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Scoping the environmental and social footprint of horticultural food production in Wales

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EXECUTIVE SUMMARY

Background

While traditionally very little research has been undertaken on the social and environmental aspects of horticulture in Wales the combination of devolution and recent reforms in the Common Agricultural Policy make it timely to consider the impact horticulture can have on the environment, society and economy of Wales.

Although not considered a major sector in the Welsh countryside recent estimates suggest that the value of horticulture in Wales is approximately £ 350 million per annum, and is likely to grow over the short to medium term. While some of this production enters the wider UK food supply chain, a growing amount is utilised locally, either as inputs to food processing industry or for direct domestic use.

The purpose of this report is to provide an initial assessment of the environmental and social footprint of horticulture in Wales. This information can be used to identify knowledge gaps which may need to be filled in order to inform future environmental, social and economic policy.

Profitability

Horticulture is one of the most profitable forms of land use. Gross margins of horticultural crops are normally significantly higher than those of arable crops, which in turn are normally greater than those available from livestock production systems. The presence of such profitable businesses in rural areas can make a major contribution to rural development. For this reason it may be advantageous to encourage an expansion of the area dedicated to horticulture in Wales.

Labour supply and demand

The availability of labour can be a constraint on horticultural businesses. Currently the majority of labour in UK horticulture is provided by seasonal migrant workers. Although the influx of a large number of young workers could potentially bring many benefits to rural areas, to date these benefits remain largely unmeasured. Some of the constraints on maximising the benefits relate to language difficulties, lack of transport from the farms to towns and villages, a general reticence amongst workers to spend money while in the UK, and poor mental and physical health amongst workers.

The seasonality of the labour supply is a constraint on business development and there is a need to develop a continuity of labour supply. If Welsh businesses are to prosper in the future then it may be advantageous to promote the horticultural industry as a career path.

‘Local food’ and self-sufficiency

There are opportunities for marketing Welsh fruit and vegetables as ‘local’ food. While this may bring business benefits, currently there is no clear scientific evidence suggesting that 'local' food is always environmentally beneficial. The level of environmental damage caused by 'local' and 'non-local' food will vary with the crops and the source of the 'non-local' food. Clearly though, should consumers and/or the public sector preferentially purchase Welsh produced fruit and vegetables then this will have a benefit to the Welsh economy.

From a public health perspective it is clear that significant health benefits arise from increased consumption of fruit and vegetables, regardless of where they are grown. For this reason it is important that marketing messages promoting local 'Welsh' produce do not serve to confuse or counter the principle public health message.

The area of field vegetables currently grown within Wales represents about 10 % of the total area needed to meet Welsh consumption; while for apples and pears, this figure is 26.9 %. However, in theory, the consumption of potatoes can be fully met by current levels of production in Wales. Given that consumption of fruit and vegetables is projected to rise in the future, it is impossible for Wales to be self-sufficient in fruit and vegetables.

Environmental impacts

A review of the known environmental impacts of horticulture in Wales revealed two major points. Firstly, that compared with other food production systems, such as livestock and arable, relatively little is known about the environmental and social impact of horticulture in the UK. Secondly, almost no studies have been conducted on the environmental impact of horticulture in Wales.

The use of fertilisers and pesticides in horticulture raises similar issues to those surrounding their use in arable crops. However, several other environmental impacts are greater in horticulture than in other cropping systems. These include the direct use of energy, the use of irrigation water and the use of plastics.

A particular knowledge gap relates to the impacts of horticulture on climate change, both directly through on-farm operations and indirectly through use of inputs and storage/packing/transport facilities. Also of particular note was the paucity of research investigating the interactions between horticulture and biodiversity at the field and landscape scale.

Climate change

The future climate of Wales will become more favourable for horticulture, while that of current regions which produce vegetables may become less favourable. The availability of sufficient water for irrigation will become particularly important in the future, and in this regard Wales will be less affected by climate change than many other countries, including England. For this reason we may expect the production of field vegetables to shift to areas of suitable climate and water availability.

However, ultimately the location of any industry is determined by the market. So while the future climate of Wales may be more suitable for fruit and vegetable production, the amount of suitable land is limited and to some extent fragmented. This may reduce the attractiveness of Wales as an area suitable for major investment in infrastructure, e.g. stores and packing houses. Similarly, the availability of suitably skilled and priced labour may also impact significant investment in the sector.

In summary, the climate of Wales may become absolutely and relatively more attractive as a place to produce fruit and vegetables. However, the location of major horticultural investments will depend on market returns, and currently it is not possible to predict the nature of these market forces very far into the future.

Drivers for change in Welsh horticulture

There four main drivers for change in horticultural production in Wales:

- The public health agenda
- The desire for 'local' food
- Continued reform of the Common Agricultural Policy (CAP)
- Climate change

Drawing these four drivers together suggests that there will probably be an increase in the potential for horticulture in Wales. In the short term, this will be driven by the market (demand for healthy produce and local produce), and aided by continued reform of the CAP. In the long term, the combination of the market pull, the reformed policy environment and a relatively favourable climate should enable significantly greater levels of horticultural production within Wales.

If the potential for increased levels of horticultural production is accepted, then the current task within Wales is to develop a horticulture which will enhance both the rural communities and the environment. While an increased level of horticultural production should enhance farmers' incomes and local economies there are also several potential negative impacts. These relate particularly to the environmental impact of horticulture, where there are some knowledge gaps, and also to social issues, particularly surrounding the supply of labour.

Overall recommendations

The overall recommendations of the report are:

Horticulture and pollution

- Consider how best to reduce nitrogen leaching from field vegetables, particularly potatoes?
- Understand the type and amount of pesticide used in Welsh horticulture. This could be achieved by stratifying the existing Pesticide Usage Survey into England and Wales. This may require a slightly greater sampling effort to be targeted on Welsh farms than currently, but it would offer a unique dataset.
- Continue to research alternative means of managing diseases in potatoes.
- Research and develop relevant pest management techniques for the growing number of fruit and vine growers in Wales.

Horticulture and natural resources

- Communicate and demonstrate best practice for reducing soil erosion in horticulture, especially in potatoes.
- Develop and demonstrate best practice in field irrigation methods. This will be necessary under a changed climate, but is an area where current levels of awareness are low.
- Develop and demonstrate on-farm reservoirs for supplying irrigation water for horticulture (and other crops, including grass).
- Communicate the options for increasing energy efficiency in horticultural systems, and demonstrate the best methods for reducing energy use.
- Develop demonstration glasshouses in conjunction with a combined heat and power biomass plant (or equivalent).
- Develop supply systems which minimise the need for storage.
- Continue to develop sustainable alternatives to peat, paying particular attention to achieving a consistent product which would be suitable for commercial use.
- Communicate the importance of the limited amount of Grade 1 land within the Welsh Assembly Government and to local authority planning agencies, so that the productive value of this land can be considered as part of any development plan.

Horticulture and climate change

- Understand the patterns of greenhouse gas emissions from field and protected cropping.
- Develop management systems for minimising greenhouse gas emissions in horticultural systems, particularly potatoes and protected cropping.
- Research and develop a 'low carbon' horticultural system.
- Undertake a life cycle analysis from some typical Welsh horticultural products, e.g. early potatoes, daffodils, protected crops.
- Compare the results of the LCA of Welsh grown produce with similar produce imported from England, other EU countries and beyond.

Horticulture and Catchment Sensitive Farming

- Consider how to incorporate horticulture into Catchment Sensitive Farming, which is currently designed to reduce pollution from livestock systems?
- Understand the risk of water pollution from fertiliser use which may contravene standards set in the Water Framework Directive from horticulture. A first step may be to consider the water quality in the areas which currently support horticultural enterprises, e.g. Pembrokeshire, Flintshire, Llyn Peninsula and Monmouthshire.
- Understand the risk of water pollution from pesticide use which may contravene standards set in the Water Framework Directive from horticulture.

Understand the risk of soil erosion which may contribute to contravention of standards set in the Water Framework Directive from horticulture.

Horticulture and waste

- Demonstrate the use of photo- and biodegradable horticultural films.
- Enhance the opportunities to recycle wastes from horticultural systems.

Horticulture and biodiversity

- Develop and evaluate techniques for enhancing in-field biodiversity in field horticulture, *cf* beetle banks in arable crops, field boundaries, strip cropping.
- Evaluate the role horticulture can play in terms of enhancing biodiversity at the landscape level.

Horticulture and social issues

- Evaluate the social costs and benefits of hosting seasonal migrant workers in the countryside. Issues for consideration may include impact on the local economy and on the local health and social services.
- Develop / support schemes which supply continuity of employment for rural people who may wish to engage in seasonal horticultural work.
- Promote the opportunities for career development offered by the horticultural industry.
- Compare the local / regional economic impacts of horticultural enterprises with other land uses.

Table of contents

Chapter 1 Introduction

1.1 Introduction

1.1.1 Background on horticulturally related research

Over the last 20 years the major purpose of agriculturally related research in the UK has shifted from being near-market, problem solving research to being more strategic, policy related and concerned with the management and provision of public goods (e.g. biodiversity, water quality, landscape).

During the early 1980s much of the policy related research agenda focused around the Common Agricultural Policy (CAP), which at that time provided direct support to agricultural production, and particularly on the links between CAP and environmental degradation. At the political level this debate was largely driven by several non-governmental organisations (NGOs) who believed that direct support for production had a direct and negative link to environmental degradation. An important point in the debate was that the public objected to the fact that farmers were in receipt of public money, and were effectively using this money to damage the environment (Winter 1996). Amongst the evidence used to support this view was the decline in farmland birds, whose numbers have been recorded since the early 1960s. These data showed the decline to be greatest in the eastern and southern areas of England, where the land use was predominantly arable in nature.

Almost simultaneous to the debate on farmland birds was a growing awareness of the importance of agricultural pollution of all types, including the pollution of freshwaters from point and non-point sources (Edwards-Jones & Mitchell 1995). The policy relevant research which was undertaken on this topic first tended to focus on ameliorating point sources from livestock farms (silage and slurry pits), and more recently has tended to focus on non-point sources such as nitrogen and phosphorus. Given that the majority of livestock production has occurred in the north and west of Britain, research in this area has tended to focus on these regions.

Against this background it is not surprising that until very recently, much Government funded research related to agriculture and the environment has been focused on understanding, and reversing, the decline in farmland birds, and other biodiversity in the arable landscape, and on overgrazing and water quality in the grassland areas. Further, for much of the last 20 years policy related research has effectively been confined by the boundaries of the CAP. For this reason work has largely sought to develop agricultural policies which reduced the CAP related incentives to damage the environment, rather than taking a more holistic approach to achieving sustainable development.

Horticulture has always been outside of the traditional CAP, and never received direct production related support. This, alongside its relatively small land-take, meant that relatively few research topics considered the wider environmental and social impacts of horticulture. Research into horticulture was historically undertaken at Government sponsored research stations such as Horticultural Research International (HRI), formerly based at Wellsbourne (vegetables), East Malling (fruit) and Little Hampton (protected crops). Industry also funded research in these stations, largely through the levy funded Horticultural Development Council (HDC), but also via private sponsorship. Quite naturally, industry funded research tended to focus on relatively near market issues.

So in summary for much of the 1980s and early 1990s horticulture was not felt to be particularly policy relevant, and the research needs of the relatively small industrial sector were met via levy funding and dedicated research stations. Given that levy funded bodies tend to focus their work on the regions which are most relevant to their levy payers, it is not surprising that very little horticultural research of any kind was focused on Wales during this period.

However, the situation has changed in recent years. First a major reform of the CAP has occurred, within Wales it is partially decoupled from production, with more reforms expected post-2013. Also devolution means that the Welsh Assembly Government are now interested in understanding the potential of all land uses in Wales to contribute towards sustainable development. For these reasons it is appropriate to consider the impact horticulture can have on the environment, society and economy of Wales.

1.1.2 Horticulture in Wales

Traditionally horticulture has not been thought of as a major sector within the Welsh countryside. However, recent work by CALU suggests that the estimated value of horticulture is approximately £ 350 million per annum, and is likely to grow over the short to medium term (CALU 2006). Food production is an important part of Welsh horticulture and includes field based vegetable systems, salad and vegetable production within polytunnels and greenhouses, and some soft and top fruit. While some of this production enters the wider UK food supply chain, a growing amount is utilised locally, either as inputs to food processing industry or for direct domestic use. Current consumer trends suggest that the demand for 'local' products will continue for the foreseeable future, and should 'food miles' be taxed as part of climate change mitigation, then the demand for local supply systems will increase substantially.

In addition to increased demand for 'local' produce, several other drivers may come together to increase the demand for Welsh horticultural produce. These include the likely reductions in farm subsidy in 2013, a health policy which continues to encourage the consumption of '5 a day' and climate change. Climate change may facilitate change in land use for two separate reasons. Firstly, the climate in Wales will become more favourable for many horticultural crops (less rain overall, less frost, warmer summers and winters). Secondly, climate change may restrict the continued production of horticultural crops in the countries where they are currently grown on large scales. These restrictions will arise chiefly from reduced water availability, and maybe also from the development of high temperatures which would be detrimental to plant growth.

In light of these drivers for change it is timely to consider the environmental and social costs and benefits which are associated with an increased or altered horticultural sector in Wales.

1.2 Purpose and structure

The purpose of this report is to provide an initial assessment of the environmental and social footprint of horticulture in order to identify knowledge gaps which may need to be filled in order to inform future environmental, social and economic policy.

The report is in five chapters:

- Chapter 1 is the introduction.
- Chapter 2 constitutes a review of the current state of knowledge about the relationship between horticulture and the environment. This review seeks to present the state of current science, a summary of general best practice and a list of Wales-specific knowledge gaps.
- Chapter 3 considers the potential impact of climate change on both horticultural production in Wales, and on the major suppliers of horticultural produce to Wales.
- Chapter 4 considers some of the wider issues which may be relevant to increasing the amount of horticulture in Wales. These issues are discussed in the light of the on-going 'local food' debate and relate to the potential to meet Welsh consumption of fruit and vegetables from Welsh supply, and the limitations on this including land and labour.
- Chapter 5 presents conclusions and recommendations.

Chapter 2 Literature review

2.1 Fertilisers

2.1.1 General introduction

Fertiliser use in agriculture and horticulture may cause a major impact on the environment (Skinner *et al.* 1997). Crop production depends on nutrient inputs as manufactured, inorganic fertilisers, organic nitrogen (e.g. manures) and the incorporation of nitrogen fixing crops (Hofman & van Cleemput 2005). The three nutrients needed in greatest quantities are nitrogen, phosphorus and potassium (Soffe 1995).

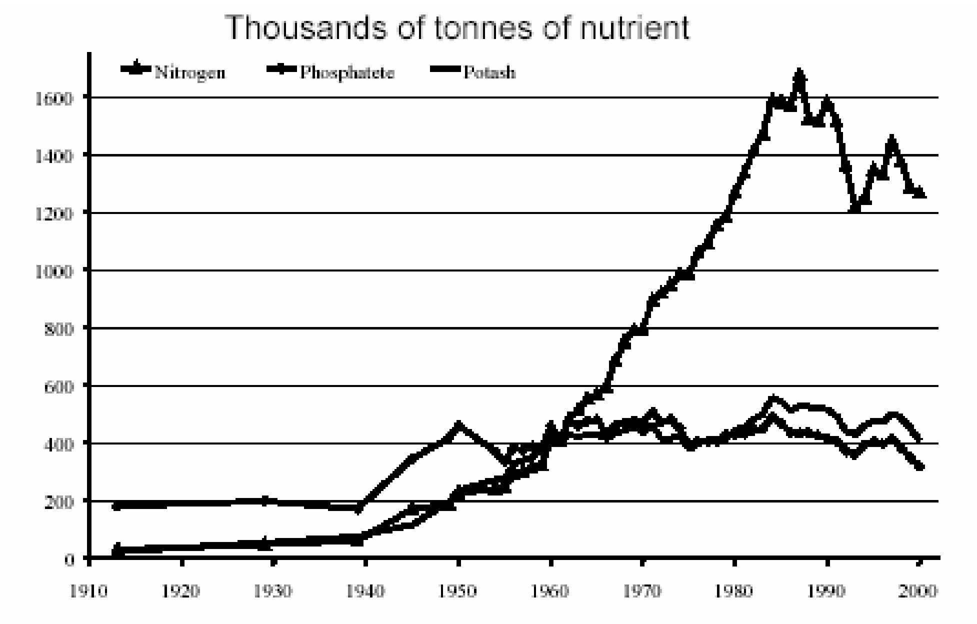
Nitrogen fertilisation impacts the environment in two ways: by polluting drainage water and by emitting gaseous forms of nitrogen to the atmosphere. An average of 10-60 % of the nitrogen applied in fertilisers is lost by leaching, denitrification and volatilization (Goulding 2000). Soil and weather conditions are important factors in the process of nitrogen cycling and determine the amount of nitrogen losses as well as how much is lost through the different pathways (Leach *et al.* 2004). Weather conditions can also influence fertiliser usage, e.g. by disrupting planned farming activities, delaying the establishment of winter sown crops, changing the ratio of winter to spring sown crops or affecting soil chemical parameters and plant nutrient requirements (Defra 2004a).

2.1.2 Fertiliser use in agriculture and horticulture

Figure 1a illustrates how fertiliser usage has increased since the early 1900s. Nitrogen usage is greater than phosphorus and potassium usage and peaked in the 1980s, and both nitrogen and phosphate usage are greater in England than Scotland or Wales (Figure 1b). Figure 2 shows overall application rates for nitrogen, phosphate and potash for major arable crops between 1983 and 2003. In 2003, total nitrogen usage on arable crops amounted to 149 kg ha^{-1}, which represented a slight reduction compared to 2002 when nitrogen usage reached its greatest level in the last five years (Defra 2004a). The main influence on nitrogen usage trends were changes in cropping areas rather than in application rates to individual crops. Reductions in nitrogen use were evident in 2003 for potatoes, oilseed rape and sugar beet (Defra 2004a). Overall phosphate and potash use declined by 4 kg ha^{-1} to 40 kg ha^{-1} and 3 kg ha^{-1} to 54 kg ha^{-1} respectively in 2003. In total, 63 % of the area of tillage crops received phosphate applications (Defra 2004a). Sulphur applications have increased in recent years, mainly on oilseed rape and cereals (Defra 2004a).

Table 1 gives examples of typical fertiliser applications in farming practice for several horticultural crops. Table 2 shows the results of the British survey of fertiliser practice for 2003. Tables 3 and 4 provide information on trends in overall fertiliser use and average field rates for major tillage crops between 1999 and 2003. Fertiliser recommendations for specific crops vary with soil type and soil nutrient status (see MAFF 2000a). Potato yield is greatest in fertile conditions, so that fertiliser applications are high for this crop (Soffe 1995). However, potatoes are not efficient at taking nutrients up from the soil because their root system is not very extensive, so that the risk of leaching is especially great (Addiscott *et al.* 1991). Other crops requiring large nitrogen inputs are leeks, cabbage, calabrese and cauliflower. Peas and beans do not require the application of nitrogen fertiliser (Table 1, Soffe 1995).

a)



b)

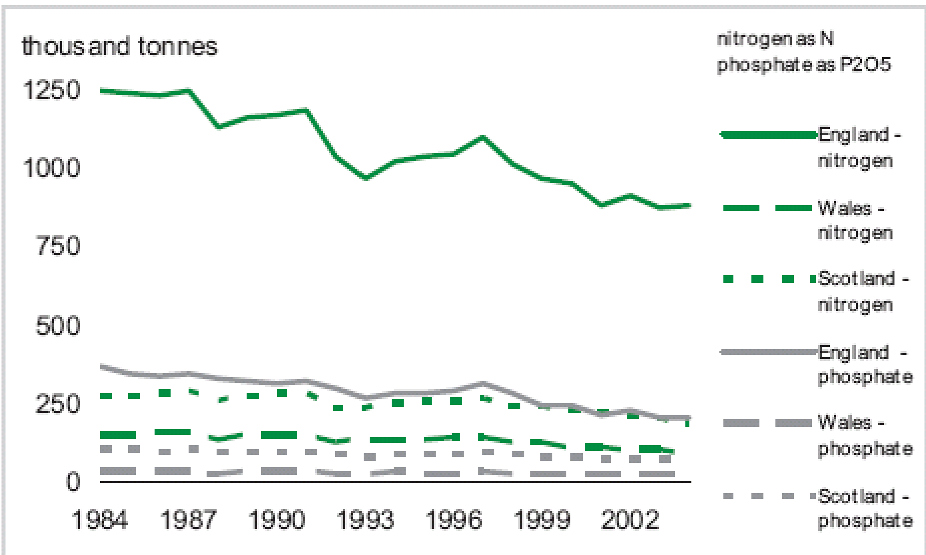


Figure 1. a) Amounts of nitrogen (as N), phosphorus (as P_2O_5) and potassium (as K_2O) applied in the UK between 1910 and 2000. Source: Sherlock (2006). b) Nitrogen and phosphate usage in England, Scotland and Wales between 1984 and 2005. Source: Defra (2005b)

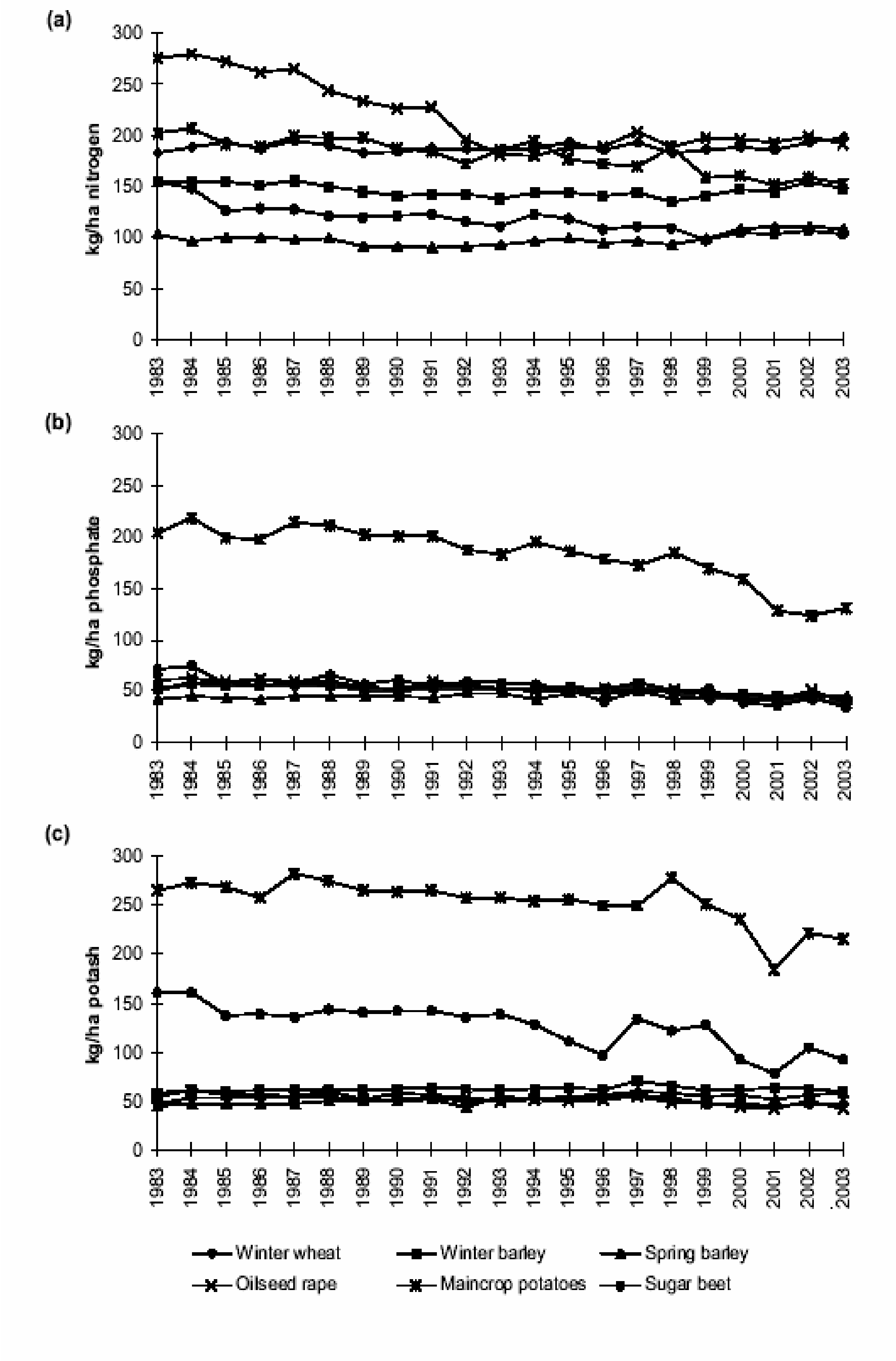


Figure 2. Overall application rates (kg ha^{-1}) of (a) total nitrogen, (b) phosphate and (c) potash on major arable crops in the UK from 1983 to 2003. Source: Defra (2004a)

Table 1. Typical applications of nitrogen, phosphorus and potassium in farming practice in kg ha^{-1}. Source: Chadwick (2005)

	N	P_20_5	K_2O
Wheat			
Winter	200	70	70
Spring	170	50	50
Field beans			
Winter	0	40	50
Spring	0	40	40
Protein peas	0	50	50
Vining peas	0	25	25
Sugar beet	100	50	75
Potatoes			
Early ware	200	150	150
Maincrop ware	220	150	250
Seed	90	200	150
Seed & ware	160	150	200
Raspberries			
First year	75	38	68
Second year	42	42	65
Strawberries	0	0	60
Carrots	50	125	125
Leeks	200	150	125
Swedes	60	175	125
Carrots	50	125	125
Cabbage	225	75	175
Calabrese	200	75	75
Cauliflower	200	75	175

Deep-rooted vegetables such as carrot and cabbage have greater nitrogen use efficiencies than shallow-rooted species such as onion and lettuce; on sandy soils in areas of high rainfall, vegetables with deep rooting can take up more nitrogen before it is lost through leaching (Thorup-Kristensen 2006). Losses from irrigated crops, e.g. potatoes, are greater than from non-irrigated crops, and losses from heavily fertilised and irrigated crops can be greater than 100 kg ha^{-1} year^{-1} (Skinner *et al.* 1997). In vegetable production, nitrogen is often applied in excess of crop requirements, whereas fruit production generally involves lower nitrogen inputs (Schenk 1998). Many vegetables and fruits have large demands for major and minor plant nutrients, and intensive organic horticulture often depends on nutrient inputs more than organic arable systems (Watson *et al.* 2002a).

In a review of nutrient budgets of arable, dairy, horticultural and mixed organic farms, the largest P and K surpluses (input minus output) were found in horticultural systems, which was due to large imports of manure (Watson *et al.* 2002b). All systems studied showed N inputs larger than outputs, with a mean surplus of 194 kg ha^{-1} year^{-1} for horticultural systems.

Table 2. Total fertiliser use in England and Wales in 2003. Source: Defra (2004a)

	Crop area receiving dressing (%)				Average field rate (kg/ha)			Overall application rate (kg/ha)			Fields in sample
	N	P_2O_5	K_2O	FYM	N	P_2O_5	K_2O	N	P_2O_5	K_2O	
Spring wheat	71	41	47	22	153	42	56	109	17	26	64
Winter wheat	99	59	59	12	199	63	76	197	38	45	1825
Spring barley	94	63	71	23	114	46	63	107	29	44	435
Winter barley	99	67	75	15	146	58	77	145	38	58	526
Oats	89	68	75	17	113	60	74	101	41	55	156
Rye/Triticale/Durum wheat	61	25	27	30	126	90	112	77	22	30	22
Seed potatoes	-	-	-	-	-	-	-	-	-	-	3
Early potatoes	50	50	50	20	201	125	205	101	63	103	8
2nd Early/Maincrop potatoes	93	85	90	40	160	150	237	149	128	212	115
Sugar beet	96	53	72	25	108	63	125	103	34	91	208
Spring oilseed rape	95	50	56	16	143	51	64	136	26	36	84
Winter oilseed rape	99	61	58	10	204	60	69	202	37	40	308
Linseed	78	41	48	6	87	53	62	68	22	30	32
Forage maize	74	57	56	92	63	75	109	47	43	61	124
Rootcrops for stockfeed	72	64	63	59	102	103	113	73	66	71	29
Leafy forage crops	73	64	64	50	98	28	31	72	18	20	15
Arable silage/Other fodder crop	51	28	47	63	128	42	85	66	12	40	24
Peas - human consumption	4	31	30	1	40	67	75	2	21	22	68
Peas - animal consumption	8	35	50	13	59	52	71	5	18	36	88
Beans - animal consumption	8	42	36	6	32	64	74	3	27	26	171
Vegetables (brassicae)	99	99	99	27	187	54	152	186	54	151	18
Vegetables (other)	64	63	64	9	137	65	160	88	41	102	61
Soft fruit	92	34	36	0	112	42	136	103	15	49	19
Top fruit	54	17	20	0	92	38	86	50	6	17	50
Other tillage	35	37	37	9	105	65	107	37	24	40	78
All tillage	89	58	61	16	170	63	83	152	37	51	4531
Grass under 5 years	82	62	67	46	167	34	57	136	21	38	702
Grass 5 years and over	64	52	50	38	108	30	35	69	15	17	2282
All grass	67	53	53	40	118	30	39	79	16	20	2984
All crops and grass	77	56	57	29	146	46	61	112	26	34	7515

Table 3. Overall fertiliser use (kg ha^{-1}) on major tillage crops in the UK from 1999 to 2003. Source: Defra (2004a)

Total nitrogen

	winter wheat	*spring barley*	*winter barley*	*maincrop potatoes*[a]	*oilseed rape*[b]	*sugar beet*
1999	185	99	141	158	197	97
2000	188	107	146	160	195	104
2001	185	111	145	151	193	103
2002	193	110	154	158	199	106
2003	197	107	148	152	191	103

Straight nitrogen

	winter wheat	*spring barley*	*winter barley*	*maincrop potatoes*[a]	*oilseed rape*[b]	*sugar beet*
1999	174	53	127	27	180	78
2000	177	62	134	32	180	91
2001	171	66	127	37	176	83
2002	178	66	132	52	181	91
2003	186	61	128	37	179	91

Compound nitrogen

	winter wheat	*spring barley*	*winter barley*	*maincrop potatoes*[a]	*oilseed rape*[b]	*sugar beet*
1999	11	46	14	131	17	19
2000	11	45	12	128	15	13
2001	14	45	19	115	17	20
2002	15	43	22	108	18	15
2003	12	46	20	116	13	13

Total phosphate

	winter wheat	*spring barley*	*winter barley*	*maincrop potatoes*[a]	*oilseed rape*[b]	*sugar beet*
1999	41	45	47	169	46	52
2000	44	47	48	159	41	39
2001	42	43	45	127	41	36
2002	41	45	46	123	50	43
2003	39	44	41	130	38	34

Total potash

	winter wheat	*spring barley*	*winter barley*	*maincrop potatoes*[a]	*oilseed rape*[b]	*sugar beet*
1999	46	54	61	251	48	128
2000	47	56	61	234	43	91
2001	45	51	64	184	42	78
2002	47	56	62	221	50	104
2003	47	57	59	214	42	91

[a] Figures for maincrop potatoes include second earlies.

