Review

Building the Evidence Base: Potatoes a Low Impact Food Crop?

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Layperson's summary

Sustainability

Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In the context of agriculture, the challenge is to increase food production to feed a growing world population whilst being constrained by a finite land area. This must be achieved alongside other uses of land and water for industrial and residential developments, conservation of biodiversity, leisure, growth of crops for non-food uses, and extraction of materials and minerals.

Crops have requirements for productive soil, water and a suitable climate to produce reliable yields. However, within these requirements crop species differ in their needs for land and input materials (e.g. fertilisers) and the size of yields that may be expected. Generally, yield is important in understanding a crops impact because the greater the level of production per unit of land the less environmental impact per unit of production there is. By considering inputs associated with different crops and the yields produced in a given geographic location it is possible to estimate the impact of each crop and in so doing make comparisons between crop species and locations.

Potato production and consumption in Great Britain

Potatoes are an important crop both nationally and internationally, representing globally the sixth largest food commodity and rank behind only maize, rice and wheat as a staple food crop. The UK is the 12th largest potato producer with production of around six million metric tonnes in 2008. Potatoes are grown on approximately 126,887 hectares in Great Britain, which represents almost 3.2% of the total area of arable crops and 0.8% of the total land area in agriculture. Potatoes are grown mainly in Eastern England and Yorkshire (52%), with smaller areas grown in the West Midlands, Lancashire and the South West. A significant area of potatoes (22%) is grown in Scotland of which 40% are seed potatoes, making Scotland the centre for seed potatoes grown in Great Britain.

As a food product, potatoes are typically 80% water and 20% dry matter. Potatoes are an important source of carbohydrates, vitamins (C, B1 and B6), folate, iron and potassium, while being very low in fat. Approximately 93 kg of potatoes were eaten per person in Great Britain in 2007, which ranks the country as the 17th biggest consumer per person internationally.

How does the production of potatoes compare with other food crops in terms of:

Water use

Potato crops grown in Great Britain typically have a water requirement per hectare that is 22% less than wheat and 18% less than barley and is comparable with field vegetable crops such as carrots. The lower water requirement of potatoes compared to cereal crops is in part because the potato crop uses the land for a shorter period of time. Potato crops also yield approximately 40 tonnes per hectare compared with wheat at approximately 8 tonnes per hectare. As a result, the volume of water used to produce every tonne of potatoes is much less than that required to produce a tonne of cereals.

However, unlike cereal crops, the potato crops demand for water is greatest during the warmer and drier summer months when availability is limited. As a consequence, potatoes continue to be the dominant outdoor crop category in terms of additional water required through irrigation. In England and Wales, potatoes accounted for 43% of the total irrigated area and 56% of the total water used to irrigate crops in 2005. A significant proportion of this irrigation is applied to potato crops grown in Eastern England, which is an area of the country where water resources are under pressure during dry summers.

To date, few growers have moved away from overhead spray irrigation to more water efficient systems such as trickle or drip irrigation applied directly to the soil surface. However, there has been a gradual increase in the proportion of growers using planning methods (scheduling) and soil moisture measurements to ensure that water is not wasted. The increased use of winter storage reservoirs by growers over the last 20 years has reduced the impact of crop irrigation on river flows during the summer months.

In addition to irrigation, potatoes are washed prior to sale or processing, albeit this uses less than 0.5% of the amount used for crop irrigation. Also, other vegetable crops require more than seven times the volume used for potatoes to wash the equivalent weight of produce. New technologies have the potential to reduce water usage for potato washing by as much as 85%.

Land use

Expanding agricultural land (e.g. converting forest to crop land) can increase greenhouse gas emissions and lead to the loss of biodiversity. Maintaining and increasing the yield of crops grown on existing agricultural land decreases pressure to convert more land to agricultural use thus avoiding these problems. Over the last 20 years, average potato yields have increased by 7 tonnes per hectare (calculated using a three year average to decrease the effect of seasonal yield variation), equivalent to a rise of 18%. This increase in yield has meant that the area of land required to produce every 1,000 tonnes of potatoes has decreased by four hectares.

There are indications that fresh potatoes imported to the UK, require relatively more land than is required to grow potatoes producing the same yield in the UK, based on national average yields. The additional land used to grow imported potatoes may be as much as 1,000 hectares in total.

It is possible to compare land use for potatoes with land use for other crops by considering the area required to grow a tonne of dry weight or the area required to produce food of the same energy content. By both measures, when potatoes are compared with wheat, rice and carrots, the land area requirement of potatoes is the lowest.

Pollution of the environment

Diffuse pollution from agricultural land occurs when nutrients in the soil, pesticides, sediment (soil particles) and pathogens (e.g. *Cryptosporidia spp)* are washed from the land and into watercourses or underground aquifers. The potato crop typically receives large inputs of the plant fertilisers, nitrogen (N), phosphate (P_2O_5) and potash (K_2O) both as manufactured product and that supplied in organic manures. Further inputs of pesticides are made in order to prevent or limit crop losses associated with diseases, most notably potato blight, weeds and pests, including aphids that can transmit plant viruses. With these inputs together with land management practices, including cultivation and irrigation, mean that there is significant potential for pollution associated with growing potatoes.

The winter before planting spring crops such as potatoes is a relatively high risk period for losses of nutrients and sediments, as the ground is often left bare and uncropped. The practice of planting a crop during the winter period to soak up nutrients and prevent soil eroding from fields is not common in the UK but is more widely used in some mainland European countries. Relatively larger amounts of nitrogen may also be at risk of being lost as a result the intense cultivation used to prepare land for potato crops compared to crops grown in land prepared using less cultivation. Compared to other crops, losses of nutrients and sediment after harvesting potatoes have the potential to be relatively high, due to high soil nitrogen levels, late harvesting when soils may be moist and soil compaction due to use of agricultural machinery. Data from England suggest that concentrations of nitrate in water leaching from land after potatoes are higher than after cereals, sugar beet or oilseed rape.

Nitrous oxide accounts for around 5.5% of total UK greenhouse gas emissions. It is currently estimated that 75% of nitrous oxide (a gas with a global warming potential that is 310 times greater than carbon dioxide) is produced from agriculture. Of the nitrous oxide produced from agriculture, approximately 60% is produced directly from agricultural soils. The husbandry factors that are associated with high nitrous oxide emission include high rates of nitrogen fertiliser, either as manure of manufactured product. Typically, emissions of nitrous oxide from potato crops are higher than from small-grain cereals or oilseed rape crops.

Compared with cereal crops, the higher total number of pesticide applications made to potato crops is largely due to the regular use of fungicides for the control potato blight. However, it is widely accepted that quantity of use if not a reflection of impact. The potential environmental impacts of pesticides are assessed as part of product approvals, and they have to meet high standards before they can be used by growers. This process considers effects on the environment and in soils and water. The pesticides used on potatoes are generally not those detected in water, apart from metaldehyde, which is used to control slugs in many crops as well as potatoes.

Carbon footprint and energy

A carbon footprint is a way of expressing an impact on global warming in standard units of carbon dioxide equivalents (CO_2e). Important greenhouse gases emitted during the production of potatoes are carbon dioxide, nitrous oxide (see above) and some gases used in cold store refrigerator units.

The carbon footprint of growing potatoes varies depending on the potato growing system, and is dependent on many factors including: crop yield, efficiency of energy use, efficiency of fertiliser use, period of storage, the temperature at which the crop is stored, which in turn is related to the market outlet, and the need for transport. Use of pesticides (e.g. fungicides to control potato blight) helps to decrease the carbon footprint because it prevents yield loss due to pests and diseases, and so minimises emissions per kg of potatoes grown.

Most crops have lower carbon footprints than most meat products. Crops that are high yielding, such as potatoes, tend to have lower carbon footprints than those that produce lower yields. The carbon footprint of potatoes per kg or tonne of production is, therefore, smaller than that of wheat grain, but when the carbon footprints are corrected for water or energy content, the carbon footprint of potatoes is greater than that of wheat grain.

Biodiversity

Biodiversity is the variety of life, including genetic diversity. Within arable crops, biodiversity is strongly dependent on the weed flora. While relatively few studies have focused on potato crops specifically, it has been shown that weed cover is lower in potatoes than in other crops due to frequent disturbance and the dense crop canopy. Root crops generally also have lower weed species richness than cereals. However, spring cropping and mixed farming practices are potentially beneficial to biodiversity. With most cereals and oilseed rape crops now sown in the autumn, potato crops remain a significant area of spring cropping. Potatoes might therefore provide additional resources for biodiversity at a landscape level.

The potato crop itself has recently been shown to provide suitable breeding sites for the endangered yellow wagtail. Bumblebees, which have also shown recent declines in numbers across Europe, may benefit from the pollen source provided by flowering potato crops. However, the greatest benefit to biodiversity is likely to come from non-cropped areas associated with potato crops that are managed to provide environmental benefit.

Waste

Increasing the amount of saleable crop can be achieved either by increasing crop yield or by decreasing the proportion of the crop lost to waste. Currently, significant amounts of potatoes are lost throughout the supply chain. Potatoes used for stock feed and other losses are currently estimated to be 24% of the total home-grown supply. Losses may be due to disease, grading both on the farm and at the factory as well as deterioration during storage.

Typically potato losses are sold as animal feed with relatively little ploughed back into the soil. Recently alternative options for using waste potatoes have become available; these include use as a feedstock for anaerobic digesters as well as starch-based biodegradable packaging. Anaerobic digesters provide a useful means of treating waste, generating renewable energy and with careful management may provide a partial replacement for artificial fertilisers. Government assistance is available to stimulate development of anaerobic digesters, with grants for capital expenditure. However, while this can be an attractive option, anaerobic digesters require a high level of management in order to maintain performance.

Comparison of GB potato production with other countries

Key factors affecting the environmental impacts of potato production and delivery to a distribution centre are crop yield, the need for refrigerated storage, and transport distance. The impact of water use is an important environmental consideration that varies greatly between places of production. To assess the impact of water use, it is first necessary to quantify all the freshwater used in the production of a crop at all steps of the product or business supply chain. From this it is possible to calculate the indirect and direct water usage. Together, this is referred to as ‘virtual’ or ‘embedded’ water, which may be used to calculate a water footprint.

For potatoes produced in the UK the virtual water content is 74 cubic metres of water per tonne of potatoes, which is lower than for any nations that are major exporters of potatoes to the UK, and 29% of the global average value of 255 cubic metres of water per tonne of potatoes.

Water is also less scarce in the UK than in all the nations that are major exporters of potatoes to the UK except the Netherlands. However, it was not possible within this study to take account of regional differences in scarcity of water within nations, in relation to the regional distribution of production for export to the UK.

How is the GB potato industry working towards more sustainable production?

Valuing the environment

Environmental Stewardship schemes were introduced in 2005. Currently 69% of the utilisable agricultural area in England is in an Environmental Stewardship scheme. A comparable Rural Stewardship scheme was introduced for Scotland and similarly seeks to encourage farmers to manage land to benefit wildlife and habitats. Data extracted from the ADAS Farmers’ Voice survey suggests that farms on which potatoes are grown have high levels (75-80%) of involvement in agri-environment schemes. This level of involvement compares favourably with levels of involvement by livestock farms (31-73%) or horticulture (43%) and is comparable with cereal farms (81-82%).

In the survey, 81%, of those farmers that grew potatoes in the 2008 confirmed that they contributed to Government funded schemes designed to enhance the environment.

Reducing fertiliser use

Between 1983 and 2006 there have been large reductions in fertiliser use on maincrop potatoes. Nitrogen fertiliser use has been reduced by 29%, phosphate fertiliser use by 40% and potash fertiliser use by 33%.

Further reductions may be achieved by taking full account of the nutrients supplied to the crop in organic manures. Adjusting fertiliser rates to take account of the length of the season, soil conditions, pest and disease levels, are likely to reduce fertiliser applications still further

Potato store efficiency

Improvement of store efficiency has formed a key part of wider sustainability initiatives developed by major potato packers, retailers and food processors. These initiatives have identified the importance of storage in terms of the crop's overall carbon footprint. Tesco, for example, have estimated that storage accounts for over 50% of the total carbon footprint of late-stored crops. Storage improvements have not been restricted to energy use and have also seen companies working to improve crop quality, for example through more use of positive ventilation, or removing the use of chemicals applied to suppress sprouting in storage.

The conditions under which potatoes have previously been stored are coming under increasing challenge. In the fresh sector the drive to keep blemish disease and sprouting suppressed has led to high energy demands. Raising temperatures would reduce the energy demand but would increase the need to control sprouting. For processed potatoes, which are typically stored at warm temperatures, there are concerns relating to the risk of acrylamide developing in storage.

At present there is no significant direct use of renewable energy by potato stores. However, there are examples of storage complexes have been recently built that have featured wind turbine generation linked to the National Grid. These examples include the anaerobic digestor constructed by McCain at its Whittlesey French fry factory, which uses wastewater from the potato chip plant to produce 1.2 megawatts of electricity (about one-tenth of the energy the plant uses). Other examples include the anaerobic digesters built by Branston Ltd, the potato buyer, packer and distributor, and Worth Farms. These systems use potatoes, which are not saleable, to generate 40% of Branston's and 66% of Worth Farms' site electricity needs.

Social & economic

On a per hectare basis, the financial value of potato production is five times higher than wheat or oilseed rape and second only to vegetables (including protected crops). Gross margins for maincrop potatoes are similarly almost six times higher than for wheat crops and almost 11 times higher than for oilseed rape crops. These figures are reflected in the size of the contribution that potato crops make to the gross margins of general cropping farms despite the relatively small percentage of the total area of potato crops. This can be significant for the viability of smaller family farms.

Potato crops are also more intensive in terms of labour use – average labour hours per hectare are eight times higher for maincrop potatoes than for winter cereals - and therefore potato production makes an important contribution to the rural economy.

The potato industry supply chain is very efficient with a large portion of the UK crop grown on contract to an agreed specification. Therefore, potato processing makes a valuable contribution to the wider economy.

Contents

1. Introduction

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

World Commission on Environment and Development (1987)

Sustainable development for agriculture requires sufficient production to meet the needs of a growing world population using a finite land area. This is made more challenging by the competing requirements for land from industrial and residential development, conservation of biodiversity, leisure, and other uses of land such as production of fibres, and building materials and mined materials (Wiltshire & Sylvester-Bradley, in press). To meet future needs there must be enough land, a suitable climate, enough water to supply crops and livestock, soils that are sufficiently productive, and technologies that ensure sufficient and reliable yields.

Against this background, there is a consensus view that global warming will reduce the productivity of Mediterranean and tropical climates. These changes will place a greater production burden on areas, such as the UK, that have a temperate climate.

The impact of a crop is related to the inputs required for crop growth and harvest. These inputs will differ between crop species as well as between the different geographic areas in which the same crop is grown. Ultimately, however the impact of a crop is reduced through increased productivity because a greater level of production per unit of land and per unit of inputs (such as fertilisers and fuel) leads to less environmental impact per unit of production.

In this context the following report summarises available evidence and expert opinion on the impact of potatoes as a food crop. The report considers how production compares with other food crops grown in Great Britain in terms of water use, land use, pollution, carbon / energy use, biodiversity and waste. Comparisons are also made between potato production in Great Britain and production in other countries. Examples are provided of the potato industry in Great Britain working to improve the sustainability of production through environmental stewardship, reducing fertiliser use, reducing waste, improving the efficiency of stores, and exploiting alternative forms of energy including potato waste. Finally the report considers the social and economic contribution that the potato industry makes to the country.

References

Wiltshire, J. & Sylvester-Bradley, R. (in press) Engagement of suppliers in management of carbon emissions will enhance food security. Environment Industry Magazine.

World Commission on Environment and Development (WCED), (1987) *Our common future.* Oxford: Oxford University Press.

2. Objectives and Methodology

This report drew on published international and UK research studies as well reports produced by government and non-government organisations (including Potato Council and commercial groups) organisations and expert opinion. These sources of information were brought together to present a consensus view of the impact on the environment of potatoes grown in the UK and steps being taken to minimise or mitigate these effects. The report also considers the social impacts of potato production.

3. How production of potatoes compares with other food crops:

3.1. Water use

Irrigated area and water use for potatoes compared with other outdoor irrigated crops

The Defra commissioned Survey of Irrigation of Outdoor Crop in 2005 for England and Wales (Weatherhead, 2007), recorded an area of 116,272 ha to have received irrigation in England. This land was irrigated with 92,883 thousand cubic metres of water; equivalent to approximately 800 cubic metres of water for every hectare of irrigated land. By comparison, the area of land irrigated and volumes of water applied in Wales were small (1,023 ha of land irrigated with 557 thousand cubic metres of water; equivalent to approximately 550 cubic metres of water for every hectare irrigated).

Based on the 2005 survey data for England, maincrop potatoes were by far the largest crop category in terms of area of land irrigated (43,140 ha) and volume of water applied (45,637 thousand cubic metres). A far smaller area of early potatoes were irrigated (6,415 ha) with a correspondingly lower volume of water (6,433 thousand cubic metres). Seed crops are generally not irrigated. It is worth noting that the rate of irrigation to potato crops was also higher, at approximately 1,000 cubic metres per hectare irrigated, compared with the average for all irrigated crops (see above). Combining maincrop and early varieties, potatoes in England, accounted for 43% of the irrigated area and 56% of the water use (Table 3.1.1).

Table 3.1.1. Percentage of total irrigated area and irrigation water use in England by crop category (Data from Weatherhead 2007). NB: error introduced from rounding up or down of values.

Crop category	Irrigated area (%)	Water use (%)
Early potatoes (before 31st July)	6	7
Maincrop potatoes (after 31st July)	37	49
Sugar beet	7	4
Vegetables	28	27
Small fruit (soft fruit)	2	3
Orchard fruit	1	1
Grass	3	2
Cereals	9	3
Other outdoor crops and trees	6	5

Trends in the irrigation of potatoes and other crops

Defra (and previously MAFF) have collected data on irrigation through 'Surveys of Irrigation of Outdoor Crops'. These data provide information on current use of irrigation in England and Wales and point to trends over recent years. This trend data has been analysed (Weatherhead, 2007) taking into account annual weather variation and irrigation need (Table 3.1.2). Overall, the analysis of data from 1982 to 2005 suggests that the rate of increase in total area irrigated and total water use grew less strongly than during the period 1982 to 2001. Indeed, while strong growth was seen both for maincrop potatoes and vegetables, declines were seen for other sectors, including sugar beet and orchard fruit. Totals for all crop sectors also indicate that the volume of water being applied is growing faster (2.1% pa) than the area irrigated (0.9%). This trend indicates that increasing depths of irrigation are being applied.

Table 3.1.2. Underlying linear growth rates (% per annum) in irrigated areas, volume of water applied and average depths, for maincrop types and in total, for 1982-2005, after allowing for annual weather variation (Source: Weatherhead, 2007).

Linear growth trends, 1982-2005			
Crop category	**Area**	**Volume**	**Depth**
Early potatoes (before 31st July)	0.3%	2.1%	2.1%
Maincrop potatoes (after 31st July)	3.0%	3.5%	1.6%
Sugar beet	-1.6%	-1.2%	-0.2%
Vegetables	3.0%	3.9%	2.0%
Small fruit (soft fruit)	0.3%	2.6%	2.4%
Orchard fruit	-2.5%	-2.7%	-0.5%
Grass	-7.1%	-4.8%	0.3%
Cereals	-2.4%	-2.9%	-0.8%
Other outdoor crops and trees	Not analysed		
Totals (overall)	0.9%	2.1%	1.7%

Comparing the 2005 survey with the previous survey completed in 2001, shows both a reduction in the irrigated area and volume of water applied for almost all crops. Overall, the irrigated area fell by 30,998 ha and water used by 38,417 thousand cubic metres. The irrigated area of maincrop potatoes fell by 26,680 ha and the volume of water used by 24,303 thousand cubic metres. As the dominant outdoor irrigated crop sector, it can be seen that maincrop potatoes accounted for 86% of the total fall in irrigated area and 63% of the total fall in water used.

As mentioned previously, it is important to interpret irrigation data in relation to the weather in each year. This is because summer rainfall and evapo-transpiration directly influence the areas irrigated and volume of water applied (Weatherhead, 2007). It is possible, using the WASIM model (Hess and Counsell, 2000) to model the irrigation needs of major irrigated crops. Using this model and data from Silsoe, Bedforshire, it can be seen that 2001 was a wet year. By comparison, the 2005 value also fell in the lower (wetter) quartile and was only very slightly drier than 2001 (Weatherhead, 2007). Therefore, the reduction in total irrigated area and volume of water used between 2001 and 2005 does not appear to be explained by weather differences in these years, although this data does not allow for seasonal variation.

In contrast to the weather, crop areas may be important in at least partly explaining the reduction in both irrigated area and water use between 2001 and 2005. The total potato area in Great Britain has fallen steadily over the past 50 years and between 2001 and 2005 fell by 14% (Potato Council, 2010). Similarly, the reduction in irrigation of sugar beet appears to reflect both the reduction in the area of sugar beet grown as well as the declining value of sugar beet crops in relation to other irrigated crops, most notably potatoes.

Despite the reduction in the water used to irrigate maincrop potatoes between 2001 and 2005, the proportion of the total volume of water used to irrigate outdoor crops has remained almost unchanged. In 2001 maincrop and early potatoes accounted for 58% of water use while in 2005 they accounted for 56% of total water use. The following figure (Figure 3.1.1) summaries the percent of the total volume of water used to irrigate outdoor crops for each crop category between 1982 and 2005. From this data it can be seen that there have been large increases in the proportion of total water use in maincrop potatoes and vegetables. By comparison, large reductions in water use as a proportion of the total have been seen in sugar beet, orchard fruits and grass.

