and steep slopes need considering. Because for organic systems nitrogen is a much more valuable asset in rotations, some of the organic practices can be introduced in conventional farming. This could be grass/clover leys for N fixation and N trap crops for trapping nitrogen over-winter.

Conclusions

The data presented are a useful information pool for any project relating to scale effects of arable and horticultural rotations in conventional and organic systems in the UK. They will be used with the finalised EU-Rotate_N model to demonstrate the use of a model based decision support system to predict effects of, either the scenarios discussed in this paper, or other catchment data. Preliminary results with the latest beta-version of the model show that very specific results can be obtained depending on weather and soil conditions. Model runs for the main production area in the East Midlands have shown that increased average temperatures and rainfall predicted for 2016 will increase N leaching with current practise. The model is designed as a decision support system to optimise rotations on various decision-making levels (farm, catchment, regional and national). By comparing different farming systems, their strengths and weaknesses in delivering environmental and economic sustainability can be assessed. With the economic sub-module of the EU-Rotate_N model, rotational gross margins are produced to predict possible economic effects of better-targeted N fertiliser recommendations or increased cover cropping. As established earlier, organic vegetable farming is currently 6.3 % of the total production area; this is low, but still a higher share then in most other sectors of agriculture or horticulture. Using the current growth predictions in UK organic consumption and UK organic production, scenarios can predict the impact of e.g. 20% organic land use in different regions or catchments of the UK on nitrogen leaching and economic sustainability.

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