[b] Single crop grouping for the combined winter and spring oilseed rape areas.

Table 4. Average field rates (kg ha^{-1}) on major tillage crops in the UK from 1999 to 2003. Source: Defra (2004a)

Total nitrogen

	winter wheat	spring barley	winter barley	maincrop potatoes[a]	oilseed rape[b]	sugar beet
1999	189	101	142	178	202	104
2000	193	112	150	174	195	108
2001	189	114	149	175	196	106
2002	197	113	156	172	201	112
2003	199	111	149	163	194	108

Straight nitrogen

	winter wheat	spring barley	winter barley	maincrop potatoes[a]	oilseed rape[b]	sugar beet
1999	182	85	134	93	188	93
2000	185	96	142	73	190	105
2001	184	95	143	96	186	100
2002	189	94	150	101	187	105
2003	193	90	143	122	185	105

Compound nitrogen

	winter wheat	spring barley	winter barley	maincrop potatoes[a]	oilseed rape[b]	sugar beet
1999	57	68	54	164	47	85
2000	49	65	44	156	47	75
2001	70	72	62	155	59	93
2002	63	63	61	129	52	81
2003	60	69	70	143	42	60

Total phosphate

	winter wheat	spring barley	winter barley	maincrop potatoes[a]	oilseed rape[b]	sugar beet
1999	72	54	62	192	71	75
2000	69	58	65	187	70	76
2001	66	55	65	163	64	76
2002	69	57	64	141	71	82
2003	64	54	60	149	60	63

Total potash

	winter wheat	spring barley	winter barley	maincrop potatoes[a]	oilseed rape[b]	sugar beet
1999	78	62	77	287	76	153
2000	77	66	80	265	75	142
2001	72	64	82	231	68	124
2002	80	68	80	235	77	129
2003	77	66	78	237	68	125

[a] Figures for maincrop potatoes include second earlies.

[b] Single crop grouping for the combined winter and spring oilseed rape areas.

2.1.3 Leaching

2.1.3.1 Background

Nitrate is the dominant form of nitrogen in the soil in the UK. It is soluble and thus prone to leaching, especially in autumn and winter because of a rainfall surplus and little or no uptake by crops (Davies 2000). Nitrogen can also enter water courses by surface run-off, sub-surface flow and soil erosion. In the UK, agriculture accounts for about 60 % of nitrates and 43 % of phosphates in rivers (Defra 2005a). Leached nitrates contribute to the eutrophication of natural habitats, e.g. marine ecosystems, coastal waters and lakes, excessive growth of some aquatic plant species and the disturbance of the ecological balance (Sherlock 2006). Increased amounts of nitrates in drinking water pose potential health risks to humans. The EU Nitrates Directive and Drinking Water Directive aim to control and limit the concentration of nitrate in surface and groundwater to 50 mg l^{-1}. In Wales, Scotland and Northern Ireland, the percentage of rivers with nitrate levels above 30 mg l^{-1} remained low in 2004; in England, this is a much greater problem, but due to decreased fertiliser use, nitrate levels in rivers are declining (Defra 2005a).

There are many factors that influence the amount of nitrogen lost through leaching, mainly the type and growth period of the crop, cropping and tillage practices, the amount and type of fertiliser used, the amount of organic and inorganic nitrogen already present in the soil, soil texture and structure, soil moisture, rainfall (especially shortly after application of fertilisers) and irrigation. Nitrogen losses by leaching are greatly influenced by the amount of rainfall (e.g. Webb *et al.* 2004). In summer, when evapotranspiration is high, leaching losses can be negligible (Neeteson *et al.* 1989). In areas or during times of high rainfall, the concentration of nitrate in waters may not represent a problem because of the dilution of inputs.

The two main farming practices leading to nitrate leaching are the application of fertilisers or manures in excess of crop requirements and the application of organic manures at inappropriate times (Davies 2000).

2.1.3.2 Leaching in horticulture

Although horticultural crops occupy only a small area in the UK (less than 0.2 million ha or 4 % of the total area under crops), they can leach very large amounts of nitrogen (Goulding 2000, Sherlock 2006). The cost-effectiveness of fertilisers stimulates their use (Sherlock 2006), and fertilisers may be overused because of the high value of the product (Schenk 1998). Sand and chalk soils have been identified as being particularly prone to leaching: in sandy soils, water flows rapidly through the soil profile, and chalk soils have only a thin soil layer. On shallow, freely draining soils, leaching is the most important loss pathway (Leach *et al.* 2004), whereas less leaching occurs on medium or heavy soils. Some crops, e.g. potatoes, peas, beans and oilseed rape, leach large amounts of nitrate because of their large residues or, in the case of potatoes, their poor root growth (Goulding 2000 and references therein, Sherlock 2006). Of the 300 kg N ha^{-1} that remain in the soil after cultivation with brassicas, about two thirds will be leached (Sherlock 2006). Research has shown that 30-50 % of the nitrogen applied to arable crops is either stored in the soil or lost by leaching, denitrification or volatilisation (Sherlock 2006).

Van Faassen & Lebbink (1994) report nitrogen losses from potatoes of 0-100 kg ha^{-1} over one growing season on a silt loam soil, and concluded that potatoes have higher nitrogen losses in spring than cereals because nitrogen uptake starts later in the season. Shepherd & Lord (1996) and Webb *et al.* (2004) also reported higher leaching losses from potatoes than cereals. On seven organic farms in Belgium, the crops most at risk of leaching were potatoes, maize and beans, while cereals, chicory and cabbage had a low risk (Van Bol & Peeters 1997). Early potatoes have a higher risk of leaching than maincrop potatoes because they receive similar amounts of fertiliser but have lower yield and thus leave more residual nitrogen in the soil (Williams *et al.* 2006).

On sandy loam, Sainju *et al.* (2000) found that nitrogen potentially leaches more easily from soil under tomato than under most agronomic crops, and these authors conclude that no more than 90 kg ha^{-1} should be applied in order to reduce nitrogen leaching.

Little leaching loss occurs under sugar beet which is a good nitrogen scavenger (Shepherd & Lord 1996). Nitrate leaching under sugar beet is minimal compared with other crops; Tzilivakis *et al.* (2005) recorded an average leaching loss of 3.3 kg N ha^{-1} across several different production systems. However, average fertiliser nitrogen removal in the harvested roots was only 27 % in an experiment in South East England (MacDonald *et al.* 1997). In the same experiment, only 13 % of nitrogen applied to beans was removed in the harvested crop, and 49 % in potatoes (MacDonald *et al.* 1997).

For some crops, residues are ploughed into the soil or left on the soil surface after harvest, which returns fertiliser nitrogen to the soil in organic form. If the residues are ploughed in during summer, the nitrogen they contain can be taken up by the next crop after mineralization or lost by leaching, which can be a problem for residues containing high nitrogen contents, e.g. brassicas (Goulding 2000). Pea and bean residues were found to contain 80 kg total N ha^{-1} and 25 kg plant available N ha^{-1} after incorporation; in comparison, these values were 25-50 kg N ha^{-1} and 1-10 kg N ha^{-1} respectively for cereals (Berry *et al.* 2002). The concentration of organic nitrogen in the crop is the most important factor influencing mineralization of nitrogen after the incorporation of crop residues (Trinsoutrot *et al.* 2000, Berry *et al.* 2002). Recovery of nitrogen contained in crop residues is greater by autumn-sown crops than by spring-sown crops, which is probably due to leaching losses during the winter as was shown for pea residues by Jensen (1994). Crop residues can affect the amount of nitrate leaching for up to two years after their incorporation because they mineralise and release the nitrogen slowly (Sherlock 2006).

Because phosphate is rather immobile in the soil, it is less likely to be lost by leaching. It can however be lost from agricultural fields through soil erosion and then contribute to eutrophication of water bodies. For reviews on phosphorus losses and use in the UK, see Sims *et al.* (1998), Haygarth & Jarvis (1999) and Withers *et al.* (2001). Significant leaching of potash only occurs on sandy soils containing little organic matter (Soffe 1995).

2.1.4 Emission of greenhouse gases

Microbial processes convert nitrate from fertilisers, manures and soil nitrogen reserves to the gases N_2, N_2O or NO which are lost to the atmosphere. The latter represent an environmental problem as they are greenhouse gases which may contribute to global warming and the destruction of the ozone layer. The potential of one tonne of N_2O to contribute to global warming is 310 times greater than of one tonne of CO_2 (EEA 2005). Management practices, climate, soil conditions (e.g. water availability and soil temperature) and their natural variability in time and space all influence N_2O production (Roelandt *et al.* 2005), with the main factors increasing N_2O emissions being fertiliser application and rainfall (Webb *et al.* 2004). Emissions also increase after cultivation of bare soil and incorporation of crop residues and are greatest in wet and warm soil (Baggs *et al.* 2000, MAFF 2000a). Organic fertilisers are the main source of N_2O emissions, and agriculture accounts for about 70 % of all N_2O emissions in the UK (Defra 2005a). In Wales, 83 % of total N_2O emissions result from agriculture, predominantly as a result of soil processes, including leaching of fertiliser nitrogen (27 %), synthetic fertiliser application (19 %), manure used as fertiliser (8 %), ploughing in of crop residues (1 %) and cultivation of legumes (< 0.1 %) (Baggott *et al.* 2002). NO emissions have also been shown to increase when fertiliser is applied (Veldkamp & Keller 1997). It is estimated that in temperate areas at least 0.5 % of fertiliser nitrogen is emitted as NO (Veldkamp & Keller 1997). Nitrogen in manures and some inorganic fertilisers can also be lost as ammonia, especially on sandy soils (Addiscott *et al.* 1991, MAFF 2000b). About 11 % of all NH_3 emissions on farmland in the UK are due to nitrogen fertilisation (Sherlock 2006).

Emissions of N_2O from potatoes and cereals were found to be greater than from natural or semi-natural ecosystems and strongly related to fertilisation (Smith *et al.* 1998a). Smith *et al.* (1998a) found that total emissions of N_2O were 70 % greater from potatoes than from barley and more than four times greater than from winter wheat. Webb *et al.* (2004) recorded N_2O losses of 0.3 % of fertiliser nitrogen inputs for potatoes, which was less than measured under cereals or sugar beet. In an experiment in Scotland, N_2O emissions under potatoes amounted to 1.2-3.2 kg ha^{-1}, whereas emissions from spring barley and winter wheat were 0.8 kg ha^{-1} and 0.3 kg ha^{-1} respectively; for all these crops, emissions were less than 1 % of nitrogen applied (Smith *et al.* 1998b). In a modeling study on sugar beet, losses of nitrogen via denitrification amounted to an average of 15.2 kg ha^{-1} (Tzilivakis *et al.* 2005). N_2O emissions from glasshouse crops are similar to those from field-grown crops (Mosier *et al.* 1998a). Hosono *et al.* (2006) measured increased daily N_2O and NO emissions after basal fertiliser application to greenhouse tomatoes, with the peaks lasting for 40 to 140 days. For cucumbers grown in a soilless rockwool system, Daum & Schenk (1996) measured an emission rate of 0.62 kg nitrogen ha^{-1} greenhouse area and day, with an average emission of 12.4 % of the nitrogen input as N_2O and N_2. Table 5 shows some estimates for N_2O losses from different agricultural crops.

Table 5. Estimated losses of N_2O from crops. Source: Tzilivakis *et al.* (2005)

Crop	**kg N_2O ha^{-1} $year^{-1}$**
Potato	1.1-2.9
Sugar beet	0.5-2.0
Winter wheat	0.3-0.9
Oilseed rape (*Brassica* ssp.)	0.7-0.8
Spring barley	0.5-0.8
Pea (*Pisum* ssp.)	0.2

2.1.5 General best practice

Advice on best practice is available from MAFF (1998a, 1998b, 1998c, 2000a), EA (2003) and Defra (2005b). Measures that can reduce the environmental impacts of fertilisation are also discussed by e.g. Drinkwater *et al.* (1998), Lord *et al.* (1999), Berry *et al.* (2002) and Di & Cameron (2002). Geypens & Vandendriessche (1996) discuss recommendation systems based on soil analysis, plant analysis and simulation models. The application of fertiliser is very cost-effective; however, over-application does not only increase the amount of nitrate at risk from leaching, but may also decrease yield (Sherlock 2006).

Nitrate losses through leaching can be influenced by management techniques. For example, the application of compost can help reduce nitrogen fertiliser inputs (ADAS 2006). The effectiveness of cover crops in reducing nitrate leaching has been shown by Shepherd & Lord (1996) and Shepherd (1999). Beaudoin *et al.* (2005) conclude that nitrogen fertiliser optimisation, cover crops and straw incorporation can significantly reduce nitrate concentrations in the soil. However, Shepherd & Webb (1999) reported that the overall reduction in over winter nitrate drainage achieved by cover crops was only about 2 % compared with bare soil before spring planting. Kramer *et al.* (2006) showed how the use of organic fertilisers significantly reduced harmful nitrate losses in apple orchards, a finding they believe will also apply to vegetable systems. The establishment of green cover after harvest and before the winter can help remove nitrogen from the soil and minimise leaching losses (Shepherd & Lord 1996, Beaudoin *et al.* 2005). However, this does not apply to potatoes because they are harvested too late in the year for a cover crop to establish before the start of winter (Shepherd & Lord 1996). The risk of leaching also depends on harvest date – the earlier the harvest the greater the risk of leaching as shown for winter and spring peas by McEwen *et al.* (1989).

Leaching losses of nitrogen are generally smaller in organic than conventional systems, but the difference is small if best practice management is applied in both systems (Stockdale *et al.* 2001, Stopes *et al.* 2002).

More precise applications of fertilisers and avoidance of over-application will also reduce N_2O emissions, as soil nitrogen availability is the most important factor influencing N_2O fluxes in agricultural ecosystems (Robertson & Grace 2004). NH_3 emissions from using urea based fertilisers range between 5-40 % of the nitrogen applied; for ammonium nitrate based fertilisers, this value is 0.3-3 % (Sherlock 2006). It is estimated that agricultural NH_3 emissions from fertilisers in the UK could be reduced by 22 % by using ammonium nitrate instead of urea (Sherlock 2006).

Models are now available commercially as decision support tools, aiming to predict optimum nitrogen application rates and losses by leaching, denitrification and volatilisation (Sherlock 2006). Fertiliser applications to brassica rotations can be reduced by 50 % while maintaining yields by taking residual nitrogen into account when calculating application rates, and nitrogen losses can be reduced by 75 % for vegetables by using starter or banded fertilisers with predictive models (Sherlock 2006).

2.1.6 Recommendations for best practice

In summary, best practice recommendations to minimise nitrate leaching include the following (Sherlock 2006):

- an appropriate crop variety must be chosen,
- a green cover must be maintained for as much of the year as is practicable,
- crops should be drilled early,

- fertiliser requirements should be calculated using a recommendation system and allowance made for soil mineral nitrogen and any manures applied,
- fertilisers should be spread evenly with a properly calibrated spreader, perhaps using split applications,
- starter fertilisers and banding of fertilisers should be used where appropriate to reduce losses from vegetables,
- use appropriate controls to minimise pest, disease and weed infestation,
- irrigate carefully where required to support crop yield and using a scheduling system that takes account of crop nitrogen use and the weather.

Opportunities to mitigate N_2O emissions from arable soils include (Sherlock 2006):

- reducing nitrogen inputs,
- use of winter cover crops,
- changes in crop mix and irrigation of crops,
- growing energy crops to offset emissions from the previous components and indirect emissions from the manufacture of inputs.

2.1.7 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to the use of fertilisers in Welsh horticulture:

- Consider how to incorporate horticulture into Catchment Sensitive Farming, which is currently designed to reduce pollution from livestock systems?
- Understand the risk of water pollution from fertiliser use which may contravene standards set in the Water Framework Directive from horticulture. A first step may be to consider the water quality in the areas which currently support horticultural enterprises, e.g. Pembrokeshire, Flintshire, Llyn Peninsula and Monmouthshire?
- Consider how best to reduce nitrogen leaching from field vegetables, particularly potatoes?
- Estimate the level of N_2O emissions from protected cropping, e.g. in polytunnels and glasshouses?
- Consider how to reduce the N_2O emissions from field vegetables, particularly potatoes?

2.2 Greenhouse gas emissions

2.2.1 General introduction

Agriculture greatly contributes to global emissions and fluxes of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from the biosphere to the atmosphere. The net contribution of the whole agricultural sector to global fluxes of CH_4 and N_2O is 40 % (Oenema *et al.* 2001). Soils are the largest source of terrestrial carbon (1200 Pg C) and will be greatly affected by land use change and global climate change. Agricultural development has extensively converted forests and grasslands to arable land for farming, thereby releasing carbon and nitrogen to the atmosphere by processes such as burning, removal of biomass and disturbance of soil for forming of fields. Crop production generally produces CO_2 and N_2O and decreases the soil sink for CH_4 (Mosier *et al.* 2005). The overall net exchange of these gases represents the global warming potential of a crop production system (Mosier *et al.* 2005). In the UK, agriculture accounts for about 7 % of total greenhouse gas emissions (Defra 2005a).

2.2.2 Fluxes of greenhouse gases between soils and atmosphere

The three greenhouse gases largely responsible for emissions from agriculture, CO_2, CH_4 and N_2O, each have a global warming potential (GWP), which is the warming influence relative to that of carbon dioxide. The GWP is expressed as equivalent tonnes of carbon dioxide (equiv. t CO_2) (Maunder 1992). Important factors of a molecule contributing to GWP are ability to capture infrared radiation, current concentration in the atmosphere, concentration of other greenhouse gases and its atmospheric lifetime. The GWP indicates how rapidly a molecule cycles in the atmosphere. For example, the 20 year and 100 year GWPs for N_2O are 275 and 296 respectively, indicating persistence. Conversely, CH_4 cycles more rapidly with 20 year and 100 year GWPs of 62 and 23 CO_2 equiv. respectively. A useful interpretation in an agronomic context is, for example, over a 20 year time period, if a management practice reduced N_2O emissions by 1 kg ha^{-1}, this would be equivalent to sequestration of 275 kg ha^{-1} CO_2 as soil carbon (Robertson & Grace 2004). In comparison, intensively managed grassland may receive fertilisation in the range of 300 to 600 kg N ha^{-1} per year. Applying a typical emission factor of 2.2 %, leads to an emission of 6.6 to 13.2 kg N_2O-N ha^{-1} (Tzilivakis *et al.* 2005). Since the GWP of N_2O is 296 times greater, this is equivalent to a CO_2 emission in the range of 3 to 6 T ha^{-1}. Therefore, relatively small emissions of N_2O can exert a strong influence on the total GWP of an ecosystem.

Management practices can have an effect on greenhouse gas fluxes. For example, Flessa *et al.* (2002) found increased emissions of N_2O and decreased uptake of CH_4 in tractor-compacted soil under potatoes, whereas soil loosening by tillage had the opposite effect. The main reason for increased N_2O emissions from compacted soil is the increase in the amount of water-filled pore space, along with a reduction in nitrogen uptake by plants (Ruser *et al.* 2006). Emissions of N_2O were also increased after potato tops were killed by herbicide application.

2.2.3 Carbon budgeting in agricultural soils

Carbon losses from cultivated soil are due to reduced inputs of organic matter, increased decomposability of crop residues and tillage effects that decrease the amount of physical protection to decomposition (Post & Kwon 2000). Changes in land use over the period 1850-1990 have already released 156 Pg C to the atmosphere (Houghton 2003), about half as much released from combustion of fossil fuels. Within the UK, soil was calculated to have lost 0.013 Pg C yr^{-1} between 1978 and 2003 (Bellamy *et al.* 2005). In Wales, the mean organic carbon content of the upper 15 cm of arable and permanent grassland soils declined by an estimated 0.5 % between 1980 and 1996 (CEH 2002). On average, soil carbon in the upper metre of soil is reduced by 25-30 % as a result of cultivation (Houghton & Goodale 2004, Amundson 2001). Other studies comment that there is uncertainty in the amount of carbon lost from soils (Janssens *et al.* 2003, Smith 2004). Improved terrestrial management over the next 50-100 years could sequester up to 150 Pg of carbon, the amount released since 1850 (Houghton 1995, Houghton 2003). Other less important sources of CO_2 in agriculture include the on-farm use of fuel and indirect fuel consumption for the manufacture, transport and application of fertilisers and pesticides, manufacture and repair of machinery, construction of buildings and the generation of electricity (Oenema *et al.* 2001).

In a study on annual CO_2 fluxes, Anthoni *et al.* (2004a) found moderate uptakes of -193 g C m^{-2} yr^{-1} for winter wheat and -34 g C m^{-2} yr^{-1} for potatoes. When carbon offtake by harvest was taken into account, both winter wheat and potato fields became net CO_2 sources of +97 to +386 g C m^{-2}. Annual changes in cultivation of crops can have a large influence on a region's seasonal and annual carbon exchange, and land-use history and site-specific management decisions will affect the large-scale carbon balance.

Calculation of a carbon budget or net ecosystem production (NEP) was originally defined by Woodwell and Whittaker (1968) as the difference between the amount of organic carbon fixed by photosynthesis in an ecosystem (gross primary production, or GPP) and total ecosystem respiration, R_t (the sum of autotrophic, R_{auto} and heterotrophic respiration, R_h) (Lovett *et al.* 2006). When NEP is positive, net sequestration of carbon into the agro-ecosystem has occurred and is termed a 'carbon sink'. If NEP is negative then there has been a net emission of CO_2 and is termed a 'carbon source'. Autotrophic respiration is not easy to measure over the course of a year so in practice, NEP is often calculated from the difference between net primary production (NPP) and heterotrophic respiration (rearranging above, $GPP = NEP + R_{auto} + R_h$ and $GPP = NPP + R_{auto}$, therefore $NEP = NPP - R_h$) (Melillo *et al.* 1995). NPP can be estimated from crop biomass and heterotrophic respiration can be estimated from bare soil (Hanson *et al.* 2000), or calculated using modelling.

Calculation of NEP for large spatial areas is possible from measuring net ecosystem exchange (NEE) in carbon dioxide, water vapour, and energy because they are facilitating the NEP of an agro-ecosystem (NEP = – NEE) (Anthoni *et al.* 2004b). Calculation from airborne remote sensing relies on the relationship between NEE and different plant functional types (PFTs). Eddy covariance uses weather stations placed in fields to record daily micrometeorological measurements of the net exchanges.

A further calculation is of net biome production (NBP), which is NEP minus non-respiratory losses such as harvest. NBP is also expressed as a rate of carbon sequestration (Hu *et al.* 2004). In the study of Anthoni *et al.* (2004b), grain harvest was 290 g C m^{-2} in 2001, therefore NBP ranged from -45 to -105 g C m^{-2} depending on whether calculated NEP (252 ± 34 g C m^{-2}) or measured NEP (185-245 g C m^{-2}) was used. The negative values for NBP indicate that carbon has been lost from this ecosystem due to harvest.

2.2.4 Nitrous oxide (N_2O)

Farming affects the nitrogen cycle's production of N_2O and the terrestrial sink capacity for CH_4 under aerobic conditions. The conversion of forests and grasslands to croplands has also accelerated nitrogen cycling. After a forest had been cleared and turned to pasture N_2O emissions increased 3-fold, though reduced to background after 10-20 years (Mosier *et al.* 1998b). Two-thirds (IPCC 2000) or about 70 % (Bouwman 1990) of N_2O emissions are derived from soil. A third of CH_4 emissions come from soils (IPCC 2000). While emission quantities of N_2O and CH_4 are smaller compared to CO_2, they have greater global warming potential. Globally, agriculture accounts for 65-80 % of total N_2O emissions, mainly from nitrogenous fertilisers on cultivated soils and animal wastes (Metz *et al.* 2001).

Nitrous oxide is produced primarily from the natural microbial processes of nitrification and denitrification in soil (Verma *et al.* 2006). The current atmospheric concentration of N_2O is around 310 ppbv and is increasing at a rate of 0.3 % per year due to human related activities (Verma *et al.* 2006). With further increases this could result in increased skin cancer and other health problems (Lijinsky 1977, Mosier *et al.* 1998b). Nitrous oxide is also important in the chemistry of the stratosphere as nitrous oxide oxidation is involved in the ozone equilibrium (Jambert *et al.* 1997). The annual increase in atmospheric N_2O is largely a result of fertiliser applications to agricultural ecosystems (Mosier *et al.* 1998b). Nitrogen (N) fertiliser use and biological N-fixation are projected to increase over the next 100 years due to increased global food production (Mosier *et al.* 1998b). In a study of arable rotations in England, crop off take ranged from 54-98 % depending on crop type and whether residue was left, while total annual loss of N_2O never exceeded more than 2 kg ha^{-1} N and ranged between 0.2 and 2.8 % of fertiliser application (Webb *et al.* 2004). Nitrous oxide emissions followed a seasonal pattern, peaking in the summer and autumn when the soils are usually warm and moist (Webb *et al.* 2004). Studies of emissions of N_2O from presumably similar agricultural systems show highly variable results in both time and space (Mosier *et al.* 1998b).

2.2.5 Methane (CH_4)

Under anaerobic conditions, soils can be an important source of methane, e.g. in natural wetlands or flooded rice. Aerobic soils, on the other hand, are important sinks of methane, where CH_4 is oxidised to CO_2 which is 21 times less radiatively active (Powlson *et al.* 1997). Land management has a great impact on the ability of soil to oxidise methane, with uncultivated soils generally representing a greater sink than cultivated soils (Powlson *et al.* 1997, Smith *et al.* 2000, Oenema *et al.* 2001). Inorganic fertilisers have been shown to inhibit CH_4 uptake and oxidation by arable soils (Hütsch *et al.* 1993, Powlson *et al.* 1997). Soil compaction also reduces CH_4 uptake (Hansen *et al.* 1993). It has been estimated that land conversion to agriculture, disturbance of ecosystems, changes in agricultural practice and increased atmospheric deposition may have decreased the soil methane sink by 7 Tg y^{-1} (Willison *et al.* 1995). In the study by Powlson *et al.* (1997), 150 years of arable cultivation had resulted in an 80 % reduction in the rate of CH_4 uptake. Smith *et al.* (2000) estimated that conversion of Northern European natural soils to agriculture reduces oxidation rates by about two-thirds and that recovery of the oxidation rate from land use change or fertilisation is slow, taking more than 100 years to return to pre-disturbance rates. For a review of the effects of crop production on methane oxidation, see Hütsch (2001).

2.2.6 Greenhouse gas emissions from protected horticulture

Greenhouse horticulture emits CO_2, CH_4, N_2O and sulphur dioxide (SO_2). In contrast to field horticulture, where CH_4 and N_2O represent a significant part of total emissions, CO_2 is the single most important greenhouse gas produced by protected horticulture. CO_2 emissions result from the combustion of natural gas for heating and for increasing CO_2 concentrations in the greenhouse to stimulate crop growth; in Dutch greenhouse horticulture, the combustion of natural gas accounts for 99 % of total greenhouse gas emissions (Pluimers *et al.* 2001). Tomato production requires greater inputs of natural gas and fertilisers and thus produces more CO_2 emissions per hectare than the greenhouse horticultural sector as a whole. Biogenic emissions in the form of N_2O amount to 1 % of total emissions. In the Netherlands, total greenhouse gas emissions per hectare are more than 50 times higher for protected horticulture than field based agriculture. N_2O and NO_x emissions from glasshouse production are also greater because of higher nitrogen fertiliser inputs (Pluimers *et al.* 2001). These estimates do not include emissions from the production of fertilisers, pesticides, electricity etc. For cucumbers grown in a soilless rockwool system, Daum & Schenk (1996) measured an emission rate of 0.62 kg nitrogen ha^{-1} greenhouse area and day, with an average emission of 12.4 % of the nitrogen input as N_2O and N_2.

2.2.7 General best practice

Advice on how to reduce greenhouse gas emissions is available from MAFF (1998b) and Sherlock (2006), including more efficient use of energy, exploitation of alternative non-fossil fuels as energy sources and measures to decrease N_2O and CH_4 emissions. A summary of techniques and new technologies to reduce greenhouse gas emissions in the agricultural sector is presented in Metz *et al.* (2001) (Table 6). Practices enhancing carbon sequestration in biomass and soils will generally increase the soil organic matter (SOM) content of soils which in turn will have a positive impact on environmental, agricultural and biodiversity aspects of ecosystems. The increase of SOM can improve aggregation and the stability of soil structure; infiltration rate and water retention; and resistance to erosion. Minimum and zero cultivation techniques can save tractor fuel, conserve soil moisture and reduce soil erosion; however, they may require greater chemical weed control (Metz *et al.* 2001). Cheap and accurate soil moisture sensors are needed in order to reduce water and energy demand for irrigation (Metz *et al.* 2001). Improved soil management will not only help mitigation efforts but also provide other benefits, e.g. improved water quality, reduced soil erosion, nutrient retention and nutrient cycling capacity (Metz *et al.* 2001).

The potential of different agricultural management options for carbon sequestration in soils was measured on a European scale (Freibauer *et al.* 2004). Practices were identified that had realistic potential to sequester up to 16-19 Mt C $year^{-1}$ or 2 % of the anthropogenic CO_2 emissions during the first Kyoto Protocol (KP) commitment period (2008-2012). These included: the promotion of organic inputs on arable land instead of grassland, the introduction of perennials (grasses, trees) on arable set-aside land for conservation or biofuel purposes, to promote organic farming, to raise the water table in farmed peatland, and – with restrictions – zero tillage or conservation tillage. Hütsch *et al.* (1994) also suggest set-aside and afforestation as options for increasing the CH_4 sink strength of soils; however, this benefit is lost if soils become acid.