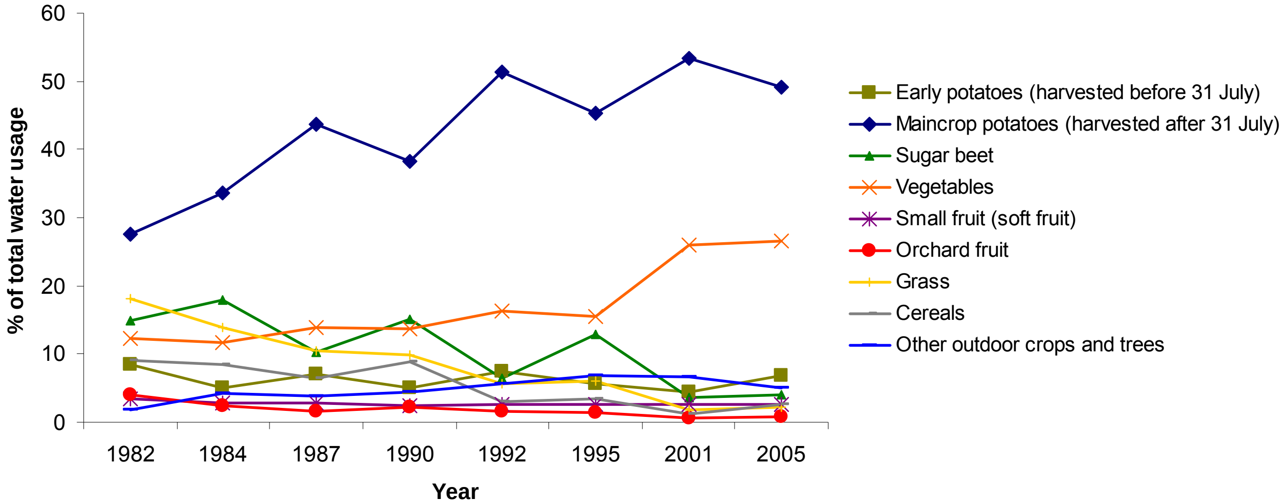

Figure 3.1.1. Percentage of the total volume of irrigation water used to irrigate each crop category between 1982 and 2005 (Data from: Weatherhead 2007).

Water use for livestock production

As a proportion of total water use in agriculture, livestock production uses similar volumes of water to that used in the irrigation of field crops. Water use in livestock production is mainly for consumption (drinking) as well as cleaning housing etc. The cattle sector is the biggest user, accounting for 82,000 thousand cubic metres of water used, followed by sheep at 17,000 thousand cubic metres, poultry at 1,000 thousand cubic metres and pigs at 8,000 thousand cubic metres (King et al. 2006).

Within the cattle sector, the dairy industry uses the most water, as a dairy cow requires about 33,000 L of drinking water a year compared with about 7,000 L for a beef cattle.

Crop production per unit of water used

'Virtual water' contained within an agricultural product refers to the water consumed in the production of the product (Allan, 1998). In primary products, such as cereals, potatoes, vegetables and fruits, the relationship between production and water consumption are quite clear. In this way production (kg) and water evapotranspiration (m^3) form the basis of the virtual water estimation (m^3/kg) (see Zimmer & Renault 2003). This basic estimation of 'virtual water' may be modified by correction factors that take into account water efficiency (e.g. recycling or losses associated with irrigation). Taking this approach is has been possible to estimate virtual water contents of crops grown in the UK (Table 3.1.3).

Table 3.1.3. Estimated crop water requirements and virtual water contents of selected primary products produced in the UK (Source: Chapagain & Hoekstra, 2004).

Crop	Crop water requirement (mm/crop period)	Virtual water content (m^3/tonne)
Wheat	381	501
Barley	361	650
Potatoes	297	74
Sugar beet	299	56
Vegetables	271	201
Apples	421	255

Under UK conditions potatoes are estimated to have a water requirement that is 22% less than wheat and 18% less than barley and is comparable with field vegetable crops. However, when yields are taken into account through estimates of the virtual water content of these crops the differences become much larger. This is because typical potato yields are 40 tonnes per hectare while for wheat yields are only 8 tonnes per hectare. As a result the virtual water content for wheat is almost seven times higher than for potatoes.

Irrigation demand by Environment Agency region

King et al. (2006) produced a regional breakdown of water usage expressed according to Environment Agency (EA) regional boundaries (Figure 3.1.2), which relate more closely with river basin districts within which water is gathered and abstracted. Regional differences are apparent both in terms of total water usage as well as the relative importance of all livestock, glasshouse and nursery stock and irrigation of field crops. Overall water use is highest in the Anglian region. The relative importance of irrigation of field crops was also highest in the Anglian as well as the Southern and Thames regions. By comparison, water use by livestock was more important in the South West, North East and North West regions. Water use in glasshouse and nursery crops was relatively low in all regions, but the highest use was in the Midlands region, which saw a more even split between the three water use categories than the other regions. These regional differences describe the different uses of water in that area but also point to differences in the timing of water use. While water used for field irrigation will be required in the summer, livestock water use will be spread across the year.

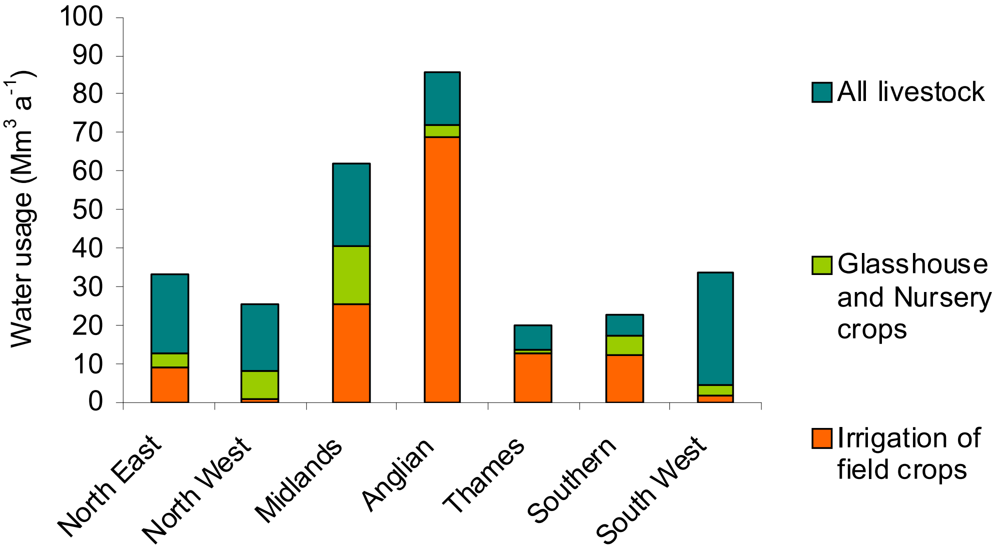

Figure 3.1.2. Annual water use by agriculture according to EA regions in England (M m^3 a^{-1}). The proportion of the total contributed by the three largest sector categories of field irrigation, all livestock and glasshouse and nursery crops, are shown. (Source: King et al. 2006)

Potato Council data (Potato Council, 2010) shows that in 2005 Eastern counties accounted for 26% of the total potato growing area in Great Britain. Furthermore, the data also shows that the relative proportion of the potato growing area in Eastern counties is growing steadily and was at 28% of the total in 2010. Considered by EA regions covering England and Wales, 60% of water used to irrigate outdoor crops was in the Anglian region in 2005 (Weatherhead, 2007). Within the Anglian region, the irrigation of potatoes accounted for 60% of the total volume of water used to irrigate outdoor crops. Vegetable crops were also an important use of water in the Anglian region, accounting 27% of the total.

The greatest demand for water for the irrigation of field crops and potatoes in particular can be seen to lie in the Eastern and South of the country. However, when water resources in England and Wales are considered, Eastern and the South East of England can be classified as areas 'under stress from water abstraction', with more than 22% of freshwater resources abstracted (Environment Agency, 2008). Indeed, in Europe only drier countries such as Cyprus, Malta, Spain and Italy are under greater water stress than these parts of England. Water resources that are available for abstraction are assessed through Catchment Abstraction Management

Strategies. Using this approach the Environment Agency has produced a comprehensive baseline for all catchments in England and Wales (Figure 3.1.3).

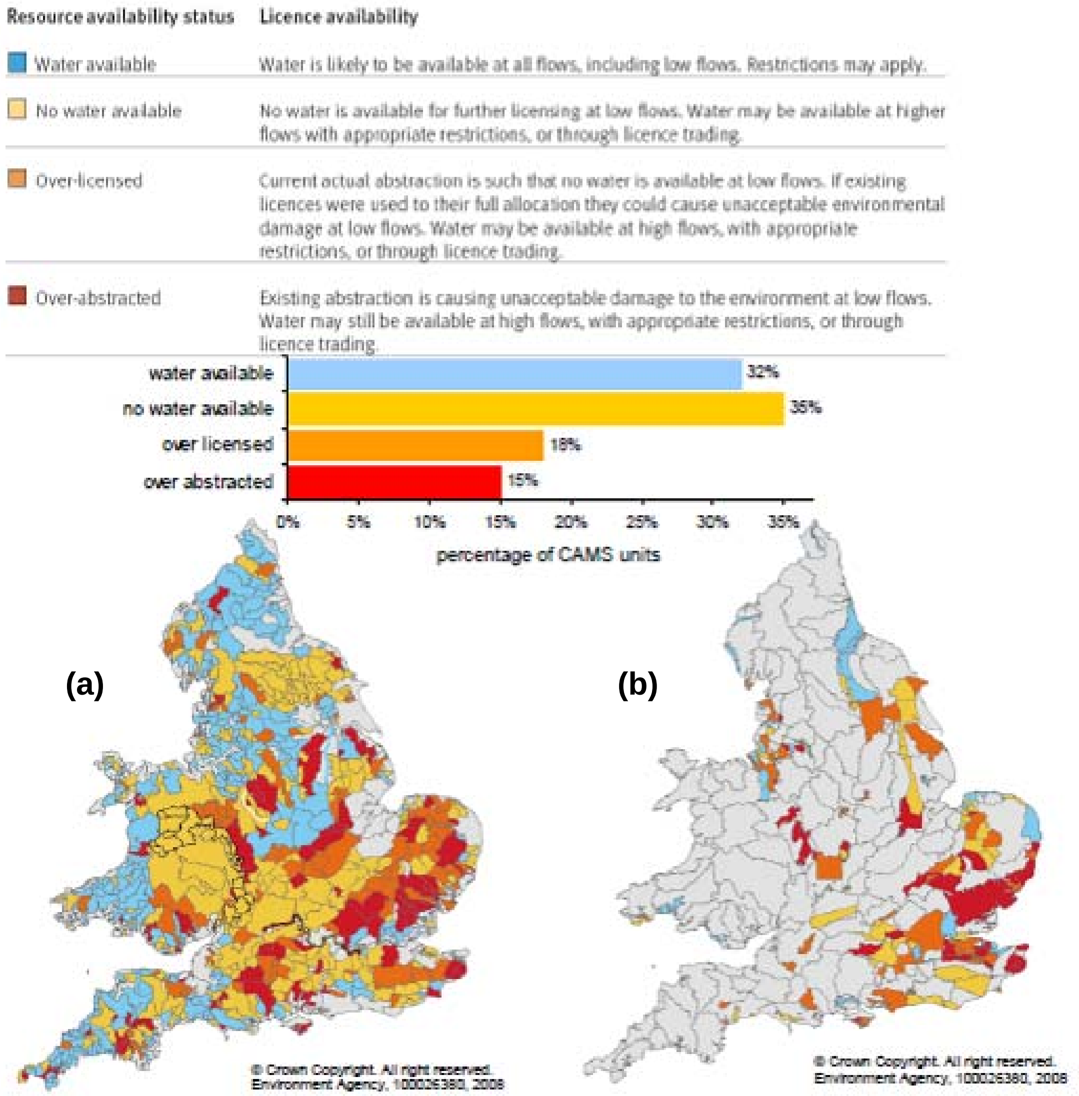

Figure 3.1.3. Water available for abstraction: (a) surface water combined with groundwater; (b) groundwater (Source: Environment Agency, 2008)

It is important to acknowledge that farmers use less than 1% of the total amount of water abstracted in England and Wales for spray (overhead) irrigation (Environment Agency, 2008). However, whilst total irrigation demand is relatively small, in comparison with average yearly availability, there are a number of catchments where the summer demand exceeds availability (Lord *et al.* 2007). These catchments are mainly located in East Anglia where the summer demand (June to August) exceeds the summer available water in *c.* 30% of the area (Figure 3.1.4).

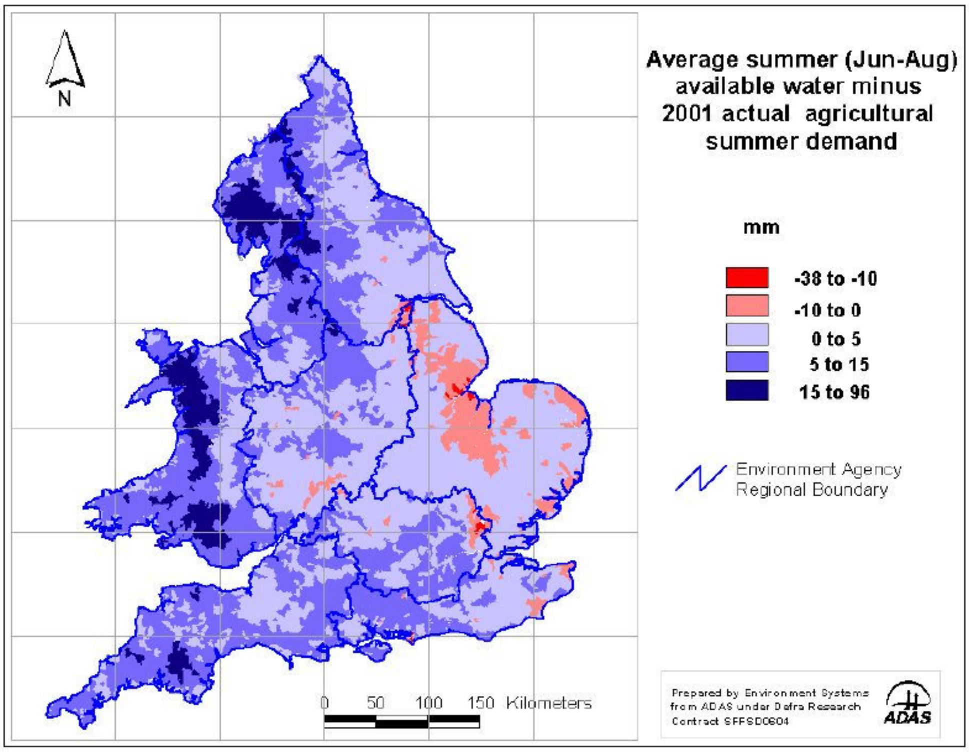

Figure 3.1.4. Average summer (June- Aug) available water minus 2001 agricultural summer demand (Source: Lord et al. 2007)

This area is extended in a year with a dry summer (defined as a year with a summer flow, which is exceeded in 80% of years) when agricultural demand exceeds the availability in *c.* 60% of East Anglia (Fig 3.1.5).

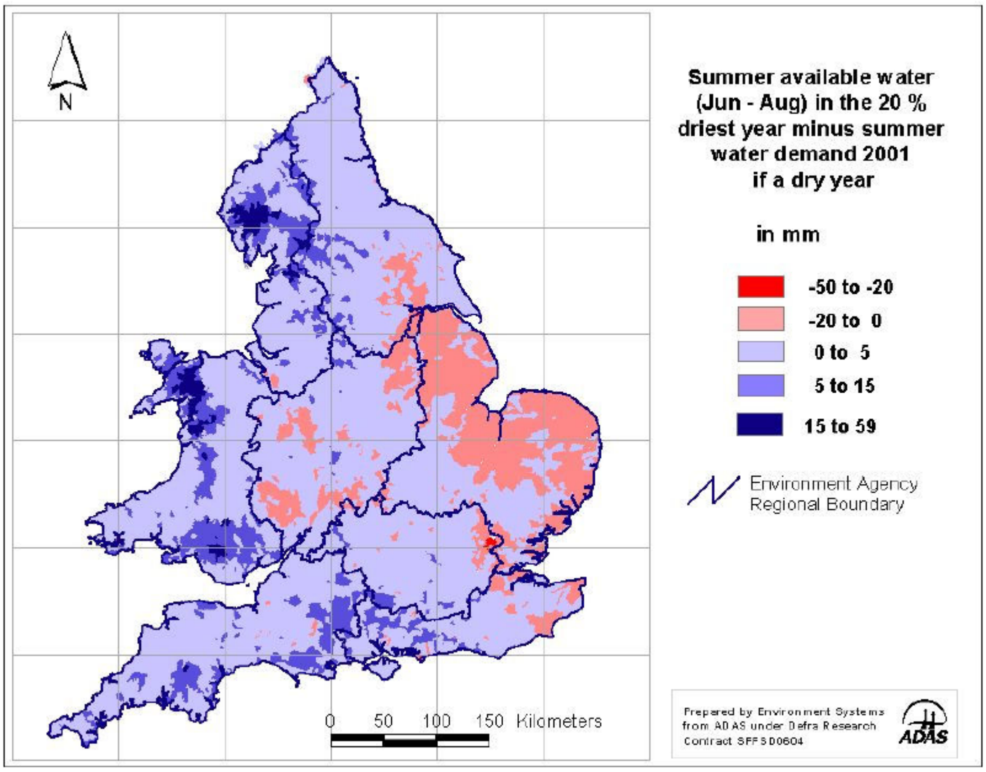

Figure 3.1.5. Summer (June- Aug) available water exceeded in 80% of years, minus summer agricultural summer demand for 2001 if a dry year. (Source: Lord et al. 2007)

Water abstraction licensing

The Environment Agency issues licenses that allow for the abstraction of water. These licenses define the maximum amount that is allowed to be abstracted. Up to 2003, a licence was only required for irrigation needs applied as a spray according to the 1991 Water Resources Act and previous legislation. As such the total annual amount licensed rose from about 55 million cubic metres in 1974 to about 145 million cubic metres in 1997 according to the analysis of future irrigation needs by Weatherhead and Knox (2000). Actual use for spray irrigation has declined as a proportion of the licensed amount steadily from 43 to 17% between 1995 and 2008 (Figure 3.1.6). Part of the apparent reduction may be due to deregulation, which has meant that abstractions of less then 20 cubic metres per day became exempt from licensing from 1 April 2005. Recent changes to the way that abstraction licences are issued, has seen an increase in the proportion of licences that have an expiry date (Environment Agency, 2008). The increase in time limited abstraction licences has introduced greater flexibility in water management in order to protect the environment in response to future pressures.

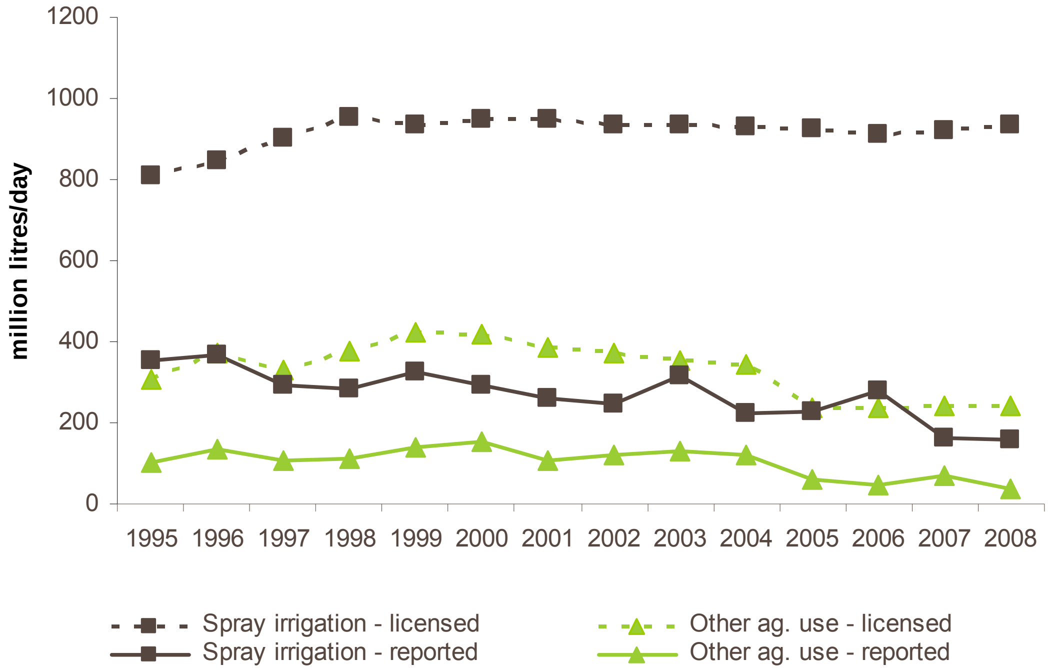

Figure 3.1.6. Water abstracted for spray irrigation in England and Wales between 1995 and 2008 (Source: Environment Agency, 2010[1]).

Water used on farm can come from either one of two broad categories of supply, either directly abstracted water used solely for the farm application, or from the public mains supply, which is ultimately abstracted from the same natural sources but treated to provide a standard quality. Irrigation surveys from 1982 onwards have included the source of the water used in England and Wales (Weatherhead 2007) (Table 3.1.4). These data indicate that surface water abstraction accounts for 54% and groundwater abstraction for 41% of the total used to irrigate outdoor crops (2005). By comparison, public supply accounted for less than 1% of the total. The average actual rate of daily usage of abstraction water was highest (2003 data) in the Anglian region for both surface and groundwater (Defra e-Digest of environmental statistics[2]). However, the relative amounts of surface and groundwater used were similar to the figures for England and Wales as whole.

[1]http://www.defra.gov.uk/evidence/statistics/foodfarm/enviro/observatory/indicators/documents/DA5.pdf accessed 31 January 2011

[2]http://www.defra.gov.uk/environment/statistics/index.htm accessed 31 January 2011

Table 3.1.4. Volume of water used for irrigated outdoor crops ('000 m^3) in England and Wales (1995 & 2001 England only) taken from different sources. (Source: Weatherhead, 2007)

	1982	**1984**	**1987**	**1990**	**1992**	**1995**	**2001**	**2005**
Surface water	34,390	57,210	19,250	74,070	41,820	90,860	75,760	50,343
(watercourse)		(47,480)		(62,330)		(76,760)		
(lake or pond)		(9,730)		(11,740)		(14,660)		
Groundwater	16,680	32,420	11,800	50,540	28,470	61,620	47,810	38,184
(spring or well)		(7,580)		(8,590)		(8,620)		
(deep borehole)		(24,840)		(41,950)		(53,710)		
Public supply	2,040	3,840	1,100	3,860	2,620	4,390	4,300	813
Other source	1,830	3,540	1,470	5,330	2,160	4,880	3,430	1,939
(collected rain)							(2,050)	617
(re-used water)							(670)	986
Total	**54,940**	**97,730**	**33,630**	**133,790**	**75,070**	**164,070**	**131,300**	**92,883**

Water used for crop irrigation is required during the summer months, when river flows are typically at their lowest. However, 42% of holdings in England responding to the 2005 survey were recorded as having reservoir storage capacity (Weatherhead, 2007). Reservoir storage allows farms to abstract water from watercourses during the winter when flows are higher; thereby helping to reduce the overall impact. In 2005, total water used coming from storage reservoirs was 30%. Despite this only 50% of the reservoir capacity was used, suggesting that there is potential for improving management of storage reserves. However, in seasons dryer than 2005 reservoir depletion is likely to be higher. Considered by EA region, there were large differences (14% in the North East and 55% in the Southern region) in the percent of holdings with reservoir storage. A high proportion of holdings in the Anglian region, the largest user of surface water, were recorded to have reservoir storage (43%). Mirroring national trends reservoir storage in the Anglian region accounted for 32% of water used but again only 53% of reservoir storage was used in 2005.