Table 6. Uptake of management techniques and new technologies to reduce greenhouse gas emissions in the agricultural sector. Source: Metz *et al.* (2001)

	Techniques and technologies to be considered
Management techniques	
Conservation tillage	Conventional tillage consumes 60 % of the tractor fuel used in industrialised crop production and decreases soil carbon. Minimum and zero cultivation techniques save tractor fuel, conserve soil moisture, and reduce soil erosion. Uptake is continuing worldwide. Greater chemical weed control may be required. Benefits need to be achieved without reducing crop yields which is more likely under dry conditions as a result of moisture conservation. Globally, 150-175 Mt C year^{-1} sequestration is possible.
Soil carbon uptake	Typical agricultural soils contain 100-200 t C ha-1 to 1 m depth. Overuse of soils leads to degradation, salinization, erosion and desertification, and will lead to lower organic matter contents with consequent carbon emission. A change of land use of intensively cultivated soils could result in increased organic matter and carbon sequestration till the soil finds a new balance. Total sequestration potential of world cropland is around 750-1000 Mt C year-1 for 20-50 years from: erosion control (80-120 Mt C year-1), restoration (20-30 Mt C year-1), conservation tillage and crop residue management (150-170 Mt C year-1), reclamation of saline soils (20-40 Mt C year-1), improved cropping (180-240 Mt C year-1) and C offsets through energy crop production (300-400 Mt C year-1).
Nitrogenous fertilisers	Anthropogenic agricultural nitrous oxide emissions (over 800 Mt C year-1) released after application of N fertilisers as a result of nitrification and denitrification and from animal wastes exceed carbon emissions from fossil fuels used in agriculture. Measuring emissions is difficult (± 85 %) because of soil variability. Reductions resulting from use of N fertiliser strategies, slow release fertilisers, organic manures and nitrification inhibitors could tentatively cut emissions by 30 % on a global scale. Costs would be between US$ 0-14 t C-1 in Europe for 3-4 Mt C year-1. Genetically engineered leguminous plants may have further potential.
Tractor operation and selection	Correct operation of tractors and size matching to machinery can save fuel, improve tyre life, reduce soil compaction and save time. Behavioural change by driver education is required but with cheap diesel fuel there is little incentive.
Irrigation scheduling	Applying water only as needed saves both water and energy for pumping. Cheap and accurate field soil moisture sensors are necessary but not yet available.
New technologies	
Postharvest crop losses	A reduction in postharvest crop losses could make a significant impact on energy use, particularly in developing countries. Solar drying on the ground leads to vermin and pest losses. Storage in sealed buildings with natural ventilation and solar heated air will reduce losses for minimal energy inputs. For fresh crops, refrigeration and heat pumps are used to maintain the cool chain but energy inputs can be significant. Solar panels on refrigerated truck roofs are technically feasible but not economic.
Global positioning systems	Commercially available GPS and GIS systems are available to map the monitor the position of working tractors to enable strategic applications of fertilisers and chemicals to be applied depending on crop yields and soil types. Plantation forest mapping is also used to plan roads and harvests. Energy inputs can be saved as a result.
Controlled environment	Crops grown in greenhouses can use less energy per production unit if the available growing area is increased and better control of heating and ventilation occurs.

Inclusion of cover crops in the rotation cycle considerably enhances carbon sequestration. Inclusion of rotational crops also conserves soil quality. They reduce wind-erosion, losses of fine silt and clay particles, and sequester C, N and other macro- and micro-nutrients. There was a positive increase (C sequestration) for SOM-C with increases in crop residue (Al-Sheikh *et al.* 2005). This has been shown for several other studies (Larson *et al.* 1972, Rasmussen *et al.* 1980, Havlin *et al.* 1990, Campbell & Zentner 1993). For a more detailed discussion of the various measures suggested to reduce greenhouse gas emissions from agriculture and the associated constraints and challenges, see Oenema *et al.* (2001).

Smith *et al.* (2001) conclude that some agricultural management options have considerable potential for carbon mitigation, but it is necessary to consider all three gases, not only CO_2, when assessing the mitigation potential of land management options. This is because management practices to reduce one greenhouse gas can lead to increases in other gases. For instance, reducing CO_2 emissions by applying more fertilisers and irrigation to increase plant production and hence carbon sequestration in the soil can conversely increase emissions of N_2O from fertiliser denitrification. Emissions of N_2O might also be increased from changing to reduced tillage because associated increasing of soil moisture stimulates nitrifying and denitrifying bacteria (Robertson 1999). In addition to management options that increase the potential of farmed soils for carbon sequestration, non-cropped areas of farmland can also be used for carbon mitigation. For example, set-aside areas and field margins can potentially sequester large amounts of carbon in above-ground biomass and soil organic matter (Falloon *et al.* 2004).

Options to achieve reductions in CO_2 and NO_x emissions in protected horticulture are listed in Table 7 (Pluimers *et al.* 2001). For example, reductions of gas use can be achieved by decreasing heat demand through better insulation or by increasing heat production efficiency through the use of condensers etc. Pluimers *et al.* (2001) believe that the implementation of these technical reduction options could reduce CO_2 and NO_x emissions from tomato cultivation by about 70 % and 75 % respectively compared to the early 1990s when none of these measures were implemented yet. At net zero annual cost, smaller reductions of 42 % and 59 % respectively could be achieved. Metz *et al.* (2001) argue that protected horticulture can reduce energy consumption per production unit by increasing the available growing area and better controlling heating and ventilation.

Table 7. Options to reduce farm level abiogenic emissions of CO_2 and NO_x that result from the combustion of natural gas in Dutch tomato cultivation and their technical potentials to reduce remissions. Source: Pluimers *et al.* (2001)

Reduction options	**Reduction of CO_2 [a]**	**Reduction of NO_x [a]**
Condensers: single, retour and combi	4-12 %	4-12 %
Screens: fixed, movable and double	8-25 %	8-25 %
Wall insulation: wall screens, double glass and coated glass	0.5-8 %	0.5-8 %
Roof insulation: double and coated glass	20-35 %	20-35 %
Alternative CO_2 application: heat buffer or pure CO_2	10 %	10 %
Alternative gas combustion: low NO_x burner	0 %	40 %
Temperature management: climate computer, decrease of average temperature and temperature integration	7-16 %	7-16 %
Greenhouse construction: better insulation	1-2 %	1-2 %

[a] Technical potential to reduce emissions on the farm level as a percentage of the emissions in the unabated situation.

2.2.8 Recommendations for best practice

In summary, options to reduce greenhouse gas emissions and enhance sinks in agriculture and protected horticulture include:

- more efficient use of energy,
- exploitation of alternative non-fossil fuels as energy sources,
- improved soil management for crop production,
- uptake of management techniques such as conservation tillage, careful use of nitrogenous fertilisers, better tractor operation and irrigation scheduling, etc.,
- uptake of new technologies, e.g. reduction of inputs by using genetic selection or modification,
- use of crop residues (if not returned to the land) for heat and power generation,
- set aside of surplus farmland and introduction of perennials (grasses, trees) on arable set-aside land for conservation or biofuel purposes,
- promotion of organic farming which reduces energy consumption and CO_2 emissions due to reduced inputs of fertilisers and pesticides.

2.2.9 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to managing the emission of greenhouse gases in Welsh horticulture:

- Understand the patterns of greenhouse gas emissions from field and protected cropping.
- Develop management systems for minimising greenhouse gas emissions in horticultural systems, particularly potatoes and protected cropping.
- Research and develop a ‘low carbon’ horticultural system.

2.3 Irrigation

2.3.1 General introduction

Irrigation is the most significant use of water in agriculture (MAFF 2000b). The crops that benefit most from irrigation in terms of increased yield and quality are potatoes, sugar beet, root vegetables (e.g. carrots, parsnips, turnips), orchard fruit and soft fruit (EA 2001). The most important of these are maincrop potatoes, accounting for over 50 % of all irrigation water used (Downing *et al.* 2003). Other irrigated crops include peas, beans, asparagus, celery, leeks, cabbage and cauliflower (Knox & Wheatherhead 2003).

The irrigated area in Wales comprises about 40 km^2 and is rather small compared to England (EA 2001a). Large concentrations of irrigated area occur in East Anglia, the Midlands and the North East of England. Because irrigation is supplementary to rainfall, there is variation in the total amount of irrigated area per year, within England and Wales between 140 000 ha and 200 000 ha (Vecino & Martin 2004).

Boreholes and watercourse abstractions provide most of the water used, with groundwater and surface water sources accounting for 35 % and 58 % of total abstraction for irrigation respectively (Vecino & Martin 2004). Unreliable abstraction supplies can result in significant reductions in crop yield and quality (EA 2001a).

Irrigation in England and Wales is mainly applied in order to enhance quality, e.g. size, shape, appearance, skin condition and delivery time to markets, rather than yield (Vecino & Martin 2004). More than half of all potatoes are irrigated, mainly in order to ensure high quality (Vecino & Martin 2004). In 2001, field vegetables accounted for 27 % of the total irrigated area and 26 % of the total volume of irrigation water in England and Wales (Downing *et al.* 2003). The amount of water used by agriculture depends on factors such as the type and quality of crops produced and the world market for these products, and may increase in the future in some parts of England and Wales (EA 2001a). For horticultural products, net margins per ha decrease significantly if the production system is changed from irrigated to rain fed (Vecino & Martin 2004). The potential financial benefits of irrigation were estimated at £ 144 million per year for the Anglian region, illustrating the importance of irrigation to the economy and the significant impact that water restrictions in dry years can have on the economy (Knox *et al.* 2000). Average total irrigation costs range from £ 0.3 m^{-3} to £ 0.7 m^{-3} depending on the need for water storage. Because the cost of the irrigated water accounts for only 5-7 % of total irrigation costs, demand for water is currently not very responsive to price (Morris *et al.* 2004a).

The Environment Agency (EA 2001a) concludes that water can be a scarce resource in England and Wales and that in some areas, environmental improvements need to be implemented. About 140 million m^3 are abstracted for irrigation in England and Wales each year (Vecino & Martin 2004). Although this only accounts for 1.5 % of total water abstraction, it can be significant in intensively irrigated areas (Knox *et al.* 1996, Vecino & Martin 2004). Between 1975 and 2000, the volume of water used for irrigation doubled (Vecino & Martin 2004) (Figure 3), which is mainly due to an increase in the production of more water dependent crops (MAFF 2000b). In many catchments, particularly in the east of England, increasing demand has led to concern about the sustainability of water supplies (Knox *et al.* 2000). Future irrigation demand in the UK is estimated to increase by 52 % in 2021 as compared to 1995 (Institute for European Environmental Policy 2000). If present trends of water usage continue, there may not be enough water resources to meet demand beyond

2025 (Defra 2002). Figure 4 illustrates predicted changes in irrigation need between 1996 and 2021. In most of Wales, irrigation demand will remain unchanged, but is predicted to increase slightly in some south-western areas and decrease on Anglesey and in the north-east.

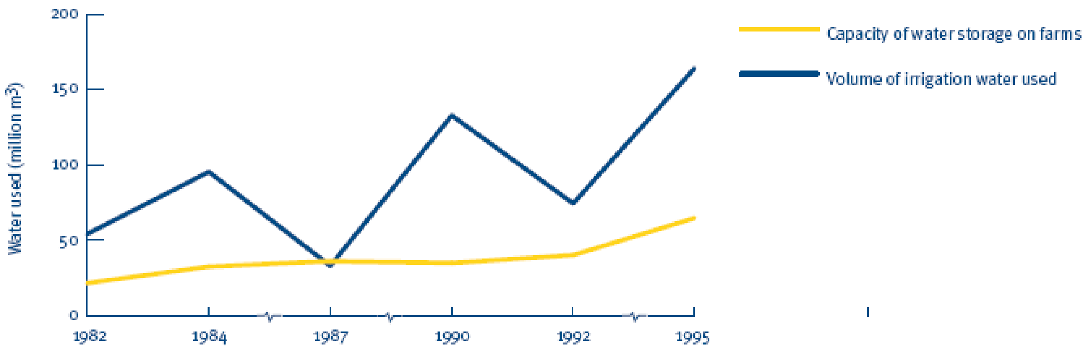


Figure 3. Capacity of water storage on farms and volume of irrigation water applied in the UK between 1982 and 1995. Source: MAFF (2000b)

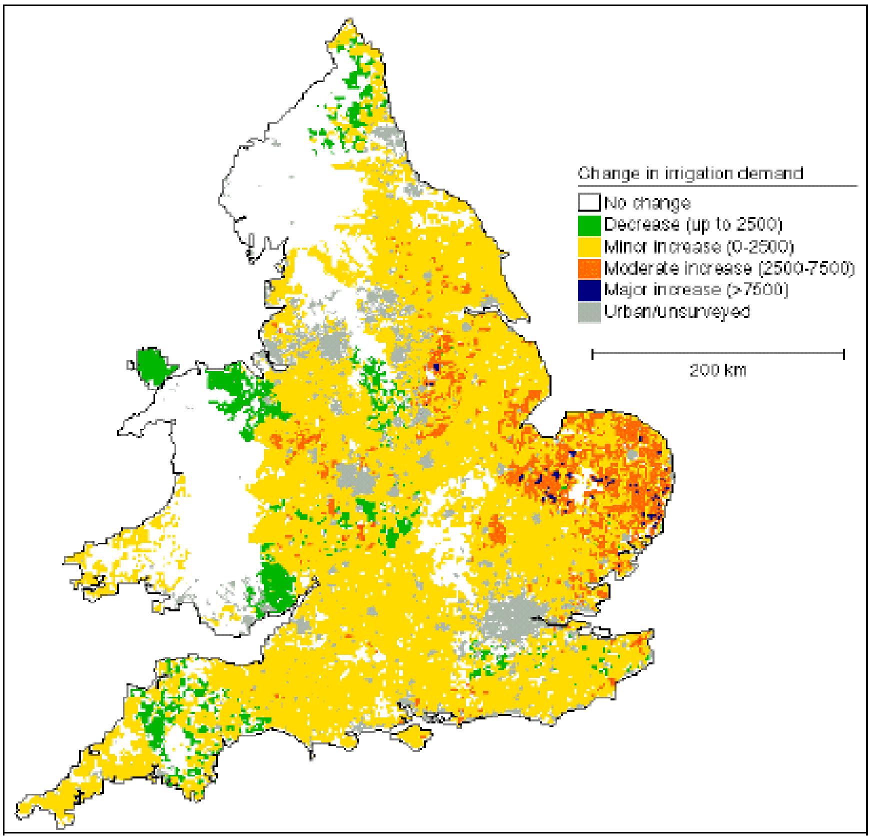


Figure 4. Predicted changes in the spatial distribution of irrigation demand between 1996 and 2021. Source: Weatherhead *et al.* (1997)

Within Europe, the irrigable area increased by 12 % between 1990 and 2000, with the largest increase in France, Greece and Spain (EEA 2006). During the same decade, water efficiency has improved through the adoption of new irrigation technology (EEA 2006).

Spray irrigation is the most important use of water by agriculture (EA 2001a, Defra 2002). It is mainly applied during the summer months and dry periods and thus has its greatest impact when river flows already are at their lowest (EA 2001a). In many areas, no new spray irrigation licenses for summer abstraction are granted. As a consequence, winter abstraction and storage of water to provide supplies to be used during the summer have increased significantly between 1982 and 2001 in the UK (EA 2001a, Defra 2002) (Figure 3). Large areas of Wales have no or little scope for further summer surface water abstractions, whereas the supply of winter surface water poses no problem (EA 2001a).

Increased water abstraction for agriculture results in decreased groundwater and river levels, aquifer exhaustion and habitat loss, which impacts negatively on aquatic and riparian habitats and biodiversity (EEA 2006). Other environmental problems related to irrigation include water pollution from nutrients and pesticides, land degradation and increased erosion on slopes (Institute for European Environmental Policy 2000). Agricultural drainage and abstraction for irrigation can also change the flow of water bodies, speed up overland flows and contribute to flooding and soil erosion (Defra 2005a). Horticultural crops are often abundantly fertilised and overwatered, which increases the risk of nitrate loss and groundwater pollution (Schenk 1998, Vázquez *et al.* 2005, Vázquez *et al.* 2006). The risk of nitrate and pesticide leaching is generally greater under irrigated crops than under rain fed cereals, but not necessarily greater than under similar rain fed crops (Vecino & Martin 2004). Greenhouse production is about five times more water efficient than field production of vegetables (Stanghellini *et al.* 2003).

Tyrrel *et al.* (2006) discuss health risks associated with poor-quality irrigation water and microbiological contamination of vegetables, concluding that monitoring of water quality in the UK is currently very limited. Similarly, Beuchat (2006) calls for more research into the prevention of pre-harvest contamination in order to minimise the risk of disease by bacteria, parasites and viruses. Robertson & Gjerde (2001) reported on the occurrence of parasites in irrigation water in Norway. Plant pathogens in irrigation water are also a significant problem for crop health (Hong & Moorman 2005).

2.3.2 Irrigation of horticultural crops

Table 8 illustrates total area of irrigation and volume of water applied for several horticultural crops within England and Wales. Table 9 shows the percentage of total irrigated area and water used for several horticultural crops. Season of cultivation can be an important factor in determining water demand: maincrop potatoes receive more water and are irrigated on a greater percentage of their area than second or first earlies (Williams *et al.* 2006). Figures 5 and 6 show the volumetric irrigation demand in a design dry year in England and Wales for a variety of horticultural crops. Irrigation demand is greatest in the east and south and generally low in Wales.

Table 8. Areas of irrigated crops within England and Wales and volume of water applied in 2001. Source: Vecino & Martin (2004)

	Area (ha)	Water volume (1000 m^3)	Irrigation as % of total crop area
Early potatoes	7628	5872	43
Maincrop potatoes	70006	70057	47
Sugar beet	9755	4633	13
Orchard fruit	1578	896	10
Small fruit	3774	3312	32
Vegetables	39164	34114	23

Table 9. Percentage of total irrigated area and water used for several horticultural crops in England and Wales. Source: Downing *et al.* (2003)

	Irrigated area (%)	Water used (%)
Early potatoes	5	4
Maincrop potatoes	47	53
Sugar beet	6	3
Orchard fruit	1	1
Small fruit	3	3
Vegetables	27	26

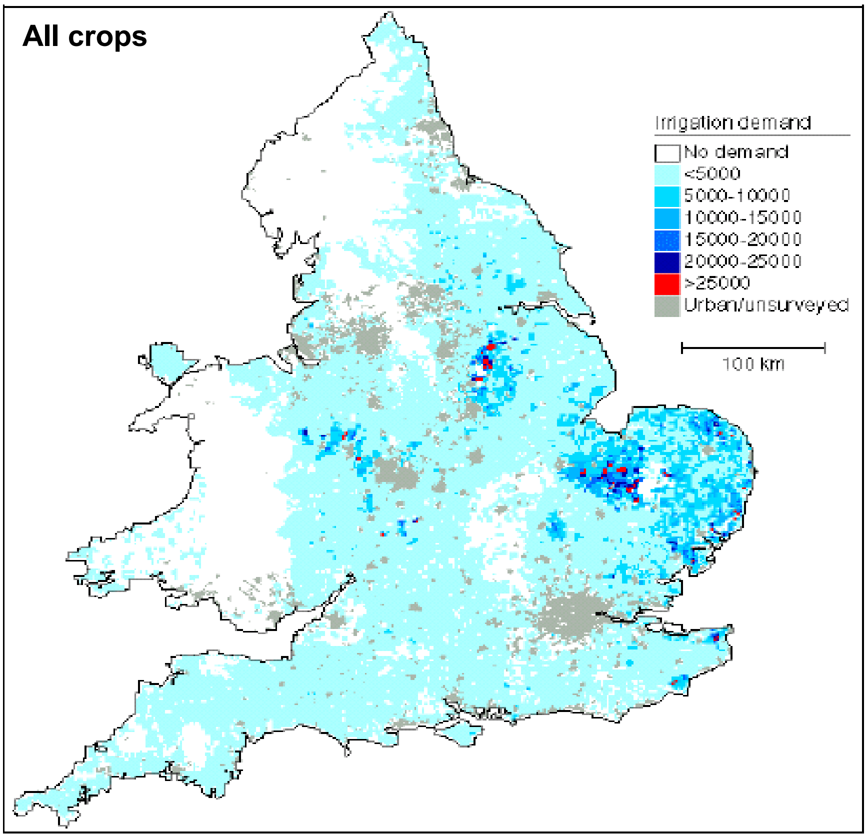


Figure 5. Volumetric irrigation demand (m^3 km^{-2}) in a design dry year for all crops. Source: Weatherhead *et al.* (1997)

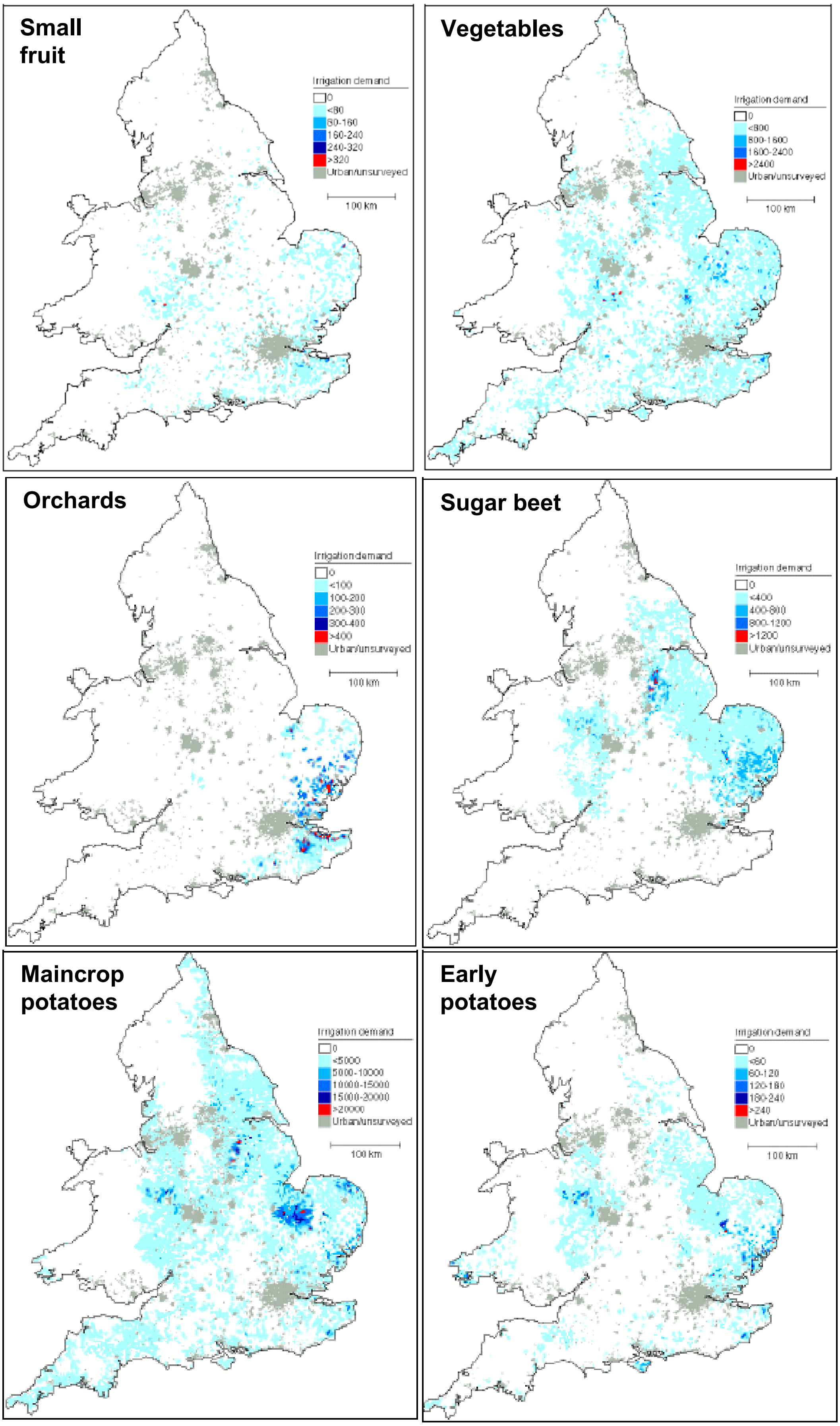


Figure 6. Volumetric irrigation demand (m^3 km^{-2}) in a design dry year for different horticultural crops. Source: Weatherhead *et al.* (1997)

As irrigation is used supplementary to rainfall, the average depth of application is relatively small, ranging from 40-60 mm for soft fruit to 150-220 mm for potatoes (Morris *et al.* 2004a). Irrigation of high value crops, e.g. potatoes, small fruit and vegetables, has increased since the 1980s and is currently growing at 2-3 % per year (Downing *et al.* 2003).

The impact of water restrictions was modelled by Morris *et al.* (2004a) for several horticultural crops. For potatoes, incremental reductions in the availability of water for irrigation resulted in progressive reductions in the area grown and a switch to rainfed crops. On potato and vegetable farms, reductions in irrigation water supply led to reductions in the areas of potatoes, carrots and onions. For large scale vegetable and horticultural farms, reductions in water availability resulted in a gradual switch to rainfed cultivation of cereals; rainfed vegetable growing would be too unreliable in areas of irrigation need. Soft fruit production would not be viable without reliable irrigation.

2.3.3 General best practice

Recommendations for best practice irrigation include assessments of crop requirements, avoidance of run-off and erosion, cessation of application if run-off occurs, prevention of pipework leaking and prevention of surface sealing by using small droplet size (MAFF 1998c, 1999). Surplus water run-off from protected crops can contain nutrients and pesticides. In order to minimise these losses, the amount of water applied should be controlled and matched to crop requirements, time of year, stage of growth, and the substrate and growing system used (MAFF 1998a). For field crops, the application of too much water or uneven application results in increased losses of nitrate (MAFF 1998a). Measures that can be taken to reduce the quantity of water used for irrigation include: economic and regulatory policies (e.g. water metering, charging, licensing and time-limited abstraction permits), promotion of appropriate technologies and research into new technologies (Institute for European Environmental Policy 2000). The great cost of investing in new irrigation technology may prevent its uptake by smaller businesses (Institute for European Environmental Policy 2000). EA (2002) presents a guide to implementing a water management plan on farms. ADAS have produced best practice guides for top and soft fruit growers (ADAS 2003a), field vegetable growers (ADAS 2003b) and potato growers (ADAS 2005a).

Trickle irrigation is assumed more efficient than spray irrigation, which is why the Government is promoting its increased use (Defra 2002). For a discussion of trickle irrigation efficiency in comparison with spray irrigation, see Knox & Wheaterhead (2003). In 2005, trickle irrigation systems accounted for only 5 % of all irrigation abstractions, predominantly in the high value crop sector, but their use has increased fivefold since the 1990s (Know & Wheatherhead 2005). They are widespread in soft fruit, orchard fruit and glasshouse production, and are increasingly used for field-scale vegetable production in England and Wales as well (Knox & Wheaterhead 2003). An estimated 16 % of all irrigated farms used some trickle irrigation (Know & Wheatherhead 2005). It is expected that the use of trickle irrigation will increase most in the high value horticultural vegetable and fruit sector (Knox & Wheaterhead 2003). Chawla & Narda (2001) showed that trickle irrigation of potatoes can save 30 % of water compared to furrow irrigation. Stalham & Allen (2001) demonstrated how the maintenance of soil conditions optimal for root growth can increase water uptake and efficiency of irrigation. Aeration of roots can also increase water use efficiency (Bhattarai *et al.* 2006). Some recent research investigates the suitability of alternative water sources for irrigation, e.g. industrial or municipal wastewater, reuse of agricultural drainage water, and brackish water (e.g. Patel *et al.* 2003). The application of compost can also help reduce irrigation rates (ADAS 2006). Mulches can reduce water loss from soil by reducing soil evapotranspiration (Weatherhead *et al.* 1997). Techniques with a potential for reducing irrigation needs also include choice of varieties more tolerant of low soil moisture, e.g. some Sarpo potato varieties.

Models and methods available to estimate crop water requirements and optimise timing and amount of irrigation are discussed by e.g. Shayya *et al.* (1990), Ejieji & Gowing (2000), Lascano (2000), Alderfasi & Nielsen (2001), Gowing & Ejieji (2001), Pedras & Pereira (2001), Lizarraga *et al.* (2003), Ojeda-Bustamante *et al.* (2004), Amayreh & Al-Abed (2005), Helmer *et al.* (2005) and Hanson & May (2006). Knox *et al.* (1997) present a method for predicting future irrigation demand in England and Wales as a decision support system for catchment management planning and irrigation management. In 2001, scientific methods to apply water according to crop requirements were only employed on 52 % of the total irrigated area in England and Wales (Knox & Wheatherhead 2003).

2.3.4 Recommendations for best practice

The following measures can be used to achieve a reduction of irrigation:

- irrigation scheduling ensures more efficient use of water by matching irrigation to crop requirements, time of year, stage of growth, the substrate and growing system used,
- increased use of trickle irrigation instead of overhead irrigation,
- avoidance of run-off and erosion,
- cessation of application if run-off occurs,
- prevention of pipework leaking,
- prevention of surface sealing by using small droplet size,
- where possible, reduction of irrigation needs by advancing planting dates using plastic films, reducing the growing season or selecting varieties that are tolerant of higher soil moisture deficits,
- maintenance of soil conditions optimal for root growth to increase water uptake and efficiency of irrigation,
- reduction of soil evapotranspiration by using mulches.

2.3.5 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to the use of irrigation in Welsh horticulture:

- Develop and demonstrate best practice in field irrigation methods. This will be necessary under a changed climate, but is an area where current levels of awareness are low.

- Develop and demonstrate on-farm reservoirs for supplying irrigation water for horticulture (and other crops, including grass).

2.4 Soil erosion and degradation

2.4.1 Introduction

Intensive crop production is often associated with soil erosion, loss of organic matter and pollution from fertilisers and pesticides. Within Britain, erosion has become more widespread since the late 1960s due to conversion from grass and spring-sown cereals to winter cereals, the introduction of bare tractor wheelings (tramlines) within the crop for pesticide spraying, the need for finer and flat seed beds for arable and vegetable crops to help establishment and increase herbicide efficiency, enlargement of fields, the removal of field boundaries and the compaction and degradation of soil structure (MAFF 1998c, Evans 2005, Defra 2005b). The risk of soil erosion is greatest where there is little or no vegetation cover to protect the soil, which is why arable land is more at risk than grasslands or other semi-natural vegetation such as heathlands (CEH 2002). Factors influencing erosion risk are slope and topsoil texture. Sandy and silt soils erode more easily than soils with higher clay contents and soils containing calcareous material and basic minerals which bond the soil aggregates chemically. Highly fertile soils are less prone to erosion by wind, rainfall and run-off than less fertile and shallow soils because they have good plant cover, a structure that does not break down easily and a high infiltration capacity (CEH 2002). Soil organic matter is important in maintaining soil quality, structural stability, water holding capacity and buffering capacity (McHugh 2003). Cultivation generally leads to a loss of soil organic carbon, and Welsh arable soils have lost about 0.5 % of their soil organic carbon between 1980 and 1996 in the upper 15 cm (CEH 2002). As soils with low organic matter content have an increased risk of erosion (MAFF 1998c), the decline of Welsh arable soil organic carbon may have potentially lead to an increase in the erodibility of agricultural soils (CEH 2002). Increasingly heavy rainfall in autumn may also contribute to increased erosion (Evans 2005). Soil losses due to harvest, e.g. soil adhering to the crop, can be significant too, varying between few to tens of Mg ha^{-1} per harvest depending on harvesting technique and soil moisture content at harvest time (Ruysschaert *et al.* 2007). When harvesting potatoes, the harvesting machine lifts the entire soil ridges that potatoes are grown on, and some clods that can not be separated from potatoes will be exported from the field, as well as soil adhering to the potatoes. In Belgium, total soil losses during potato harvest range from 0.2 to 21.4 Mg ha^{-1} per harvest (Ruysschaert *et al.* 2006).

Factors that exacerbate erosion are (Morgan 1995):

- farming steep slopes,
- up-and-down hill cultivation,
- continuous use of the land without fallow periods or rotation,
- inadequate use of fertilisers and organic manures,
- late sowing of winter cereals,
- compaction of the soil through the use of heavy machinery,
- use of heavy machinery on wet soils, and
- pulverisation of the soil when trying to create a seed bed.

Erosion may lead to yield losses because it depletes the soil of organic matter and nutrients, including nitrogen and phosphorus, and reduces water availability for crops and the depth of soil available for rooting. Short-term damage and financial cost to the farmer may be caused by the loss of seeds, seedlings, fertilisers and pesticides, the need to repeat field operations, soil being washed from the roots, young plants being blasted with sand during wind erosion and the need to level out eroded surfaces by extra cultivations (Defra 2005b). Environmental problems resulting from erosion include eutrophication of water courses, lakes and coastal waters, contamination of water by pesticides absorbed onto soil particles, reduced infiltration and increased run-off following rainfall, more frequent flooding and reduced summer river flows (CEH 2002). Soil erosion contributes significantly to the transfer of phosphorus from agricultural land to water bodies (Defra 2005b). Increased siltation and eutrophication of watercourses can reduce river oxygen contents and negatively impact on aquatic biodiversity. Highly organic peat soils in Wales are a significant carbon sink. When these soils degrade and erode, they release carbon into the atmosphere, which may contribute to climate change (CEH 2002).

Within Wales, soil erosion resulting from land use and management practices is considered as a major threat to soil systems (CEH 2002). The extent and frequency of soil erosion in Wales are poorly documented, and no quantitative data on soil erosion are available for Wales (CEH 2002). According to the Soil Association, across the UK, an estimated 44 % of arable land is prone to erosion, losing an average of 1 t ha^{-1} $year^{-1}$ and a total of up to 2.3 million tonnes of soil per year. Estimates of vulnerability to erosion shown in Figure 7 illustrate that within Wales, large areas are potentially at risk. However, the areas most at risk are mainly in the uplands, where erosion is primarily due to over stocking with grazing animals and extensive recreational use (CEH 2002). The main form of erosion on lowland arable fields in Wales is channelled erosion, especially rilling (CEH 2002). The risk of erosion is greatest under autumn-sown crops. Minimum cultivation and drilling following ploughing and pressing reduce the risk of erosion (CEH 2002).

2.4.2 Horticulture and erosion

Moderate to serious soil erosion problems can result from the continuous cultivation of cereals, grape vines, maize, sugar beet, broccoli and Brussels sprouts (Morgan 1995). Row crops (e.g. potatoes and sugar beet) pose a great risk of erosion because of the need to prepare a seed bed and the high percentage of bare ground, particularly in the early stages of development (Morgan 1995). Root crops, vegetables and potatoes grown on ridges generally are particularly at risk from water erosion (MAFF 1998c). Table 10 shows rates of erosion for some crop categories.

Land cultivated with potatoes is most vulnerable from April to June. Run-off water can become concentrated in furrows between potato ridges, leading to the development of rills. Over-irrigation or unexpected heavy rainfall after recent irrigation increase erosion risk (Defra 2005c). Land that is particularly vulnerable to erosion may be unsuitable for potato cultivation.

Vegetable production can lead to erosion problems during most of the year, and is often carried out under unsuitable conditions due to market demand for continuous supply (Defra 2005c). During the cultivation of vegetables, soils are at the greatest risk after seedbed preparation and during the early stages of crop development. Irrigation and harvesting may also increase erosion risk, while winter harvesting can cause soil compaction and increased problems with run-off water (Defra 2005c).

In the production of soft fruit, a large proportion of the soil remains uncovered due to the use of herbicides between cropped rows or individual plants (Defra 2005c). Run-off from mulches or crop cover can be a problem. Where grass cover is maintained in orchards, erosion risks are reduced.

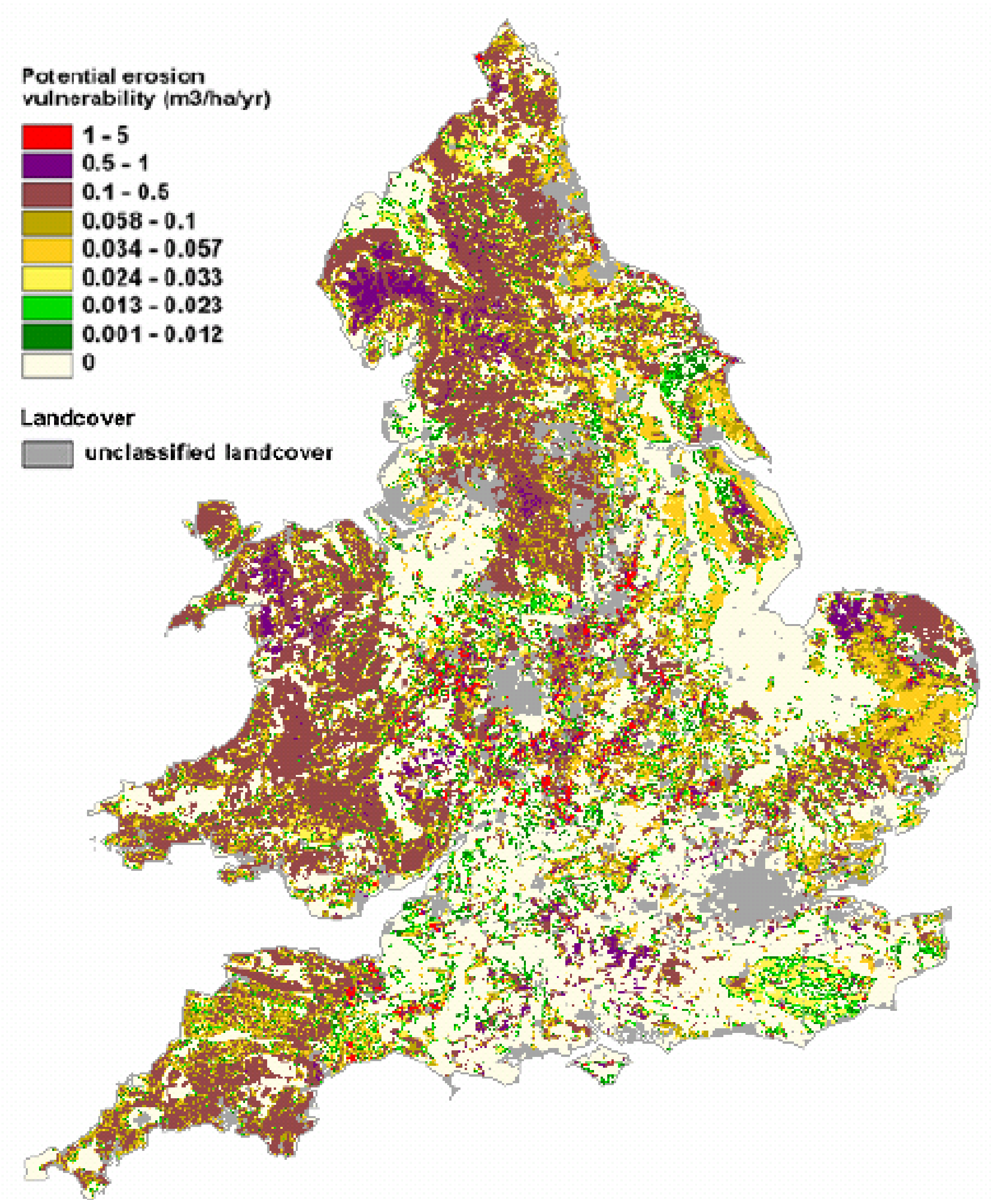


Figure 7. Distribution of erosion vulnerability estimates expected to occur annually in England and Wales (1-in-10 year erosion events). Data derived from national-scale monitoring of changes in soil erosion extent and causes within upland, lowland arable and lowland grassland environments. Source: Pagella *et al.* (2005)

Table 10. Rates of erosion in soils drilled to different crops. Source: Boardman (2002)

	Mean rate ($m^3 ha^{-1}$)	**Median rate ($m^3 ha^{-1}$)**
Market garden and vegetables	5.08	1.47
Maize	4.48	1.00
Sugar beet	3.04	0.92
Soft fruit, root crops for stock feeding, orchards, linseed etc.	2.67	1.07
Potatoes	2.53	1.01
Winter cereals	1.85	0.68
Spring cereals	1.75	0.71
Bare soil/fallow	1.61	0.27
Peas	1.21	0.91
Field beans	0.47	0.22

2.4.3 General best practice

Advice on how to avoid and control erosion is given in Defra (2005a, b) and MAFF (1998c, 2000b). CEH (2002) carried out a critical appraisal of the state of Welsh soils and implementation of control measures for soil protection. This report concluded that current policy response to soil erosion is not adequate and that soil conservation and erosion control should be integrated into agri-environment schemes such as Tir Gofal.

Erosion control measures include strategies that aim to establish and maintain ground cover, which depend on the choice of crop and how quickly they can grow under local climatic and soil conditions (Morgan 1995). Crops grown in rows, tall tree crops and low-growing crops with large leaves offer the least protection (Morgan 1995).

For the control of soil erosion, row crops should be combined with crops that better protect the soil. In a crop rotation, the frequency of row crop cultivation should depend on the vulnerability of the soil to erosion. In areas with high erosion risk, they should only be grown every 5-7 years (Morgan 1995). Legumes and grasses are suitable for use in rotations; they provide good ground cover, maintain or improve the organic status of the soil, contribute to soil fertility and aid development of a more stable aggregate structure of the soil (Morgan 1995).

Methods that can be used to minimise the length of time that the ground is bare include leaving crop residues on the land after harvest, delaying ploughing until the following spring, and early sowing for winter- and autumn-sown crops which will result in a better ground cover before winter temperatures inhibit crop growth (Morgan 1995). Cover crops can be effective in reducing erosion if they establish quickly, provide an early canopy cover and have a deep root system that improves the macroporosity of the soil (Morgan 1995). Mulching involves covering the ground with crop residues (e.g. straw, maize stalks, standing stubble), which protects the soil from wind and water erosion. At least 70-75 % of the soil surface should be covered by the mulch. Potential problems associated with this method are a delay of crop emergence and increased difficulty of controlling weeds and pests. The mulch can also be incorporated in the soil which helps bind the soil and increases infiltration rates; however, this method is less effective at reducing soil erosion than surface mulches (Morgan 1995).

Soil compaction should be avoided because it reduces infiltration of water into soil and can lead to increased run-off and erosion. If soils have become structurally damaged and have reduced organic matter contents, measures such as deep cultivation followed by several years in grass may be necessary to restore the soil (MAFF 1998c).

Fine seedbeds are vulnerable to erosion, capping and slaking after heavy rain. If used, they need to be managed well and covered quickly, especially on lighter soils, and mulches, light rolling and nurse crops can help reduce erosion.

Landscape features such as hedges and walls can help reduce erosion by acting as a barrier (MAFF 2000b).

Management measures for the control of erosion in potatoes (Defra 2005c):

- where practicable, remove any compaction present before establishing the crop, and time operations to minimise risks of causing further compaction,
- leave the soil surface protected with stubble, a cover crop or rough cultivated for as long as possible before preparing ground for planting,
- avoid stone and clod separation when the soil is wet,
- avoid overworking the soil,
- leave soil surface as rough as possible,
- use tied ridges and dikes in furrow bottoms to improve infiltration and reduce run-off,
- plan irrigation carefully to avoid over-application leading to run-off,
- plant varieties for early harvesting on land most at risk to allow timely establishment of a winter cereal or cover crop,
- following harvest, carry out a tined cultivation or rough plough as early as possible to minimise erosion from bare, rutted surfaces.

Management measures for the control of erosion in vegetables and salad crops (Defra 2005c):

- leave the soil surface protected with stubble, a cover crop or rough cultivated for as long as possible before drilling or planting,
- remove any compaction present before establishing the crop, and time operations to minimise risks of causing further compaction,
- avoid overworking the soil, drill into as coarse a seedbed as practically possible,
- on the most vulnerable land, avoid varieties selected for early sowing or late harvesting,
- consider using modular transplants rather than direct seeding to promote more rapid establishment of crop cover,
- wherever possible, avoid trafficking the land under wet soil conditions,
- remove excessive compaction in wheelings by using tines fixed behind tractor wheels when soils are in a dry condition, especially when using bed systems,
- plan irrigation carefully to avoid over-application leading to run-off, use trickle systems or fine sprays in preference to systems producing coarse droplets,
- when planning to use impermeable mulches or crop covers consider how to deal with increased run-off,
- if harvesting under wet conditions is inevitable, carry out a tined cultivation or rough plough the land as soon as possible following crop removal to minimise erosion from bare rutted surfaces.

Management measures for the control of erosion in fruit (Defra 2005c):

- remove any compaction present before establishing the crop, and time operations to minimise risks of causing further compaction,
- avoid planting after late harvested vegetable and root crops,
- plant rows across slopes wherever possible, and interrupt long rows periodically with grass access strips,
- avoid trafficking the land under wet soil conditions
- if compaction/rutting is present in established crops, consider removal with single leg subsoiler, if not too damaging to crop root growth,
- establish an overall grass cover on susceptible soils under top fruit,
- use a thin mulch of straw or farmyard manure to protect bare ground between rows in other situations,
- when planning to use impermeable mulches or crop covers consider how to deal with increased run-off,
- plan irrigation carefully to avoid over-application leading to run-off and use trickle systems or fine sprays in preference to systems producing coarse droplets,
- minimise erosion risks when finally removing plants/trees by avoiding wet soil conditions, and establishing the following crop as soon as practicable.

2.4.4 Recommendations for best practice

Measures that can be taken to reduce the risk of erosion are (MAFF 1998c):

- consider minimum tillage or reduced cultivation techniques,
- use organic inputs (manure, straw, composted materials, non-agricultural bio-wastes) to help preserve soil organic matter and improve soil stability,
- change seedbed cultivation to produce a coarser tilth; fine seedbeds can increase erosion risk, destabilise soil structure and lead to sealing or capping of the soil surface,
- avoid working on the land when it is too wet,
- avoid unnecessarily deep or numerous cultivations,
- plant winter crops early, aiming to achieve at least 25 % of ground cover by early winter,
- consider using undersown cover crops to help control wind and water erosion,
- consider using crops such as rye or mustard that are sown in late summer and early autumn and ploughed in or killed off before drilling in spring,
- leave stubbles, chopped straw or other residues on the soil surface after harvest,
- use soil walls to bridge furrows across the slope and small pits along furrow bottoms to help improve water absorption and reduce run-off on land cultivated with potatoes and vegetables,
- apply irrigation water in a way that avoids run-off and erosion (e.g. assess crop needs, do not over-apply, do not use too great a droplet size),
- plant hedges or shelterbelts or build new ditches to restrict run-off,
- insert grass or set aside into arable rotations to improve soil structural stability.

2.4.5 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to managing soil erosion in Welsh horticulture:

- Understand the risk of soil erosion which may contribute to contravention of standards set in the Water Framework Directive from horticulture. A first step may be to consider the water quality in the areas which currently support horticultural enterprises, e.g. Pembrokeshire, Flintshire, Llyn Peninsula and Monmouthshire?
- Communicate and demonstrate best practice for reducing soil erosion in horticulture, especially in potatoes.

2.5 Pesticides

2.5.1 General introduction

Only products that are listed on Annex I to the EC Plant Protection Products Authorisations Directive (Directive 91/414/EEC) can be marketed in the member states of the European Union. Within the European Union, pesticide use increased by 20 % from 1992 to 1999 (EEA 2005). Pesticide consumption has remained unchanged in recent years; however, many of the more hazardous pesticides have been banned recently and less hazardous alternatives have been developed (EA 2004). The amount of pesticides applied depends on the type of crop, weather conditions and timing of application (EA 2004). In 2004, 31,5000 t of active substances were sold for a total of £ 467 million, with agriculture and horticulture accounting for 86 % of sales and 80 % of the amount used (Defra 2006b). Pesticides are not only used during the production phase of fruit and vegetables, but also to protect the produce after harvest and during storage and to treat seeds (Garthwaite *et al.* 2003).

Pesticides are defined here to include herbicides, insecticides, fungicides, acaricides and molluscicides. They potentially contaminate water and soil and impact on human health, fauna and flora. For example, many pesticides are toxic to aquatic species (EA 2004). Spray drift and over-spraying can have an impact on hedges, grass banks, field margins and other habitats bordering the sprayed area (Defra 2003a). Some pesticides persist in the soil and impact on natural soil processes (Defra 2003a). Contamination of drinking water supplies also represents a significant economic cost (Pretty *et al.* 2000, EA 2004). According to the EA, in 2005 almost 8 % of samples taken from regular monitoring sites in England and Wales contained pesticide concentrations greater than that required for drinking water (0.1 ug l^{-1}), which represented a significant increase compared to the previous years (www.environment-agency.gov.uk). Pesticides are often applied as mixtures, so that wildlife is exposed to combinations of different pesticides which can be additive or synergistic in their impact (Thompson 1996, Deneer 2000).

A recent survey showed that the public are concerned about the use of pesticides on crops, especially in relation to human health (Crane *et al.* 2006). At the same time, customer desire for unblemished produce in perfect condition leads to increased pesticide use. Negative effects on the environment were also cause for concern, especially for attractive species, e.g. songbirds or badgers. In spite of this, only 20 % of consumers were prepared to pay significantly more for food produced without the use of pesticides (Crane *et al.* 2006).

2.5.2 Pesticides in horticulture

<u>2.5.2.1 Fruit</u>

In the UK, strawberries accounted for 44 % of pesticide treated area for field grown soft fruit, blackcurrants for 29 % and raspberries and vines both for 12 % each in 2001 (Garthwaite & Thomas 2001). In Wales, strawberries and blackcurrants are the most important soft fruits (Garthwaite & Thomas 2001). The total weight of pesticides applied declined by 26 % between 1998 and 2001, which was almost entirely due to a reduction in use of soil sterilants as pre-planting treatments to a limited area of soft fruit, mainly strawberries.

Many crops grown in orchards receive pesticide treatments, e.g. Cox apples received an average of 18 pesticide sprays including 35 products and 38 active substances in 2000 (Garthwaite *et al.* 2000). Some less susceptible crops may receive fewer applications, with 32 % of cider apples and perry pears, 22 % of plums and 7 % of cherries not receiving any pesticides (Garthwaite *et al.* 2000). The weight of active substances applied in British orchards decreased by 19 % between 1996 and 2000 (Garthwaite *et al.* 2000).

2.5.2.2 Protected crops

Between 1999 and 2003, the area of edible protected crops treated with pesticides increased by 18 %, but the weight of active substances had decreased by 77 % since 1991 and 41 % since 1999 (Garthwaite & Thomas 2003). Strawberries represented 3 % of the area grown, but 14 % of the pesticide treated area of protected crops. Fungicides were used on 51 % of the area, insecticides 26 %, growth regulators 6 %, acaricides 6 %, herbicides 6 % and sulphur 2 %.

2.5.2.3 Vegetables

Brassicas accounted for 25 % of the total pesticide treated area in the UK in 2003, onions and leeks for 25 %, peas and beans for 21 % and carrots, parsnips and celery for 18 % (Garthwaite *et al.* 2003). Pesticide usage generally reflected the area of crops grown, however usage was relatively greater for onions and leeks (10 % of the area grown) and carrots, parsnips and celery (11 % of the area grown). Herbicides accounted for 52 % of the total weight of pesticide active substances applied, fungicides 23 %, sodium chloride 7 %, sulphur for 6 %, insecticides 5 %, soil sterilants for 4 %, mollucicides and repellents 2 % and growth regulators 1 % (Garthwaite *et al.* 2003). Herbicides and desiccants were applied to 94 % of the total area of vegetable crops, with an average of three applications comprising four products and four active substances. Onions and leeks are the crops treated most intensively with herbicides (repeat low-dose applications of an average six applications of ten products and ten active substances) and fungicides (94 % of the crop area). Insecticides were used most intensively on carrots, parsnips and celery (90 % of the crop) and brassicas (89 % of the crop). Molluscicides were applied to 9 % of the area of all crops, mainly on root crucifers (62 % of the crop treated), brassicas (17 % of the crop treated) and lettuce, endives etc (13 % of the crop treated). About 3 % of all crops remained untreated. Peas receive intensive insecticide and nematicide treatments (Garthwaite *et al.* 2004).

Ware potatoes represented 3 % of the total area of arable crops grown in 2004 and 5 % of the total pesticide treated area, accounting for 64 % of all sulphuric acid usage, 9 % of the total area treated with fungicides, 27 % of the total area treated with molluscicides, 4 % of the total area treated with insecticides and nematicides and 0.4 % of the total area treated with growth regulators (Garthwaite *et al.* 2004). On average, ware potatoes received ten pesticides applications with a total of twelve products and eight active substances (Garthwaite *et al.* 2004). Fungicides, mainly for the control of potato blight, accounted for 62 % and 44 % of the total pesticide-treated area of ware potatoes and seed potatoes respectively; between 1994 and 2004, the rate of fungicide applications to ware potatoes decreased from 1.07 kg ha^{-1} to 0.84 kg ha^{-1}. In farm stores, 46 % of potatoes were treated with an average of 2.4 pesticide applications; at merchant stores, 58 % were treated, receiving on average 1.5 treatments (Anderson *et al.* 2002).

Although the area of production declined for Brussels sprouts and carrots between 1986 and 1999, total pesticide usage increased, while the total weight of pesticide applied declined (Thomas 2003). For onions, the area grown, total pesticide usage and total weight applied increased (Thomas 2003). Figure 8 shows the amount of pesticide used to produce one hectare of carrots, Brussels sprouts and onions from 1986 to 1999. On all crops surveyed, the frequency of treatment increased due to applications at lower doses and of more active substances (Thomas 2003). This trend was also evident in a survey of vegetable crops in Britain in 2003 (Garthwaite *et al.* 2003).

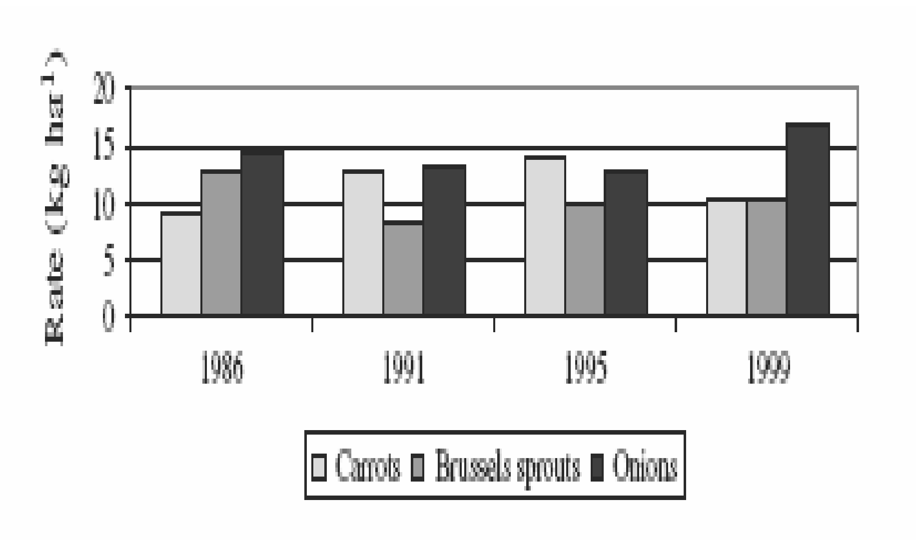


Figure 8. Amount of pesticide used to produce 1 ha of crop, 1986-1999. Source: Thomas (2003)

2.5.3 Environmental impact of pesticides

Since the 1980s, the use of less persistent pesticides and application frequencies has increased (MAFF 2000b). Changes in application rates between 1991 and 2003 are illustrated for several crops in Figure 9. Environmental impact quotients (EIQ) are used to rate the hazard posed by pesticides on farm workers, consumers and the environment. Multiplied by the actual usage of a pesticide, i.e. the kilograms of active ingredient applied, the resulting environmental impact (EI) represents an estimate of the overall hazard posed by a particular pesticide. From 1991 to 2003, the overall EIQ decreased by 19 % and the EI by 34 % for brassicas, peas, beans, onions, leeks, lettuce and endives produced in the UK (Cross & Edwards-Jones 2006). The average EI per hectare, however, only decreased by 3 %, while at the same time (Figure 10), production of several of these crops decreased significantly and imports from foreign countries increased. This suggests that the overall reduction in the EI in the UK is due to a decrease in crop area and not to changes in pesticide usage and management (Cross & Edwards-Jones 2006).

In a similar study, pesticide ecotoxicity scores were calculated and modelled by Tzilivakis *et al.* (2005) for several crops. Potatoes have the highest score and pose the greatest risk, followed by oilseed rape and peas (Table 11).

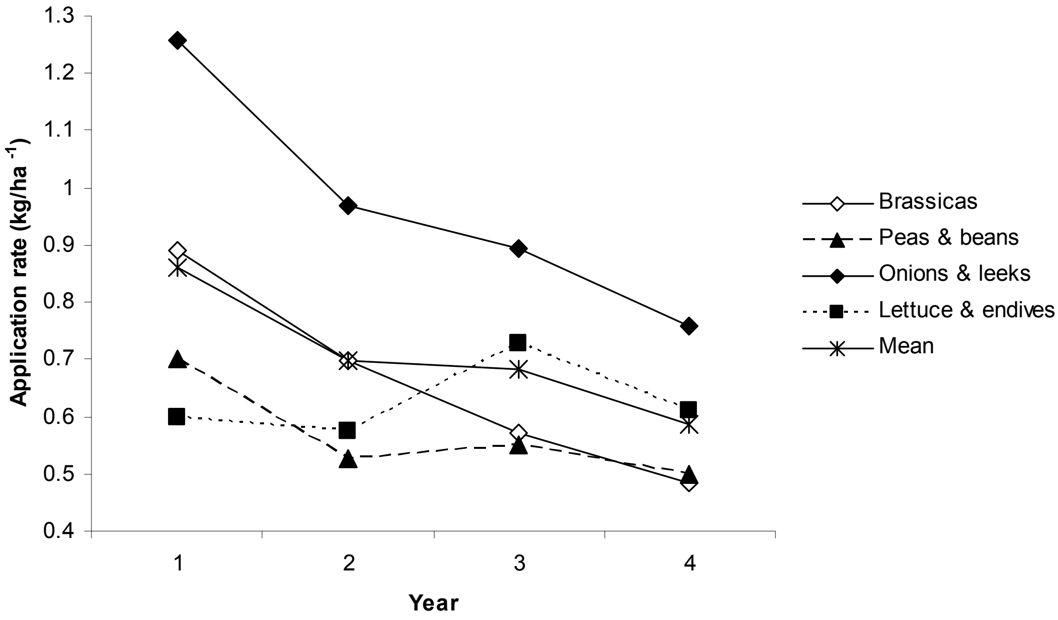


Figure 9. Mean application rates of brassicas, peas and beans, onions and leeks, lettuce and endives in the UK from 1992 to 2003. Source: Cross & Edwards-Jones (2006)

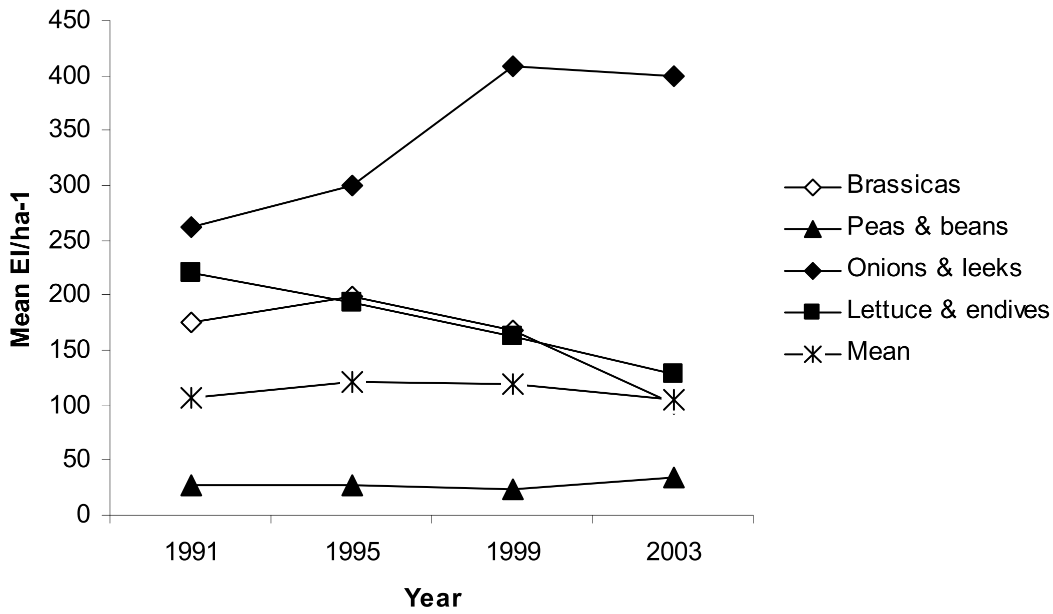


Figure 10. Mean environmental impact per hectare for brassicas, peas and beans, onions and leeks, lettuce and endives grown in the UK from 1992 to 2003. Source: Cross & Edwards-Jones (2006)

Table 11. Comparison of pesticide ecotoxicity scores for a range for crops. Source: Tzilivakis *et al.* (2005)

	Average pesticide ecotoxicity score
Potato	230
Oilseed rape	85
Pea	75
Winter wheat	35
Spring barley	30
Sugar beet	26

2.5.4 General best practice

Increased customer desire for pesticide-free food, growing resistance of pests against conventional chemical control, and concerns about the environmental impact of pesticides are all reasons for attempts to reduce pesticide use and implement best practice measures. Advice on best practice can be found in Defra (2003a, 2004b, 2006a), including information on handling, transporting, storing and application of pesticides, disposing of pesticide waste and training and certification. A strategy for the sustainable use of pesticides is presented in Defra (2006b). A voluntary initiative introduced by pesticide and farming industries in the UK in collaboration with environmental bodies tries to encourage best practice and minimise the harmful effects of pesticides on the environment by improving application techniques, application timing, implementing better stewardship and crop protection plans (www.voluntaryinitiative.org.uk). Increased efficiency of pesticide use can also help farmers by reducing their costs of production. A recent modelling study has shown that adoption of the measures suggested by the voluntary initiative can reduce pesticide contamination from farmyards, spray drift and field run-off, but might be less effective at reducing pesticide leaching and contamination of surface waters from field drainage (Garratt & Kennedy 2006). Certain retailers, e.g. Marks & Spencer and the Coop, are taking efforts to reduce the amount of pesticides used in the production of their goods due to increased customer concern about pesticide residues and food quality.