Trends in water management practices

The management of water applications can affect the efficiency of water use by the crop and the impact on the environment. The employment of a recognised scheduling technique to ensure that the correct amount of water is applied at the correct time can be an important element in any management plan. Survey data suggest that there has been an increasing trend towards the use of water balance and soil measurements to plan irrigation with such techniques accounting for 25% and 35% respectively of the irrigated area (Weatherhead, 2007). However, other, perhaps less measurable approaches, still account for the management of the remaining irrigation applications. No survey data have been collected since 2005 but industry contacts suggest that the current position has remained relatively unchanged since 2005.

The use of drip as apposed to spray irrigation has been associated with efficiency savings both in terms of energy and water use. In 2005 it was estimated that 5% of the land irrigated received water via this method; unchanged from 2001 (Weatherhead, 2007). Whilst there are no data to report on the use of drip systems since 2005, industry contacts suggest that the total area irrigated is likely to have declined with the proportion used for potato crops now regarded as negligible.

Produce washing

Vegetable and potato washing amounts to less than 300,000 cubic metres nationally (King et al. 2006) and as such is equal to less than half of one percent of the volume of water used in spray irrigation. Approximately 80% of crisping potatoes are required to be washed on-farm. Potato washers tend to be barrel rather than brush washers and work by washing the potatoes in a rotating barrel. The potatoes emerge from the barrel on elevator where they are rinsed, before going straight into a lorry for delivery to the factory. Using 9 cubic metres of water a barrel washer can be expected to wash 180 tonnes of potatoes lifted straight from the field and 230 tonnes out of store. The exact tonnage of potatoes washed per 9 cubic metres of water will be determined by the amount of mud on the potatoes. Potatoes washed out of store are likely to have less mud and will be the source of potatoes for washing for eight months of the year, assuming that the factory is supplied year round. It is possible to calculate the volume of water used to wash crisping potatoes (Table 3.1.5). The estimated maximum volume of water used to wash the 600,000 tonnes of crisping potatoes is 25,650 cubic metres of water or 0.04 cubic metres of water per tonne of potatoes. By comparison, water used in washing field vegetables, according to regions where washing takes place, indicates far higher usage at 206,808 cubic metres of water (Table 3.1.6). In addition, the volume of water used per tonne of vegetables 0.27 cubic metres or approaching seven times the volume estimated to wash a tonne of crisping potatoes.

Table 3.1.5. Water used in washing potatoes for crisping, according to regions where washing takes places; showing the tonnage washed (t) and water used (m^3) for England. (Source: King et al. 2006)

Government Office Regions	Approx. % of crisping crop	Tonnage washed	Maximum water used m^3
North East	4%	24,000	1,026
Yorkshire & The Humber	10%	60,000	2,565
East Midlands	22%	132,000	5,643
East of England	33%	198,000	8,464
South East	3%	18,000	770
South West	7%	42,000	1,795
West Midlands	15%	90,000	3,848
North West	6%	36,000	1,539
London	0%	0	0
Total	**100%**	**600,000**	**25,650**

Reference: BPC Yearbook of Potato Statistics in Great Britain, May 2006.

Table 3.1.6. Water used in washing field vegetables, according to regions where washing takes place, showing the tonnage washed (t) and water used (m^3) for England and Wales. (Source: King et al. 2006)

Government Office Regions	Tonnage washed	Water used m^3
North East	5,354	1,359
Yorkshire & The Humber	83,227	11,256
East Midlands	165,888	28,103
East of England	333,576	48,307
South East	17,707	18,495
South West	20,702	7,717
West Midlands	37,913	72,821
North West	107,915	18,431
London	1,235	319
Total	**777,517**	**206,808**

References: Vegetable Survey by Government Office Region, January 2004.

Crisping accounted for 13% of the total consumption and processing of potatoes in Great Britain in 2009 (Potato Council, 2010). By comparison, fresh potatoes accounted for 48% of the total consumption and processing. By this measure, washing of potatoes destined for the fresh market will use far larger volumes of water than potatoes used for crisping. In order to reduce the volume of water used to wash fresh potatoes Greenvale AP launched project Cascade, which brings together other technologies from the food industry to reduce water used to clean potatoes and root vegetables (Greenvale AP Cascade project[3]). To date where project Cascade has been trialled, a saving of 60 million litres of water has been achieved in the washing of 140,000 tonnes of fresh potatoes. This saving compares to the standard system which used 82 million litres of water to wash the same amount of potatoes. Adopting project Cascade has therefore saved almost 75% of water used to wash potatoes; however, savings of 85% may ultimately be reached.

Conclusions

Potatoes are the dominant irrigated outdoor crop in England and Wales, accounting for 43% of the total irrigated area and 56% of the total water used to irrigate crops. Much of this irrigation is applied to potato crops grown in Eastern England, an area of the country classified by the Environment Agency as 'under stress from water abstraction'. Measures to reduce the impact of water abstraction for potato irrigation in this region include the use of soil measurements to determine the need for irrigation (either direct or indirect) and on-farm reservoir storage to allow abstraction of water during the winter. For management and cost reasons, few growers have moved away from overhead irrigation to more water-efficient systems such as trickle irrigation.

Although potato crops grown in Great Britain are a major use of water for irrigation the actual water requirement of potato crops is 22% less than wheat and 18% less than barley and is comparable with field vegetable crops. This is in part because potato crops use the land for a shorter period than cereal crops. Potato yields (approximately 40 tonnes per hectare) are far higher than for cereal crops (for wheat this is approximately 8 tonnes per hectare). However, potatoes have a higher water content than cereal crops and so relatively more potato is required to provide the same nutrition.

In addition to irrigation, washing potatoes is another water use albeit the volumes used are very small compared to irrigation. Recent innovations such as project Cascade could help to reduce water usage here by as much as 85%.

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[3] http://www.greenvaleap.net accessed 31 January 2011

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Glossary

Evapotranspiration – the sum of evaporation and plant transpiration from a given area.

Virtual water - refers to the water consumed in the production of the product. In primary products, such as cereals, potatoes, vegetables and fruits, production (kg) and water evapotranspiration (m^3) form the basis of the virtual water estimation (m^3/kg).

3.2. Land use

Introduction

A conclusion of the recent Foresight report, The Future of Food and Farming (2011), was that if food security is to be provided for the future predicted world population, action has to occur on the following four fronts simultaneously:

- More food must be produced sustainably,
- Demand for the most resource-intensive types of food must be contained,
- Waste in the food system must be minimized, and
- The political and economic governance of the food system must be improved to increase food system productivity and sustainability.

The land area for growing crops is finite, and there is competition for this land from industrial and residential development, conservation of biodiversity, leisure, and other uses of land such as production of fibres, and building materials and mined materials. Expanding agricultural land can increase greenhouse gas emissions and lead to the loss of biodiversity (e.g. converting forest to crop land). Maintaining and increasing crop yield decreases pressure to convert more land to agriculture, and so avoids greenhouse gas emissions and biodiversity loss associated with land use change (LUC).

The yields of potato crops have risen in the UK in recent decades, and less land is used for production than was used 20 years ago. However, there are also other land use considerations for potato crops, in addition to the total amount of land used. Potato growers seek to produce on land that is 'clean' (i.e. where there are not commercially unacceptable levels of soil-borne pests and diseases through previous cropping with potatoes) and has a suitable soil type and water availability for the required crop quality and yield. This is particularly so for seed potato production where high grade seed stocks are grown in arable areas of generally low ware production. These high health status areas for seed production are protected regions (Scottish Government[4]). Whereas the total area used for potato crops has global implications for climate change and biodiversity loss, the actual location of crops can have implications for local environmental impacts associated with water use, diffuse water pollution and soil erosion.

Land use trend

Total domestic (i.e. UK) consumption and production have remained approximately static over the last 20 years (Figure 3.2.1). Potato yields in the UK over the same period have risen (Figure 3.2.2), although there has been large seasonal variation, and yield estimates vary by source of data. The Defra yield data are for the UK; Potato Council data are for GB, and FAOSTAT data are for UK.

In further analysis we have chosen to use Defra data where possible, as a recognised independent source; we have also used data from other sources where

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[4] http://www.sasa.gov.uk/sites/www.sasa.gov.uk/files/SPCS%20in%20Scotland%20Leaflet_0.pdf accessed 17 February 2011

needed for consistency, e.g. when using data from multiple countries these were not available from Defra or Potato Council and we used FAOSTAT data for the UK to provide consistency with other countries.

Because of the large yield variations between seasons we have used three-year means in some calculations, to decrease the extent of seasonal variation. Alternative approaches would be to fit curves to the data sets and use modelled values in analysis of yield changes; however, attempts to do this using regression analysis gave fitted lines with a poor fit. We believe it is better to use actual data values with some averaging to smooth the annual variation.

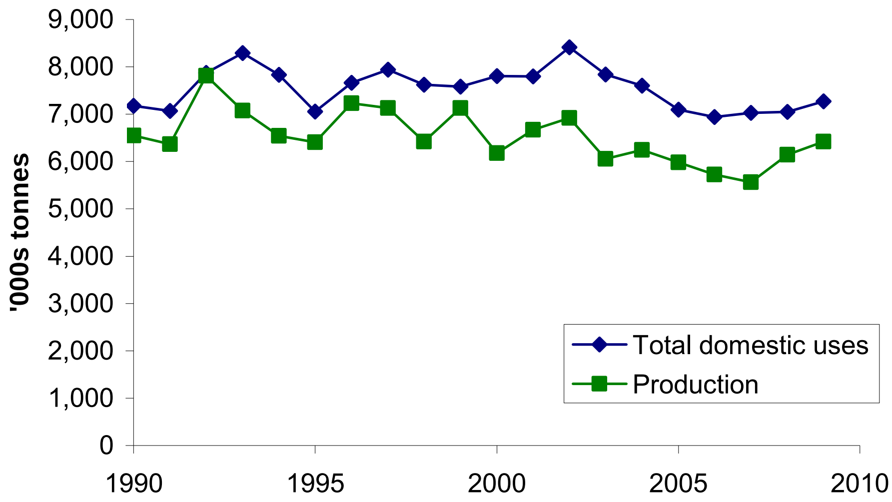

Figure 3.2.1. Use and production of potatoes in the UK from 1990 to 2009 (Source: Defra).

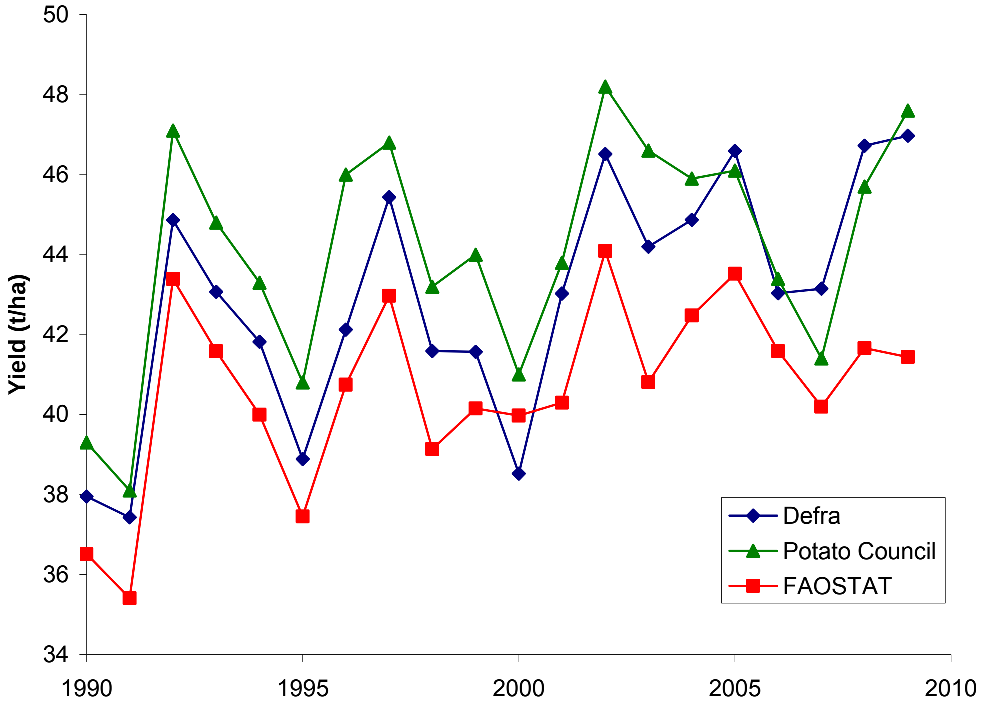

Figure 3.2.2. Potato yields, 1990 to 2009, using data from Defra (UK), Potato Council (GB) and FAOSTAT (UK).

Production tonnage for 1990 and 2009, from three data sources, are shown in Table 3.2.1, together with a calculation of the yield change over 20 years and the consequences of this for the area used for production. Using three-year average yields to decrease the seasonal yield variation, this analysis shows that average yield has risen by 7 tonnes in the last 20 years, which is a rise of 18.1%. The yield increase for maincrop potatoes may in fact have been higher than this data indicates due to the increase of products with more niche markets e.g. early bakers, loose and set skin punnets/babies, which have lower yields.

The negative change in land area used over the last 20 years is very similar when calculated using three-year average yields (-28,663 ha) compared with the actual difference in land use between 1990 and 2009 (-28,458). This change (16.9% fall in land use) is partly accounted for by a small fall in production (1.9% based on Defra data). The land used per tonne shows a fall of 4 hectares per 1000 t of production.

Table 3.2.1. Production (Defra, Potato Council and FAOSTAT data), yield and land use (based on Defra data) for 1990 and 2009.

	1990	**2009**	**Difference (2009-1990)**
UK production (Defra) (t)	6,546,842	6,422,903	-123,939
GB production (Potato Council) (t)	6,198,000	6,196,000	-2,000
UK production (FAOSTAT) (t)	6,467,000	6,423,000	-44,000
Yield (3 year rolling mean; t/ha)	38.6	45.6	7.0
Land used per tonne (ha/t)	0.0259	0.0219	-0.0040
Calculated land requirement for total production (ha)	169,482	140,819	-28,663
Actual land use (ha)	177,387	148,929	-28,458
Calculated land requirement to supply domestic use (ha)	185,806	159,372	-26,434

The land use implications of importing potatoes are estimated for imports of fresh potatoes (Table 3.2.2). The top 10 exporters of fresh potatoes were identified from the HM Revenue & Customs (HMRC) Overseas Trade Statistics (OTS) of the UK, and these 10 countries are responsible for 99.7% of total fresh imports to the UK.

Many assumptions are necessary for this analysis and it is unlikely that these are fully justified, so the estimates must be used with caution. For example, it is assumed that the average country yields are the average yields of the potatoes exported to the UK, which may not be the case because the potatoes may be grown for special markets.

The imports of potatoes shown in Table 3.2.2 do not include imports of potatoes imported as processed products. According to Defra data, these processed imports amounted to 1,309,453 tonnes of raw equivalent potatoes in 2009, so these processed imports far outweigh the imports of fresh potatoes. However, we do not have data for the sources of the potatoes used for imported processed products to allow these imports to be included in the analysis.

With these caveats, the data in Table 3.2.2 indicate that growing potatoes in other countries for import fresh to the UK uses approximately 1000 ha more land than would be needed to grow the same tonnage of potatoes in the UK.

Table 3.2.2. ***Calculated land use for growing fresh imports of potatoes from the top ten exporting countries to the UK, assuming that FAOSTAT average yield data are appropriate for the imported potatoes. Import data are from HM Revenue & Customs (HMRC) Overseas Trade Statistics (OTS) of the UK.[5] Yield data are from FAOSTAT, being the three-year average yield (2007-2009) for each country, and the equivalent UK yield value was used for calculations. A positive value in the final column indicates that more land was used in the producing country than would have been used in the UK to grow the same tonnage of potatoes.***

Country (top ten exporters of potatoes to UK)	**Imports to UK (tonnes)**	**Yield (average 2007 to 2009; t/ha)**	**Land used (ha)**	**Difference in land use compared with UK (ha)**
Israel	80,477	33.1	2,428	470
France	61,276	44.3	1,384	-107
Netherlands	31,842	45.2	704	-70
Germany	22,700	43.4	523	-29
Belgium	18,194	45.9	396	-46
Egypt	18,025	26.4	684	245
Spain	17,136	29.1	590	173
Ireland	14,990	31.0	483	118
Cyprus	14,059	24.0	585	243
Italy	2,359	24.4	97	39
Totals	281,058 [1]	-	7,874	1,035

[1]HMRC data show that this total from 10 countries represents 99.7% of total fresh imports.

Comparison with other crops

Of particular interest for comparison with potatoes are crops that fulfil a similar function in the diet, such as other vegetables and other high carbohydrate foods. Land requirement for potatoes, carrots, wheat and rice are shown in Figure 3.2.3., calculated using the three-year mean yields for 2007 to 2009 harvest years, using FAOSTAT data for rice yield in India (the largest exporter of rice to UK) and Defra data for yields of other crops.

To help understand the significance of land use associated with the food we eat it is useful to express the land use per unit of dry matter and energy content. Land requirement is shown per tonne fresh weight, per tonne dry weight and per kJ energy content.

[5] https://www.uktradeinfo.com/index.cfm?&hasFlashPlayer=true accessed 3 February 2011.

Compared with carrots, potatoes use more land per tonne of fresh weight, but a similar area of land per tonne of dry weight. Compared with wheat, potatoes use less land per tonne of fresh weight (only 19% of the value for wheat), and a little less area of land per tonne of dry weight (91% of the value for wheat). Compared with rice, potatoes use less land per tonne of fresh weight and less land per tonne of dry weight.

Of these four crops, potatoes have the lowest land area requirement per kJ of energy content.

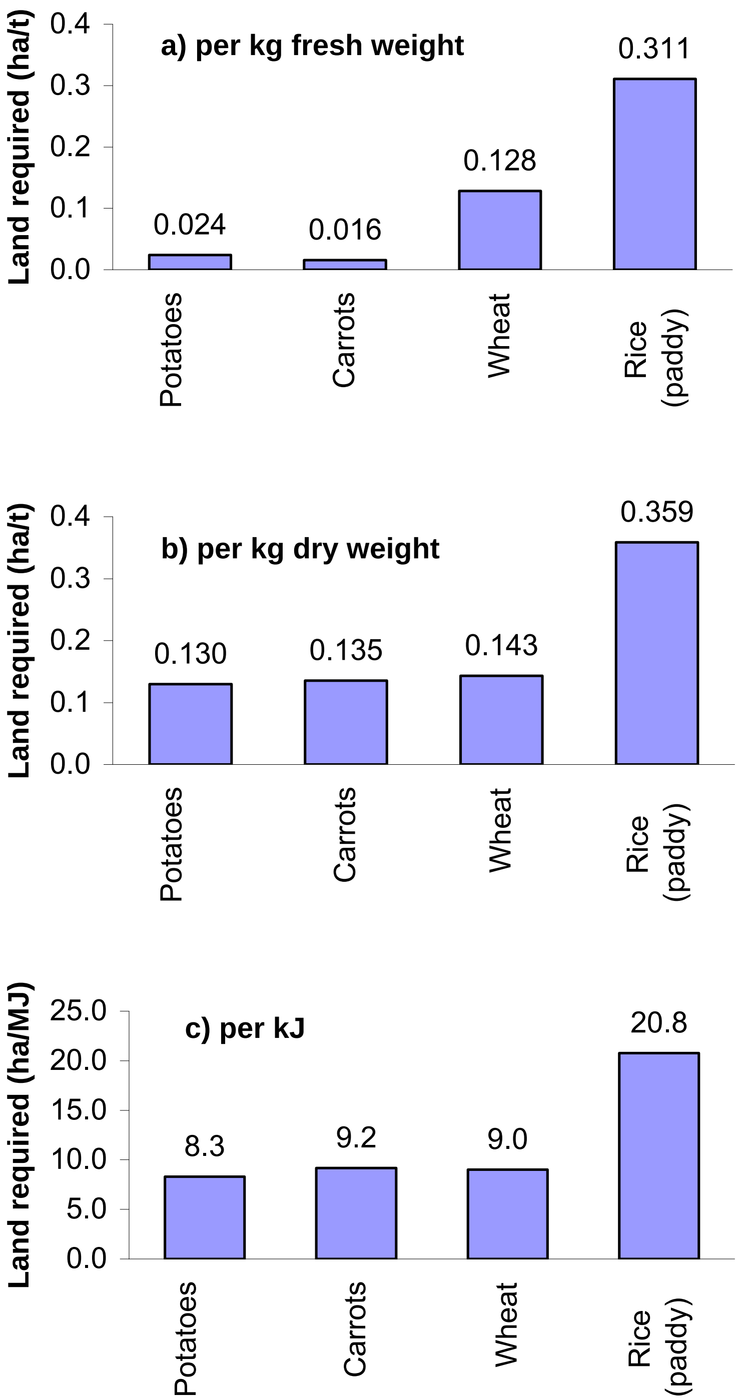

Figure 3.2.3. ***Land requirement for potatoes, carrots, wheat and rice calculated using the mean yields for 2007 to 2009 harvest years, using FAOSTAT data for rice yield in India (largest exporter of rice to UK) and Defra data for yields of other crops. Dry matter and energy contents were from USDA[6]: a) kg CO_2e/kg fresh weight; b) kg CO_2e/kg dry weight; and c) kg CO_2e/kJ energy content.***

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[6] USDA National Nutrient Database for Standard Reference, http://www.nal.usda.gov/fnic/foodcomp/search/ accessed 3 February 2011.