Integrated pest management (IPM) is increasingly applied in Northern Europe (Finch & Collier 2000). IPM involves the use of chemical, biological and cultural methods in order to reduce the harmful effects related to pesticide use. The presence of pests and diseases, weather conditions and crop development are monitored so that pesticides are only applied when a threshold is reached and conditions make the crop especially susceptible. IPM is commonly used in British orchards (Garthwaite *et al.* 2000). Methods used for IPM of brassica and carrots are presented in Finch & Collier (2000). Guidelines for integrated production of various fruit and vegetables can be downloaded from the website of the International Organisation for Biological and Integrated Control of Noxious Animals and Plants (IOCB) at www.iobc.ch/download_docs.html.

Buffer zones of 3 m width around field margins that remain unsprayed by pesticides can reduce pesticide spray drift by 95 %, and increase floristic diversity, phytophage insects and insectivorous birds (de Snoo 1999). An economic analysis suggested that it is economically feasible to include unsprayed crop edges in winter wheat and potato cultivation, but not for sugar beet (de Snoo 1999).

Cultivation techniques, e.g. diversification of crop sequences and crop rotation, cover crops, intercrops and soil amendments (crop residues, animal manures and composts), can aid weed management and help reduce pesticide inputs (Liebman & Davis 2000). However, Worrall *et al.* (2001) found no reduction in pesticide leaching through organic matter amendments. Other options for reducing pesticide use relate to new technical developments, e.g. the detection of weed patches to match applications more accurately to targeted patches of pests (Miller 2003). Lešnik *et al.* (2005) compared the effectiveness of conventional and drift-reduced nozzles in controlling pests in orchards in Slovenia and concluded that further research is needed before a conclusive assessment can be made.

Most of the fungicides applied to potatoes are used to control potato blight (*Phytophthora infestans*) which is a major limiting factor on potato production in the UK. Strategies for the reduction of the usage of these mainly copper-based fungicides include agronomic practices and the use of resistant varieties. New varieties are being developed which have greater resistance to blight and could greatly contribute to a reduction of fungicide use, e.g. Sarpo cultivars developed originally in Hungary and Lady Balfour & Stirling developed in Scotland. For information on the potential of growing blight resistant potatoes in the UK, see Shaw & Johnson (2004), Frost & Clarke (2005) and ADAS (2005b). Sarpo varieties can also help reduce the usage of anti-sprout chemicals used as growth inhibitors during storage and possibly offer some resistance to potato cyst nematodes (David Shaw, pers. comm.).

About 100 species of organism are currently commercially available for the biological control of insect and mite pests in greenhouses, whereas research into biological control of diseases is ongoing (van Lenteren 2000). A strong increase in the use of biological control and integrated systems is expected for greenhouse food production, which not only reduces harmful effects on the environment, but also has several advantages for the grower, e.g. there are no toxic effects on young plants, while at the same time costing about the same as chemical pest control (van Lenteren 2000).

In protected greenhouses, polytunnels and stores biological pest control can be very effective due to the enclosed environment that enables targeted management. El-Bendary (2006) reviews the production of *Bacillus thuringiensis* and *B. sphaericus* for biological pest control. Solomon *et al.* (1993) discuss biological control of mites in apple orchards. Charudattan & Dinoor (2000) describe success and limitation of plant pathogens for the control of weeds, and Chellemi (2000) discusses pest control in low-input agriculture. The potential of essential plant oils to repel insects and function as insecticides and fungicides is reviewed by Isman (2000). During post-harvest storage of fruit and vegetables, biological control can also be applied to successfully to fight disease and pest (Wilson *et al.* 1991). A review of alternative pest control methods and their potential for wider use can be found in Edwards-Jones *et al.* (2004), including pheromones, entomopathogenic fungi, bacteria and viruses, antagonistic fungi and bacteria, mycoherbicides, eating deterrents, plant extracts, modified atmospheres during storage and transport of produce, physical and mechanical control, rotation and nutrient management and natural predator management. Vermicomposts that can be used as peat substitute in growing media have also been shown to suppress insect attacks on several greenhouse crops (Arancon *et al.* 2005)

An example of successful biological pest control is tomato production in the UK. The parasitoid wasps *Encarsia formosa* and *Diglyphus isaea* are used to control whitefly and Dipteran leaf miner respectively and the predatory mite *Phytoseiulus persimilis* to control two spotted spider mites (Edwards-Jones *et al.* 2004). Between 1985 and 1995, the number of species used for biological control increased from four to 16 (Edwards-Jones *et al.* 2004). In 1995, over 70 % of the area of tomatoes grown in the UK was treated with biological control agents (Garthwaite 2000). The use of biological control is now increasing in other protected crops too, e.g. cucumbers and strawberries (Edwards-Jones *et al.* 2004). Between 1999 and 2003, the use of biological control on mushrooms by area more than doubled (Stoddart *et al.* 2003). In protected edible crops, 49 % of the total area treated for pest, disease and weed control in 2003 was under biological control (Garthwaite & Thomas 2003). In contrast, in British orchards and fruit stores, biological control accounted for less than 1 % of all pesticide usage in 2000 (Garthwaite *et al.* 2000). In outdoor vegetable crops, physical control agents, growth stimulants and biological control agents accounted for less than one 1 % each, with *Bacillus thuringiensis* used to control caterpillars on a range of crops and *Phytoseilus persimilis* to control two-spotted spider mite on runner beans only (Garthwaite *et al.* 2003).

2.5.5 Recommendations for best practice

Pesticide usage can be reduced by:

- implementing best practice measures regarding handling, transport, storing, application and disposal of pesticides,
- increasing efficiency of pesticide use,
- improving application techniques,
- improving application timing,
- implementing better stewardship and crop protection plans,
- use of resistant crop varieties,
- implementing integrated pest management techniques,
- reducing spray-drift and field run-off,
- introducing unsprayed buffer zones around field margins,
- applying cultivation techniques such as diversification of crop sequences and crop rotation, cover crops, intercrops and soil amendments (crop residues, animal manures and composts),
- applying biological control in greenhouses.

2.5.6 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to the use of pesticides in Welsh horticulture:

- Understand the type and amount of pesticide used in Welsh horticulture. This could be achieved by stratifying the existing Pesticide Usage Survey into England and Wales. This may require a slightly greater sampling effort be targeted on Welsh farms than currently, but it would offer a unique dataset.
- Consider how to incorporate horticulture into Catchment Sensitive Farming, which is currently designed to reduce pollution from livestock systems?
- Understand the risk of water pollution from pesticide use which may contravene standards set in the Water Framework Directive from horticulture. A first step may be to consider the water quality in the areas which currently support

horticultural enterprises, e.g. Pembrokeshire, Flintshire, Llyn Peninsula and Monmouthshire?

- Continue to research alternative means of managing diseases in potatoes.
- Research and develop relevant pest management techniques for the growing number of fruit and vine growers in Wales.

2.6 Energy consumption

2.6.1 General introduction

Agriculture accounts for less than 1 % of total energy consumption in the UK, with direct and indirect energy consumption accounting for 0.5 % and 1.3 % respectively (MAFF 2000b, Defra 2005a). Direct use of energy comprises fuel and electricity inputs for heating, lighting, power, irrigation, ventilation etc., and has decreased by 40 % since 1995 (Figure 11). Petrol consumption decreased from 64 % to 28 % of total direct energy consumption since 1995, while the use of electricity increased to 40 % in 2004 (Figure 11). Indirect energy consumption comprises inputs for the manufacture of fertilisers, pesticides, machinery etc. Total indirect energy consumption in agriculture decreased by 20 % since 1985 (Figure 12). Nitrogen fertilisers accounted for 51 % of indirect energy use in 2004 (Figure 12), although the amount of energy used to produce fertilisers has declined by 33 % since 1985. Pesticides accounted for 13 % of indirect energy use in 2004 (Figure 12), and energy consumption for the production of pesticides has increased by 19 % compared to 2003. Grading, storage and cooling of vegetable crops after harvest also represent significant energy uses (Biffaward 2002). Highly perishable vegetables are cooled quickly but not long-term, whereas crops such as potatoes or cabbage are cold stored for longer periods of up to a year (Biffaward 2002). In potatoes, the cooling and refrigeration period accounts for 50 % of total primary energy input (Williams *et al.* 2006). In 1998, energy use represented about 6.7 % of the total cost of farm inputs (MAFF 2000b).

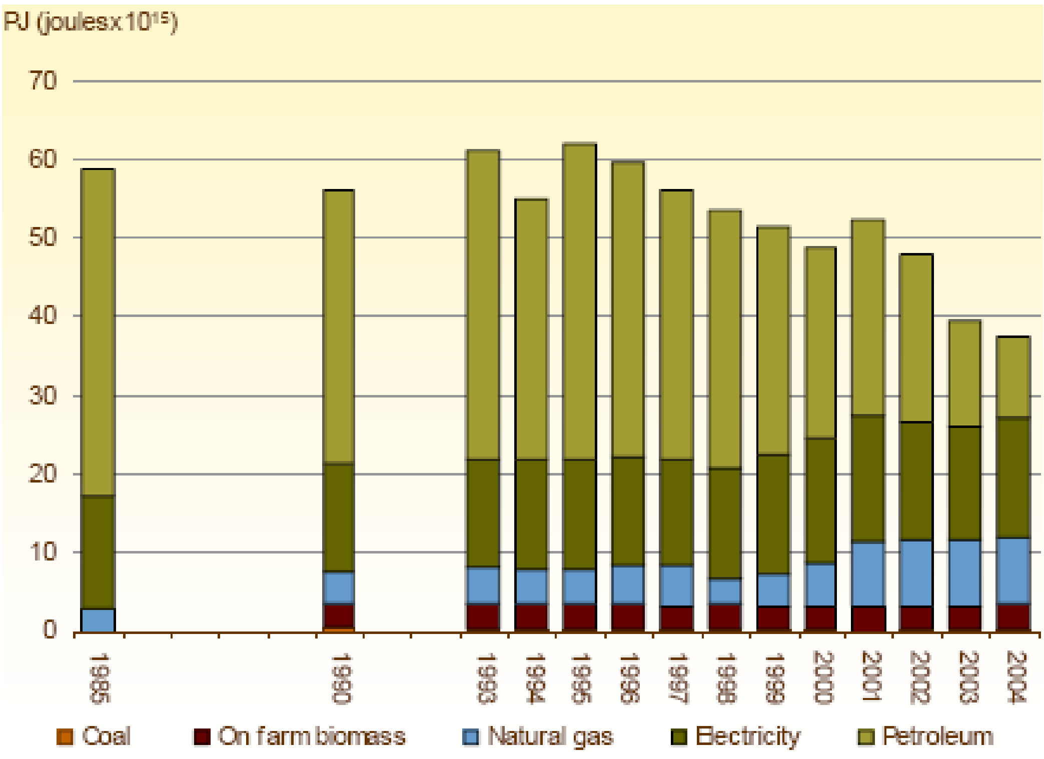


Figure 11. Direct energy use in UK agriculture in petajoules.
Source: http://statistics.defra.gov.uk/esg/indicators/pdf/c407.pdf

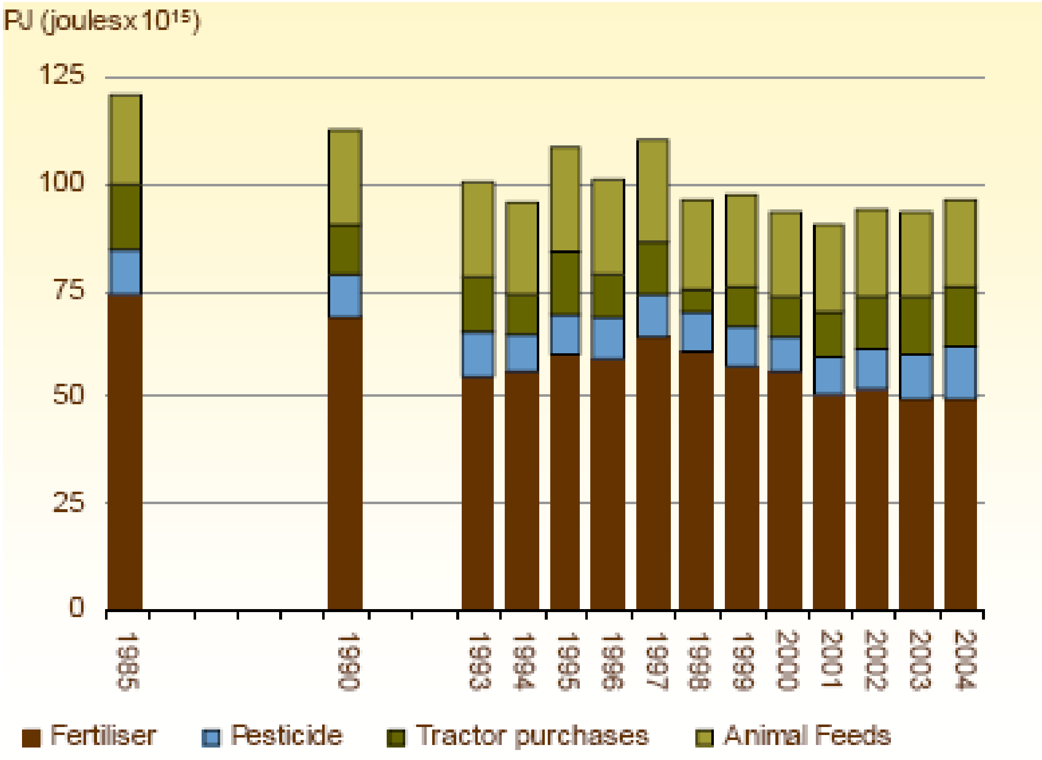


Figure 12. Indirect energy use in UK agriculture in petajoules.
Source: http://statistics.defra.gov.uk/esg/indicators/pdf/c407.pdf

2.6.2 Energy consumption in horticulture

The amount of energy input in agricultural production depends on environmental factors (e.g. soil conditions, climatic conditions), the amount of inputs and cultivation techniques used (Esengun *et al. in press*). In northern countries, production in heated glasshouses increases yield and quality at the cost of an added 40 MJ kg^{-1} product (Dutilh & Kramer 2000). In total, protected cropping of fruit and vegetables in the UK is estimated to use about 20,250 TJ of energy per year, or 74 % of the total energy consumption of the agricultural sector (Garnett 2006). In UK tomato production, about 97 % of direct energy consumption is for heating and lighting used to extend the growing season in glasshouses (Williams *et al.* 2006). Generally, photoperiods of 14-17 hours are used in glasshouse vegetable production (Demers *et al.* 1998). Tomatoes, peppers and cucumbers are amongst the more energy intensive crops (Plackett 2005). According to Plackett (2005), tomato production in the UK comprises 200 ha and uses 500-800 kWh m^{-1} $year^{-1}$, cucumber production comprises 200 ha and uses 350-650 kWh m^{-1} $year^{-1}$ and pepper and other edibles comprise 80 ha and use 350-650 kWh m^{-1} $year^{-1}$. A typical tomato grower may consume 600 kWh m^{-1} $year^{-1}$, 350 kWh m^{-1} $year^{-1}$ of which are used for heating, 125 kWh m^{-1} $year^{-1}$ for humidity control and 125 kWh m^{-1} $year^{-1}$ for CO_2 generation (Plackett 2005). Primary energy use to produce 1 t of tomatoes is 125 GJ, much more than needed to produce arable crops such as potatoes (Williams *et al.* 2006). Per unit area, energy consumption is very similar for different tomato types, which means that the production of the highest yielding tomatoes (e.g. non-organic and loose) is least energy intensive (Williams *et al.* 2006). Energy costs can amount to 40 % of variable costs in protected crop production, especially in intensive salad production (www.hdc.org.uk/sectors/PC_RandD.htm).

For sugar beet, Tzilivakis *et al.* (2005) recorded an average energy input of 21.4 GJ ha^{-1} across several different production systems, or 19.8 GJ ha^{-1} when transport to the factory was excluded. Energy input is a significant issue in the production of potatoes, sugar beet and winter wheat, while peas and spring barley require less energy input and contribute less to global warming (Tzilivakis *et al.* 2005) (Table 12). Energy efficiency in sugar beet production was found to range between 0.32 and 0.49 GJ t^{-1}. Fertilisers accounted for 18-50 % of total energy input. Irrigation can consume large amounts of energy, e.g. 10 % of total energy inputs for sugar beet (Tzilivakis *et al.* 2005). The effects of different growing seasons for potatoes on energy usage and energy usage proportions are illustrated in Table 13. Total energy consumption for the production of apples in Europe ranges between 0.4 and 3.8 MJ kg^{-1} (Milà i Canals *et al.* submitted). A life cycle assessment analysis for apples produced in Europe and consumed within the country of production found that cultivation is the main energy consuming stage, followed by storage or packaging (Milà i Canals *et al.* submitted). However, in August, when European apples have been in storage for about nine months, storage uses more energy than the other life cycle stages (Milà i Canals *et al.* submitted).

Table 12. Energy inputs and Global Warming Potential (GWP) for producing 1 ha of a range of crops in the UK. Source: Tzilivakis *et al.* (2005)

Crop	**Energy input (GJ ha^{-1})**	**Equivalent t CO_2 ha^{-1} GWP**
Potato	31.3	3.0
Sugar beet	19.8	1.0-1.8
Winter wheat	20.8	1.7
Oilseed rape	15.5	1.2
Spring barley	9.3	0.7
Pea	6.7	0.7

Table 13. Total primary energy used and energy usage proportions for maincrop potatoes, second earlies and earlies in the UK. Source: Williams *et al.* (2006)

	Maincrop	**Second earlies**	**Earlies**
Total primary energy used per t	1510 MJ	775 MJ	1220 MJ
Energy usage proportions:			
Field work	28 %	61 %	61 %
Crop storage and drying or cooling	49 %	0 %	0 %
Pesticide manufacture	4 %	8 %	6 %
Fertiliser manufacture	19 %	31 %	33 %

In a case study on tomato, cucumber, pepper and eggplant greenhouse production in Turkey, crop yields were found to increase as a function of energy inputs (Canakci & Akinci 2006). Amongst these crops, cucumber production is the most energy intensive (Ozkan *et al.* 2004). Total energy input for the production of stake tomatoes in Turkey was estimated at 97,000 MJ ha^{-1} (Esengun *et al. in press*). Pelizzi (1992) presents energy inputs for various vegetable crops and fruit trees in Italy. A study of Greek apple production systems concluded that energy savings could be made without significant loss of yield by reducing fertiliser inputs and increasing pesticide efficiency through the use of more appropriate techniques (Strapatsa *et al.* 2006). In Belgium, energy consumption by glasshouse vegetable production increased by 44 % between 1986 and 1994 due to a change to more energy intensive crops (Taragola 1996).

Figure 13 presents energy demand for different inputs into the production of several agricultural crops using integrated production methods in Switzerland.

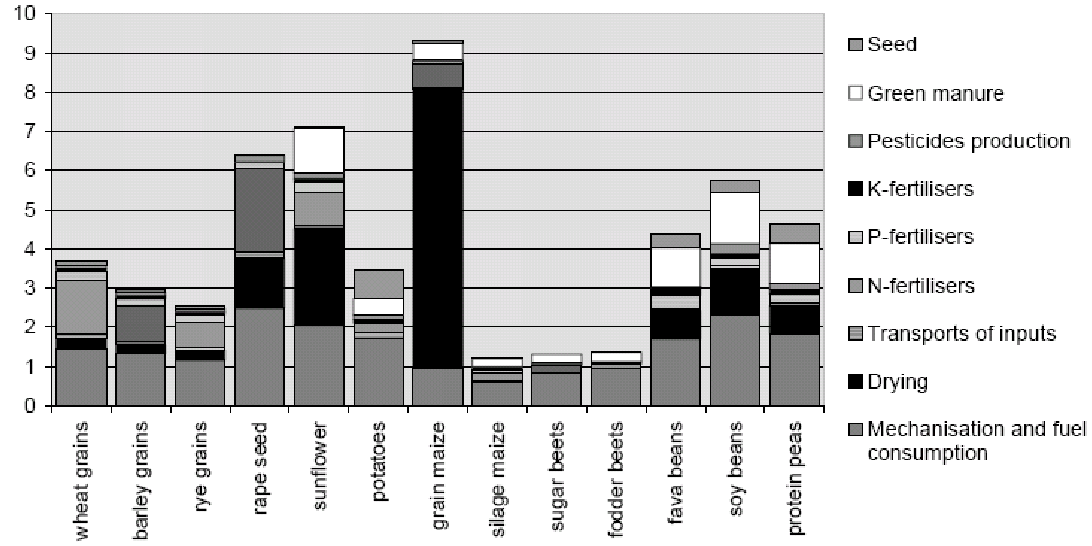


Figure 13. Cumulative energy demand of non-renewable energy resources for agricultural crops from integrated production in MJ per kg dry matter. Source: Nemecek *et al.* (2004)

2.6.3 General best practice

Advice on best practice options for energy savings in agriculture and horticulture can be found in Carbon Trust (2002) and RHS (2004). The Horticultural Development Council conducts research in order to maximise efficient use of energy inputs in protected cropping. This includes strategies for increasing efficiency of all sources for heating (e.g. energy audits, training of operatives in the use of climate control equipment, temperature integration, dynamic climate control, the use of new cladding materials, closed greenhouses, high light transmission thermal screens, energy efficient strategies for improved humidity control, new energy conversion systems, heat storage, transfer and control systems), strategies for the maximisation of natural light reception by crops (e.g. research into the effects of plant responses to light quality and quantity, best practice for cleaning of cladding material, development of high transmission cladding materials and structures) and optimisation of CO_2 enrichment, including the development of optimal generation and distribution systems.

Because nitrogen fertilisers represent the greatest indirect input of energy for field crops, a reduction in fertiliser use has the potential to greatly reduce total agricultural energy consumption (MAFF 2000b). Minimum and zero cultivation techniques save tractor fuel, may however require greater herbicide inputs for weed control. Some Sarpo potato varieties have a natural deep dormancy, which can reduce energy usage during storage significantly (David Shaw, pers. comm.). In glasshouse production, energy consumption is dominated by heating and lighting. If the use of Combined Heat and Power systems was maximised across the UK, energy consumption in tomato production could be reduced by 70 % (Williams *et al.* 2006). Glasshouses lose as much as 40 % of light by reflection from the glazing or from absorption by glazing, dirt and the structure itself. Hence, any other shading should be avoided, especially in winter (RHS 2004). Wall insulation, roof insulation and better temperature management also have the potential to lower energy consumption (Pluimers *et al.* 2001).

Table 14 shows energy saving technologies and potential for the horticultural sector as estimated by Biffaward (2002).

Table 14. Energy saving technologies and potential for the horticultural sector. Source: Biffaward (2002)

Energy conservation measure	Potential energy reduction
Efficient light sources	80-85 %
Variable-speed motor drives (pumping and irrigation)	40 %
Combined heat and power	30 %
Heat pumps for heating	30 %
More efficient greenhouse design	25 %
Thermal storage	20 %
Improved greenhouse heating controls	15 %
Boiler flu gas condensers	15 %
Decentralised boiler plant	15 %
Monitoring and targeting, energy awareness training	5 %
High-efficiency motors for various motor applications	2 %

2.6.4 Recommendations for best practice

Options for a reduction in energy consumption in field based and protected horticulture include:

Field based horticulture:

- reduction in fertiliser use,
- reduction in pesticide use,
- correct operation of tractors,
- more efficient irrigation scheduling to apply water only when needed,
- exploitation of alternative non-fossil fuels as energy sources,
- minimum and zero tillage techniques to reduce tractor fuel consumption,
- more efficient use of energy for post-harvest storage and cooling.

Protected horticulture:

- efficient light sources,
- variable-speed motor drives (pumping and irrigation),
- combined heat and power,
- heat pumps for heating,

- more energy efficient greenhouse design, roof and wall insulation,
- thermal storage,
- better control of heating and ventilation,
- boiler flu gas condensers,
- decentralised boiler plant,
- energy awareness training,
- high-efficiency motors for various motor applications.

2.6.5 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to energy efficiency in Welsh horticulture:

- Communicate the options for increasing energy efficiency in horticultural systems, and demonstrate the best methods for reducing energy use.
- Develop demonstration glass houses in conjunction with a combined heat and power biomass plant (or equivalent).
- Develop supply systems which minimise the need for storage.

2.7 Waste

2.7.1 General introduction

Agriculture in the UK produces about half a million tonnes of waste per year, mainly plastics (mostly polyethylene and polypropylene), agrochemicals and animal health products (Defra 2005a). Agricultural waste plastics account for about 5 % of total plastic consumption in the UK. Other components include tyres, oils, batteries, machinery, building waste, cardboard and paper packaging (Table 15). This figure excludes organic materials (e.g. slurries, manures and crop residues) that are re-used on farm. In addition, an estimated 600,000 tonnes of scrap metal, tyres and asbestos are currently stored on farms without plans for disposal (Agricultural Waste Stakeholders' Forum 2004). Between 2001 and 2004, the amount of plastic waste recycled declined from 14 % to 8 % for silage wraps and from 14 % to 7 % for fertiliser bags, while burning remained the main means of disposing of waste, especially for plastics and packaging (Defra 2005a). Only 1-5 % of farmers use landfill sites (Defra 2005a).

Table 15 gives an overview of the types of waste produced by agricultural holdings and the percentage of holdings generating the different types of waste. In the 2003 agricultural waste survey conducted by Defra, 97 % of respondents produced plastic packaging waste and 74 % waste agrochemical packaging (Defra 2003b). On horticultural farms, plastic waste is generated through the use of greenhouse, tunnel, mulch or crop cover films, seed trays and pots (Table 15). Table 16 shows estimated tonnes of selected plastic waste produced in England, Scotland, Wales, Northern Ireland and the whole UK per year. Figures 14 and 15 present total plastic arisings and low density polyethylene plastic density respectively in England and Wales by county, showing that arisings in Wales are relatively high. The total quantity of packaging waste has declined over recent years due to reductions in the weight of packaging plastic, increased efficiency of fertilisers and pesticides that are now being applied at smaller doses and increases in the size of containers and bags for the supply of agrochemicals (EA 2001b). The total amount of plastic waste from non-packaging purposes is estimated at 60,000 tonnes per year in the UK, with the weight of plastic horticultural films accounting for about 23 000 tonnes (including 80 % contamination of crop cover and mulch film) (EA 2001b). Figure 16 illustrates different packaging waste streams in agriculture. In protected tomato production in Spain, an estimated 1750 kg ha^{-1} of plastic waste is generated per year (Munoz *et al.* 2004).

New regulations with regard to agricultural waste management were introduced in England and Wales in 2006 by the UK government in order to comply with the European Waste Framework Directive (75/442/EEC). Until now, waste disposal by agricultural businesses was not controlled, and most waste was disposed by open air burning or in on-farms tips and dumps (Defra 2006c). The new regulations mean that agricultural waste is from now on subject to the same legislative controls as waste from other industries and that disposing of waste in farm tips and dumps, burning in incinerators or open fires and burying waste is no longer legal. On-farm options for disposal will be limited and there will be a legal obligation to have waste removed by registered waste contractors.

Table 15. Agricultural holdings generating specific waste streams in the UK in 2003. Source: Defra (2003b)

Waste streams	Holdings generating each waste		
	Percentage of holdings surveyed[1]		Estimated number of holdings in GB[2]
Machinery and other metal			
Batteries	87%	(84–90%)	176,000
Vehicles or machinery	74%	(69–79%)	150,000
Machinery/vehicle parts	71%	(66–76%)	143,000
Scrap metal (e.g. roof sheeting)	93%	(90–96%)	188,000
Refrigeration equipment	17%	(13–21%)	34,000
Large-scale electrical equipment	10%	(7–13%)	20,000
Oils	86%	(83–89%)	174,000
Tyres	85%	(81–89%)	172,000
Plastic packaging			
Agrochemical packs (rinsed)	71%	(66–76%)	143,000
Agrochemical packs (unrinsed)	7%	(4–10%)	14,000
Fertiliser bags	79%	(75–83%)	160,000
Seed bags	34%	(29–39%)	69,000
Feed bags	64%	(59–69%)	129,000
Shrink wrap	33%	(28–38%)	67,000
Sheep dip/drench packaging	31%	(26–36%)	63,000
Cardboard and paper packaging			
Agrochemical packaging (outer)	64%	(59–69%)	129,000
Fertiliser bags	4%	(2–6%)	8,000
Seed bags	36%	(31–41%)	73,000
Feed bags	35%	(30–40%)	71,000
Other packaging			
Wooden pallets	75%	(71–79%)	151,000
Metal sheep dip/drench packaging	8%	(5–11%)	16,000
Medicine containers	77%	(73–81%)	155,000
Animal health outer packaging	75%	(71–79%)	151,000
Miscellaneous packaging	74%	(69–79%)	149,000
Oil containers	85%	(81–89%)	172,000
Silage plastics, bale twine and net wrap			
Silage wrap	58%	(53–63%)	117,000
Silage sheet	27%	(22–32%)	55,000
Silage bags	9%	(6–12%)	18,000
Plastic cores for silage plastic wrap	44%	(39–49%)	89,000
Cardboard cores for silage sheet	28%	(23–33%)	56,000
Bale twine and net wrap	84%	(80–88%)	169,000
Plastic cores for bale twine and net wrap	33%	(28–38%)	66,000
Cardboard cores for bale twine and net wrap	34%	(29–39%)	68,000
Horticultural plastics			
Greenhouse or tunnel film	6%	(4–8%)	12,000
Mulch or crop cover film	5%	(3–7%)	10,000
Mushroom bags	1%	(0–2%)	2,000
Seed trays and pots	10%	(7–13%)	20,000
Waste agrochemical concentrate	14%	(11–17%)	28,000
Animal health products			
Used syringes and needles	78%	(74–82%)	158,000
Aerosol containers	72%	(67–77%)	145,000
Waste medicines	28%	(23–33%)	57,000
Other animal health products (e.g. gloves, swabs, dressings)	50%	(45–55%)	101,000
Sheep dip			
Waste sheep dip concentrate	6%	(4–8%)	12,000
Waste sheep dip drench (pour-on)	6%	(4–8%)	12,000
Dilute sheep dip	16%	(12–20%)	32,000
Building waste			
General building waste (e.g. bricks)	80%	(76–84%)	162,000
Asbestos cement-bonded roof sheeting[3]	31%	(26–36%)	63,000
Other asbestos (e.g. pipe-lagging)	3%	(1–5%)	6,000

1 Base = all 380 agricultural holdings surveyed. Figures in brackets represent the 95% confidence limits for each percentage. For information on confidence limits, see Appendix B.

2 These figures have been extrapolated from the survey results using the June Agricultural Census figure for the total number of agricultural holdings in Great Britain (201,926). They are rounded to the nearest thousand.

3 Only those holdings that have or had generated waste asbestos sheets. Note that this figure does not refer to the number of holdings with asbestos-roofed buildings.

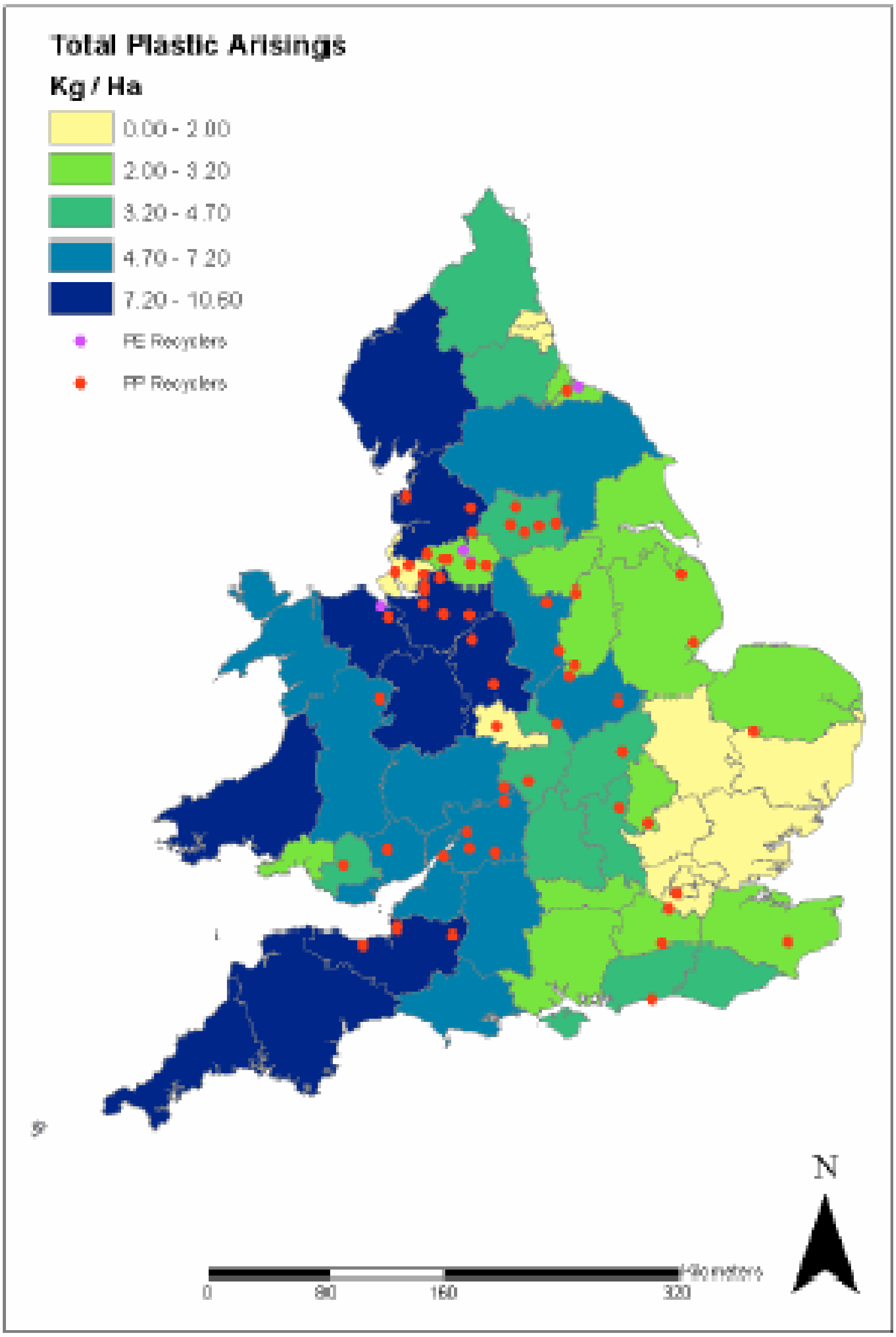


Figure 14. Total plastic density (kg ha^{-1}) of all agricultural plastics by county, including recycler locations. Source: EA (2005)

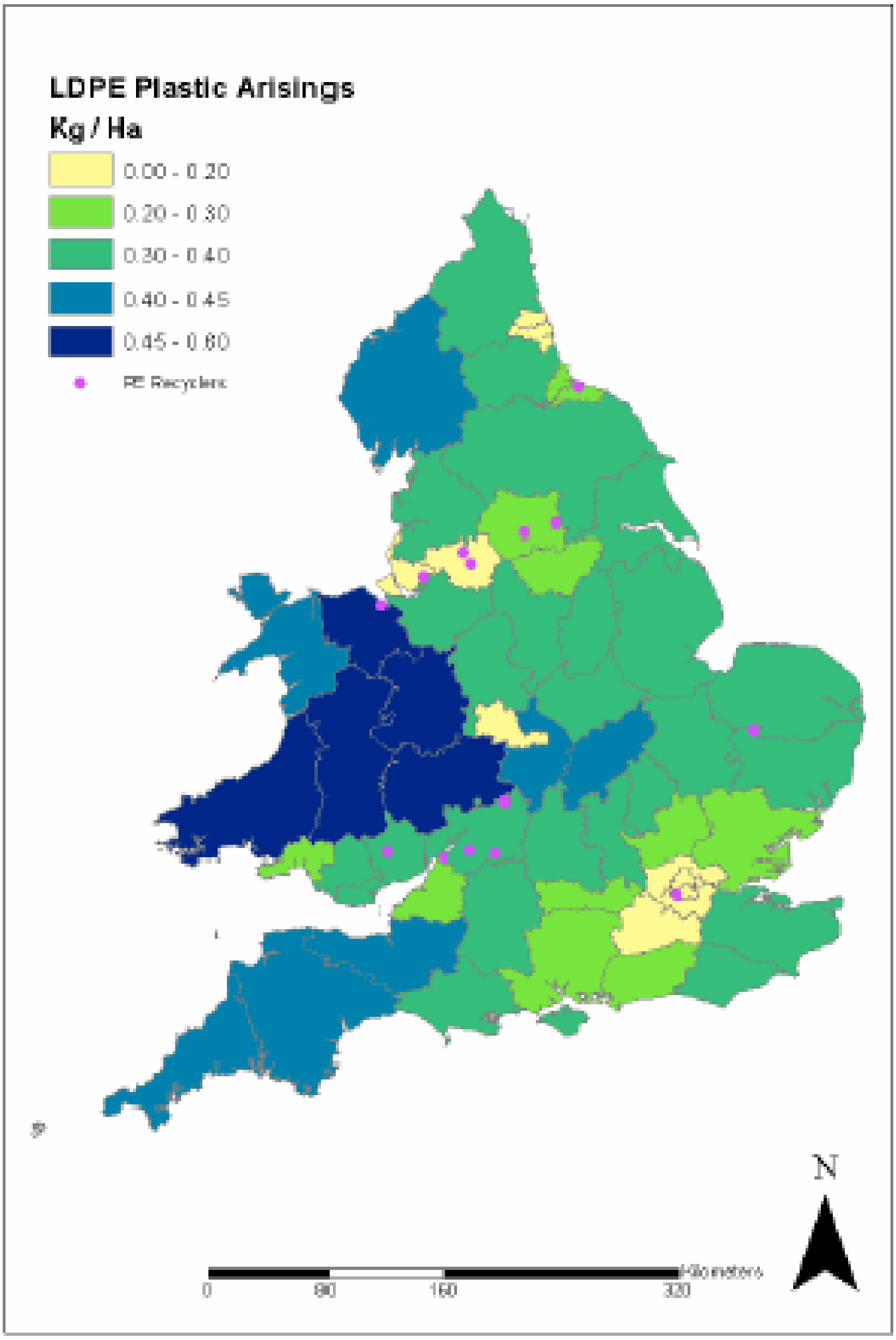


Figure 15. Low density polyethylene (LDPE) plastic density (kg ha^{-1}) by county, including recycler locations. LDPE is normally used as sheeting for silage clamp and horticultural crop covers and polytunnels, small sacks and the inner lining of bulk fertiliser bags. Source: EA (2005)

Table 16. Estimated tonnes of selected plastic waste produced in the UK, England, Wales, Scotland and Northern Ireland in tonnes per year (1998). Source: Defra (2003b)

	UK total	England	Wales	Scotland	Northern Ireland
Greenhouse and tunnel film	500	468	10	12	11
Mulch film and crop cover	4500	3738	30	657	76
Mulch film and crop cover + contamination	22500	18689	148	3283	380
Other horticultural plastics	6000	5617	114	143	127
Plastic agrochemical packaging	2400	1720	30	276	374
Plastic fertiliser bags	12200	8748	984	1654	815
Plastic seed bags	1000	840	15	134	12

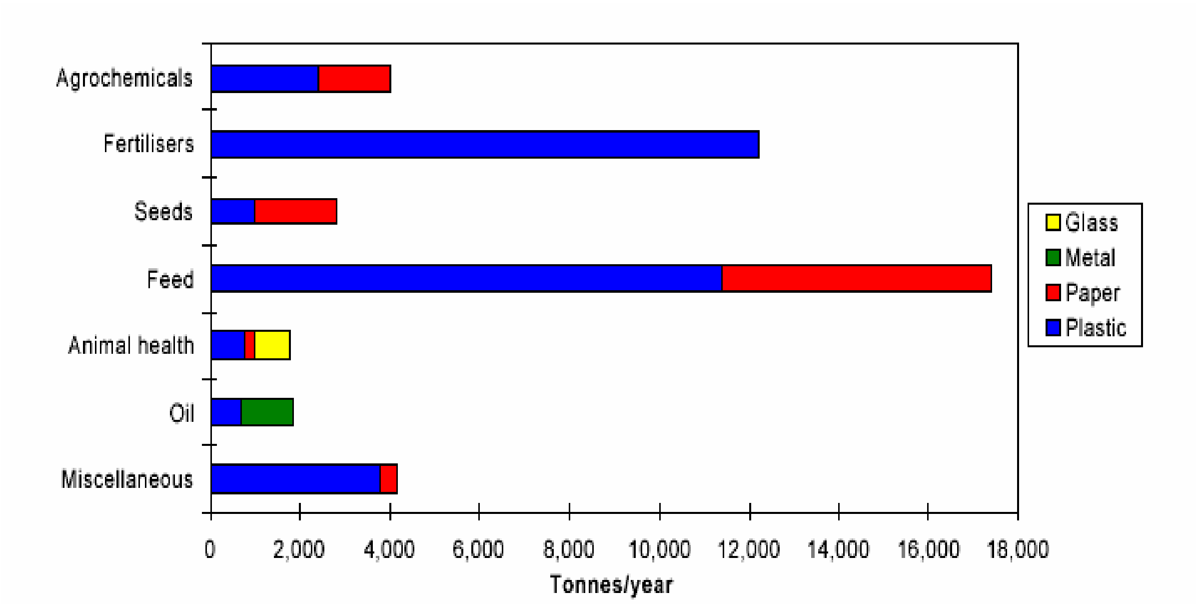


Figure 16. Packaging waste streams in agriculture. Source: EA (2001b)

2.7.2 Waste production in horticulture

Horticultural and dairy farms are the greatest agricultural producers of plastic waste (EA 2005). Almost half of all plastic consumed by agriculture worldwide is used for protected cropping, including greenhouses, mulching, small tunnels, temporary coverings of structures for fruit trees, etc. (Dilara & Briassoulis 2000). Usage and production of waste from plastic covers and mulches, pots and trays has increased significantly over the last few years for fruit and field vegetable crops, including potatoes (EA 2001b, 2005, Defra 2006c).

For field vegetables, horticultural film is used early in the season to protect crops from frost; it is usually removed in early June. It is estimated that plastic horticultural mulch waste weighs 1010 kg ha^{-1} for early potatoes, 1020 kg ha^{-1} for field vegetables and 1940 kg ha^{-1} for soft fruit (EA 2005). Unfortunately, the study that provided these figures did not consider fruit production and the overall use of plastics in horticulture in any detail (EA 2005). Plastic mulches offer several advantages for growers:

increased soil temperatures, allowing for earlier planting, increased soil moisture retention and irrigation efficiency, control of weed infestation which reduces competition for water and nutrients, accelerated plant growth and crop ripening, and increases in yield and quality of the crop (Tocchetto *et al.* 2001). They can also reduce the leaching of nutrients into the groundwater and reduce development of diseases coming from the soil, thus reducing the amount of pesticides used (Scarascia-Mugnozza *et al.* 2006). Disadvantages of plastic mulches include greater initial costs, manual removal after harvest which increases costs, disposal and an increased level of management. If not removed, the portion of the film that is buried in the soil can pollute the site and lead to problems growing the next crop because it binds to the roots and so restricts growth (Tocchetto *et al.* 2001).

Because of the decaying effects of solar radiation, rain, hail, wind, high air temperatures, high air humidity and agrochemicals used during crop production and agricultural practices such as soil tilling, plastic mulches have a short lifespan of one to two cultivation periods only (Scarascia-Mugnozza *et al.* 2006). Different colour mulches have different advantages, e.g. black plastic does not increase soil temperature much but effectively controls weed infestation, while clear plastic increases soil temperatures but cannot control weeds unless treated with herbicides.

The plastic sheeting used for polytunnels has a short lifespan of up to five years for the thicker plastics (Entec 2006). The plastics are not biodegradable and are difficult to dispose of at the end of their lifecycles, e.g. burning will release harmful chemicals (Entec 2006).

2.7.3 General best practice

Advice on how to minimise agricultural waste and thus increase farm profitability is given in Defra (2006c) and Soil Association (2005), including waste reduction and avoidance related to pesticides and fertilisers, plastic covers, crop and produce waste.

Generally, waste is only stored on farm if no other cost-effective options such as collection by a waste contractor are available (Defra 2003b). Although re-use on farm is common practice on almost all holdings, only an estimated 1 % of agricultural waste is currently recycled (Defra 2003b, EA 2005). A report by the Environment Agency in 2005 concluded that at present, there are not enough options for waste recycling in an environmentally friendly way (EA 2005). EA (2001b) and Defra (2003b) highlighted the lack of cost-effective on-farm techniques for waste recovery, high logistic costs for off-farm recovery, inconsistencies in the provision of take-back services by suppliers, poor markets for recycled products, high processing costs and limited facilities as barriers to the increased uptake of recovery and recycling. There is also a need to further communicate best practice measures to farmers (Defra 2003b). A directory that helps agricultural and horticultural businesses to find companies that can recycle and dispose of waste can be accessed at www.wasterecycling.org.uk.

A life cycle assessment of tomato production in Mediterranean greenhouses found that non-yield biomass and plastic wastes represented the main negative impact, thus suitable waste management is of great importance in improving the overall environmental impact (Anton *et al.* 2005a). Segregation of biomass from other wastes followed by composting of biodegradable components reduced the effect on climate change by 40 % if the other waste was disposed of in landfill and 70 % if it was incinerated (Anton *et al.* 2005b).

Photo- and biodegradable products only make up a very small segment of the market for horticultural films, and R&D is ongoing to improve their performance (EA 2001b). Biodegradable polymers can be used successfully in agriculture for mulch films, plant pots, composting containers and fertiliser and chemical storage bags. They degrade to non-toxic products through exposure to sunlight, bacteria, fungi or algae in the soil, thus protecting the environment and increasing the grower's profits by removing costs for labour and disposal (Tocchetto *et al.* 2001). Polymer structure, polymer morphology, molecular weight, radiation and chemical treatment all affect biodegradation. Chandra & Rustgi (1998) review use and applicability of biodegradable polymers. Scarascia-Mugnozza *et al.* (2006) present a case-study comparing traditional plastic mulch covers and biodegradable mulches containing starch used for the production of strawberries. Twelve months after tillage, only 4 % of the initial weight of the biodegradable film remained in the soil, no ecotoxicity was found in the soil, yields were greater and harvest earlier compared to traditional plastic films (Scarascia-Mugnozza *et al.* 2006). Other authors reporting on the suitability of biodegradable films include Anderson *et al.* (1995), Weber (2003) and Candido *et al.* (2003, 2006).

Horticultural crop cover can be highly contaminated with residual soil, which can amount to up to 80 % of total weight. This represents a problem for recycling because it increases costs and makes it uneconomic especially for small to medium sized businesses and farms in remote areas. Used foils can also represent hazardous waste because of fertiliser and pesticide residues.

2.7.4 Recommendations for best practice

Options for minimising agricultural waste on farms include:

- waste reduction and avoidance, e.g. a reduction in pesticides applied decreases the amount of waste containers produced,
- composting of biodegradable components,
- use of photo- and biodegradable horticultural films,
- use of other alternatives to plastic crop cover sheets, e.g. organic materials, straw or compost mulches,
- if possible, keep plastic sheets in a cleaner conditions so that they can be recycled,
- re-use and recycling,
- use of reusable containers and bulk delivery to reduce packaging waste,
- use of biodegradable packaging.

2.7.5 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to managing waste in Welsh horticulture:

- Demonstrate the use of photo- and biodegradable horticultural films.
- Enhance the opportunities to recycle wastes from horticultural systems.

2.8 Peat

2.8.1 General introduction

Peat is a valuable resource in horticulture. It has a good water-holding capacity, retains sufficient air for healthy growth of roots, increases the structural complexity of the soil, has an appropriate pH and low nutrient contents which means that nutrient levels can be entirely controlled by the user (DETR 2000, Moore 2002). When it is mixed with soil, it leads to increased nutrient cycling through the activity of soil invertebrates and microbes, and its chemical properties increase the ability of the soil to retain nutrients (Moore 2002).

Horticulture is the single most important user of peat extracted in the UK, including professional growers, amateur gardeners, private sector landscapers and local authority ground maintenance (DETR 2000). About 94 % of lowland raised bogs have been destroyed or damaged by drainage, agricultural intensification, afforestation and commercial peat harvesting. Drained and fertilised peatlands can produce high yields of vegetables and root crops, but drainage and cultivation eventually result in a reduced depth of peat, soil erosion and loss of value of the land for agriculture (MAFF 1998c). Today, only about 6,000 ha of lowland raised bog retaining a largely undisturbed surface remain (UK Biodiversity Group 1999). This does not only impact on biodiversity, but can also contribute to climate change because intact peatlands form an important carbon sink. As peatlands degrade, this carbon is released into the atmosphere (Cannell *et al.* 1999, Moore 2002, EN 2006). UK peat extraction accounted for 40 % of peat consumption in 1999, whereas the amount imported from countries such as Ireland and the Baltic states, increased steadily between 1993 and 1999 (www.communities.gov.uk/index.asp?id=1143439#). The professional sector uses more imported peat than amateur gardeners (Holmes 2004).

2.8.2 Peat consumption in horticulture

Total peat consumption in the UK amounts to 3.4 million m^3 per year. Professional horticulture accounts for about 22 % of this (Holmes 2004). Between 2000 and 2003 there was an overall 10 % decrease of the volume of peat used by professional horticulture in England and Wales to a total of 756,000 m^3 (Holmes 2004). Peat is used for mushroom casing and as part of the mushroom growing compost. Between 2000 and 2003, peat use for the production of mushrooms declined by 39 % and glasshouse salads by 44 % (Table 17). This is not a reflection of the increased use of alternative materials, but rather of the decline in the mushroom and salad producing sectors in the UK (Holmes 2004). Peat use for the production of soft fruit, mainly strawberries, increased by 24 % between 2000 and 2003 and by 85 % since 1995/96, which is due to an increase in production (Holmes 2004). However, the total volume used for soft fruit production is comparatively low. In glasshouse salad production, peat is mainly used for the propagation of lettuce and tomatoes; however, increased competition has led to an increase in the import of young plants and a resulting decrease in the volume of peat used in England and Wales (Holmes 2004). Pot herb production for supermarkets uses mainly peat based substrates and is increasing (Holmes 2004). Competitive market conditions have led to a decline in the area of outdoor vegetables, especially brassicas, in England and Wales, which has resulted in a decline of peat use by this sector since the 1990s (Holmes 2004).

Table 17. Peat use for some horticultural products in 2003. Source: Holmes (2004)

	Peat use in m^3	%	Change from 2000
Mushrooms	90 000	12	-39 %
Vegetable transplants	59 000	8	0 %
Soft fruit	21 000	3	+24 %
Glasshouse salads	10 000	1	-44 %

2.8.3 Best practice – alternative materials

In the UK, 94 % of growing media used are still based on peat, whereas soil improvers are mainly (92 %) based on alternatives (DETR 2000). The main materials being used as alternatives to peat are: by-products from forestry, agriculture and horticulture (e.g. bark and wood fibre), inorganic minerals and recycled wastes (DETR 2000).

Alternative materials are described in more detail in DETR (2000) and EN (2006), including bark, coir, wood waste, paper waste, spent mushroom compost, composted waste (e.g. green waste from landscape gardeners), animal manures and inorganic materials (e.g. vermiculite and perlite). In 1993, members of the Peat Producers Association produced more than 100 low-peat or peat-free alternatives (Robertson 1993). Vermicompost is the end product of the breakdown of organic matter by earthworms in high densities, which can consume a variety of organic wastes, including sewage sludge, animal wastes, crop residues, paper waste and industrial wastes (Zaller 2007). A recent study on tomatoes confirmed that vermicompost has the potential to substitute peat in potting substrates because of its stimulatory effects on emergence, growth and biomass allocation of seedlings (Zaller 2007). However, vermicompost effects were different between crop varieties, which should be taken into account when giving recommendations on the proportion of vermicompost amendments potting to substrates (Zaller 2007). This study also found that no additional fertilisation appeared to be needed when using vermicompost to grow tomatoes (Zaller 2007). Increases in yield were also observed for field-grown tomatoes, peppers and strawberries treated with vermicompost (Arancon *et al.* 2003, 2004). The suitability of other materials as peat substitutes was investigated e.g. by Hartz *et al.* (1996), Roe *et al.* (1997), Arenas *et al.* (2002), Evans & Karcher (2004), Hu & Barker (2004), Veeken *et al.* (2004), Kahn *et al.* (2005), Gruda & Schnitzler (2006).

The uptake of peat alternatives has been slow over the last 10-15 years for a number of reasons: lack of customer demand, lack of confidence in alternative materials by customers, especially commercial growers, often higher prices of alternative products, concerns over increased cost of production and lower quality (Holmes 2004). It is expected that peat will become more expensive which may help increase the use of alternatives in the future (Holmes 2004). Many professional growers are concerned about consistency and quality of alternative growing media (DETR 2000). The EN and RSPB initiative 'Peatering out – towards a sustainable UK growing media industry' explores alternative growing media to protect remaining peatlands and how peat use could be ended in 10 years in the UK (www.rspb.org.uk/ Images/peateringout_tcm5-31088.pdf). On the 'Peatering Out' website, a service is provided for finding the producers and sellers of plants grown in peat-free media (www.peateringout.com). The NFU believes that at the current rate of development of alternative materials, the Government aim to replace 90 % of the peat used by

2010 is neither achievable nor commercially sensible (www.nfuonline.com/x1183.xml, accessed 30.11.2006). Most British tomatoes are now grown in rockwool which has replaced the use of peat, provides good growing conditions for the roots and results in better quality crops (www.britishtomatoes.co.uk/newsite/facts/growing.html). Several major multiple retailers in the UK have introduced policies of peat reduction, e.g. Marks & Spencer and Homebase (Holmes 2004).

2.8.4 Recommendations for best practice

Government could encourage the uptake of peat replacements by:

- introducing tax incentives,
- supporting industry and initiatives to speed up production and supply of alternative materials,
- supporting research, development and trials of alternative materials,
- introducing quality standards for composted waste and other alternative materials,
- raising public awareness of the problem and alternative materials.

The horticultural industry should:

- replace peat-based growing media by peat-free alternatives,
- become familiar with peat alternatives and their advantages,
- develop industry standards for composts and other materials to ensure quality and consumer confidence in new alternative materials.

2.8.5 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to peat and growing media in Welsh horticulture:

- Continue to develop sustainable alternatives to peat, paying particular attention to achieving a consistent product which would be suitable for commercial use.

2.9 On-farm biodiversity and landscape

2.9.1 General introduction

Widespread declines of farmland biodiversity associated with agricultural intensification have been observed in Britain and north-west Europe since the 1940s. Many different taxa have been affected (Benton *et al.* 2003), with population sizes of about half of plants, a third of insects and four-fifths of birds decreasing (Robinson & Sutherland 2002). These declines are most serious for habitat specialist, while the taxa that are still widespread on farmland are mainly habitat generalists (Robinson & Sutherland 2002). Arable plants are the most critically threatened group of plants in Britain today (www.arableplants.org.uk). Because many arable weeds support a high diversity of insect species, declines in host plants can affect many insects and taxa that feed on them (Marshall *et al.* 2003). Nutrient-poor habitats and associated plant species are declining while species of fertile habitats are increasing (Haines-Young *et al.* 2003, Smart *et al.* 2003). Abandonment of extensively farmed land can also lead to the loss of biodiversity (EEA 2005).

Because farmland represents the single largest habitat in Europe, covering about 50 % of the total European land area, it is vital to understand how farmland biodiversity is affected by agricultural intensification and how agriculture can contribute to the conservation of biodiversity (Donald *et al.* 2006). Biodiversity in agroecosystems depends on four main factors: the diversity of vegetation within and around the agroecosystem; the permanence of the crops within the system; management intensity; and the extent of isolation from natural vegetation (Altieri 1999). Habitat heterogeneity at the landscape scale, between-field scale and within-field scale is positively associated with diversity for a variety of taxa, e.g. weeds, various invertebrates and birds (Benton *et al.* 2003). Agricultural intensification leads to a loss of heterogeneity of habitats at large and small scales, e.g. through the spread of monocultures, the decline of mixed farming and non-cropped habitat on farmland, reduction of traditional crop rotations, loss of fallow land, hedgerows and field margins, clearance of woodlands, filling of ponds, habitat drainage, etc. The existence of non-cropped habitat is important as refuges, nesting grounds, feeding areas, and dispersal corridors.

Habitat degradation results from changes in crop types, crop structures and farming practices, including a switch from spring to autumn tillage, simplification of crop rotations and increased use of agrochemicals. The reduction in spring sowing, for example, can affect birds through a loss of nesting and foraging habitat during the breeding season and loss of weedy stubbles and associated food sources during winter (e.g. Morris *et al.* 2004b). Spray drift from fertilisers into field margins reduces plant density and diversity, and changes in soil nutrient status can lead to the disappearance of plant species adapted to nutrient-poor conditions. In addition, the size of weed populations is reduced by improved seed-cleaning techniques. Pesticides can have direct and indirect effects, e.g. the reduction of food resources following the application of herbicides or insecticides (e.g. Boatman *et al.* 2004, Morris *et al.* 2005, Taylor *et al.* 2006). Water pollution through leaching and run-off of fertiliser nutrients and silt can impact on aquatic biodiversity. Organic matter, e.g. from manures, that runs off into water courses, is broken down by biological processes that consume oxygen. In very severe cases, this may lead to the suffocation of aquatic animals (Defra 2005d). Figure 17 illustrates the relationship between agricultural intensity and biodiversity. Tables 18 and 19 summarise some of the temporal and spatial mechanisms causing increased homogeneity of agricultural habitats in Britain as a result of agricultural intensification.