Conclusions

Expanding agricultural land can increase greenhouse gas emissions and lead to the loss of biodiversity (e.g. converting forest to crop land). Maintaining and increasing yield and reducing waste decreases pressure to convert more land to agriculture, avoiding greenhouse gas emissions and biodiversity loss associated with land use change. Over the last 20 years potato yields have increased by seven tonnes per hectare (calculated using a three year average to decrease seasonal yield variation), equivalent to a rise of 18.1%. This increase in yield has meant that the area of land required to produce every 1,000 tonnes of potatoes has decreased by four hectares.

When fresh potatoes imported to the UK are considered there are indications that relatively more land is required to grow these potatoes than if they had been grown in the UK. The additional land used to grow imported potatoes may be as much as 1,000 hectares; however, it should be remembered that it is currently not clear if the national average yield data for producing countries is applicable to the imported potatoes.

It is possible to compare potatoes with other crops in terms of land use by considering the area required per tonne of dry weight or the area required per KJ of energy content. By both measures when potatoes are compared with a range of other crops, including wheat, rice and vegetables such as carrots, the area requirements of potatoes are the lowest.

Reference

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3.3. Pollution

Diffuse pollution of nutrients and sediments in potato rotations

Soils are inherently “leaky” systems, as plants are relatively inefficient at scavenging the nutrients present in soils. Environmental legislation includes a focus on losses of nitrogen (N) and phosphorus (P) to water systems, and these are also the two most significant nutrients applied to managed agricultural land. Soil erosion moves suspended and particulate sediment to rivers, with negative impacts on aquatic ecology (such as fish spawning) due to the siltation of river beds. Soil compaction can increase the risk of soil erosion, as it reduces the rate at which water from rain or irrigation can infiltrate into soils, and/or the drainage of water through the soil profile.

A variety of factors influence the risk, magnitude and timing of losses of the nutrients nitrogen and phosphorus from agricultural land, including land management practices (cultivations, land use, planting and harvesting dates, irrigations etc.), land vulnerability (soil type, slope, hydrological connectivity etc.), and climatic factors. These nutrient losses are key contributors to the pollution of surface and ground waters, and current estimates are that nutrient losses from agricultural land may account for as much as 25% of phosphorus and around 50% of nitrogen entering UK water bodies each year (e.g. Defra, 2007). Diffuse pollution of nutrients may occur before a crop is planted, during the cropping phase itself, and following harvesting.

Before planting

Before the potato crop is planted the method of cultivation and possible use of cover crops affect N availability. Cultivation practices prior to planting potatoes are relatively intense, commonly including ploughing or non-inversion tillage, bed-forming and de-stoning processes. Cultivation stimulates mineralisation of soil nitrogen into plant-available forms (which are also vulnerable to leaching). This occurs as soil clods and aggregates are fractured to create a finer soil tilth and soil microorganisms are brought into contact with fresh, previously unavailable substrates (Silgram & Shepherd, 1999). There are limited recent data on the effects of different cultivation methods prior to potatoes under UK conditions. Historic evidence from cultivation research indicates that differences in soil N supply between mouldboard ploughing and minimum cultivations can be as much as 65 kg N/ha (but is often around half this figure) (Silgram & Shepherd, 1998).

As potatoes are a spring sown crop, farmers have options on how to manage land the winter before planting. Leaving land bare overwinter presents a high risk of pollution and erosion. Cover crops are not widely used in the UK, but are more popular in some mainland European countries (including the Netherlands and Denmark) and are often linked to national Nitrate Vulnerable Zone (NVZ) regulations. This link with nitrate leaching mitigation is based on evidence that growing cover crops can take up 10-60 kg N/ha which would otherwise be leached over-winter, depending on species, weather, soil type and establishment and destruction dates, (Harrison & Silgram, 1998). The ability of cover crops to reduce nitrate leaching is supported by results from the Nitrate Sensitive Area (NSA) scheme. Under the main NSA scheme, reductions of 12% in mean over-winter nitrate concentrations and 60% in mean nitrate fluxes were measured in winter 1999/2000 for fields following winter cereals where cover crops had been grown compared to fields left without cover crops (Silgram, 2005). In research at two sites in Eastern England, Harrison & Silgram (1998) found that 25-33% of cover crop N was released within three months of destruction, making it available to the following crop. The actual amount of N released into plant-available forms is, however, influenced by factors including cover crop species and chemical composition (e.g. C/N ratio) at destruction, which affects the rate of decomposition and N release (Silgram & Harrison, 1998).

Historic results from ADAS research by Davies (1996) showed that combining a cover crop with delayed cultivation could decrease the average over-winter nitrate leaching loss. In that research, losses were reduced from 37 kg N/ha per year under standard farming practice to 5 kg N/ha per year in a spring cropping rotation with cover crop. Other historic research Harrison & Peel (1996) found the effect of cover crops on the yield of potatoes or peas was small and not statistically significant ($P<0.05$) in individual site-years. However, if test crop yields were expressed as a percentage of the overall average yield for individual cover crop sowing date treatments and N rate applied to the following crop, then treatments did indicate a small but consistent trend. In this work yield of the following crop was reduced by *ca.* 2% with early cover crop sowing in August but increased by 1-3% with cover crops sown in October. Furthermore, the date of cover crop destruction also influenced test crop yields, with later destruction (February) suppressing test crop yields in comparison with earlier destruction (December). The evidence from these experiments indicate that greater amounts of N are taken up by early sown cover crops, but that their greater maturity may lead to wider C/N ratios at destruction and hence less rapid mineralisation and release of N in their residues for the next spring crop.

There is relatively little published UK-based research on cover crops in the last decade. In addition to the above benefits in reducing nitrate leaching, the latest results from the current Defra-funded MOPS2 project (WQ0127)[7] show that growing cover crops the winter before potatoes can significantly reduce ($P<0.05$) runoff, sediment, and phosphorus loss compared to bare soil or over-winter stubble, with runoff typically halving where a cover crop was grown.

Within the crop

Unlike most crops, just under half the UK potato crop receives irrigation (Potato Council, 2010, Weatherhead, 2007). Irrigation water is more vulnerable to runoff compared to rainfall due to the much greater intensity of water applied, which may exceed the infiltration rate of the soil surface. This risk can be greatest using application methods which may be less uniform (e.g. rain guns) and can be smallest with correctly timed use of drip irrigation systems.

Soil compaction in potato systems may be near surface (e.g. due to wheelings from spraying or irrigation activities) or deeper compaction (e.g. created during bed-forming processes) (e.g. Stalham et al., 2005; Hatley et al., 2005). Soils have differing inherent susceptibilities to soil compaction. However, where it does occur, it can limit rooting depth and the availability of water and nutrients, promote waterlogging and associated tuber rot diseases, and encourage surface runoff and associated diffuse pollution of soil (erosion), N, P and surface applied products to water courses. The latest evidence suggests that where soil compaction does occur, surface runoff is much greater down stone rows (rather than no-stone rows) between

[7] http://www.potato.org.uk/department/knowledge_transfer/grower_gateway/index.html?did=3583&pg=1 accessed 1 February 2011

potato beds, which can divert irrigation water as surface runoff to the edges of fields (e.g. see initial results from the Defra-funded MOPS2 project).

Data from the Woburn Erosion Reference Experiment (Quinton & Catt, 2004) also gives some insights into the magnitude of the risk of soil compaction in potato rotations. At Woburn, during the 10 year period of the experiment, potatoes were grown twice, with no supplementary irrigation, and one erosion event in each period was recorded. In the monitored events, cultivating on the contour was successful in reducing the losses of sediment and P almost to zero, and had no impact on tuber yield. However, anecdotal evidence suggests that if practiced on more convoluted non-planar slopes, then this can promote the concentration of water in hollows and the catastrophic failure of ridges leading to gully erosion. The effectiveness of contour cultivation can be attributed to the storage of water behind the ridges, which prevent it from running off the field. This suggests that other cultivation practices, which produce storage features (e.g. tied ridging, Aqueel), or lift the compaction in the stone rows (e.g. a carefully placed tine) may provide a mechanism for reducing runoff and therefore diffuse pollution risk, which has the potential to promote more efficient use of water applied by irrigation.

Catchment sediment yield via losses through the tile drain network on a silty clay loam soil in Herefordshire were estimated to be as high as 60% (Walling et al., 2002). Evidence from some artificially drained sites suggests that sediment may originate from the topsoil, being mobilised at the soil surface before being transported through the soil (Chapman et al., 2005; Foster et al, 2005). Apart from surface runoff, drainflow can therefore be a highly efficient hydrological pathway in the 40% of agricultural catchments in the UK which are artificially drained (Robinson & Armstrong, 1988). However, research suggests that the transport of P via drainflow may also be independent of soil P sources, with one study having found no relationship between soil P and drainflow P concentrations for five farms in the south of England (Gardner et al., 2002).

Post harvest

There is relatively limited UK research on the risks of, and methods for mitigating, erosion and diffuse pollution associated with spring sown crops, even though crops such as potatoes and maize are perceived to pose a relatively high risk. This relatively high potential risk of diffuse pollution is due to the combination of the risk of shallow or deep soil compaction (during ground preparation before planting, from traffic during the season, or from late harvesting), coupled with the high N applications to these crops (which can lead to high residual levels of soil mineral N available for leaching after harvest). In addition, the late harvesting of maincrop potatoes can cause compaction under moist soil conditions and limit opportunities to establish good ground cover before winter (see, for example, the Diffuse Pollution manual; Cuttle et al., 2005). Measurements of soil mineral nitrogen (SMN) in late autumn 2004 and 2005 in Defra project NIT18 show greater nitrate leaching risk from break crops, including potatoes (but excluding sugar beet), when compared to cereals (Figure 3.3.1). Such measurements of SMN serve as an indicator of nitrate leaching risk around the onset of winter drainage, and high values of autumn SMN are generally associated with greater losses of nitrate in water draining from soils over the winter months (Figure 3.3.2).

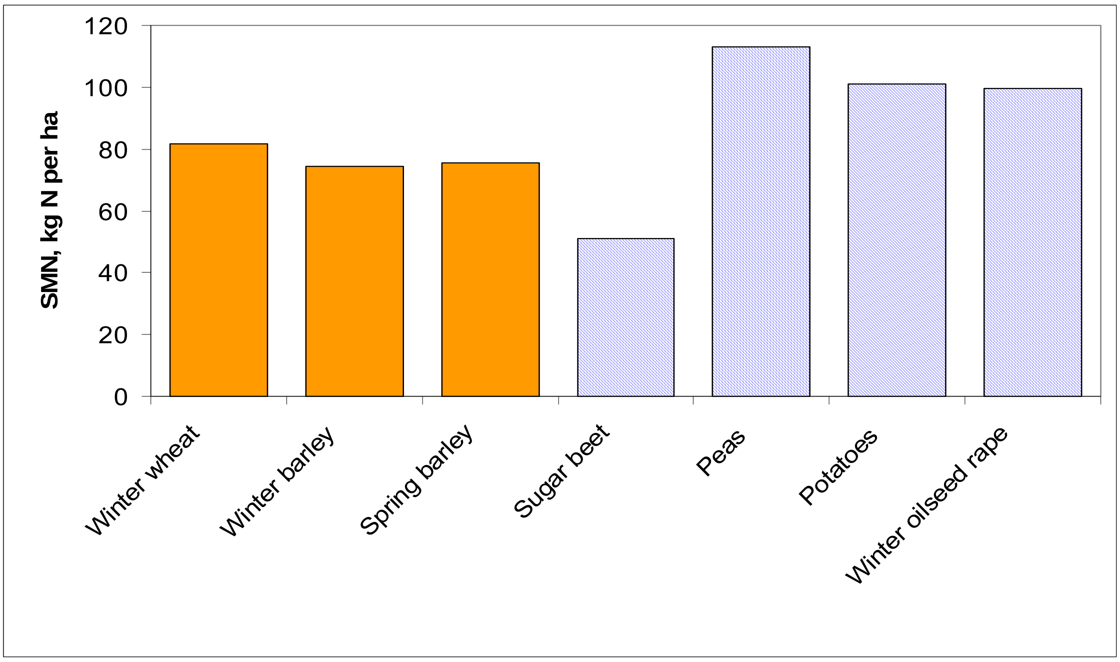

Figure 3.3.1. Soil mineral nitrogen (0-90 cm depth) in autumn following the specified arable crops in NVZs in England. Data represent the means over winters 2004/5 and 2005/6. Source: Defra project NIT18: Lord et al. (2007).

Evidence from Shepherd & Lord (1996) (Table 3.3.1) and from long-term monitoring under the Nitrate Sensitive Areas scheme and within existing NVZs in England (Defra, 2007) (Figure 3.3.2) show nitrate concentrations in leachate were smallest following sugar beet; and were greatest following break crops including potatoes and legumes such as peas.

Table 3.3.1. Summary of the effects of husbandry practices on nitrate loss, winters 1989/90 to 1995/96: Gleadthorpe rotational experiment (Source: Shepherd & Lord, 1996).

Previous Crop	**Post harvest treatment**	**Code**	**Mean drainage (mm)**	**Mean N loss (kg/ha)**	**Mean nitrate concentration (mg/l)**
Potatoes	winter cereal	S	232	71	136
	spring cereal	B	246	75	138
Cereal 1	fallow	S	223	46	103
	cover crop	B	181	19	40
Sugar beet	Oct. harvest	S	185	17	42
	Nov. harvest	B	188	7	16
Cereal 2	fallow	S	219	47	108
	cover crop	B	177	26	58

S= standard practice; B = best practice

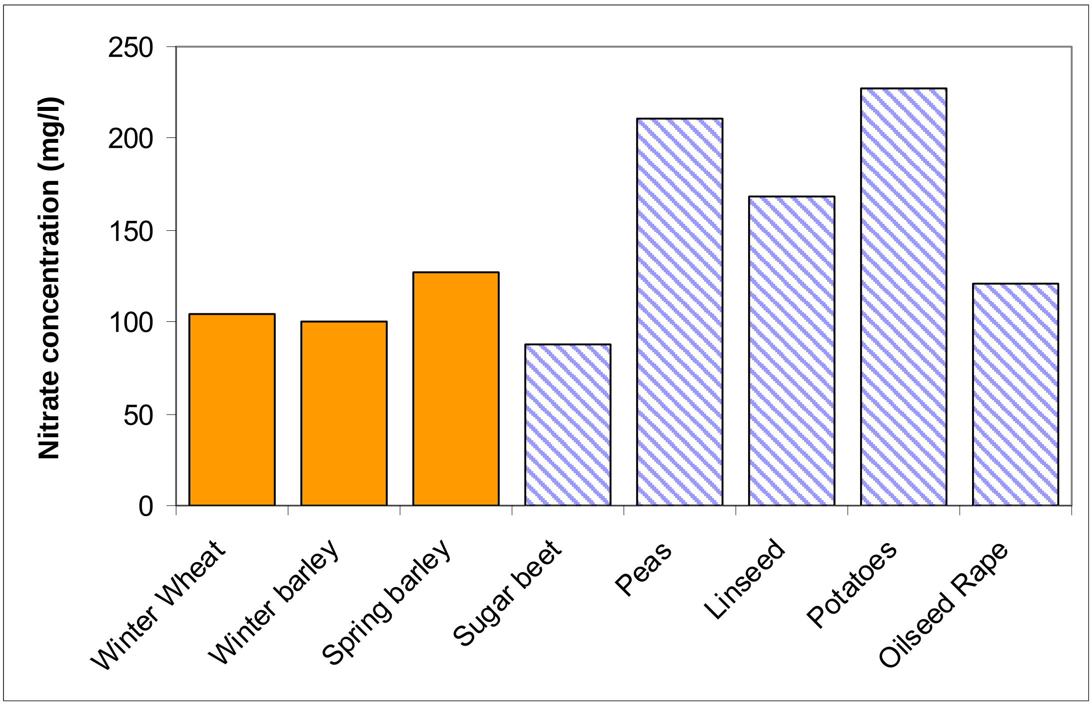

Figure 3.3.2. Nitrate concentrations in over-winter drainage from arable land in NSAs and NVZs in England following different previous crops, 1990-2006 (Source: Defra NVZ Action Programme consultation document D3, 2007).

Greenhouse gas emissions in potato rotations

Background

The atmospheric abundance of the greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has increased considerably over recent years as a result of human activity. Emissions of N_2O and CH_4 are particularly important, as their respective global warming potentials are 310 and 21 times greater than CO_2 (IPCC, 2007). As a signatory to the Kyoto Protocol, the UK has agreed to achieve a reduction in GHG emissions of 12.5% of 1990 levels by 2008-2012. Furthermore, GHG emission reductions are required from agriculture (in common with all other sectors) in order to meet the reduction targets set by the UK Climate Change Act 2008, as detailed in the Low Carbon Transition Plan recently published by DECC. It has therefore been necessary to establish a national inventory of GHGs, which aims to accurately assess all anthropogenic sources, including N_2O, CH_4 and CO_2. Currently, the UK GHG Inventory is calculated annually using the default Intergovernmental Panel on Climate Change (IPCC) methodology (IPCC, 1997).

The current UK greenhouse gas emissions inventory (MacCarthy *et al*., 2010, inventory year 2008) estimates that 75% of nitrous oxide is produced from agriculture, amounting to 82,070 tonnes N_2O (25,443,160 t CO_2e). Approximately 60% of the N_2O produced from agriculture is *directly* emitted from agricultural soils e.g. following the application of livestock manures and manufactured N fertiliser and after the incorporation of crop residues. Less than 10% of agricultural N_2O is emitted from manure management and *c*. 30% is emitted *indirectly* from soils from two mechanisms, namely: following initial N loss via ammonia (NH_3) volatilisation/NO_x emission (*c.* 20%) or nitrate (NO_3^-) leaching (*c.* 80%). Nitrogen directly lost from agricultural soils, either by NO_3^- leaching or NH_3 emissions to the atmosphere, may subsequently become potentially available for loss as N_2O.

Both *direct* and *indirect* soil N_2O emissions can be estimated using IPCC default emission factors (EFs). The default EF for *direct* soil emissions, which is used in the current UK GHG inventory, states that there is a linear relationship between N applied and N_2O emitted, where 1.25% of total N applied remaining after NH_3 loss (10% of total N applied) is emitted as N_2O-N (IPCC, 1997). As a result of new global research and scientific understanding, the 1996 (revised) IPCC inventory methodology has recently been updated, such that the default value for *direct* soil emissions has been reduced to 1.0% of total N applied lost as N_2O-N and no longer takes account of NH_3 loss before the N_2O EF is applied (IPCC, 2006). Furthermore, the EF used to calculate *indirect* N_2O losses following NO_3 leaching has also been reduced from 2.5% to 0.75% of leached N is lost as N_2O-N (IPCC, 2006). Defra, however, has no immediate plans to use the IPCC 2006 methodology to calculate N_2O emissions from agricultural soils in the UK GHG inventory (Cardenas pers. comm.).

Nitrous oxide emissions from agricultural soils are predominately produced via the microbially mediated processes of nitrification and denitrification (Firestone and Davidson, 1989). The key factors which control the magnitude of N_2O emissions include; soil mineral nitrogen content (particularly soil nitrate), soil temperature and soil moisture content (Dobbie & Smith, 2001; Dobbie & Smith, 2003).

Nitrous oxide emissions from potato crops

The current UK GHG inventory EFs used to calculate soil N_2O emissions do not distinguish between crop type or N source, although there is evidence that some differences may occur.

Following a literature search we were able to identify a limited number (5) of published papers where N_2O emissions had been measured from potato crops in the UK, as well as a handful (5) of published non-UK studies to provide additional supporting evidence. Table 3.3.2 shows summary details of the UK and non-UK field experiments where N_2O emissions were measured from potato crops and in some cases where N_2O emissions were also measured from cereals at the same site or under similar conditions (e.g. soil type, climate etc.). Dobbie & Smith (2003) analysed the data of N_2O EFs determined at sites in Great Britain (predominantly Scotland) during 1992-2001 and concluded that the magnitude of the EFs for potato crops are similar to those for leafy vegetables (e.g. Broccoli) and grassland, and are greater than those EFs for small-grain cereal crops and oil-seed rape (Table 3.3.2). Such a finding was also reported by Buchkina *et al*. (2010) who measured smaller N_2O emissions from a barley crop compared to a potato crop at a site in north-west Russia, and also Ruser *et al*. (2001) who measured smaller emissions from a winter wheat crop compared to a potato crop at a site in Southern Germany (Table 3.3.2). In contrast, in central and eastern England N_2O emissions measured from potatoes, regardless of soil type or position in the crop rotation, were small and as shown in Table 3.3.2, the cumulative emissions were less than those from winter wheat (Webb *et al*., 2004). It should be noted that the N_2O EFs shown in Table 3.3.2 can not be directly compared to the IPCC default EF for *direct* soil emissions of 1.0% or 1.25%. This is because the EFs in Table 3.3.2 have not been corrected for 'background' N_2O emissions, whereas the IPCC default EF has. Furthermore, the majority of the EFs in Table 3.3.2 correspond to a sampling period of <12 months, whereas the default

IPCC EF is calculated over 12 months. The EFs in Table 3.3.2 do, however, indicate the range of EFs measured from potatoes and how they compare to other crops.

There appear to be a number of reasons why N_2O emissions from potato crops may potentially be greater than from small-grain cereal crops and oilseed rape and why emissions from potatoes do not necessarily fit the linear relationship between N applied and N_2O emitted adopted by the IPCC.

a) Cultivation technique (and fertiliser N placement)

Potato cultivation is distinctly different from that of cereals with 18% of UK potatoes grown in wide beds and 82% in rows i.e. ridges and furrows (Mohammed pers. comm.). As a result of the soil management required to produce potatoes in beds or rows, potato fields are likely to have a large spatial variability in soil properties (Ruser *et al*., 1998), especially compared to cereal production. Nitrous oxide emissions may be considerably influenced by differences in soil bulk density and soil pore size distribution between the ridge soil, the uncompacted furrow soil and the tractor (and other machinery) compacted furrow soil. Soil compaction by tractor traffic in potato fields is likely to be more significant than in fields cropped with cereals. This is because the working width of the implements used for planting and ridging up are commonly relatively narrow and because the field is passed over several times with plant protection products (Ruser *et al*., 1998). In particular, when large emissions from potatoes have been reported, it is the N_2O measured from the furrow areas that are a key cause, contributing a large proportion to the total emission. Emissions of N_2O in Scotland were 3 to 5 fold greater from the furrow area than from the ridges (McTaggart *et al*., 1996; Smith *et al*., 1998), 1.5 to 14 fold (Ruser *et al.*, 1998; Ruser *et al*., 2001) and up to 1.5 fold greater from the furrows (Buchkina *et al*., 2010) in southern Germany and north-western Russia, respectively. The furrow areas tend to have a higher water filled pore space (WFPS), a measure of soil moisture, generally as a result of a higher soil bulk density (especially in tractor compacted furrows), which may be exacerbated by surface runoff of water from the ridge and rain-water accumulating in the furrows (Smith *et al*., 1998; Ruser *et al*., 2001). Indeed, in an experiment in Germany, the furrow soil compacted by tractor traffic was the major contributor (68%) to the overall field N_2O emission from the cropping period (Ruser *et al*., 1998). Additionally, Ruser *et al*. (2001) suggested that poor rooting of potato plants in the furrows may reduce the crop uptake of water, which may also contribute to a greater soil moisture content than in the potato ridges. Although the response of N_2O to soil moisture content is typically non-linear, the largest emissions frequently occur under anaerobic soil conditions i.e. when the soil is relatively wet, but not saturated. Emissions are therefore likely to be greater from the wet furrow soil, as opposed to the drier soil in the ridges.