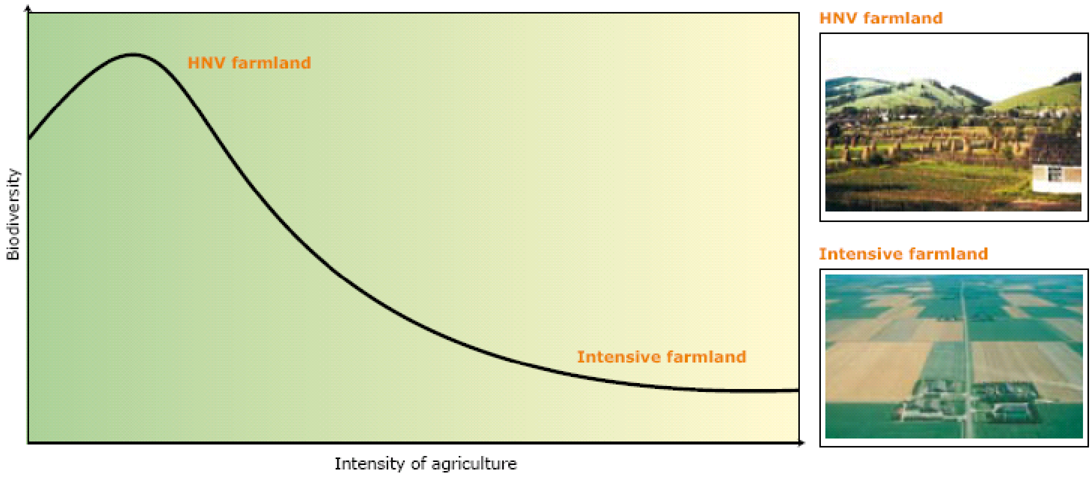


Figure 17. General relationship between agricultural intensity and biodiversity. HNV = high nature value. Source: EEA (2006)

Table 18. Some of the temporal mechanisms causing increased homogeneity of agricultural habitats in Britain as a result of agricultural intensification. Source: Benton *et al.* (2003)

Cause	**Consequence**
Simplification of crop rotations	Continuous cropping and loss of ley grassland and fallowed land means that fields remain under similar and agriculturally productive management for longer continuous periods.
Mechanisation and increasing power of agricultural machinery	Agricultural operations (e.g. sowing and harvesting) can be completed more quickly and are less limited by weather conditions. More fields are therefore in the same state of management at any one time.
Agri-environment schemes	Management prescriptions generally serve to increase heterogeneity, but regulations binding farmers to threshold dates for operations (e.g. weed control on set-aside land) can reduce spread in timing of management operations that would previously have occurred.
Crop breeding advances and agro-chemical nutrition and protection of crops	Crops are in the ground for a greater proportion of the year (e.g. autumn sowing of cereals replacing spring sowing) with reduced fallowing and use of break crops or undersowing.

Table 19. Some of the spatial mechanisms causing increased homogeneity of agricultural habitats in Britain as a result of agricultural intensification. Source: Benton *et al.* (2003)

Cause	Consequence for heterogeneity
Between nations	
Common Agricultural Policy	Starkly differing rates of agricultural intensification between EU and non-EU countries, with rates of biodiversity loss especially high in EU nations with high proportions of land under tillage crops.
Between farms and between regions	
Farm unit specialisation (livestock versus arable)	Larger contiguous areas (regions) dominated by either tilled land or grassland, replacing landscapes formerly characterized by mixed farming systems with spatially intimate mixes of tillage and grassland.
Consolidation of farm units	Agriculture increasingly dominated by fewer larger farm units and hence larger contiguous areas under common management systems and/or crop rotations.
Between fields	
Simplified crop rotations	A reduction in the botanical and structural variety of crops and grassland grown on a single farm, increasing the probability of larger blocks of land being under the same management at any given time.
Removal of noncropped areas	Loss of semi-natural habitat features, such as ponds, uncropped field margins and scrub. Recently in the UK, some of these changes have begun to be reversed through positive management of noncropped management features through agri–environment scheme support.
Removal of field boundaries	Larger fields, and hence larger contiguous areas under identical management, as a consequence of maximizing efficiency of operation of agricultural machinery and reduce management costs in arable systems where hedgerows and other field boundary structures no longer serve stock-proofing functions.
Within fields	
Mechanization	More uniform swards owing to mechanized, high-precision sowing.
Agrochemical use	Nutrition and protection of crops increases uniformity of establishment and subsequent growth, and reduces species and structural diversity of vegetation by killing and shading out of noncrop species in favour of dense, homogeneous crop swards.
Drainage/irrigation	Soil moisture has important effects on yield, so drainage and irrigation are designed to maximise yield, which results in more uniform establishment and crop growth.
Crop breeding	Increased competitive ability of crop relative to noncrop species encouraging monocultural vegetation cover in combination with agrochemical use.
Grassland improvement	Reduction in species diversity by killing weeds, re-seeding with palatable, competitive grass species and favouring those species through drainage and fertilizer use.
Increased duration and intensity of grazing on improved fields	Reduced vegetation height and structural heterogeneity owing to higher grazing intensity and lack of unpalatable species in improved swards.

The effects of intensive agricultural production have been researched most extensively for farmland birds, e.g. Fuller *et al.* (1995), Chamberlain *et al.* (1999, 2000a), Blackburn & Arthur (2001), Boatman *et al.* (2004), Bracken & Bolger (2006), Devictor & Jiguet *in press*, Donald *et al.* (2006) and Orlowski (2006). This is because birds are regarded as indicators of the state of wildlife in the countryside: they have a wide habitat distribution, are near the top of the food chain and reflect changes in habitat diversity and the food chain (Defra 2005a). A third of bird species of highest conservation concern in Britain occur on farmland (Robinson & Sutherland 2002). During the last twenty years, an estimated ten million breeding individuals of ten species of farmland birds have disappeared in Britain (Krebs *et al.* 1999). Within Europe, 71 % of 58 farmland bird species showed population declines between 1990 and 2000, continuing a trend that started in the 1970s (Donald *et al.* 2006). Thirteen British bird species living exclusively on farmland have declined in abundance by an average of 30 % between 1968 and 1995; at the same time, generalist species have increased by 23 % (Siriwardena *et al.* 1998). Figure 18 illustrates this decline of farmland specialist species and how farmland generalist populations remained relatively stable between 1970 and 2005. The decline of farmland birds that occurred between 1990 and 2000 across Europe was not evident in bird assemblages of other habitats (Donald *et al.* 2006). These declines are partly caused by the reduction of plant and insect food sources as a result of fertilisation and pesticide use (e.g. Krebs *et al.* 1999, Boatman *et al.* 2004); other reasons include direct mortality by farming operations and the lower abundance of nesting habitat. Bird populations are more stable the more diverse the surrounding habitat is (Devictor & Jiguet *in press*), which stresses the importance of large and small scale habitat heterogeneity. A study by Gillings & Fuller (1998) on bird population trends on lowland farms in England suggested that loss of habitat quality, e.g. the height and width of hedgerows or adjacent land use, is a more important cause of bird population decline than habitat loss.

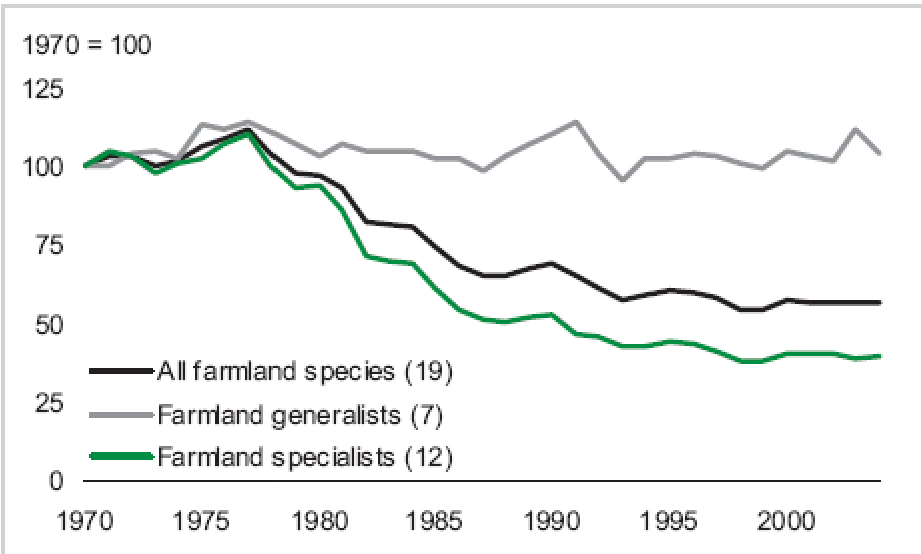


Figure 18. UK farmland bird index 1970-2005. Source: Defra (2005a)

In summary, the main agricultural practices that impact on biodiversity are the following (Commission of the European Communities 2001):

- unsustainable use of fertilisers and plant protection products,
- traditional practices giving way to more mechanisation,
- specialisation of production systems and intensification of certain practices (e.g. abandonment of mixed cropping systems and of cereals growing in grazing systems),

- reduction in number of species and varieties used,
- conversion of natural ecosystems to agriculture and abandonment of farm land,
- re-parcelling (larger parcel size, disappearance of field margins, hedges, ditches, etc.),
- drainage and irrigation (especially when dimensions are not adapted to conditions, i.e. overexploiting of ground waters or rivers).

2.9.2 Horticulture and biodiversity

Research specifically on the effects of horticulture on on-farm biodiversity is very rare. In a study on overwintering birds in Poland, a greater average bird density was found in fruit and vegetable crops than winter cereals, rape and cereal stubbles, young and permanent fallow or weedy root crop stubbles (Orlowski 2006). The highest average number of individuals within a single field was also found in fruit and vegetable crops (Orlowski 2006). Because of the small study area of the fruit and vegetable crops, these were merged into one group and not analysed separately. The abundance of seed-eating bird species was positively influenced by the weediness of the fields, with fruit and vegetables, young fallows, cereal and root crop stubbles having the most abundant weed communities. Tucker (1992) recorded little use of oilseed rape fields by invertebrate-feeding birds in winter. Arable weed species may have a variety of functions in agriculture and horticulture, including the provision of food resources, habitat heterogeneity in space and time, cover and reproduction sites; however, information in the literature is far from comprehensive (Marshall *et al.* 2003).

Areas of intensive farming of sugar beet, wheat and oilseed rape support lower abundances of birds than areas of low intensity farming, including fallow fields (Siriwardena *et al.* 2000). In a study on skylark abundance, Chamberlain *et al.* (2000b) found the highest probability of occurrence in winter cereals, brassicas and spring cereals, whereas rough grazing, permanent pasture, root and other vegetables had the lowest probability of occurrence. In a survey of the botanical composition of field margins, Firbank *et al.* (2002) recorded fewer species per plot in cereal field margins than root crop and vegetable field margins. In a study of eight bird species in an arable area with autumn-sown wheat, barley and oilseed rape as well as spring-sown crops such as sugar beet, peas, beans, potatoes, salad, oilseed rape and linseed, Mason & Macdonald (2000) recorded greater skylark densities in spring-sown crops such as peas and linseed as well as spring-sown oilseed rape as compared to autumn-sown oilseed rape. Spring-sown crops, especially potatoes, held more territories of breeding yellow wagtail than autumn-sown crops, while linnets showed a strong preference of oilseed rape fields for feeding and yellowhammers avoided field boundaries without hedges and weakly preferred pea fields (Mason & Macdonald 2000). Green *et al.* (1994) surveyed 18 passerine bird species and ranked different crops from most to least preferred: oilseed rape, potatoes, autumn-sown cereal, peas, beans, sugar beet and spring cereal.

Protected cropping in polytunnels can have a negative impact on biodiversity through the destruction of natural habitats and feeding areas (Entec 2006). Soil sterilisation is a common practice associated with polytunnels which is applied to minimise the risk of disease, and can lead to a reduction of soil biodiversity (Entec 2006).

2.9.3 Landscape issues

Farming plays a key role in shaping and maintaining landscapes (EEA 2006). Increased agricultural intensification leads to a homogenisation of landscapes as documented e.g. by Hietala-Koivu (1999). Landscape issues resulting from intensive agriculture and horticulture include (Buckwell & Armstrong-Brown 2004):

- expansion of monocultures,
- loss or fragmentation of field boundaries and woodlands,
- improvement of fields,
- drainage of wetlands,
- canalisation of rivers,
- insensitive development.

Another landscape problem can be the development of greenhouses and polytunnels covering large areas. In England, the total area of protected cropping in glasshouses and plastic covered structures was 1967 ha in June 2006, which represented an increase of 9.9 % since June 2005 (National Statistics 2006).

2.9.4 General best practice

Much of Britain's wildlife has been shaped and maintained by extensive agriculture. By farming in an environmentally friendly way, the diversity of the farming landscape, habitats and species can be maintained and enhanced (Defra 2005d). Some studies have suggested that changes to farming practices can increase bird species abundance, e.g. a reduction in pesticides input, provision of overwinter stubbles and grass margins (Krebs *et al.* 1999 and references therein). Management options that are expected to benefit wildlife, in particular birds, include: recreation of grass or heath on arable land, encouragement of stubbles and fallow arable land, encouragement of spring crops and rotations, creation and management of field margins and grass strips, restoration and management of hedges (Henderson *et al.* 2003). Overall, farming practices that encourage heterogeneity at various spatial and temporal scales will benefit biodiversity by providing resources throughout the year for a variety of taxa (Benton *et al.* 2003). A general extensification of farming practices is proposed by some as the best way to reverse the decline of farmland birds by Chamberlain *et al.* (2000a).

Policy measures that can be used to halt or reverse biodiversity decline on farmland include site protection, agri-environment measures, codes of good farming practice and conversion to organic farming (EEA 2005). Many European countries administer agri-environment schemes that aim to reduce pesticide and nutrient inputs, protect and promote biodiversity, restore landscapes and prevent rural depopulation (Kleijn & Sutherland 2003). Set-aside land provides seeds and grain stubbles in the winter, weedy nesting cover and food sources in the summer as well as field diversification. It typically supports higher densities of seeds, plants, invertebrates and birds than crops (Henderson *et al.* 2003). Some studies did not record any beneficial effects of agri-environment schemes on biodiversity, e.g. Kleijn *et al.* (2001, 2004) did not find any positive effects on plant and bird diversity and only slight increases in hoverfly and bee species richness in the Netherlands; four species of wading bird were even recorded more frequently on fields without management agreements. Similarly, Feehan *et al.* (2005) did not report any significant benefits of an agri-environment scheme on flora and carabid beetle fauna in their study area in Ireland. In an analysis of 62 published studies testing the effectiveness of agri-environment schemes across Europe, Kleijn & Sutherland (2003) were not able to come to a definitive conclusion because of a lack of robust data. Overall, 54 % of the examined taxa increased in areas managed under agri-environment schemes and 6 % decreased, with some studies reporting increases in species abundance, some decreases, some no effects and some positive effects on some taxa and negative effects on others. Butler *et al.* (2007) conclude that unless agri-environment schemes place more emphasis on improving the biodiversity value of the cropped area rather than non-cropped habitats such as hedgerows, the population decline of farmland birds will continue. Contrary to these findings, a meta-analysis of 127 published studies in North America and Europe concluded that land withdrawn from conventional agriculture unequivocally enhances biodiversity, with the number of species of plants, birds, insects and spiders increasing by 1-1.5 standard deviation units and population densities increasing by 0.5-1 standard deviation units on set-aside land (van Buskirk & Willi 2004). The potential of agri-environment schemes for enhancing farmland biodiversity was also shown by e.g. Chamberlain *et al.* (1999, 2000b), Henderson *et al.* (2000), Mason & Macdonald (2000) and Woodcock *et al.* (2007). In addition to set-aside, management of bordering hedgerows and the development of tall and low scrub in field corners would benefit several species of farmland birds (Mason & Macdonald 2000).

Buffer zones of 3 m width around field margins that remain unsprayed by pesticides can reduce pesticide spray drift by 95 %, and increase floristic diversity, phytophage insects, butterflies and insectivorous birds (de Snoo 1998, 1999). An economic analysis suggested that it is economically feasible to include unsprayed crop edges in winter wheat and potato cultivation, but not for sugar beet (de Snoo 1999). Sown grass margins of 6 m width benefited plants, bees and grasshoppers in a study by Marshall *et al.* (2006), who also advocate the importance of small scale landscape structures. Precision farming which uses less pesticides and fertilisers is expected to increase nesting opportunities for skylarks in winter cereals (Chamberlain *et al.* 1999).

Bradbury & Kirby (2006) discuss practices such as cover cropping and non-inversion tillage where the soil is only shallow-cultivated. These techniques reduce the disruption of soil structure and invertebrate biodiversity and increase moisture retention, thus reducing the risk of run-off and erosion and associated pollution of waters by sediment, fertilisers and pesticides. If winter cover crops are planted, the protection of water and soil may come into conflict with the protection of biodiversity, e.g. birds, whose access to food resources in the soil may be restricted by the cover crop. The provision of overwinter stubble fields will attract birds and may help reverse declining population trends and should be promoted in agri-environment schemes (Gillings *et al.* 2005).

In a study of orchards in Italy, greater bird diversities were recorded in orchards under organic and integrated management than conventional management (Genghini *et al.* 2006).

Organic farming contributes to an increased diversity of land use patterns and habitats, increasing landscape values (Mander *et al.* 1999, Hendriks *et al.* 2000). In Finland, implementation of EU agri-environmental protection schemes has had a positive impact on the visual quality of landscapes (Tahvanainen *et al.* 2002).

2.9.5 Recommendations for best practice

Recommendations to increase on-farm biodiversity include:

- provision of overwinter stubble fields,
- provision of fallow arable land,
- recreation of grass or heath on arable land,
- encouragement of spring crops and rotations,
- creation and management of unsprayed field margins and grass strips,
- restoration and management of hedges,
- precision farming, organic farming and integrated management to reduce agro-chemical inputs,
- use of cover crops and non-inversion techniques,
- encouragement of farming practices that increase habitat heterogeneity at various spatial and temporal scales.

2.9.6 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to enhancing biodiversity in Welsh horticulture:

- Develop and evaluate techniques for enhancing in-field biodiversity in field horticulture, *cf* beetle banks in arable crops, field boundaries, strip cropping.
- Evaluate the role horticulture can play in terms of enhancing horticulture at the landscape level.

2.10 Life Cycle Analysis (LCA)

Life Cycle Assessments (LCA) can be used to compare the environmental impacts of different products on air, water and land. An LCA analysis takes into account resource consumption, emissions, waste production and waste disposal during all life cycle stages, including production, processing, transport and consumption. LCA analyses on a variety of products can be found in Halberg (2004). A review of life cycle analyses highlighted the scarcity of studies on horticultural products, especially studies conducted in Britain (Table 20, Foster *et al.* 2006). Most research has looked at the production phase only, and only few studies cover processed foods and specific food systems in the UK (Foster *et al.* 2006). Another problem is that studies differ in their approach and impacts considered, with most studies focussing on energy consumption, climate change implications and eutrophication impacts (Table 20, Foster *et al.* 2006). Some results of life cycle assessments applicable to the UK are (Foster *et al.* 2006):

- Organic agriculture impacts less on the environment than conventional agriculture for many foods, but can also produce environmental problems. No definitive answer to the question whether organic or conventional food production is more environmentally friendly can be given.
- Evidence for a lower environmental impact of locally produced food is weak, and global sourcing may be the better option for some foods.
- Both transportation and cold storage/preservation of foods lead to high impacts from energy consumption.
- Emissions from long-distance air import of food are predicted to increase. At the moment, environmental impacts related to car-based shopping and home cooking appear to be greater than from long-distance transport.
- Some foods, e.g. bottled drinks, have a high environmental impact from packaging; the exact impact depends on local consumer behaviour, e.g. discard and recycling rates, and recovery or recycling facilities.

A summary of the main findings of Foster *et al.* (2006) for fruit, vegetables and basic carbohydrate foods, including potatoes, is presented in Table 21. For potatoes, the cultivation phase is responsible for the greatest impact on eutrophication, with organic and conventional systems causing similar eutrophication impacts. Other environmental impacts of potato production are summarised in Table 22. Energy use is important in all life cycle stages for potatoes and pasta, with car-based shopping and home cooking representing significant contributions to overall energy consumption, global warming and acidification. Cold-storage of potatoes accounts for about 40 % of total energy consumption, which masks any potential differences in energy use between organic and conventional farming systems. For carrots, consumer activities as well as freezing, frozen storage and packaging (where cans are not recycled) represent important environmental costs. The impacts of apple production are highly dependant on location and agricultural techniques employed. Heating represents the main energy-related environmental burden of tomato production in glasshouses, which can also use significant amounts of water (Foster *et al.* 2006). Current patterns of food consumption in developed countries exceed the level of sustainability by at least a factor of 4 (Carlsson-Kanyama 1998). Freight transport in the food, drink and agriculture sector is estimated to account for at least 10 % of total transport carbon emissions in the UK (ADAS 2005c).

Table 20. Examples of life cycle assessment analyses of horticultural products.

Country of production	Product	Main findings	Reference
Europe, South America and New Zealand	Apples	• Primary energy requirement for production in: Europe and South America: 0.4-3.8 MJ kg^{-1}, New Zealand: 0.4-0.7 MJ kg^{-1} • Storage for 5-9 months in Europe increases energy requirements by 8-16 % • Specific farming practices introduce significant differences in energy consumption • Season of production and consumption and storage losses affect total energy consumption	Milà i Canals *et al.* submitted
New Zealand	Apples	• Specific farming practices introduce significant differences in energy consumption (30-50 %) and other environmental impacts • Fuels, fertilisers and pesticides have an important impact on many environmental variables and careful selection of products can reduce environmental impacts • Direct energy input for field operations represent 64-71 % of total energy consumption; most environmental impacts are related to energy-related emissions • Percentage of total energy consumption: Pesticide production: 10-20 % Machinery manufacture: 7-12 % Fertiliser production: 5-11 %	Milà i Canals *et al.* (2006)
UK	Apples	• Transportation accounts for a considerable percentage of total energy consumption in the life cycle of fresh apples • Transportation in most cases exceeds the energy consumed in commercial apple cultivation • Development of local production and marketing systems can help reduce transport demand	Jones (2002)
Switzerland	Apples	• Apple production is represented by 37.6 GJ eq. ha^{-1} for energy use, 4.7 kg Zn eq. ha^{-1} for aquatic ecotoxicity and 1.0 kg PO_4 eq. ha^{-1} for aquatic eutrophication • Potatoes, sugar beet and carrots have similar energy consumption and aquatic ecotoxicity • Aquatic eutrophication caused by apple production is much lower than all arable crops because of low P-fertiliser needs • Area-related energy use is 50 % higher for apple growing compared to arable crop rotation • The key impact categories energy use, aquatic ecotoxicity and aquatic eutrophication can be managed by keeping the inputs of machinery, pesticides and fertilisers low	Mouron *et al.* (2006)
Sweden	Potatoes	• Agricultural production accounted for almost all the emissions contributing to eutrophication and acidification • Agricultural production, production of packaging materials and the household phase were the main contributors to global warming • Energy use was evenly distributed among life cycle stages	Mattsson & Wallen (2003)

Table 20 continued

Country of production	Product	Main findings	Reference
UK and Spain	Greenhouse tomatoes	• Importing tomatoes from Spain to the UK during the winter is more energy efficient than growing them in heated glasshouses in the UK	Defra (2005e)
Spain	Greenhouse tomatoes	• Main sources of environmental impact were: production and use of fertilisers and manufacture of greenhouse structures	Anton *et al.* (2004b)
Spain	Greenhouse tomatoes	• Main negative impact derives from the waste of biomass and plastics • Recommendations: Segregation of different wastes followed by composting of biodegradable matter Improving material composition of structures and auxiliary materials More rational management criteria for supply of nutrients	Anton *et al.* (2005a, b)
Spain	Greenhouse tomatoes	• Relative impacts of pest control depend on the selection of specific pesticides and crop stage development at the time of application • Both integrated pest management and chemical pest management could be improved by a careful selection of pesticides	Anton *et al.* (2004a)
The Netherlands	Greenhouse tomatoes	• Tomato production uses relatively more natural gas, fertilisers and rock wool than the greenhouse horticulture sector as a whole, but less electricity	Pluimers (2001)
The Netherlands	Greenhouse tomatoes	• Substrate cultivation with recirculation of the drainage water results in less environmental effects per kilogram of tomatoes than soil cultivation and free drainage • Reusing the drainage water leads to a lower emission of N and P and consequently to a much lower score for nitrification • The lower consumption of phosphate fertilizers in crops with recirculation results in much lower scores for toxicity to water and soil organisms • These conclusions are also valid for other fruit and vegetable crops grown on substrate • The energy consumption at the glasshouse holding of natural gas and electricity has a great share in the total environmental pressure	Nienhuis & de Vreede (1996)
UK	Sugar beet	• Mean impacts per ha: Consumption of 21.4 GJ of energy Emission of 1.4 equiv. t of CO_2 3.3 kg nitrogen leached 15.2 kg nitrogen lost to denitrification • Low ecotoxicity score	Tzilivakis *et al.* (2005)
Switzerland	Several arable crops	• Energy use dominated by mechanization, use of mineral fertilisers and grain drying • Eutrophication is mainly caused by nitrogen compounds Field emissions are of decisive importance for many environmental impacts	Nemecek & Erzinger (2005)

Table 21. Main findings of Foster *et al.* (2006) for basic carbohydrate food, fruit and vegetables.

Food group	LCA studies	Water and eutrophication impacts	Energy use impacts (Global Warming Potential GWP and acidification)	Non-CO_2 Global Warming Impacts	Processing impacts	Refrigeration and packaging impacts	Other impacts
Basic carbohydrates (bread, potatoes, rice, pasta)	Several for bread and potatoes, few for rice and pasta.	For bread and potatoes, the agricultural stage of the life cycle contributes most to eutrophication. Organic wheat production has higher impact than non-organic.	Energy use spread evenly over life cycles. Consumer stage very significant for potatoes/pasta. Organic wheat production has lower energy requirements than non-organic. Organic potato production has same energy requirements as non-organic.	N_2O emissions from soil account for approx. 80 % of total GWP for primary production of arable food commodities. This is almost independent of farming method.	Potato processing has high energy requirements. Data about bread-making impacts not conclusive.	Refrigerated storage post-harvest is relatively significant.	Land use is higher for organic than non-organic produce, but pesticides use lower.
Fruit and vegetables	Studies have been conducted on carrots, tomatoes, apples and peas. Coverage of themes and stages variable.	Water use is a significant issue for tomato production.	Energy requirements vary greatly, depending on growing methods and location.	Wide variation: for soil-grown produce, N_2O is very significant.	Can be considerable when foods are subject to major processing, e.g. tomatoes to ketchup.	Big differences depending on whether fresh, frozen, canned etc.; packaging impacts depend on degree of end-use recycling.	Land use is higher for organic than non-organic produce, but pesticide use is lower.

Table 22. Environmental impacts of potato production in the UK per kg. Source: Williams *et al.* (2006)

Environmental theme and units	Value
Energy used, MJ	1.3
Global Warming Potential, g 100 year CO_2 equivalent	215
Eutrophication potential, PO_4^{3-} equivalent	1.1
Acidification potential, g SO_2 equivalent	1.9
Pesticides used, dose ha	0.0005
Abiotic depletion, g Antimony equivalent	0.9
Land use (Grade B), ha	0.000022

2.10.1 Knowledge gaps relevant to Welsh horticulture

The following are areas of research and technology transfer which are particularly relevant to LCA in Welsh horticulture:

- Undertake a life cycle analysis from some typical Welsh horticultural products, e.g. early potatoes, daffodils, protected crops. Experience from the on-going Bangor RELU project suggests that when farmers and growers see the results of a Life Cycle Analysis of their enterprises they work to bring about improvements.
- Compare the results of the LCA of Welsh grown produce with similar produce imported from England, other EU countries and beyond.

Chapter 4 Enhancing 'local' production of horticultural produce in Wales: Social costs and benefits

4.1 Introduction

Food production systems have associated costs and benefits which can impact wider society. These can affect the well-being of society through direct impacts on individuals' finances, influences on regional economies, influences on health, ecosystem services and on the aesthetic and spiritual contributions of the environment.

The purpose of this chapter is to consider some of the wider impacts which may accrue from increasing horticultural production in Wales. The chapter is cast against the debate for and against 'local food' and will provide a particular focus on farm profitability, food security and employment. These themes are developed further in Chapter 5.

4.2 The advantages and disadvantages of producing food locally

4.2.1 Background

Changes in the UK food chain over the past fifty years mean that food now travels a greater distance from the point of production to the point of consumption than in previous years (Defra 2005e). The concept of "food miles"[1] has generated considerable interest among environmental groups, academic researchers, government agencies, the media and the general public. While many foodstuffs are highly perishable commodities, new transport and storage technologies allow produce to be shipped and air freighted around the world. Consequently, the former constraints of seasonality have largely been overcome, allowing consumers to purchase fresh produce throughout the year.

Enormous claims are made for the advantages to be derived from shortening the links between producers and consumers along the food chain, and strengthening local food economies. For example, it has been claimed that shortening the food chain will combat "global joblessness, the erosion of community, an acceleration in the depletion of natural resources, and breakdown of the environment" (Norberg-Hodge & Gorelick 2002). The benefits of more local production are also said to include absence of packaging, reduced use of fossil fuels, less pollution, and lowered amounts of greenhouse gases, as well as greater food diversity, security and enhanced social capital. There is also a general presumption that localness, quality, and nutritional value are positively correlated, although currently the science on this point is lacking.

These arguments are countered by those who believe that economic benefits are greatest where production costs are lower, and growing conditions more favourable, which for many fruits and vegetables means in the Mediterranean rim, Africa and

[1] The 'distances travelled by foodstuffs from farm gate to consumer', measured in ton-kilometres (Defra 2005e). However, many references to food miles are usually given as distance only.

Asia. It has also been suggested that consumers show a preference for cheap, standardised, and reliable supplies no matter how far away they are produced. Indeed, yet to be published results from an ongoing research project on local foods suggest that the majority of a representative sample of UK consumers rated the place of origin of vegetables very low on their priority list, while freshness and price were the most important features consumers desired in their vegetables (Bangor RELU unpublished data). So against this background it is clear that it is not a simple task to disaggregate the costs and benefits of local food, as discussed below.

4.2.2 What is 'local'?

One major problem in the debate over local food relates to the definition of 'local'. The Institute of Grocery Distribution (IGD) (2005a, 2005b and 2006) report that 22 % of respondents in their survey expected local food to be produced within 30 miles of where they live (IGD 2006, p.4). Other respondents extended their notion of local to country limits (e.g. England, Wales, Scotland or to Britain as a whole). Overall though, respondents considered county of origin to be the main criterion by which they judged food to be 'local'. The National Farmers Union and Defra tend to have a broader view than this and they tend to think of 'local' as meaning British food. However, much agri-food marketing within Wales has promoted the 'Welsh' brand, and for the purposes of this discussion, local will mean from within Wales.