Another major factor contributing to greater N_2O emissions from potato furrows compared to potato ridges is the higher soil nitrate contents frequently reported in the furrows. Placement and/or subsequent movement of fertiliser N may be highly important in determining the size of N_2O losses. Ruser *et al*. (2001) reported, that despite the fact that the N fertiliser was applied using a broadcast spray, the soil nitrate content in the furrows were 3x greater than compared to the ridges. The authors attributed the greater soil nitrate content to transport of the fertiliser N from the ridges onto the furrows via surface runoff or lateral leaching, and a low N uptake from a poorly rooted furrow soil. These results indicate that placement of N fertiliser may significantly influence the size of the N_2O emission and that direct placement of fertiliser into the ridge soil may reduce nitrate contents of the furrows and hence reduce N_2O emissions (Ruser *et al*., 2001).

In the UK there is a minority of potato growers who currently use nitrification inhibitors, which is in contrast to cereal growers who currently do not use them. Nitrification inhibitors may be injected into the seed bed in order to slow down the conversion of ammonium to nitrate so that N availability is more in sync with crop N uptake. Nitrification inhibitors are also a potential mitigation method to reduce N_2O losses from agriculture and are being investigated in more detail in Defra project AC0213 – 'Potential for nitrification inhibitors and fertiliser application timing strategies to reduce direct and indirect nitrous oxide emissions from UK agriculture', although potatoes are not one of the crops being studied. In the UK, the effect of nitrification inhibitors on N_2O emissions from potatoes has, however, been studied in one experiment in Scotland (McTaggart *et al*., 1996). The emissions from potato ridges were not reduced following the spay application of dicyandiamide (DCD) nitrification inhibitor concurrently with either the injection of urea ammonium nitrate (UAN) or the incorporation of ammonium nitrate (AN) granules into the ridges. There was an indication of reduced N_2O emissions from the furrows. The authors attributed the lack of a strong mitigating effect to the failure of the DCD to efficiently come into contact with the N fertiliser.

To our knowledge there are no N_2O emission experiments that have been carried out in the UK or abroad that have grown potatoes using the bed system. It is likely that N_2O emissions from such a system may not be as large as from those from a ridge & furrow system, since there will be a smaller proportion of the cropped area in the wet furrow like situation prone to increased water filled pore space and potentially large N_2O emissions.

b) Irrigation/rainfall

The WFPS of the soil is controlled by the water addition processes of rainfall and irrigation, and the water removal processes of evapotranspiration and drainage. Consequently, the amount and distribution of rainfall is frequently considered to be a strong driver of N_2O loss, particularly during the crop growing season. Following N fertiliser application N_2O emission from soil is unlikely to be limited by the mineral N content and, therefore, temperature and moisture are likely to be more critical in influencing the magnitude of loss.

A consistent conclusion from all the field experiments, whether carried out in the UK or abroad, was that with soil N not limited and following heavy rainfall, large N_2O emissions were measured during the warm months of the potato growing season. In particular, re-wetting of dry soil stimulated short-term pulses of high N_2O emissions (Ruser *et al*., 2001, Webb *et al*., 2004). These emissions are commonly short-term episodic events that develop with the onset of anaerobic soil conditions, as a result of the increase in soil WFPS.

Irrigation of potatoes has also been shown to induce high N_2O emissions e.g. on a loamy sand in central England (Webb *et al*., 2004), although this did not result in a large total annual N_2O emission (Table 3.3.2), possibly due to the very light sandy soil at the site. On a heavier soil, the effect of irrigation is likely to lead to much greater emissions of N_2O, because the soil WFPS will be maintained at a higher value where anaerobic soil conditions are more probable. Weekly irrigation (40-60 mm each occasion) of a Spanish potato crop, grown on a clay loam soil, kept the soil at a WFPS ideal for the production of N_2O and a subsequent relatively high total emission (Table 3.3.2) (Vallejo *et al*., 2006). As just under half the UK potato crop is irrigated (Potato Council, 2010, Weatherhead, 2007) there is a potential for large emissions of N_2O in the warm summer months, although this may be influenced by soil type.

c) Incorporation of crop residues

Nitrous oxide emissions may also be produced following the incorporation of crop residues. Indeed Smith *et al*. (1998) found that N_2O emissions in Scotland following the potato harvest contributed to a large part of the total emission from potatoes and suggested this may be due to the development of anaerobic soil conditions as a result of the decomposition of potato residues. In other UK experiments, soil cultivation after potatoes and the incorporation of residues was also observed to stimulate N_2O emissions (Dobbie *et al*., 1999; Webb *et al*., 2004). High post potato harvest N_2O emissions were also measured in Germany, alongside elevated soil nitrate levels. The soil nitrate content from the potato field after harvest was significantly greater than was found in the wheat crop, a reflection of the composition of the crop residue (Ruser *et al*., 2001). At a southern German site when potatoes were grown for seed, following the killing off of potato tops (on the ridges) by herbicide application, more than 75% of the total N_2O emitted from the ridges during the cropping period was emitted (Flessa *et al*., 2002). The emission from the dead potato leaves and stalks were probably caused by nitrification and denitrification of the residue N.

It should be noted that the majority of the UK studies and the non-UK studies have measured N_2O emissions from potatoes at sites, which are generally in wetter areas (mean annual rainfall >830 mm) and are therefore more likely to experience conditions conducive to significant N_2O emission. The results from studies in the UK carried out in lower rainfall areas (mean annual rainfall 550-600 mm), that are typical of Eastern England where 27% of potatoes are produced and where there was a comparison with small-grain crops did not show greater N_2O emissions. In fact emissions were smaller from potatoes despite irrigation of some of the crops. It is evident that the local weather and soil conditions (particularly the amount and distribution of rainfall) is a key factor in determining the magnitude of the N_2O emissions from potato crops and that more research is required to fully understand the disparities in emission size observed to date.

Table 3.3.2. Summary of N_2O-N emission factors following the application of manufactured N to potato crops & comparable cereal crops

Reference	Soil type	Potato variety or crop & production method	N product applied & placement	Application rate (total N applied kg/ha) per application	Total N_2O-N emission (kg/ha)	Emission factor (% of total N applied)*	Length of N_2O sampling period	Location
UK field studies								
McTaggart *et al*., 1996	Sandy clay loam?	Unknown, rows	AN, incorporated into ridges	140	4.0	2.9	96 d	Midlothian, Scotland
Smith *et al*., 1998	Loam	Unknown, rows	AN, granules placed in ridges	170	3.1	1.8	Unknown	Midlothian, Scotland

Reference	Soil type	Potato variety or crop & production method	N product applied & placement	Application rate (total N applied kg/ha) per application	Total N_2O-N emission (kg/ha)	Emission factor (% of total N applied)*	Length of N_2O sampling period	Location
Smith *et al*., 1998	Loam	Unknown, rows	Urea, granules placed in ridges	170	3.2	1.9	Unknown	Midlothian, Scotland
Smith *et al*., 1998	Sandy clay loam	Unknown, rows	UAN, injected in ridges	140	1.2	0.9	~10 mo	Midlothian, Scotland
Smith *et al*., 1998	Sandy clay loam	Winter wheat	AN	180	0.3	0.2	~10 mo	Midlothian, Scotland
Smith *et al*., 1998	Sandy clay loam	Spring barley	AN	120	0.8	0.7	~10 mo	Midlothian, Scotland
Dobbie *et al*., 1999	Loam	Unknown, rows	AN, incorporated in seedbed	170	3.0	1.8	Growing season?	Midlothian, Scotland
Dobbie *et al*., 1999	Loam	Winter wheat	AN	200	0.7	0.4	Growing season?	Midlothian, Scotland
Dobbie *et al*., 1999	Sandy clay loam	Unknown, rows	AN, incorporated in seedbed	180	4.7	2.6	Growing season?	Midlothian, Scotland
Dobbie *et al*., 1999	Sandy clay loam	Winter wheat	AN	200	0.9	0.5	Growing season?	Midlothian, Scotland
Dobbie & Smith, 2003	Sandy loam	Unknown, rows	AN	165	2.4	1.5	12 mo	Mansfield, central England
Webb *et al*., 2004	Silty clay loam	Unknown, rows	AN	250	0.5	0.2	12 mo	Norfolk, East England
Webb *et al*., 2004	Silty clay loam	Winter wheat	AN	180	1.1	0.6	12 mo	Norfolk, East England
Webb *et al*., 2004	Loamy sand	Unknown, rows	AN	255	1.1	0.4	12 mo	Mansfield, central England
Webb *et al*., 2004	Loamy sand	Unknown, rows	AN	270	0.6	0.2	12 mo	Mansfield, central England

Reference	Soil type	Potato variety or crop & production method	N product applied & placement	Application rate (total N applied kg/ha) per application	Total N_2O-N emission (kg/ha)	Emission factor (% of total N applied)*	Length of N_2O sampling period	Location
Webb *et al*., 2004	Loamy sand	Winter wheat	AN	180	1.0	0.6	12 mo	Mansfield, central England
Non-UK field studies								
Ruser *et al*., 1998	Silt loam	Calla, rows	UAN solution, broadcast spray	150	16.0	7.8	May - Sept	Southern Germany
Ruser *et al*., 1998	Silt loam	Calla, rows	UAN solution, broadcast spray	50	8.0	9.4	May - Sept	Southern Germany
Ruser *et al*., 2001	Silt loam	Calla, rows	UAN solution, broadcast spray after planting	150	4.2	2.8	April - Oct	Southern Germany
Ruser *et al*., 2001	Silt loam	Calla, rows	UAN solution, broadcast spray after planting	50	2.4	4.8	April - Oct	Southern Germany
Ruser *et al*., 2001	Silt loam	Winter wheat	UAN solution, broadcast spray	180	2.1	1.2	April - Oct	Southern Germany
Ruser *et al*., 2001	Silt loam	Winter wheat	UAN solution, broadcast spray	90	1.3	1.4	April - Oct	Southern Germany
Flessa *et al*., 2002	Silt loam	Solara, rows	Unknown	75	1.6	2.2	May - Sept	Southern Germany
Flessa *et al*., 2002	Silt loam	Agria, rows	Unknown	40	2.0	5.5	May - Sept	Southern Germany
Vallejo *et al*., 2006	Clay loam	Desiree, rows	Pig slurry,	175	5.6	3.2	Mid May – mid Oct	Madrid, Spain
Vallejo *et al*., 2006	Clay loam	Desiree, rows	Urea	175?	7.3	4.2	Mid May – mid Oct	Madrid, Spain

Reference	Soil type	Potato variety or crop & production method	N product applied & placement	Application rate (total N applied kg/ha) per application	Total N_2O-N emission (kg/ha)	Emission factor (% of total N applied)*	Length of N_2O sampling period	Location
Buchkina *et al*., 2010	Sandy loam	Unknown, rows	AN, 1st split broadcast before ridge formation, 2nd split to furrows	120	R = 1.1 F = 1.5	R = 0.9 F = 1.3	End April – early Oct	North-west Russia
Buchkina *et al*., 2010	Sandy loam	Barley	AN	110	0.8	0.7	End April – early Oct	North-west Russia
Buchkina *et al*., 2010	Sandy loam	Unknown, rows	AN, 1st split broadcast before ridge formation, 2nd split to furrows	120	R = 0.6 F = 0.9	R = 0.5 F = 0.8	End April – early Oct	North-west Russia

*uncorrected for 'background' emission and therefore not directly comparable to the IPCC default soil EF.

Methane emissions from potato crops

Currently, both of the standard IPCC methodologies (IPCC, 1997; IPCC, 2006) do not include a specific EF for direct CH_4 emissions from soils, recognising that in most circumstances (i.e. under aerobic soil conditions) emissions are likely to be low. However, within the manure management section of the IPCC methodology, it is acknowledged that there is a small emission e.g. from dung/urine deposited during grazing. Indeed, well-drained aerated soils can act as a sink for CH_4 (Yamulki *et al*., 1999). The notable exception is CH_4 emissions associated with paddy rice farming, where soil conditions are anaerobic and these emissions are included in the IPCC methodologies.

Methane emissions from potato crops have not been reported from the UK, although they have been measured in Germany (Ruser *et al*., 1998; Flessa *et al*., 2002). Methane uptake by the soil in the potato field was measured, particularly from the well aerated ridge soil. Tractor compacted furrows, however, were a source of CH_4 emissions due to their anaerobic status (Ruser *et al*., 1998). Neither CH_4 uptake nor emission was of a significant amount and roughly balanced each other out.

Diffuse pollution of plant protection products (PPPs)

Pesticide usage data has been collated from across Great Britain for the last 40 years. Surveys, which are funded by the Chemical Regulation Directorate (CRD)[8], collate data at regular intervals for each agricultural sector, which allows comparisons between crops and of individual crops over time to be made. Data for arable crops are collected every two years and the last year for which data are available is for crops sown or planted between autumn 2007 and harvested in 2008. Considered as a whole, pesticide applications to wheat constituted 58% of the total weight of active substance applied. By this measure, the third largest use of pesticides (9% of the total) by weight of active substance was applied to ware potato crops (excluding sulphuric acid, which at the time the survey was carried out, was still available as a desiccant, see below). Ware potato crops were, however, recorded as only representing 3% of the total arable crop area in 2008, suggesting a higher intensity of pesticide usage in this sector. Seed potatoes, which are mainly grown in Scotland, were recorded to have used 1% of the total weight of active substances applied and also to represent 1% of the total arable crop area.

Between 1998 and 2008 there has been a 39% reduction in the total weight of pesticides applied to arable crops in Great Britain. A large contributing factor to this decline has been the reduction in use of sulphuric acid as a desiccant, primarily on ware and seed potato crops. Between 1998 and 2008, use of sulphuric acid on ware and seed potato crops has declined from 12,726 tonnes to 1,032 tonnes. In contrast to the overall reduction in weight of active substance applied to arable crops, the same period has seen the number of products per crop rise from nine to 13, while an increase in treated area but decrease in total crop area has seen the average number of sprays applied to all crops rise from 4 to 6. Herbicides and fungicides are the dominant groups of pesticide both in terms of percent of total pesticide treated area and the percent of total weight of active ingredient (Table 3.3.3).

Table 3.3.3. Pesticide usage on arable crops in Great Britain in 2008 (Source: CRD Pesticide Usage Survey).

Pesticide	% of total pesticide treated area	% of total weight of active substance applied
Herbicide	30	44
Fungicide	38	27
Insecticide & Nematicide	9	2
Seed treatment	9	-
Molluscicide	3	3
Growth regulator	10	17
Desiccant	<1	6
Biological control agents	<1	-

Of the national statistics described, ware potatoes accounted for 10% of the total mollusicide treated area and 9% of the fungicide treated area (see report no. 224). Ware potato crops also accounted for all biological control agent (the nematode *Phasmarhabditis hermaphrodita* used to control slugs) use in arable crops. When compared with other arable and non-arable crops by weight of active substance,

[8] http://www.fera.defra.gov.uk/plants/pesticideUsage/fullReports.cfm accessed 5 February 2011

ware potato crops can be seen to have relatively high input of plant protection products (PPPs) (Figure 3.3.3).

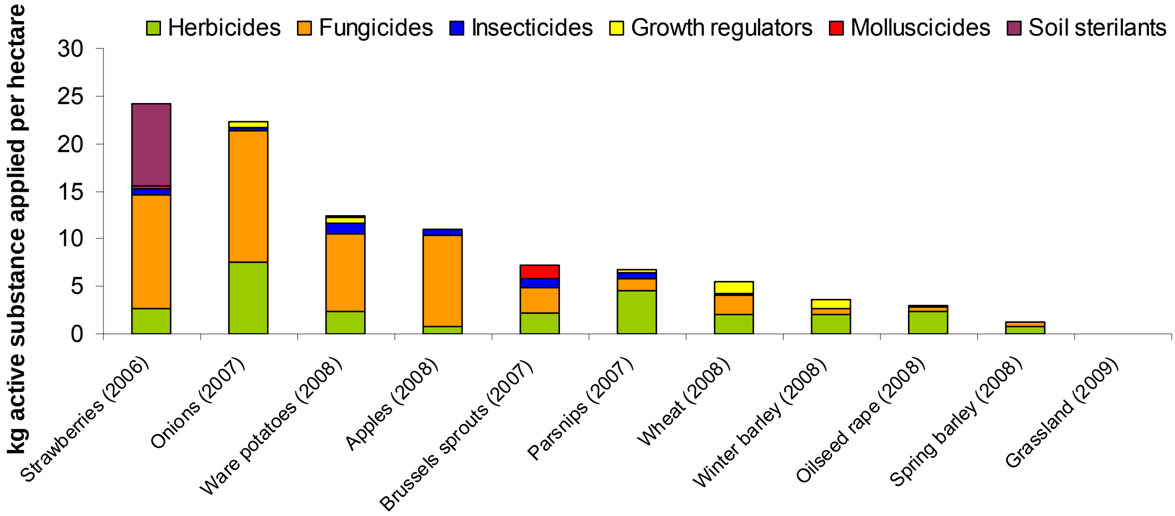

Figure 3.3.3. Pesticide average inputs per crop (kg active substance applied per crop) in Great Britain (Source: CRD Pesticides Usage Survey 2008).

On average, ware potato crops in Great Britain received 11 fungicides, three herbicides, two molluscicides and one insecticide applications in 2008 (see report no. 224). Most fungicide applications were made between June and September, principally for the control of blight (*Phytophthora infestans*). In total, these fungicide applications applied approximately 1,000 tonnes of active substance to ware potato crops in this year, with the entire potato crop receiving at least one application. Herbicide applications, including desiccants, were applied throughout the season, but with a peak in May. In total, these herbicide applications applied approximately 300 tonnes of active substance to ware potato crops and again almost all crops received at least one application. Insecticide and nematicide applications were primarily made in April, June and July. Most applications (96%) were for the control of aphids, however, in terms of weight of active substance applied, this was dominated by applications of products for control potato cyst nematode. In total, insecticide and nematicide applications applied approximately 150 tonnes of active substance to around two thirds of ware potato crops. Molluscicide applications totalled 29 tonnes of active substance of which 55% was metaldehyde and 43% methiocarb. The only growth regulator recorded from the 2008 survey was maleic hydrazide. Applications of this product were made between July and September and amounted to 76 tonnes of active substance.

By comparison with ware potato crops, seed potato crops received fewer fungicides and molluscicides but more insecticides and nematicides (see report no. 224). Again, fungicides were primarily applied for the control of blight and herbicides for general weed control and pre-harvest desiccation. Similarly, insecticide applications were mainly applied for control of aphids, which for seed potato crops are of particular concern due to the risk of virus transmission.

Data for 2008 shows ware potatoes to be a high input crop in terms of PPPs applied compared to other arable crops. In terms of weight of active ingredient (excluding desiccants as reductions in use of sulphuric acid mask any other changes that may be apparent) applied per hectare of crop between 1996 and 2008 (based on data presented in reports 224, 213, 202, 187, 171, 159 and 141) there has been an 8% increase for potato crops (ware and seed potato crops). By comparison, over the same period wheat has seen a 3% increase while for oilseed rape there has been a 40% increase (Figure 3.3.4). These changes have meant that over this 12 year period PPP inputs to potato crops have remained approximately two and half times higher than inputs to wheat. However, the difference in inputs between potato crops and oilseed rape crops has declined from five times higher to four times higher. For potato crops, this recorded increase in weight of active substance is largely due to an increase in fungicide use. This increase is in large part be due to more aggressive blight strains, which require more frequent applications. As a result, the total number of spray applications between 1998 and 2008 for ware potatoes has risen from 12 to 15 (Figure 3.3.5) while the number of products applied has risen from 15 to 21 over the same period. Over the same period numbers of spray applications to wheat have increased from 5.5 to 7 and for oilseed rape crops from 4.5 to 7. Similarly, the number of products applied to wheat has increased from 11 to 15 and for oilseed rape from seven to 11 over the same period.

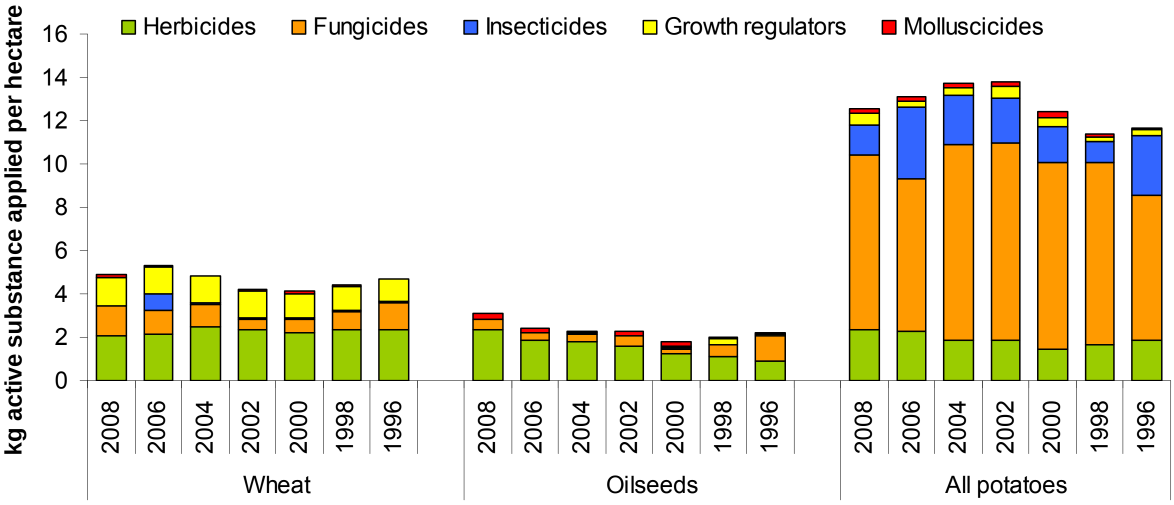

Figure 3.3.4. Pesticide average inputs per crop (kg active substance applied per crop) in Great Britain 1992-2008 (Source: CRD Pesticides Usage Survey).