4.2.3 Science and the local food debate

To date the local food debate has tended to focus on the distance food has travelled and the amount of greenhouse gases emitted during the transport stage of the food chain. However, the greenhouse gases emitted during transport are only part of the overall environmental impact of a food chain. As discussed in Chapter 2, greenhouse gases are also emitted from the soil during crop growth, during the production of inputs such as fertilisers and pesticides, during the generation of electricity which may be used to pump irrigation water and during storage, processing and cooking.

So in order to decide whether or not local food has a lower impact on climate change, or any other facet of the environment, it is necessary to compare the impacts of the entire food chain – from plough to plate. Currently there are very few (if any) such studies available in the literature (see discussion of LCAs in Chapter 2). For this reason there is very little scientific evidence which either supports, or refutes, the benefit of producing food locally.

However, these studies are now being undertaken by several research groups, and Bangor University currently leads an on-going research project entitled 'Comparative assessment of environmental, community and nutritional impacts of consuming fruit and vegetables produced locally and overseas' funded under the Rural Economy and Land Use (RELU) programme of the Research Councils (www.bangor.ac.uk/relu/). This project is explicitly concerned with comparing UK and overseas vegetable production. The work compares the production of five vegetable crops on farms in Lincolnshire, Herefordshire and Worcestershire and Anglesey, with production of the same crops on farms in Spain, Kenya and Uganda. Data are collected on direct greenhouse gas emissions, worker health, inputs and nutritional quality. These are then compared in a Life Cycle Analysis (LCA).

The Bangor RELU project is not yet complete, but preliminary results suggest that for potatoes produced and consumed in the UK, transport only accounts for about 18 % of total energy use in the plough-plate life cycle, while processing and cooking in the home accounts for 42 %. Similar results have been obtained for chicory. Here the greatest production of greenhouse gases occurs in the storage and forcing process. Shifting the distance chicory travelled by road from the minimum theoretical distance within the UK to the maximum theoretical distance within the UK increased the percentage greenhouse gas emissions associated with transport up from 12 % to 20 % of the total life cycle emissions. Similar results have been reported for the USA where transport has been estimated to be responsible for 11 % of total energy used in the food chain, as compared with home preparation which uses 26 %, and processing which uses 29 % (Singer & Mason 2006).

In addition, it should be noted that if the supply of local food requires an increase in small to medium sized processors, then this may affect the overall energy efficiency and levels of greenhouse gas emissions from the food chain. Indeed Schlich & Fleissner (2005) suggest that the energy efficiency of global food systems is enhanced by the increased size of producers and that this efficiency more than compensates for the increased energy consumption of the associated transportation. This general point is exemplified by Sundkvist *et al.* (2001) who studied bread production with locally sourced flour versus bread produced in other regions of Sweden, and concluded that the smaller scale of the local mills resulted in reduced energy efficiency.

There are also hypothesised social benefits derived from local food. For example, increased availability of local fruit and vegetables may serve to increase consumption, thereby bringing potential health benefits. Further, the development of ‘local food cultures’ may enhance the wealth of an area, *cf* Ludlow, and provide feelings of pride and social cohesion amongst citizens. However, the hard evidence supporting these assertions is also largely absent at this time.

The next section considers the level of financial benefit that may accrue to farmers in Wales, should they choose to adopt some level of horticultural production.

4.3 Farm profitability

Horticulture is one of the most profitable forms of food production. Gross margins of horticultural crops are normally significantly higher than those of arable crops (Table 29), which in turn are normally greater than those available from livestock production systems. For example, the gross margins of brassicas can be in excess of £ 2,000 ha^{-1} while lettuce can exceed £ 5,000 ha^{-1}. (NB These returns do not include any element of subsidy). The average net profit per farm in 2004/05 in England as a measure of farm business income after all actual costs and depreciation was: horticulture £ 30,700, cereals £ 29,800, Less Favoured Areas grazing livestock £ 15,900, lowland grazing livestock £ 8,900 (Defra 2007a).

However, in order to achieve these levels of return it is important that crops are of high quality and are presented to market in a timely fashion, often over an extended season. This requires considerable management skill and investment in suitable technology and machinery. For this reason many of the major horticultural suppliers in the UK are large businesses with high levels of integration between growing, packing and storage. Smaller growers can also receive considerable financial returns but these are normally associated with supply to small, well defined markets e.g. box schemes and farm shops.

There is no doubt that the presence of such profitable businesses in rural areas can make a major contribution to rural development. For this reason it may be advantageous to encourage an expansion of the area dedicated to horticulture in Wales. However, here are two major constraints on such a strategy – the availability of labour and land, and these are discussed in the next sections.

Table 29. Gross margins for horticultural and arable crops. Source: Nix (1999), Chadwick (2004, 2005), Lampkin *et al.* (2006)

	Gross margin conventional in £/ha	**Gross margin organic in £/ha**
Horticultural crops		
Potatoes		
early ware	1,180-2,972	2,540
Maincrop ware	1,317-1,941	2,186
Peas	839	
Field beans	-48-232	
Winter		364
Spring		379
Carrots		6,326
Ware	6,663	
small processing	2,352	
Lettuce	5,550 outdoor	
Little Gem		13,409
Cos		12,713
Cauliflower	2,475	2,014
Cabbage	2,016	
Savoy		6,112
summer pointed		584
red		3,250
white		2,085
Onions	2,275 dry bulb	1,387
Sprouts	3,100	
Broccoli	1,516	1,026
Apples		7,598
Tomatoes	19,665 £/unit	
Strawberries (fruiting)	4,647 £/ha field	10,034
Arable crops		
Wheat		
winter	256-614	505
spring	165-524	337
Barley		
winter	262-511	459
spring	159-448	417
Oats		
winter	238-590	378
spring	127-389	298
Triticale	95-429	481
Oilseed rape		
winter	128-398	
spring	89-251	

4.4 Could Wales meet its horticultural demands from local production?

4.4.1 Introduction

The UK operates in a world market for food, and there is no formal policy relating to target levels of self-sufficiency or consumption of 'local food'. However, there is a desire by some to increase the production of local food within the UK, and this concern is parallel to the arguments in favour of maintaining the capacity for home-based production, particularly in view of the threat of increased geo-political unrest which may impact world trade. Any analysis of self-sufficiency could be undertaken at a variety of scales. For example, an analysis at the UK level may be most appropriate for strategic analysis, but given the interest in local food and the 'Welsh' brand the following analysis considers the potential for self-sufficiency in fruit and vegetables at the all-Wales level.

This analysis proceeded in two stages. Stage 1 estimated current levels of consumption of fruit and vegetables in Wales (assessment of demand). Stage 2 then considered how much land would be needed to meet this level of demand. These are described in detail in the next sections.

4.4.2 Stage 1. Estimating the consumption of fruit and vegetables in Wales

Data on average weekly UK fruit and vegetable consumption was obtained from the 'National Diet and Nutrition Survey' carried between June 2000 and June 2001 (Henderson *et al.* 2002) (Table 30). The survey data are presented for four age groups: 19-24, 25-34, 35-49 and 50-64 for men and women separately. Because of a lack of survey data for consumers aged 65 and over, for the purpose of this study, it was assumed that eating habits of the over 65 years olds were the same as for ages 50-64.

The weekly amount of fruit and vegetables consumed was extrapolated to an annual basis in order to represent the total average consumption per year per age group. This amount was then multiplied by the population size in Wales as determined during the 2001 census in each age group (www.statswales.wales.gov.uk, Table 31) to give the total consumption in Wales by age group, and as a total for all adults (19 and over) (Table 32). This calculation did not include public sector consumption of fruit and vegetables. The 'National Diet and Nutrition Survey' age groups and the population size data age groups did not overlap for the youngest age group (nutrition survey: 19-24, census: 20-24), so that population size data for age 19 was obtained from a separate data set on the StatsWales website.

The diet and nutrition survey results showed no significant differences in fruit and vegetable consumption between regions across the UK and because of this it was justified to use overall UK consumption data for this study.

Table 30. Average weekly consumption of fruit and vegetables in g. Source: Henderson *et al.* (2002)

age group	19-24		25-34		35-49		50-64	
Gender	**Men**	**Women**	**Men**	**Women**	**Men**	**Women**	**Men**	**Women**
Carrots – all [a]	45	46	60	49	72	70	92	87
raw	5	11	9	8	9	12	13	8
not raw	40	35	51	41	63	58	79	79
Tomatoes – all [b]	61	87	128	139	142	152	192	170
raw	55	74	96	106	106	124	138	143
not raw	6	13	32	33	36	28	54	27
Other raw & salad vegetables [c]	78	102	121	158	137	176	150	162
Peas [d]	49	46	70	46	94	64	115	68
Green beans [e]	11	16	11	14	22	19	42	37
Leafy green vegetables [f]	30	41	46	55	76	82	121	126
Potatoes - all	864	768	777	599	811	635	849	670
potato chips [g]	455	327	319	217	289	180	233	152
other fried/roast potatoes&products [h]	92	72	95	60	94	76	111	78
potato products-not fried [i]	22	9	12	2	10	4	11	7
other potatoes&potato dishes [j]	295	360	351	320	418	375	494	433
Vegetable dishes [k]	48	101	112	182	116	147	72	87
Other vegetables [l]	101	98	171	166	196	176	247	199
Apples & pears [m]	76	113	158	183	242	188	296	294

[a] includes raw, not raw, fresh, frozen, canned
[b] includes raw, not raw, fried, grilled canned, sundried
[c] includes all types of raw vegetables, including coleslaw and fresh herbs, not salads made with cooked vegetables or potato salad
[d] not raw, includes canned, dried, mushy, frozen, mange tout, Pease pudding canned
[e] not raw, includes fresh, canned and frozen, French beans, runner beans, green beans
[f] not raw, includes fresh and frozen, broccoli, spinach, cabbage (all types), Brussels sprouts
[g] includes fresh and frozen, oven and microwave, French fries
[h] includes roast potato, fried sliced potato with or without batter, fried waffles, croquettes, crunchies, alphabites, fritters, hash browns
[i] includes croquettes, waffles, fritters, hash browns, alphabites, ketchips, grilled or oven baked
[j] includes boiled, mashed, baked (with or without fat), canned, potato salad, instant potato, potato based curries, cheese and potato pie
[k] not raw, includes curries, pulse dishes, casseroles and stews, pies, vegetable lasagne, cauliflower cheese, veggie burger, bubble and squeak, vegetable samosas, pancake rolls, ratatouille, vegetable fingers, etc.
[l] not raw, includes lentils, dried beans and pulses, mushrooms, onion, aubergine, parsnips, sweetcorn, peppers, mixed vegetables, TVP/soya mince, quorn, tofu
[m] not canned, includes raw, baked, stewed, (with or without sugar), dried, apple sauce

Table 31. Welsh population size data in 2001. Source: www.statswales.wales.gov.uk

Age	Men	Women
19	20,736	19,652
20-24	84,382	85,111
25-29	81,245	85,103
30-34	95,552	102,758
35-39	103,804	108,367
40-44	95,603	99,878
45-49	90,847	93,641
50-54	103,267	105,079
55-59	87,518	89,324
60-64	75,175	77,749
65-69	66,314	72,145
70-74	57,237	68,495
75-79	45,803	64,026
80-84	26,294	46,079
85-89	11,569	27,408
90-94	3,436	11,870
95-99	688	2,898
100 and over	106	406
All ages	1,403,782	1,499,303

4.4.3 Stage 2. Estimating the potential for Wales grown fruit and vegetables to meet demand

Long-term average yield data for fruit and vegetables in the UK were used to calculate the area needed to meet the total Welsh consumption of each crop. The area needed to supply Welsh consumption was then compared to the area currently used for the production of fruit and vegetables in Wales (Table 32).

For field vegetables, this analysis shows that the area currently grown within Wales represents about 10 % of the total area needed to meet Welsh consumption; while for apples and pears, this figure is 26.9 %. In contrast, in theory the consumption of potatoes can be fully met by current levels of production in Wales.

In Wales, there are 4,142 ha of Grade 1 and 39,347 ha of Grade 2 agricultural land (Table 33). In order to obtain maximum yields and minimum costs of production, field vegetables should ideally be grown on Grade 1 land. If we assume that all potatoes are grown on Grade 2 land, which is possible, then Welsh horticulture would need to utilise all current Grade 1 land, in addition to a further 820 ha of Grade 1 land, in order to achieve self-sufficiency in vegetables.

4.4.4 Future trends in consumption

Consumption of fruit and vegetables in the UK is increasing over time. In 2005/06, quantities of fruit and vegetables (excluding potatoes) purchased for the household were 7.7 % higher than in 2004/05, with a 12.9 % and 6.3 % increase in household expenditure on fruit and vegetables (excluding potatoes) respectively. The increase in purchase between 2004/05 and 2005/06 was 2.5 % for potatoes, 4.5 % for vegetables (except potatoes), 6.9 % for vegetable based ready meals, 10.6 % for fruit, 6.3 % for fresh fruit and 3.7 % for fresh apples (Defra 2007b). If this trend continues, Wales will have to increasingly rely on fruit and vegetable imports.

Table 32. Total consumption in Wales in tonnes per year, average yield in tonnes per hectare, area needed to meet Welsh consumption and area currently grown in Wales for horticultural crops. Data sources: Henderson *et al.* (2002), Basic Horticultural Statistics 2006 published by Defra (http://statistics.defra.gov.uk/esg/publications/bhs/2006/default.asp), StatsWales website (http://www.statswales.wales.gov.uk)

Food survey category	Crop	Consumption in t/year	Average yield in t/ha	ha needed to meet consumption		Area grown in Wales in ha in 2004
All potatoes	Potatoes	85,121	41.6	2,046		2,100
Peas	Peas	8,914	4.1	2,174		
Green beans	Green beans	3,155	7.7	410		
Raw + not raw carrots	Carrots	8,578	63.6	135		
Other raw & salad vegetables	Lettuce	17,002	24.3	700		
Other vegetables	Cauliflower Onions	22,045	13.6 33.3	940	4,962	500
Leafy green vegetables	Sprouts Broccoli Cabbage	10,520	13.3 9.0 30.0	603		
Raw + not raw tomatoes	Tomatoes	17,685	268	66		?
Apples and pears	Apples Pears	26,942	18.1 13.2	1,489		400

Table 33. Agricultural land classification (ALC): areas of grades in Wales. Grade 1: excellent, Grade 2: very good, Grade 3: good to moderate, Grade 4: poor, Grade 5: very poor. Source: Land and Water Service Technical Notes TN/RP/01 TFS 846 (February 1983)

Grade	% of agricultural land	% of total land	ha
Grade 1	0.2	0.2	4,142
Grade 2	2.3	1.9	39,347
Grade 3	17.5	14.6	302,350
Grade 4	44.2	36.8	762,087
Grade 5	35.8	29.8	617,125
Non agricultural		4.2	86,977
Urban		12.5	258,861
Total	100	100	2,070,888

4.4.5 Conclusion

The results of this analysis suggest that even if all suitable land was used for the production of vegetables and salad stuffs, the volumes produced would fail to meet current consumption. Given that there are significant health benefits associated with the consumption of fruit and vegetables, it is imperative that fresh produce enters Wales. Dogged adherence to a local food agenda would not enhance social well-being at the national level. This does not mean that individual producers should not seek to market their food as ‘local’ should this bring them financial benefits. Indeed any marketing activity that seeks to add value would seem to be in line with the agrifood strategy.

However, one constraint on producing high quality horticultural produce is an appropriately skilled labour force, and the issue of labour supply is discussed in the next section.

4.5 The supply of labour

4.5.1 Background

Despite increasing development of automation, many parts of the horticultural sector remain labour intensive. Manual labour is normally required during crop establishment (sowing, transplanting, weed control), crop growth (crop walking, pest and disease control, scheduling, irrigation, pruning) and for harvesting and packing. While these general tasks tend to be common across crops there is variation in labour demand between crops, for example carrot and root vegetable enterprises tend to have smaller labour demands than lettuce and mushroom enterprises (Napier *et al.* 2005).

Given its importance to the enterprise it is not surprising that labour constitutes a major cost to the business, comprising up to 40 % of production costs. This includes the direct cost of wages, and the additional costs of finding, training and supporting the labour force. It is these costs which drive the search for increased mechanisation and automation. However, the relatively small size of some sectors of the industry tends to restrict levels of investment in new machinery, and for this reason the demand for manual labour is likely to remain high for the foreseeable future.

Indeed the changing nature of UK horticulture may dictate even higher labour costs in the future. This may occur if demand for sustainable production increases and/or growers seek to undertake additional processing of produce in order to 'add value'. Tighter environmental legislation may also increase labour demand, particularly in relation to environmental management, responsible use of waste and pest control products (Promar International 2006).

Because the horticultural sector is relatively unattractive to UK workers, the UK horticulture sector is almost entirely dependent on migrant labour, with Eastern Europe currently being the primary source for recruitment. There are some concerns that the supply of labour from these countries may lessen over time as the migrants either decrease in number or choose to work in other sectors – but to date there is no evidence that this has occurred. The maintenance of labour supply is partly related to the Seasonal Agricultural Workers Scheme (SAWS) which is operated by the Home Office. Under SAWS students from outside the EU are allowed to come to the UK to undertake seasonal agricultural work between March and November (the 2007 quota was 16,250, *cf* a total of 64,100 temporary workers employed in agriculture and horticulture in England & Wales in 2005 (Defra 2006d)). These students have limited other wage earning opportunities, and hence are expected to continue working in UK horticulture.

While SAWS maintains labour flow, the seasonal nature of the horticultural labour force means that developing and maintaining skilled staff is difficult. For this reason there has been some effort invested into securing continuous employment for staff across the year, and so increasing the possibility that they would return to the horticulture sector the following year. For example, some schemes seek to 'share' staff between seasonal jobs, retail over Christmas and horticulture, and ornamental and food horticulture which have different seasons. To date these schemes are relatively limited in scope (Promar International 2006).

4.5.2 Costs and benefits

The dependence of large horticultural enterprises on migrant seasonal labour can bring costs to the workers themselves and to wider society. For example, seasonal workers may not have high levels of support and can be susceptible to problems of language, poor access to health care and violence (FAO-ILO-IUF 2005, Villarejo 2003). These issues may be exacerbated by poor rates of pay and low quality living accommodation.

Many of the larger horticultural enterprises tend to offer accommodation to their workers and the presence of large numbers of young, foreign workers can be felt by some residents to diminish the levels of social cohesion in rural areas. For example, the locals often treat the migrant workers with suspicion and perceive them as a threat and drain of resources. These perceptions are not helped by the general desire of the migrant workers to minimise their expenditure in the local community, seeking rather to save their wages for their return home.

4.5.3 Discussion

The availability of a skilled and committed workforce can be a constraint on the development of horticultural enterprises. The seasonal nature of the work inevitably leads to the employment of migrant workers. Although the influx of a large number of young workers could potentially bring many benefits to rural areas, to date these benefits remain largely unmeasured. Some of the constraints on maximizing the benefits relate to language difficulties, lack of transport from the farms to towns and villages, a general reticence to spend money in the UK and poor mental and physical health amongst workers (Cross *et al.* unpubl.).

4.6 Conclusions and recommendations

It is clear that horticulture is a potentially a very profitable land use. Its level of profitability is affected by the quality of the land, the availability of good labour at reasonable costs and access to markets.

The current land resource offers considerable potential to increase the amount of vegetable production which occurs in Wales. However, even if all Grade 1 land were utilised for vegetable production, it is unlikely that Wales could be self-sufficient in vegetables.

There are opportunities for marketing Welsh fruit and vegetables as ‘local’ food. While this may bring business benefits, currently there is no clear scientific evidence suggesting that ‘local’ food is always environmentally beneficial. The level of environmental damage caused by ‘local’ and ‘non-local’ food will vary with the crops and the source of the ‘non-local’ food. Clearly though, should consumers and/or the public sector preferentially purchase Welsh produced fruit and vegetables then this will have a benefit to the Welsh economy.

From a public health perspective it is clear that significant health benefits arise from increased consumption of fruit and vegetables, regardless of where they are grown. For this reason it is important that marketing messages promoting local 'Welsh' produce do not serve to confuse or counter the principle public health message.

The availability of labour can be a constraint on horticultural businesses, and at the moment most labour is supplied by non-UK nationals. There is a need to develop a continuity of labour supply, and if Welsh businesses are to prosper in the future then it may be advantageous to promote the horticultural industry as a career path.

The existence of large 'camps' of seasonal migrant workers can in theory bring costs to a local community, although hard evidence on this area is currently absent.

Recommendations

- Communicate the importance of the limited amount of Grade 1 land within the Welsh Assembly Government and to local authority planning agencies, so that the productive value of this land can be considered as part of any development plan.
- Evaluate the social costs and benefits of hosting seasonal migrant workers in the countryside. Issues for consideration may include impact on the local economy and on the local health and social services.
- Develop / support schemes which supply continuity of employment for rural people who may wish to engage in seasonal horticultural work.
- Promote the opportunities for career development offered by the horticultural industry.

Chapter 5 Drivers, summary and overall recommendations

5.1 Drivers for change in Welsh horticulture

There are four main drivers for change in horticultural production in Wales:

- The public health agenda
- The desire for ‘local’ food
- Continued reform of the Common Agricultural Policy
- Climate change

Each of these is discussed in turn below.

5.1.1 The public health agenda

There are clear health benefits from consuming at least five portions of fruit and vegetables a day. This message is continually being communicated to the general public, and is now being engrained into schools in Wales, e.g. the ‘Healthy schools’ initiative. This is one of the reasons why consumption of fruit and vegetables has increased in recent years. However, the increase has largely occurred in middle income households, and there is still considerable potential for increased consumption in low income households. If the public health message continues to be communicated effectively to everyone in society, then we should expect consumption of fruit and vegetables to continue to increase for the foreseeable future.

5.1.2 The desire for ‘local’ food

There is increasing demand for ‘local’ food which currently does not show any sign of abating. Indeed in response to this demand at least two major retailers in Wales are seeking to provide more ‘local’ vegetables in their stores and are currently commissioning new growers in Wales. If there is real market demand for local food then we should expect further initiatives like this from retailers and others in the food chain. This in turn should stimulate production. However, many consumers will buy on price, and so while some middle income households may be willing to pay a premium for local produce, others may not be so willing to do so. Thus the stimulus for increased production will be related to the costs of production. If Welsh producers can offer local produce at a cost which is acceptable to the majority of producers, then we may expect to see increased levels of production. Should this not be the case, then, as the majority of consumers will inevitably buy on price, the market led stimulus will be weaker.

5.1.3 Continued reform of the Common Agricultural Policy

The move to the Single Farm Payment (SFP) in Wales has not yet fully decoupled production from the subsidy regime. So currently farmers who wish to change land use from beef to vegetables would lose their single farm payment. It can be argued that given that the SFP is relatively small in relation to the financial returns available from vegetables then this small policy detail is not important. However, it can also be argued that it is important simply because it serves to act as a barrier to innovation. Many farmers are risk averse and the loss of the SFP may be sufficient to restrict any changes in their enterprise mix.

While this issue may have been important in the first few years of the reform, in the long term it will not be important. This is because in the long term all production related subsidies are expected to disappear, and any support will solely be related to the provision of public goods, e.g. biodiversity, water, landscape. When this occurs financially rational farmers will seek to maximise their incomes from production related activities. Given the relatively high levels of return to horticulture, compared to other land uses, we may expect to see those farmers who control appropriate land to switch to horticultural enterprises.

5.1.4 Climate change

As discussed in Chapter 3, the future climate of Wales will become more favourable for horticulture, while that of current regions which produce vegetables may become less favourable. The availability of sufficient water for irrigation will become particularly important in the future, and in this regard Wales will be less affected by climate change than many other countries, including England. For this reason we may expect the production of field vegetables to shift to areas of suitable climate and water availability.

However, ultimately the location of any industry is determined by the market. So while the future climate of Wales may be more suitable for fruit and vegetable production, the amount of suitable land is limited and to some extent fragmented. This may reduce the attractiveness of Wales as an area suitable for major investment in infrastructure, e.g. stores and packing houses. Similarly, the availability of suitably skilled and priced labour may also impact significant investment in the sector.

So in summary, the climate of Wales may become absolutely and relatively more attractive as a place to produce fruit and vegetables. However, the location of major horticultural investments will depend on market returns, and currently it is not possible to understand the power of these market forces very far into the future, and certainly not as far as 2020 and beyond.

5.2 Integrating the drivers and the way forward

Pulling these four drivers together suggests that there will probably be an increase in the potential for horticulture in Wales. In the short term this will be driven by the market (demand for healthy produce and local produce), and aided by continued reform of the CAP. In the long term the combination of the market pull, the reformed policy environment and a relatively favourable climate should enable significantly greater levels of horticultural production within Wales.

If the potential for increased levels of horticultural production is accepted, then the task now within Wales is to develop a horticulture which will enhance both the rural communities and the environment. While an increased level of horticultural production should enhance farmers' incomes and local economies there are also several potential negative impacts. These relate particularly to the environmental impact of horticulture, where there are some knowledge gaps, and also to social issues, particularly surrounding the supply of labour. An assessment of these impacts, including knowledge gaps, is summarised in Table 34, and a list of the overall recommendations made throughout this document is presented below:

5.3 Overall recommendations

5.3.1 Horticulture and pollution

- Consider how best to reduce nitrogen leaching from field vegetables, particularly potatoes?
- Understand the type and amount of pesticide used in Welsh horticulture. This could be achieved by stratifying the existing Pesticide Usage Survey into England and Wales. This may require a slightly greater sampling effort to be targeted on Welsh farms than currently, but it would offer a unique dataset.
- Continue to research alternative means of managing diseases in potatoes.
- Research and develop relevant pest management techniques for the growing number of fruit and vine growers in Wales.

5.3.2 Horticulture and natural resources

- Communicate and demonstrate best practice for reducing soil erosion in horticulture, especially in potatoes.
- Develop and demonstrate best practice in field irrigation methods. This will be necessary under a changed climate, but is an area where current levels of awareness are low.
- Develop and demonstrate on-farm reservoirs for supplying irrigation water for horticulture (and other crops, including grass).
- Communicate the options for increasing energy efficiency in horticultural systems, and demonstrate the best methods for reducing energy use.
- Develop demonstration glasshouses in conjunction with a combined heat and power biomass plant (or equivalent).
- Develop supply systems which minimise the need for storage.
- Continue to develop sustainable alternatives to peat, paying particular attention to achieving a consistent product which would be suitable for commercial use.
- Communicate the importance of the limited amount of Grade 1 land within the Welsh Assembly Government and to local authority planning agencies, so that the productive value of this land can be considered as part of any development plan.

5.3.3 Horticulture and climate change

- Understand the patterns of greenhouse gas emissions from field and protected cropping.
- Develop management systems for minimising greenhouse gas emissions in horticultural systems, particularly potatoes and protected cropping.

- Research and develop a ‘low carbon’ horticultural system.
- Undertake a life cycle analysis from some typical Welsh horticultural products, e.g. early potatoes, daffodils, protected crops.
- Compare the results of the LCA of Welsh grown produce with similar produce imported from England, other EU countries and beyond.

5.3.4 Horticulture and Catchment Sensitive Farming

- Consider how to incorporate horticulture into Catchment Sensitive Farming, which is currently designed to reduce pollution from livestock systems?
- Understand the risk of water pollution from fertiliser use which may contravene standards set in the Water Framework Directive from horticulture. A first step may be to consider the water quality in the areas which currently support horticultural enterprises, e.g. Pembrokeshire, Flintshire, Llyn Peninsula and Monmouthshire.
- Understand the risk of water pollution from pesticide use which may contravene standards set in the Water Framework Directive from horticulture. Understand the risk of soil erosion which may contribute to contravention of standards set in the Water Framework Directive from horticulture.

5.3.5 Horticulture and waste

- Demonstrate the use of photo- and biodegradable horticultural films.
- Enhance the opportunities to recycle wastes from horticultural systems.

5.3.6 Horticulture and biodiversity

- Develop and evaluate techniques for enhancing in-field biodiversity in field horticulture, *cf* beetle banks in arable crops, field boundaries, strip cropping.
- Evaluate the role horticulture can play in terms of enhancing biodiversity at the landscape level.

5.3.7 Horticulture and social issues

- Evaluate the social costs and benefits of hosting seasonal migrant workers in the countryside. Issues for consideration may include impact on the local economy and on the local health and social services.
- Develop / support schemes which supply continuity of employment for rural people who may wish to engage in seasonal horticultural work.
- Promote the opportunities for career development offered by the horticultural industry.
- Compare the local / regional economic impacts of horticultural enterprises with other land uses.

Table 34. Social costs of horticultural food production in Wales. • = low, ● = medium, ⬤ = high, ○ = no impact, ? = impact unknown.

	potatoes	legumes	Brassicas	salad crops	apples	soft fruit	protected cropping
Environmental impact							
Pollution hazard							
Fertilisers:							
Application rate	⬤	•	⬤	●	•	•	•
Air	⬤	•	?	?	?	?	•
Water	⬤	⬤	⬤	⬤	?	?	●
Pesticides:							
Air	⬤	?	?	●	⬤	●	?
Water	⬤	?	?	?	?	?	?
Soil	⬤	?	?	?	?	?	?
Wildlife	?	?	?	?	?	?	?
Food chain	•	?	?	?	?	?	?
Resource use							
Direct energy use	⬤	●	●	●	•	?	⬤
Total energy use (incl. storage)	⬤	?	⬤	?	⬤	?	⬤
Water use/irrigation	⬤	○	○	?	○	?	?
Peat	○	○	•	•	○	?	⬤
Soil erosion	●	•	⬤	?	●	●	•

Table 34 continued

	potatoes	legumes	Brassicas	salad crops	apples	soft fruit	protected cropping
Effect on in-field biodiversity	⬤	●	⬤	⬤	●	⬤	?
Landscape impact							
Polytunnels	○	○	○	●	○	⬤	⬤
Glasshouses	○	○	○	•	○	○	⬤
Mulching	•	○	○	?	○	⬤	○
Frost fleeces	•	○	•	●	○	?	○
Homogenous landscape structure (large fields, indistinct field boundaries)	●	•	•	?	○	○	○
Plastic waste/litter	●	○	?	●	?	●	⬤
Social impact							
Frequency of migrant workers	•	•	•	●	?	●	⬤
Low paid work	?	?	?	●	●	●	●
Impact on farm worker health	?	?	?	●	●	?	?

NB These are indications only and would require more research to become more accurate. Actual impacts depend on the extent to which growers use good practice, adhere to manufacturers' instructions and abide by regulatory codes.

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