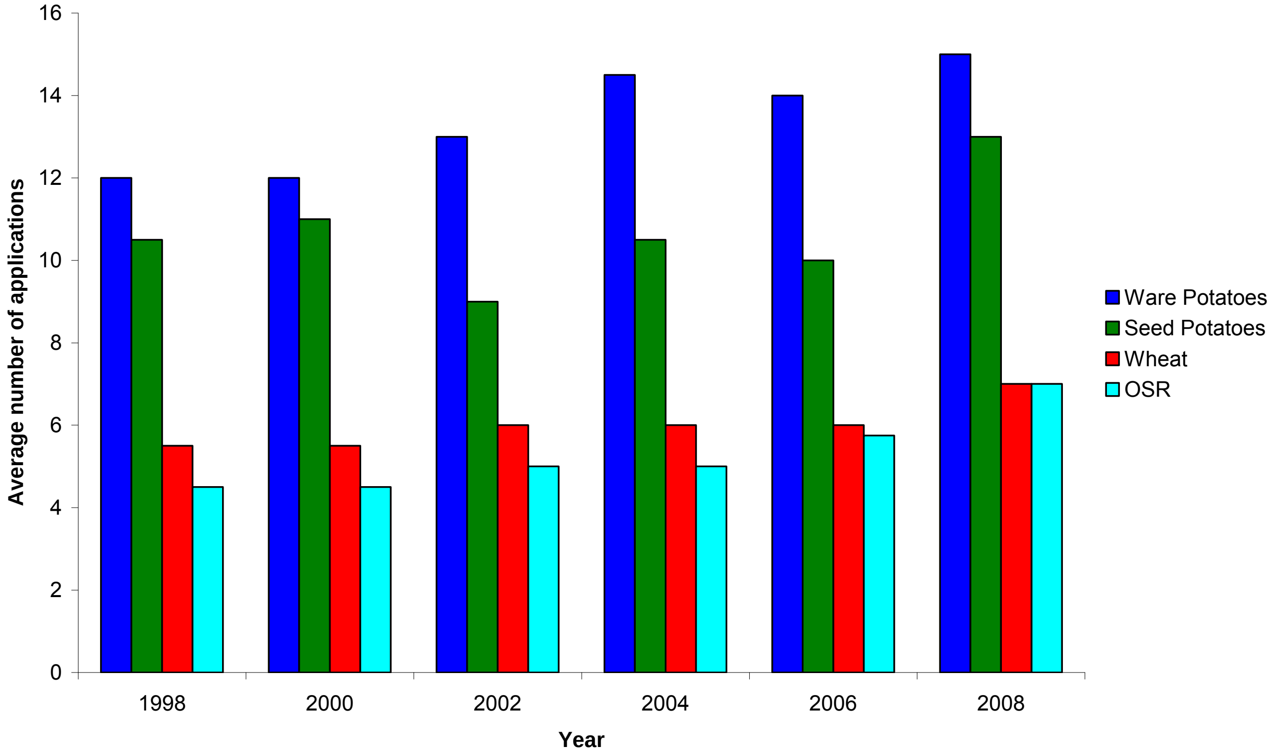

Figure 3.3.5. Average number of pesticide applications (Source: CRD Pesticide Usage Survey).

Impacts of Plant Protection Products

The above quantifies the amounts of pesticides used on the potato crop. However, it is widely accepted that quantity of use if not a reflection of impact. It is also difficult to specifically demonstrate the specific impact of pesticide use on a potato crop separately from other pesticides used in the area. The potential environmental impacts of pesticides are assessed as part of product approvals, and they have to meet high standards to receive approval. This process considers effects on ecotoxicology and fate in soil and water. Implications on biodiversity are very difficult to tie to specific crops or pesticide use, as they are affected also by season, management practices and other impacts. The Pesticides Forum Annual report (available from http://www.pesticides.gov.uk/pesticides_forum_home.asp) annually comments on impacts of pesticide use. The potato crop is not implicated as having specific impact within these. The pesticides used on potatoes are generally not those detected in water, apart from metaldehyde, used to control slugs in many crops in which potatoes are grown as well as potatoes.

It is further relevant to note that pesticides protect yield from weeds, pests and diseases and to ensure that other implications are minimised. As an example carbon footprint per tonne is a factor of yield and total inputs; hence lower footprints per tonne result from achieving from higher yields at the same level of inputs. The impacts of carbon use from pesticides are generally small.

Conclusions

The potato crop is nutrient hungry and commonly receives large inputs of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) as manufactured fertiliser and supplied in organic manures. Crops also require protection from diseases, most notably potato blight, weeds and pests, including aphids that can transmit plant viruses and potato cyst nemeatodes (PCN), which can severely reduce yield potential. With these inputs together with land management practices, including cultivation and irrigation, there is the potential for pollution associated with growing potatoes. Losses of sediments and nutrients from the potato crop may lead to pollution of surface and ground waters as well as the atmosphere through the release of greenhouse gases.

As a spring planted crop, nutrient and sediment losses may be higher overwinter where land is left without a cover crop. Cover crops are not widely used in the UK but in some mainland European countries these crops are used to reduce nitrate leaching. Larger amounts of nitrogen may also be lost as a result the intense cultivation used to prepare land for potato crops compared to crops grown in land prepared using minimum tillage.

Potato crops have the potential to emit significantly greater amounts of nitrous oxide (a gas with a global warming potential that is 310 times greater than carbon dioxide) than from small-grain cereal crops and oilseed rape. Emissions of nitrous oxide and another greenhouse gas, methane, are strongly influenced by levels of soil nitrate, soil moisture and soil compaction. These factors are in turn determined by rainfall, crop irrigation, wheelings from machinery, fertiliser inputs and incorporation of crop residues. Therefore, there is the potential to reduce greenhouse gas emissions by modifying these inputs as well as through increased adoption of nitrification inhibitors if their potential as a N_2O mitigation technique is realised.

Potato crops receive more pesticide applications than other arable crops. Compared with cereal crops, the higher total number of pesticide applications made to potato crops is largely due to the regular use of fungicides for the control blight.

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Glossary

Denitrification – the biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

Evapotranspiration – the sum of evaporation and plant transpiration from a given area.

Global Warming Potential - The Global Warming Potential (GWP) is a means of providing a simple measure of the relative radiative effects of the emissions of various gases. The index is defined as the cumulative radiative forcing between the present and a future time horizon caused by a unit mass of gas emitted now, expressed relative to that of CO_2.

Nitrification – the biochemical oxidation of ammonium to nitrate, predominantly by autotrophic bacteria.

Soil bulk density – the mass of dry soil per unit of bulk volume including the air space.

SMN – Soil Mineral Nitrogen. The sum of nitrogen present in the soil in the forms of nitrate and ammonium. This component of soil nitrogen is highly soluble, and is the fraction which is both available for uptake by plant roots, and also vulnerable to leaching losses in water moving to groundwaters and to surface water systems via installed drains.

Soil N supply – Soil Nitrogen Supply (SNS) to plants is measured as the total of soil mineral nitrogen and nitrogen taken up by crops.

3.4. Carbon footprint and energy use

Carbon footprint assessment

A carbon footprint is the same as a statement of GHG emissions (see Section 3.3) and can be defined simply as the impact on global warming, of the thing being assessed. A carbon footprint can be assessed for organisations (e.g. businesses), products, or services. For assessment of potato production, a method for the assessment of a product is appropriate. Product carbon footprint assessment can be defined as the life cycle greenhouse gas (GHG) emissions of a product or organisation.

A carbon footprint is usually expressed as mass of carbon dioxide equivalent (kg CO_2e) per product unit (e.g. 1 kg or tonne of potatoes). An assessment includes emissions of CO_2, and other gases that have global warming potential, such as nitrous oxide (N_2O), methane (CH_4) and some refrigerant gases. Emissions of N_2O are important in crop production and they have high global warming potential relative to CO_2. The contribution of non-CO_2 gases to the carbon footprint is calculated as the mass of CO_2 that would have the equivalent global warming potential as the mass of other gases emitted.

PAS 2050 (Specification for the assessment of life cycle greenhouse gas emissions of goods and services[9]), was published by the British Standards Institution (BSI) in October 2008 and is used in many parts of the world for product carbon footprint assessment. PAS 2050 builds on existing life cycle assessment (LCA) methods in ISO 14040 and ISO 14044, and is an attributional approach. Attributional LCA provides information about the impacts of processes used to produce (and consume and dispose of) a product, but does not consider indirect effects arising from changes in the output of a product. In contrast, Consequential LCA provides information about the consequences of changes in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product (Brander *et al.,* 2008).

For emissions from soils, which are important in crop production, PAS 2050 refers to the IPCC Guidelines for National Greenhouse Gas Inventories.

Methods for carbon footprint assessment are developing and a revised edition of PAS 2050 is expected during 2011. Other methods are also in development, most notably ISO 14067 for carbon footprint assessment of products, and a Greenhouse Gas Protocol method for product assessment. These methods are at draft stage (in February 2011).

For assessment of a product carbon footprint using the PAS 2050 method, spreadsheet tools can be used, including the Carbon Trust Footprint Expert tool, which is designed to enable verification of an assessment by the Carbon Trust. Another tool in development is the Cool Farm Tool developed by Unilever.

Product carbon footprint assessments have defined assessment boundaries and these can vary between methods. For example, emissions associated with the

[9] http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050 accessed 3 February 2011.

manufacture of capital goods (e.g. tractors, farm buildings) can be included or excluded. This is why it is important to use a defined method that is recognised and widely accepted. PAS 2050 is currently the leading method for product assessments, and has the following exclusions:

- Human labour, animal transport
- Transport of workers and retail consumers
- Embedded emissions in capital goods
- Offset mechanisms
- Indirect land use change

These exclusions make PAS 2050 easier to apply because the excluded emissions can be difficult to assess and often do not make a major contribution to a carbon footprint. Embedded emissions in capital goods (i.e. emissions associated with making and supplying capital goods such as machinery and buildings) are usually associated with a large amount of production, so emissions per tonne can be small. Offset mechanisms are usually considered to lie outside the boundary of a system being assessed, but can be reported separately. Similarly, indirect land use change (ILUC) is usually considered to lie outside the boundary of a system being assessed, and is usually excluded from attributional LCAs.

We can define ILUC as conversion of non-agricultural land to agricultural land as a consequence of changes in agricultural practice elsewhere. It is difficult to assess ILUC emissions, but these emissions are of great importance in food production. For example, sub-optimal N application can decrease GHG emissions and yield, but there will be consequences for production. If yield falls more land is required somewhere else to supply market demand. Although assessment of emissions from ILUC is not included in PAS 2050, ILUC should not be ignored in the interpretation of a carbon footprint assessment, nor in the development of improvement strategies.

Example carbon footprint assessments of potato crops

Potato carbon footprint assessment results are shown in Table 3.4.1. These data show a large range of carbon footprint values from 117 kg CO_2e per tonne, to 640 kg CO_2e per tonne. These carbon footprints were assessed with similar methods, all using an attributional LCA approach, and most following PAS 2050.

The range of carbon footprint values is, perhaps surprisingly, large. However, when the large differences in production systems are considered, the carbon footprint assessments appear more consistent. There is a trend towards higher emissions with increasing length of storage, and high emissions are also associated with imported potatoes (in these examples), and with crops that have relatively low yields (e.g. for unstored crops, earlies and second earlies compared with maincrops). An exception to this latter point is organic crops, which tend to have lower yields than conventional crops, but do not have higher carbon footprints in these examples. In organic production systems the relative disadvantage of lower yields, leading to higher emissions per tonne, trades off against avoided emissions from artificial N fertiliser manufacture and lower emissions of N_2O from soil because there is usually less N applied.

The third column of Table 3.4.1 gives the percentage of the carbon footprint attributable to energy use, where this information is available. The energy included in these percentages is energy used for field operations and storage. For UK produced potatoes, energy for transport of produce is not included in this percentage, but for imported potatoes, energy for transport to the UK is included. Because the boundaries of the production systems assessed, and the way data are presented in reports, both vary, it is difficult to make comparisons of the energy component in a consistent way. Nonetheless, there are indications from the data that energy is always an important contributor to the carbon footprint of potato production. As would be expected, the importance of energy varies with the length of storage. Typically, based on ADAS assessments, the emissions from field energy use (diesel for tractors and other machinery) vary between 15% and 25% of the total carbon footprint for production.

Although carbon footprint values show large variation between assessments, there are some common features in the breakdown of the total between components. An example footprint breakdown is shown in Figure 3.4.1. Fertilisers typically contribute a large portion of the footprint, in this case 30%, and a large majority of this is the carbon footprint of N fertiliser manufacture and supply. Indeed, Hillier et al. (2009) suggested N fertiliser inputs were largely responsible for explaining differences in carbon footprints between crops. Nitrogen fertiliser manufacture is energy intensive and also can emit N_20 which is a potent greenhouse gas. Soil emissions of N_2O occur as a consequence of N fertiliser application, and this is also typically a large contributor to carbon footprints of potato production, and to carbon footprints of the production of many other crops.

Table 3.4.1. ***Potato carbon footprint values (kg CO_2e/t) and contribution of farm energy use (%). Crops that were not stored were those described as fresh, imported crops, earlies or second earlies. Storage period was not consistent between stored crops.***

Type of crop	GHG Emissions (kg CO2e/t)	Contribution of farm energy use (%)	Source (Defra project code or organisation)
Pre-pack	164	35	FO0404
Processing	129	29	FO0404
Organic pre-pack	117	55	FO0404
UK maincrop fresh	150	Not available	FO0412
UK maincrop stored	300	Not available	FO0412
Israeli maincrop fresh	330	Not available	FO0412
Maincrop	149	65	IS0205
Second earlies	178	22	IS0205
Earlies	318	19	IS0205
Conventional	198	31	IS0205
Organic	173	30	IS0205
UK Maincrop (fresh)	110	20	FO0103
UK Maincrop (stored 4 months)	230	62	FO0103
UK Maincrop (stored 7 months)	280	69	FO0103
Israel Maincrop	480	40	FO0103
UK earlies	290	42	FO0103
Israel earlies	520	75	FO0103
Late stored potatoes	640	58	Branston[10]

For potato crop production the energy component is typically larger than for other arable crops because field operations are energy intensive, energy is used for irrigation, and storage can be energy intensive. The relative size of the energy component varies greatly with the type and duration of storage. Refrigerated storage has a high energy demand, especially during temperature 'pull-down' after store loading, and for long-term storage in spring and early summer when ambient temperature is higher than in the winter. Refrigeration units can also leak refrigerant gases, which can be important greenhouse gases and contribute to the carbon footprint.

[10] http://www.farmersguardian.com/home/arable/arable-news/pesticides-give-best-return-on-co2-levels/34146.article accessed 3 February 2011.

Seed production and transport (of seed and produce) are important but smaller contributors.

Pesticides make a very small contribution to a potato production carbon footprint because they are used in very small quantities. Of more significance is the energy used for application, related to number of passes, which is within the energy component. A consideration of even greater significance for pesticides is the benefit that applications have for yield and the effect of this on the carbon footprint. If pesticides were not applied yield would be lower and the carbon footprint per tonne would be higher, assuming other inputs did not change.

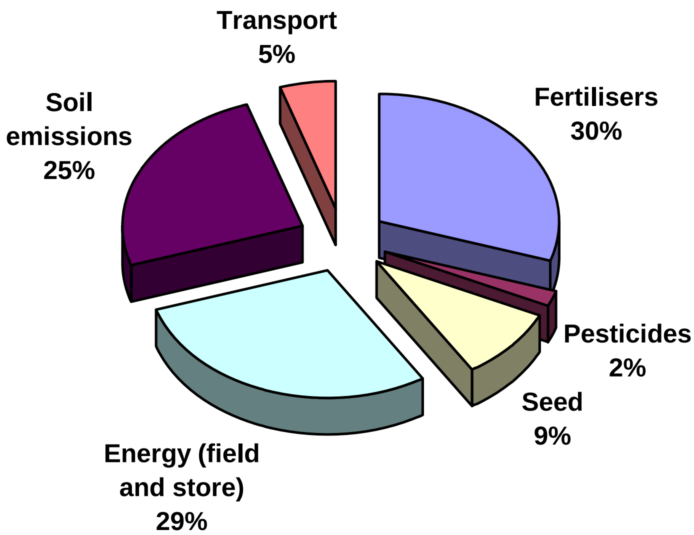

Figure 3.4.1. An example carbon footprint for processing potato production, showing the main components of the total footprint (based on data from Defra project FO0404). The energy component includes diesel used in the field and electricity for storage.

Comparison of potatoes with other crops

Some studies have assessed carbon footprints of several crops, increasing comparability compared with carbon footprints assessed in different studies. For example, Defra project FO0404 assessed a wide range of crop species.

Typical maincrop potato crops have a carbon footprint per ha that is higher than many other crops. Hillier *et al.* (2009) present carbon footprint results (to the farm gate) for legumes, spring cereal, winter cereal, winter oilseed rape and potato. Potato had the highest value (540 kg CO_2e/ha/yr) and legumes had the lowest value (125 kg CO_2e/ha/yr). Winter cereals had emissions of (388 kg CO_2e/ha/yr). However, to reflect the productivity of the crop, carbon footprint values are expressed per unit of production (e.g. tonne) rather than per ha.

In Figure 3.4.2. carbon footprints are shown for a wide range of foods, from Audsley *et al.* (2009). These values are expressed per tonne of fresh weight, regardless of nutritional content, so must be interpreted carefully. The products can be broadly categorised as follows:

- Over 12,000 kg CO_2e/t - red meats
- 2,000 to 6,000 kg CO_2e/t - other meats, together with vegetables produced under protection using heat
- Approximately 1,000 to 2,000 kg CO_2e/t - a range of low-yielding vegetables and milk (which has a high water content)
- Below 1,000 kg CO_2e/t - a large group of crop products.

Interestingly, of these 28 products, only brassicas have a lower carbon footprint than potatoes.

Of particular interest for comparison with potatoes are crops that fulfil a similar function in the diet, such as other vegetables and other high carbohydrate foods, and other bulky and perishable stored foods such as apples. In Table 3.4.2 carbon footprint values are given for products that make interesting comparisons with potatoes, and for some of these, they were assessed within the same study, which indicates consistency of assessment method. These data, which are case studies, not industry averages, show:

- Wheat emissions are high compared with potatoes;
- Apple production emissions can be higher or lower than potatoes depending on the system and case study details;
- Carrot production has higher emissions than potato production, but differences are not large;
- Emissions from production of rice are high compared with the other foods in 3.4.2.

***Figure 3.4.2.** Carbon footprints of producing a range of food commodities in the UK. (Source: Audsley et al., 2009).*

Table 3.4.2. Carbon footprints (kg CO_2e/t) of food products from three studies and contribution of farm energy use (%).

Type of crop	GHG Emissions (kg CO_2e/t)	Contribution of farm energy use (%)	Source (Defra project code or reference)
Pre-pack potatoes	164	35	FO0404
Processing potatoes	129	29	FO0404
UK Milling Wheat	640	7	FO0404
UK Apples (intensive)[1]	66	53	FO0404
UK Carrots[2]	350	20	FO0404
UK Maincrop (fresh)	110	20	FO0103
UK Maincrop (stored 7 months)	280	69	FO0103
UK Apples (fresh)	300	67	FO0103
UK Apples (stored 5 months)	350	72	FO0103
NZ Apples (fresh)	870	93	FO0103
NZ Apples (stored 3 months)	920	94	FO0103
Italian Rice	2400	Not available	Kagi *et al. (2010)*
USA Rice	2700	Not available	Kagi *et al. (2010)*
Upland rice	4500	Not available	Kagi *et al. (2010)*

[1]Ambient storage using minimal energy
[2]Stored under straw in the field

To help understand the significance of GHG emissions associated with the food we eat, it is useful to express the emissions per unit of dry matter to interpret assessments without differences in water content of the foods. Carbon footprints can also be expressed per unit of energy content. In Figure 3.4.3, moisture content and energy content data from the United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference[11] are used to compare carbon footprints per kg fresh weight of potatoes, carrots, wheat and rice (from Audsley et al., 2009), with carbon footprints per kg dry weight and per kJ energy content.

Potato carbon footprint was better than rice and carrot when expressed in all three ways. However, the carbon footprint of wheat, which is greater than that of potatoes when expressed per unit of fresh weight, is less than that of potatoes when expressed per unit of dry weight or per unit of energy content.

[11] USDA National Nutrient Database for Standard Reference, http://www.nal.usda.gov/fnic/foodcomp/search/ accessed 3 February 2011

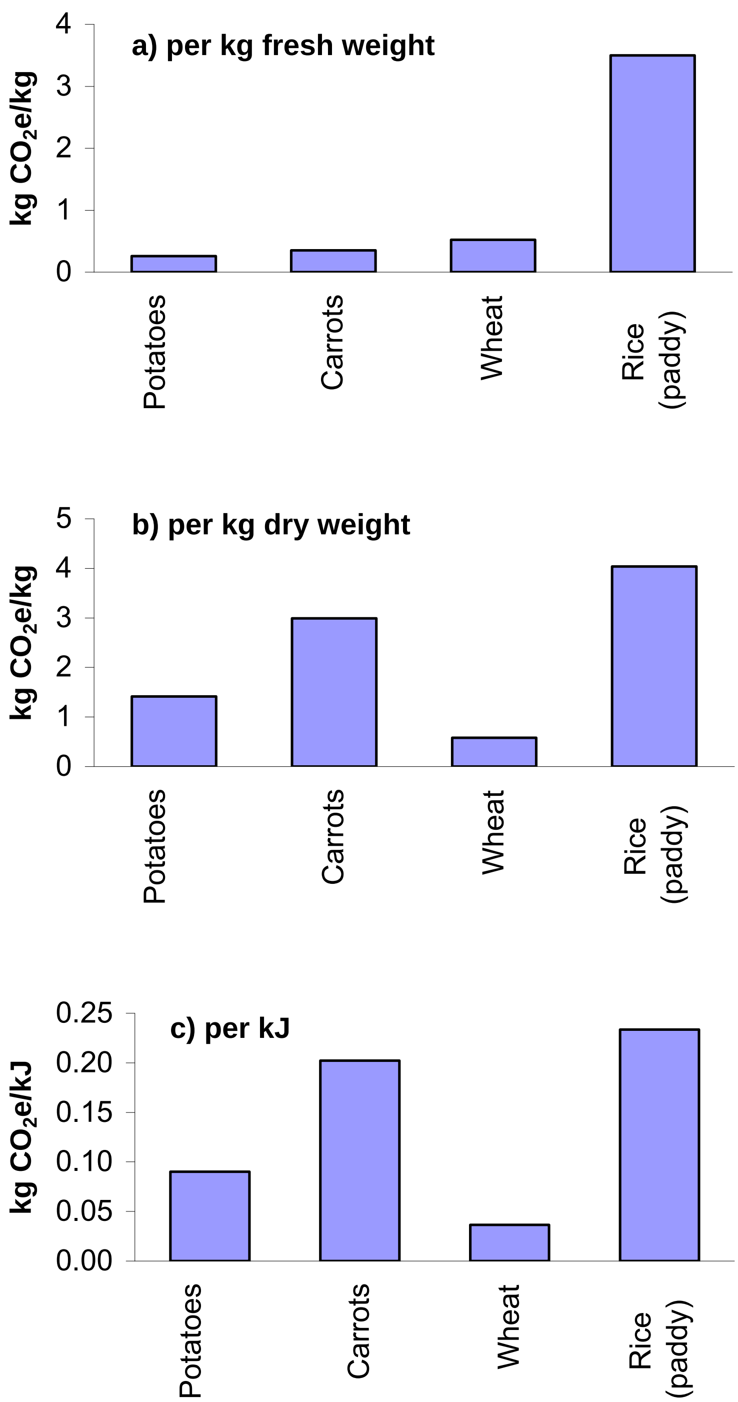

Figure 3.4.3.** **Carbon footprints of producing potatoes, carrots and wheat in the UK, and rice outside of Europe, based on from Audsley et al. (2009) and dry matter and energy contents from USDA[12]: a) kg CO_2e/kg fresh weight; b) kg CO_2e/kg dry weight; and c) kg CO_2e/kJ energy content.

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[12] USDA National Nutrient Database for Standard Reference, http://www.nal.usda.gov/fnic/foodcomp/search/ accessed 3 February 2011.

Conclusions

A carbon footprint is a way of expressing an impact on global warming in standard units of carbon dioxide equivalents (CO_2e). A carbon footprint may also be described as an amount of greenhouse gas (GHG) emissions. Important greenhouse gases emitted during the production of potatoes are carbon dioxide, nitrous oxide, methane and some gases used in cold store refrigerator units.

The carbon footprint of growing potatoes is not the same for all crops, and is dependent on many factors including: crop yield, efficiency of energy use, efficiency of fertiliser use, period of storage, and the need for transport. Use of pesticides (e.g. fungicides to control potato blight) helps to decrease the carbon footprint because it prevents yield loss to pests and diseases, and so minimises emissions per kg of potatoes.

Most crops have lower carbon footprints than most meat products. Within crops, those that are high yielding, such as potatoes, tend to have lower carbon footprints than those that produce lower yields. The carbon footprint of potatoes is, therefore, smaller than that of wheat grain, but when the carbon footprints are corrected for water or energy content, the carbon footprint of potatoes is greater than that of wheat grain.

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Glossary

Carbon footprint – is a statement of greenhouse gas emissions expressed as the impact on global warming.

3.5. Biodiversity

Within-crop biodiversity

There have been relatively few direct studies of biodiversity associated with potatoes, compared with other crops. However, in general, biodiversity in arable crops is strongly dependent on the weed flora (Marshall et al. 2003). Weed flora is important because it supports a high diversity of insect species as well as being important food resources for other taxa, including farmland birds (Holland et al., 2006; Vickery et al., 2009). Given the importance of weed flora in supporting biodiversity it is notable that root crops generally have lower weed species richness than cereals (Lososová et al., 2004; Tyšer et al. 2008), although between-field variation is higher due to more frequent disturbance (Lososová et al., 2004). Similarly, an experiment comparing six different crops in Northumberland recorded significantly lower weed cover in potatoes than in spring and winter cereals, spring beans and cabbage (Eyre et al., in press). The reduced weed cover in potatoes was attributed to repeated 'ridging' (not a common practice in the UK) to control weeds and prevent greening, and also to the dense canopy of potato foliage on the tops of ridges.

Eyre et al., (in press) recorded reduced weed cover in both conventional and organic potato crops compared with the other crops included in the study. However, O'Sullivan & Gormally (2002) recorded a greater abundance and diversity of carabid beetles in an organic potato crop compared with a potato crop managed conventionally. This difference was attributed to weed cover suggesting that although weed cover in potato crops may be low in comparison with other crops, management practice remains important in determining biodiversity. Indeed, in a farm scale study in Northumberland, differences in invertebrate assemblages were found, with some assemblages being characteristic of organic potatoes (Eyre & Leifert, in press).

Despite the generally lower weed species richness in potato crop compared with cereals for example, the impact that this may have on biodiversity may be in part off-set by the potato crop residues left following harvest. At one level, retention of potato crop residues may improve an often overlooked aspect of biodiversity, that of soil bacterial communities (Ceja-Navarro et al., 2010). Potato crop residues may also provide an important direct food source for some species of bird. In particular, potato residues have been used extensively by migratory greylag and pink-footed geese in the east of Scotland during winter (Newton & Campbell, 1973; Bell, 1988) although the value of potatoes is limited by the temporal availability of crop residues. A study of feral greylag geese in Yorkshire, English Midlands and Norfolk showed that they used harvested potato fields in July (McKay et al., 2006). In one survey, harvested potato fields were strongly preferred, as 20% of fields were used compared to availability of 2%. The status of feral greylag geese in relation to biodiversity is however controversial as they are a locally introduced, invasive species, and also cause damage to agricultural crops.

Another less controversial example of the benefit of root crop stubbles, which included potatoes, is provided by recent work in south west Poland (Orłowski & Czarnecka, 2007). In this study, root crop stubbles provided a more diverse annual weed seed diet for reed buntings, an amber-listed species in the UK, compared to cereal stubble and vegetables. This result contrasts with the reduced weed cover within the crop and may be of limited benefit if the land is quickly cultivated for a following autumn sown crop.

Fallow habitats - field headlands, margins and boundaries

Much of the biodiversity research that has looked at cultivated land has focused on uncropped areas, including headlands, field margins and boundaries. In potato crops, uncropped headlands are introduced to allow machinery to turn and are often the least productive areas of a field. Uncropped headlands are also used to avoid chemical contamination of watercourses (LERAPS) and to avoid drift of haulm destruction chemicals onto neighbouring crops and land.

Uncropped fallow areas, particularly in field headlands can support high populations of annual plants during the first year of establishment (Critchley et al., 2004). Fallow areas may then provide seed-rich habitats in winter and structurally diverse and botanically rich cover in summer (Vickery et al., 2009). Fallow areas, therefore, provide important resources for farmland birds. Areas with bare ground and a short open sward are used frequently by skylarks, woodpigeons and yellowhammers (Chamberlain et al. 2009). In addition, lapwings may also use these areas if they are away from field boundary features, such as hedgerows and woodlands. However, the benefits of fallow areas associated with potato crops will be dependent on suitable vegetation being allowed to develop, which in turn will depend on minimising disturbance associated with vehicular traffic for example. Areas managed following agri-environmental scheme recommendations are likely to provide most benefit.

Landscape biodiversity

Work by Hawes et al. (2010) has demonstrated the importance of spring cropping and mixed farming practices in increasing species richness of arable plant communities and potentially other biodiversity. Given the current dominance of winter wheat and oilseed rape in particular, potatoes as a spring planted crop may contribute to crop diversity at a landscape level. Mixed cropping at a farm-scale can also be beneficial for lowland farmland birds, with an average of 30% increase over 3 years of species of high conservation concern recorded in a field experiment in Bedfordshire (Henderson et al., 2009). However, this is dependent also on low pesticide regimes and provision of suitable habitat and food.

Insects as well as birds may benefit from landscape diversity. Bumblebees for example, require forage resources throughout the breeding season. Potatoes could provide a significant pollen source for bumblebees as they are, known to forage on the related woody nightshade (*Solanum dulcamara*) (Buglife[13]). However, insecticide applications could negate this potential benefit by reducing survival of bumblebees foraging in potato crops. Potatoes also flower for a relatively limited period of time and some hardly at all; despite this the crop may be important if other flowering plants are available locally throughout the season. The availability of sufficient pollen resources for bumblebees is of increasing importance given the decline in numbers of these insects in Europe over recent decades and their function as important pollinators for entomophilous (insect pollinated) crops (Carvell et al., 2007).

[13] Foodplants for Bees in the Countryside: http://www.buglife.org.uk/OneStopCMS/Core/SearchResults.aspx accessed 20 January 2011

Case study – yellow wagtails

The yellow wagtail (*Motacilla flava*) is a summer visitor to Great Britain, where it is most likely to be seen in central and eastern England, eastern Wales and southern Scotland (RSPB[14]). This species has been in decline since at least the 1980s, probably as a result of habitat loss and is now red-listed and of high UK conservation priority. A recent study in the East Anglian fens showed that yellow wagtails used cereal crops early in the breeding season but by June and July had shifted to potato crops (Gilroy et al., 2010). Occupancy of potato crops was low in May but by July the majority of territories were in potatoes. Nest survival rates and clutch sizes did not differ from those in cereals, although mean brood size at fledging might have been lower in potatoes. However, it does suggest that potatoes provided suitable breeding habitat later in the season when other crops were less suitable.

Conclusions

There have been relatively few direct studies of the biodiversity associated with potatoes, compared to other crops. As a spring crop with fallow areas, pollen supply and crop residues, there is potential for potatoes to contribute to the diversification of cropping, management and habitat at a landscape scale. However, the high levels of productivity and disturbance in the standing crop result in low weed populations and limit the value for associated faunal groups. Therefore, the greatest benefit to biodiversity is likely to come from potato crops managed following agri-environment scheme guidelines.

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[14] http://www.rspb.org.uk/wildlife/birdguide/name/y/yellowwagtail/index.aspx accessed 1 February 2011

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Glossary

Biodiversity – the variety of life, including genetic diversity. The simplest measure used is often species richness, the number of species present within an arbitrarily defined unit. This definition may be refined to take into account the relative abundances, biomasses or productivities of the coexisting species.

Red-listed species – in the UK, bird species can be split in to three categories of conservation importance – red, amber and green. Red-listed species are the highest in terms of conservation priority, needing urgent action. Red-listed species of bird may be either globally threatened, have declining UK breeding populations (at least 50% over the last 25 years) or a contracting breeding range (at least 50% over the last 25 years).

3.6. Waste

Waste happens throughout the supply chain, causes include disease, outgrades and deterioration during storage. In a recent project, the potato packers Solanum estimated that 42% of their fresh potatoes were lost as waste. Solanum identified the largest losses as defects removed after washing, defects removed during grading, failure at field level (e.g. bruising) and storage waste. While these losses are high, potatoes removed from the supply chain after washing may find alternative seconds markets, thereby reducing the overall losses. Waste reduction is of increasing importance and presents an opportunity to increase the amount of saleable crops without the need for further yield increases.

In a recent interview with Potato Pro, Dr Simon Bowen (representing Solanum[15]) stated that it is unlikely that the industry will be able to continue to push up yields, but there are plenty of opportunities to improve efficiency and cut out waste. In fact, growers throughout the world will have to cope with far more restraints on their production than has previously been the case (Potato Pro[16]).

Potatoes are initially graded for size and skin quality before they leave the farm, they are then graded more rigorously when they reach the factory. Potatoes which do not meet the required size, shape or which have major defects such as common scab are normally used as feed for livestock. In 2009/10 1.5 million tonnes of UK potatoes (18.6%) did not meet the required size or quality to be sold to the consumer (Potato Council, 2010).

For seed potatoes, a seasonable marketable fraction is 70-80% of the total yield (Wale pers. comm.). Of the rejected tubers, the ware fraction (tubers over 55 or 60 mm) may be sold as ware potatoes, replanted as seed, sold for processing or sold as stockfeed. Smaller tubers are more likely to be replanted as seed while ‘brock’ (diseased or misshapen tubers) will either be sold as feedstock or dumped.

In addition to the production of waste potatoes, the potato supply chain also produces many other forms of material waste including: chemical containers, fertiliser bags, potato and seed bags, net and stretch wrap, twine, crop cover, fleece and plastic sheeting and cardboard (The Packaging Federation[17]). Further packaging is generated from the final sale of potatoes, including packaging of potatoes within the supermarket, crisp packets for example.

Depending on the efficiency of a system various amounts of water, heat, fuel, nutrients and energy may also be wasted during production, storage and processing. These forms of waste, and the various reduction methods are covered by other sections of this report.

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[15] Bowen, S (2011) Waste in potato production and how to reduce it. Presentation to the SAC Association of Potato Producers January 27 2011.

[16] *Reduce waste rather than push up potato yields*: http://www.potatopro.com/Lists/News/DispForm.aspx?ID=4867 accessed 1 February 2011

[17] http://www.packagingfedn.co.uk/images/fact%20sheets/The%20UK%20Packaging%20Manufacturing%20Industry%20-%20A%20Brief%20for%20MP's%20&%20Peers.pdf accessed 2 February 2011

Regulation and recycling of material wastes

Waste and packaging are regulated in the UK under the 2003 Landfill Directive, the 2005 Producer Responsibility Obligations (Packaging Waste) Regulations and the 2006 Agricultural Waste Regulations. Each of these regulations is underpinned by EU directives. The disposal of packaging is also covered by the Farm Assurance Schemes, which requires the removal of waste products including plastics by approved contractors.

Many of the waste products produced on farms can be collected and recycled. Contractors are used to recycle fertliser bags, seed bags and agrochemical bottles. Triple washing ensures that chemical residues are removed from the containers before recycling, so as to avoid contamination. The foil seals and screw-on caps are collected and disposed of separately through the same contractors. Some plastics, including High Density Polyethylene H.D.P.E have a value of approximately £150/tonne, and therefore can create a small amount of revenue through being recycled.

Nearly all solid fertilisers now arrives on farm in 0.5 or 0.6 tonne plastic bags. However, a significant proportion of the base seedbed fertiliser is applied as a liquid and delivered in bulk to the farm. It therefore has no packaging associated with it. Anecdotal evidence suggests that around 1/3 of the base potato fertiliser arrives in this way. Further reduction to packaging is also achieved by the use of wooden boxes (subsequently used for storing ware) rather than polypropylene bags ("jumbo" bags) for seed potatoes, which typically hold 1.1 to 1.3 tonnes of seed. Alternatively seed can be delivered in bulk, resulting in no packaging at all. Anecdotally, the approximate split is currently 92% jumbo bags, 6% wooden boxes and 2% bulk. The small proportion of bulk deliveries may reflect risk of a complaint affecting the entire load.

At potato packing factories the final product tends to be packed in a plastic of some description. A wide range of plastics used includes:

- OPP - orientated polypropylene films
- PP - polypropylene plastic
- LDPE - low density polyethylene
- APET - amorphous polyethylene tetraphthalate

Packers tend to use the minimum amount of plastic they can but which is consistent with handling a relatively bulky product. It is not in their commercial interests to use more packaging than is absolutely necessary, supermarkets also stipulate that packaging is kept to minimum. Much fresh product already uses modified atmosphere packaging (MAP) to prolong the shelf-life of the fresh product and thereby cut down on waste.

Packers are looking again at paper as packaging material. Not only is it more readily recyclable than plastic packaging, but it is also good at holding bulky products such as potatoes. It is already used for value lines for the larger grab bags, but packers are also looking at it for high end product lines, which tend to be purchased by customers who are more environmentally conscious.

Outgrade potatoes

Over the last twenty years, on average 13% of potatoes per year are classified as outgrades. However, this figure fluctuates annually according to weather conditions and disease risk. For example in 1991 losses were only 8.5% and in 2009 they were 18% (Potato Council, 2010). Ensuring that outgrade potatoes are put to good use helps to minimise waste. As discussed in Section 5.4. potatoes can be used as feedstock for anaerobic digestors, thus producing heat, fuel or electricity. A further use which has been growing in the UK over the last decade is the use of waste potatoes and washing water for the creation of environmentally sustainable, biodegradable packaging.

Potato starch packaging

Packaging is one of the world's largest manufacturing sectors. The UK packaging industry employs some 85,000 people representing 3% of the UK manufacturing industry workforce and has sales in excess of £10 billion. As major recyclers and users of recycled material as well as producers of packaging, the sector has contributed to raising the UK's packaging waste recycling record from 28% in 1998 to some 65% in 2008 (The Packaging Federation[18]).

Although biodegradable packaging concepts have been around for a number of years, the uptake to date has been slow. However in recent years there has been increased interest in these technologies due to environmental concerns and UK and EU legislation.

The potato industry in Great Britain currently produces around 17,000 tonnes of starch per year as a by-product (see Roberts & Royce, 2004[19]). This currently has low value but could have added value by being used as a raw material for packaging.

European subsidies are available for growing starch potatoes, allowing potatoes to be grown specifically for packaging. However, these subsidies are not available in the UK and therefore potato starch is generally produced as by-product of potato processing, rather than being grown as a crop in its own right (Roberts and Royce, 2004).

In 2004 the Potato Council (formally the British Potato Council) conducted a collaborative research project with Imperial College London to investigate sustainable packaging for the potato supply chain in Great Britain. The research assessed the options for sustainable production of biodegradable packaging from potato starch produced in Britain. Results demonstrated that supply of by-product potato starch recovered from potato processing operations is a viable alternative to starch

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[18] http://www.packagingfedn.co.uk/images/fact%20sheets/The%20UK%20Packaging%20Manufacturing%20Industry%20-%20A%20Brief%20for%20MP's%20&%20Peers.pdf accessed 2 February 2011

[19] *Sustainable GB Potato Packaging - Supply Chain Report:* http://www.potato.org.uk/secure_downloader.php?index_id=91&secdoc_id=929 accessed 3 February 2011

produced under the EU subsidy system and imported. Advantages over the EU subsidy system and imported were identified for environmental, economic and quality measures. Overall testing to date has shown that waste starch performs better as a raw material for packaging production than imported starch (Roberts and Royce, 2004).

The diagram below (Figure 3.6.1) shows the process by which waste potatoes are converted into starch packaging.

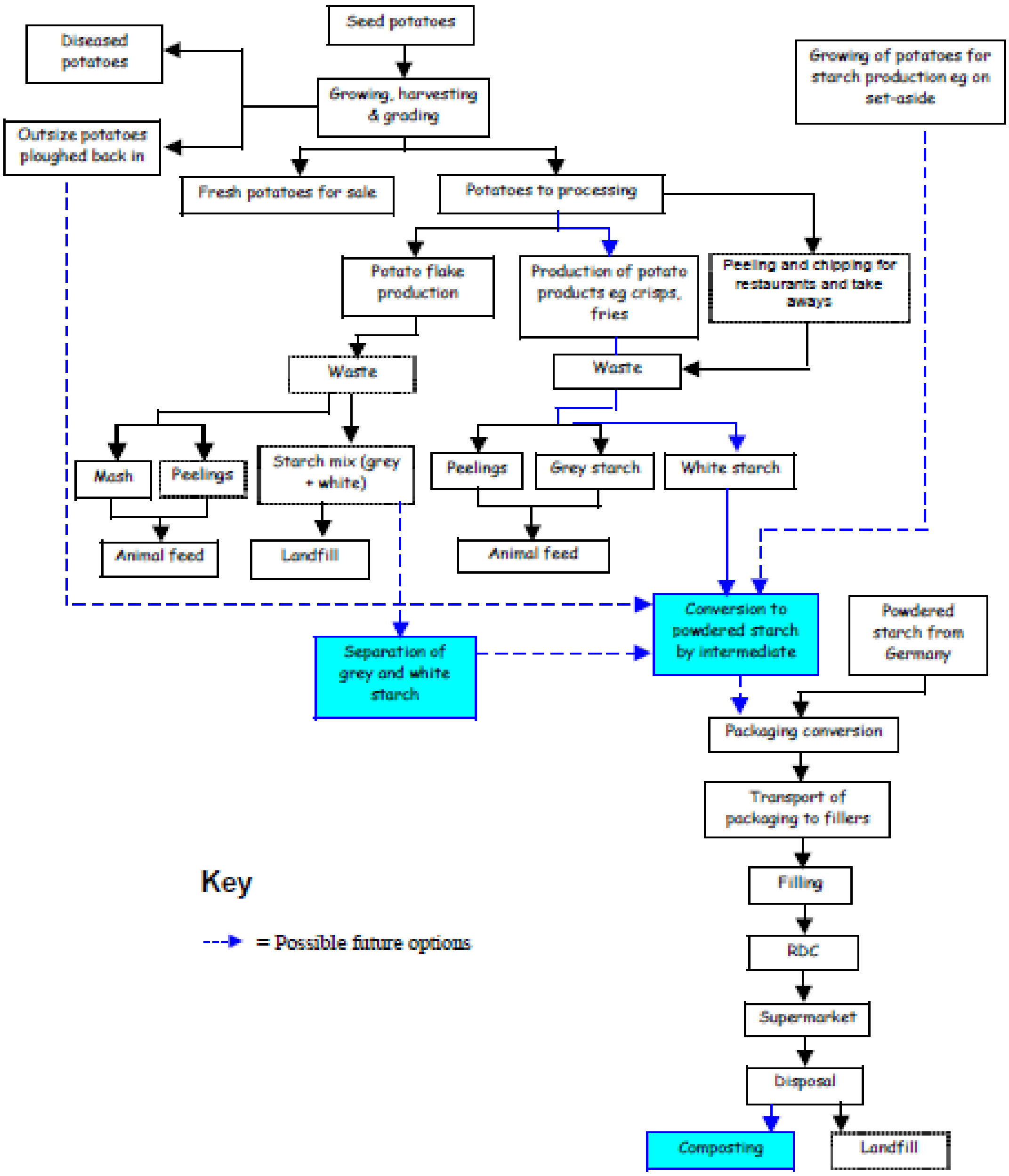

Figure 3.6.1. The potato packaging supply chain. (Source: Roberts and Royce, 2004[20])

In the UK Potato PAK is currently one of the key manufactures of potato starch packaging. The main input for the manufacture of their product is waste water from potato processing. The water used to wash and cut processing potatoes is full of starch which can be extracted to produce packaging. The packaging is fully biodegradable, through the process of composting, within four weeks of its final

[20] *Sustainable GB Potato Packaging - Supply Chain Report:* http://www.potato.org.uk/secure_downloader.php?index_id=91&secdoc_id=929 accessed 3 February 2011

disposal (Figure 3.6.2). All of the waste from this manufacturing process is disposed of in an environmentally sustainable way, mainly by being fed to livestock, fish or worms. Where possible, Potato PAK uses starch that has been reclaimed from local food processing waste streams. In locations that do not have starch extraction facilities, they import reclaimed starch from other locations that do (Potato PAK[19]).

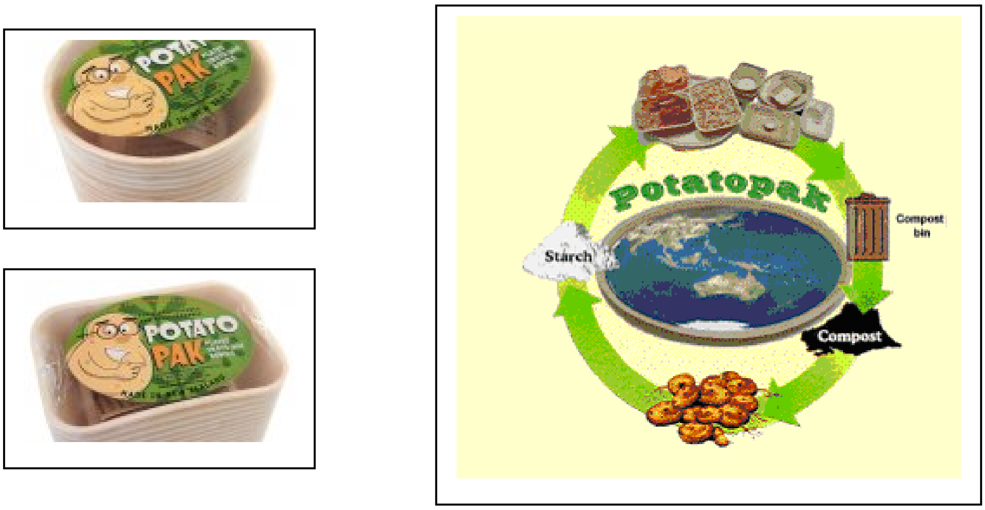

Figure 3.6.2. Potato Packaging (Source: Potato PAK[21])

Conclusions

More investigation is needed to reduce losses due to size, skin finish and storage damage. Alongside attempts to reduce crop losses following harvest, greater uses should be sought for starch and other products that could be produced from waste potatoes. As the value of recyclable waste products increases, recycling is likely to be stimulated as a consequence.

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[21] http://www.potatopak.org/home.html accessed 2 February 2011

4. How production of GB potatoes compares with other countries

Yield and land use

Yield is a key factor in assessment of sustainability, because most impacts are assessed per unit of production. Choice of land is a major influencer of yield, and yield is a major influencer of carbon footprints.

Land use is considered in Section 3.2 where a comparison is made between land use in the UK and land use in countries that export to the UK. Many assumptions are necessary for that analysis and it is unlikely that these are fully justified, so the land use estimates must be used with caution. It is assumed that the average country yields are the average yields of the potatoes exported to the UK, which may not be the case because the potatoes may be grown for special markets. The imports of potatoes shown in Section 3.2 do not include imports of potatoes imported as processed products. According to Defra data, these processed imports far outweigh the imports of fresh potatoes. However, we do not have data for the sources of the potatoes used for imported processed products to allow these imports to be included in the analysis. With these caveats, the data in Section 3.2 indicate that growing potatoes in other countries for import fresh to the UK uses approximately 1000 ha more land than would be needed to grow the same tonnage of potatoes in the UK.

Environmental impacts

Multiple environmental impacts are often assessed using a life cycle assessment (LCA). A LCA is a “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.[22]” LCA assesses, systematically, life cycle environmental aspects and impacts of product systems. The depth of detail and time frame may vary, and although there is no single method, the LCA process has become standardised in the ISO 14040 series.

Attributional LCA provides information about the impacts of processes used to produce (and consume and dispose of) a product, but does not consider indirect effects arising from changes in the output of a product. In contrast, Consequential LCA provides information about the consequences of changes in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product (Brander *et al.,* 2008). Most LCA studies are attributional and typically exclude social and economic impacts. Examples of environmental impact categories commonly considered in an LCA are:

- Global warming potential (GWP; = carbon accounting, carbon footprint)
- Stratospheric ozone depletion
- Eutrophication
- Acidification

[22] BS EN ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework

- Pesticide use
- Land occupation
- Abiotic resource depletion

LCA studies of potatoes are rare, and comparative LCA studies that show differences in impacts between countries are even scarcer. Defra project FO0103 (Williams et al., 2009) compared potatoes produced in the UK and Israel and concluded that key factors affecting the environmental burdens per tonne of food delivered to a distribution centre (i.e. not including the retail and end-use part of the life cycle) are yield, the need for refrigerated storage and transport distance. It was shown that UK potatoes have advantages over Israeli produce, because of greater yields and less need for water and transport, but this advantage can be partly lost by the need for prolonged storage of UK-produced potatoes. To give an overview of environmental impacts, Table 4.1 presents data directly from the FO0103 Defra report. This study shows that, for production and transport to a UK distribution centre, all the impact categories showed similar or better performance for UK potato production, compared with Israeli production.

Table 4.1. ***Maincrop potatoes, comparison of production in UK and Israel, total emissions per t product. Weighted mean of storage period for all UK maincrop. Taken from Williams et al., 2009 (Defra project FO0103). FG=farm gate; GWP=global warming potential, i.e. carbon footprint; PM_{10} =particles of 10 micrometers or less; ND= no data; NA=not applicable.***

	UK			**Israel**		
	pre-FG	**post-FG**	**Total**	**pre-FG**	**post-FG**	**Total**
Primary energy used, GJ	0.9	2.3	3.1	1.3	8.7	10.1
GWP_{100}, t CO_2-eqv.	0.11	0.14	0.25	0.16	0.32	0.48
Eutrophication potential kg PO_4 eqv.	0.4	0.1	0.5	0.8	1.3	2.1
Acidification potential kg SO_2 eqv.	0.3	0.6	1.0	0.6	6.0	6.6
Ozone potential depletion, g CFC-11 eqv.	0.4	NA	0.4	0.3	NA	0.3
Pesticides used, kg A.I.	0.4	NA	0.4	0.3	NA	0.3
Abiotic resource use; kg Sb eqv.	0.4	0.5	0.9	0.6	3.1	3.7
Land m^2/t	20	ND	20	24	ND	24
Water, m^3	NA	1	1	NA	1	1
Irrigation Water, m^3	16	NA	16	110	NA	110
PM_{10} kg	0.00	0.15	0.15	0.00	0.20	0.20
Photochemical oxidation potential, kg ethylene eqv.	-0.03	0.01	-0.01	-0.05	0.19	0.14
Non-methane Volatile Organic Carbon, kg C Equiv	0.02	0.11	0.13	0.03	0.56	0.59
Proportion of renewable primary energy, %	7	7	7	10	<1	3

Some unpublished ADAS work shows that for potatoes consumed in April, imported maincrop potatoes from Israel had similar impacts to stored UK potatoes, except for water footprint weighted for scarcity, photochemical oxidation and acidification. These exceptions were related to greater water scarcity in Israel compared with UK, and sea freighting, which releases NOx and SOx from combustion of marine fuels, increasing photochemical oxidation and acidification impacts.

The consequences of water use

Water availability and use at the site of production is a matter of growing global importance. The world's fresh water resources are under increasing pressure as rising population levels and standards of living are increasing the demand for fresh water. Furthermore, climate change is affecting where and when and how much fresh water is available to us.

Water use can be measured based on records of direct water withdrawals for a production process. This approach does not, however, provide a true indication of the total water used to produce a product, as, for example, the water used to produce raw materials is not included. Furthermore, it does not assess the impact of this water used.

In order to address these issues, the concept of a water footprint has been developed. A water footprint quantifies the freshwater consumed through all the steps of the product or business supply chain, i.e. the indirect and direct water used. Together, this is referred to as 'virtual' or 'embedded' water. A water footprint is the total volume of 'virtual water' required to produce a good or service or used to run and support a business or nation. A water footprint is a geographically explicit indicator providing volumes of water consumed (not abstracted) at the point of production.

The virtual water contents of potatoes produced in the UK, and in the top ten exporters of potatoes to the UK, are shown in Table 4.2. For potatoes produced in the UK the virtual water content is 74 cubic metres of water per tonne of potatoes produced, which is lower than for any of the other 10 nations, and 29% of the global average value, 255 cubic metres of water per tonne of potatoes produced.

By measuring the water footprint of a product, the impacts of water use can be considered and mitigation strategies developed. However, the 'volumetric' water footprint alone does not reflect the impact of the water use at the specific location(s) of production. This limits the extent to which comparison of water footprints leads to good environmental decisions. For example a product with a lower water footprint could be more damaging to the environment than one with a higher water footprint if the water use in the first case occurs in a place where water is scarce. To enable comparison of the food items produced in different locations, a water footprint can be weighted using a water stress index. This can be done at a national level or more locally. Because the source of potato imports is known at a national level we have presented national water scarcity indices from Chapagain and Hoekstra (2004) to give an indication of impact associated with water use in countries that export potatoes to the UK (Table 4.2). Of the top ten exporters of potatoes to the UK, only The Netherlands has a lower water scarcity index. However, it was not possible within this study to take account of regional differences in scarcity of water within nations, in relation to the regional distribution of production for export to the UK.

Table 4.2. ***Virtual water content of potatoes (m^3/t) for the UK and the top ten exporters of potatoes to the UK; and the water scarcity indices for the same countries. Data from Chapagain and Hoekstra, 2004.***

Country (UK + top ten exporters of potatoes to UK)	**Virtual water content of potatoes (m^3/tonne)**	**Water scarcity (%)[1]**
United Kingdom	74	50
Israel	190	514
France	112	54
Netherlands	78	21
Germany	97	82
Belgium	141	90
Egypt	308	119
Spain	207	84
Ireland	99	Not available
Cyprus	307	214
Italy	209	70
Global average	255	Not available

[1]Chapagain and Hoekstra (2004) defined water scarcity (WS) of a nation as the ratio of the nation's water footprint (WFP) to the nation's water availability (WA), expressed as a percentage: WS=(WFP/WA)×100. More details are provided by Chapagain and Hoekstra (2004). The national water scarcity can be more than 100% if there is more water needed for producing the foods and services consumed by the people of a nation than is available in the country.

References

Chapagain A.K. and Hoekstra A.Y. 2004. Value of Water Research Report Series No. 16: Water footprints of nations, Volume 2: Appendices. UNESCO-IHE Delft, NL.

Williams, A. G., Pell, E., Webb, J., Tribe, E., Evans, D., Moorhouse, E. & Watkiss, P. 2009 Comparative life cycle assessment of food commodities procured for UK consumption through a diversity of supply chains. (Final Report to Defra on Project FO0103). Cranfield, UK: Cranfield University.

5. Examples of GB potato industry working to better sustainable production:

5.1. Valuing the natural environment

Environmental Stewardship

Farmers and other land managers in England receive funding through Environmental Stewardship to deliver effective environment management. In England alone, over 40,000 farmers and land managers and over six million hectares of land are currently in schemes and receive around £400 million a year (Natural England[23]). Currently 69% of the utilisable agricultural area in England is in an Environmental Stewardship scheme, with the vast majority (56%) in the Entry Level Scheme (ELS). In 2010, 88% of ELS agreements were renewed. A current focus of Environmental Stewardship is to increase uptake of options to provide seed-rich habitats through the creation of weedy stubbles and planting mixtures of seed-bearing crops in both ELS and Higher Level Stewardship (HLS) agreements. These 'bird-friendly' options seek to arrest the recent decline in seed-eating farmland birds such as yellowhammer and corn bunting.

Agri-environment schemes in Scotland are similarly designed to encourage farmers and crofters to manage their land for the benefit of Scotland's wildlife and habitats (Scottish Government[24]). The Rural Stewardship Scheme, which is now closed to new applicants, provides assistance to farmers and crofters to adopt environmentally friendly practices as well maintaining and enhancing particular habitats and landscape features. Applicants to this scheme agreed to participate for at least five years to adhere to general environmental requirements such as 'Standard of Good Farming Practice and General Environmental Conditions'. These conditions follow existing codes such as Good Agricultural and Environmental Condition (GAEC) as well as standards of management consistent with reasonable good practice without artificially constraining changes. GAEC measures fall into four broad categories: soil erosion, soil organic matter, soil structure and minimum level of maintenance. It is a requirement of GAEC that land must be capable of returning to agricultural use by the next growing season.

ADAS Farmers' Voice

The ADAS Farmers' Voice survey is completed each year and records responses to questions ranging from cropping to succession planning to involvement in agri-environment schemes. Data extracted from the survey shows that the most potatoes are grown on 'general cropping' farms that also grow significant amounts of cereals (mainly winter wheat) and oilseed rape (unpublished data). 'General cropping' farms show some of the highest levels (75-80%) of involvement in agri-environment schemes. This level of involvement compares favourably with levels of involvement by livestock farms (31-73%) or horticulture (43%) and is comparable with cereal

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[23] http://www.naturalengland.org.uk/Images/esupdate13_tcm6-24724.pdf accessed 5 February 2011

[24] http://www.scotland.gov.uk/Topics/farmingrural/Agriculture/Environment/Agrienvironment accessed 5 February 2011

farms (81-82%) and mixed farms (80%). It is also noticeable that levels of involvement in these schemes are higher for larger rather than smaller farms, across all sectors.

Results were analysed for respondents growing any potatoes and the proportion that were not members of any agri-environment scheme was found to be 19%. At 81%, the majority of respondents that reported growing potatoes in the 2008 survey confirmed that they were agreement holders in an agri-environment scheme

Water Framework Directive (WFD)

The WFD was introduced as a piece of European environmental legislation aimed at improving water quality. In Scotland the WFD has given rise to Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR), which were amended when the Water Environment (Diffuse Pollution) (Scotland) Regulations 2008 were introduced. These regulations form a set of General Binding Rules (GBRs) including several that impact on agricultural activities (SAC[25]). These include fertiliser storage and application (GBR 18), cultivation of land (GBR 20), discharge of surface water run-off (GBR 21) and application of pesticides (GBR 23). GBRs enable the Scottish Government to achieve a basic level of control over specific land-use activities and are based on established agricultural best practice provided in publications. Established agricultural best practice includes Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) Code (Scottish Government[26]).

Of particular relevance to potato growers is GBR 20, which seeks to "ensure that land is cultivated in a way that minimises the risk of pollution to the water environment". Given the inherent risk of diffuse pollution from potato production growers are encouraged to assess risk by considering: slope – angle and length, history of erosion and watercourses. Where risks are identified potato growers have a number of options they can adopt including:

- Tied ridging
- Contour planting
- Grassed headlands
- Silt fencing
- Soil retention bund
- Sediment capture pond
- Increase soil organic matter (long term)
- Avoid bare ground in autumn (cover crops prior to potatoes)

Further general advice on reducing the risk of water pollution is provided by SEPA[27].

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[25] http://www.sac.ac.uk/mainrep/pdfs/ppl2010.pdf accessed 5 February 2011
[26] http://www.scotland.gov.uk/resource/doc/37428/0014235.pdf accessed 6 February 2011
[27] http://www.sepa.org.uk/water/water_regulation/regimes/pollution_control/diffuse_pollution.aspx

Conclusion

Environmental Stewardship has been widely adopted by farmers. ADAS Farmers' Voice survey data suggests that adoption by potato producers is comparable to cereal farms. It is also notable that the move to fewer larger potato producers may actually increase levels of adoption of environmental schemes. The Water Framework Directive is likely to become an increasingly important driver within the potato industry.

5.2. Reducing Fertiliser use

Nutrient management of potato crops and rotations

The potato crop is nutrient hungry and commonly receives large inputs of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) as manufactured fertiliser and supplied in organic manures. The current average use of nitrogen fertiliser on maincrop potatoes in Britain (168 kg/ha) is third highest (winter oilseed rape 189 kg N/ha; winter wheat 188 kg N/ha), and is highest of all major arable crops for phosphate fertiliser (141 kg P_2O_5/ha) and potash fertiliser (245 kg K_2O /ha) (BSFP 2010).

Large nutrient inputs based on good nutrient management decisions are usually justified in order to optimise potato yield and quality, and to maximise farm profits. However, high nutrient or manure application rates that are not justified will reduce profitability and increase the risk of pollution of the water and/or air environments. Most of the potato crop is now grown within Nitrate Vulnerable Zones (NVZs) so growers must comply with the relevant regulations which are different in England and Wales (Defra, 2009), and Scotland (Scottish Government, 2009).

Guidance on how to make the best use of organic manures and manufactured fertilisers is provided by Defra's 'Fertiliser Manual (RB209)' (Defra, 2010) and the SAC Technical Notes (SAC[28,29]). It should be remembered, however, that these recommendations do not constitute a blueprint for successful crop production (Potato Council, 2009) nor are they legal requirements for compliance with the NVZ regulations. Instead, the information should be used together with the local knowledge of the grower and a FACTS qualified advisor. For compliance with Crop Assurance Schemes, fertiliser advice must be given by a FACTS qualified advisor.

Organic manure use

Potato crops are regarded as responsive to manure applications, especially bulky organic manures (e.g. cattle and pg FYM, poultry manures), mainly due to perceived benefits from soil conditioning. As a result, 35-40% of the potato area receives one or more manure applications – this is a higher proportion than for most other tillage crops (BSFP, 2010).

Although total manure use on the national potato crop represents only a small percentage of the total national use of manures to agricultural land, the environmental risk associated with these applications is often higher than for other crops. This is because organic manures are usually applied to bare ground in the autumn, winter or early spring before planting. Increasingly manures are applied in late winter and early spring, as farmers capacity to apply manures quickly and accurately increases with improvements in application technology. Also, potato growers are increasingly aware of the nutrient value of manures and the need to avoid pollution. The latter is partly driven by NVZ regulations, and farmers enhanced

[28] SAC Technical Note TN621: Fertiliser recommendations for vegetables, minority arable crops and bulbs, www.sac.ac.uk/publications accessed 24 January 2011

[29] SAC Technical Note TN625: Nitrogen recommendations for cereals, oilseed rape and potatoes, www.sac.ac.uk/publications.accessed 24 January 2011

awareness of environmental issues associated with their activities. The crop available manure N is thus more at risk to losses by leaching than if applied to land that is cropped overwinter (e.g. winter cereals, winter oilseed rape). Any such losses will reduce the value of the manure to the farmer and increase the risk of nitrate leaching to surface or ground waters (see also Section 3.3). In addition, potatoes are mostly grown on relatively 'leaky' light or shallow soil types, where the risk of nitrogen leaching is high.

Wherever manures are applied, the risk of direct runoff to watercourses and emissions of ammonia and nitrous oxide to the atmosphere must also be minimised. If manures are applied to bare ground that is sensitive to soil erosion, then the risk of direct runoff of manures into surface watercourses can be high, causing potential pollution with nutrients and pathogens.

To minimise the risk of pollution, manures should be applied at a time and in a manner to reduce pollution risk (see Section 3.3). Also, the supply of manure nutrients should be allowed for when deciding on fertiliser application rates. On average between 2005–2009, survey data indicates that crops receiving manures did receive lower fertiliser nutrient rates - 24 kg/ha less nitrogen, 48 kg/ha less phosphate and 65 kg/ha less potash (BSFP, 2010). This is equivalent to the nutrients supplied from the following approximate application rates of cattle FYM – N from 40 t/ha (spring applied), phosphate from 25 t/ha, and potash from 8 t/ha. These data must be treated with caution but indicate that there is further potential for many potato growers to allow for the full nutrient content (especially P and K) of applied manures and, as a result, to reduce their use of manufactured fertilisers.

Nutrient use and trends

Nitrogen (N) – Throughout much of the 1990s, use of N on maincrop potatoes ranged between around 170-190 kg/ha (Figure 5.2.1). This level fell slightly at the end of the 1990s and has remained at around 140-160 kg N/ha until 2009. Around two-thirds of the total N is applied as compound N (assumed to be mostly applied in the seedbed) and one-third as straight N (assumed mostly to be top-dressed commonly at around tuber initiation stage to irrigated crops) (BSFP).

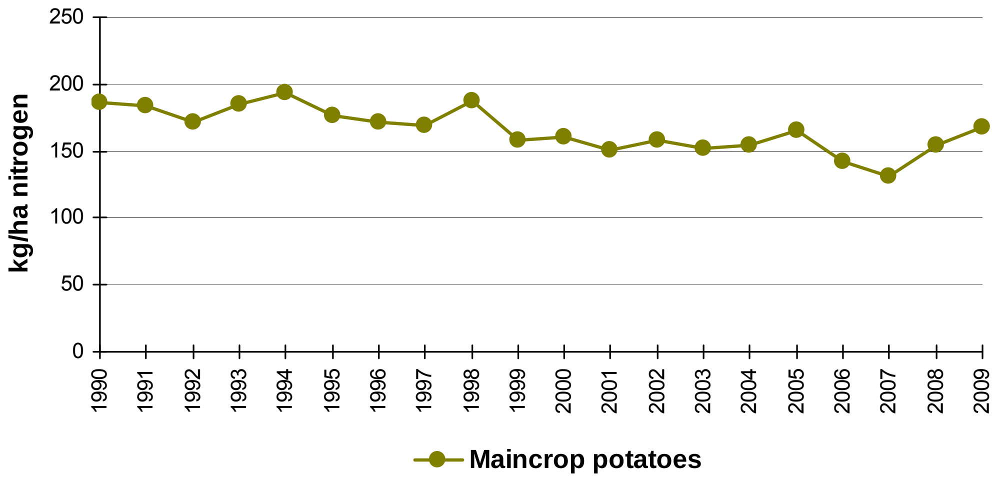

Figure 5.2.1. Nitrogen use on maincrop potatoes grown in Britain between 1990 and 2009. Source: BSFP

Trends in fertiliser nitrogen use on potatoes can also be compared with those on other crops in Britain. Between 1983 and 2006 N use has fallen between 1 and 36% for the major arable crops (Figure 5.2.2). The exception to this general trend has been winter wheat, which has seen a slight rise in N use (5%) over the same period. The largest reductions in N use have been seen in sugar beet (36%), oilseed rape (30%) and maincrop potatoes (29%).

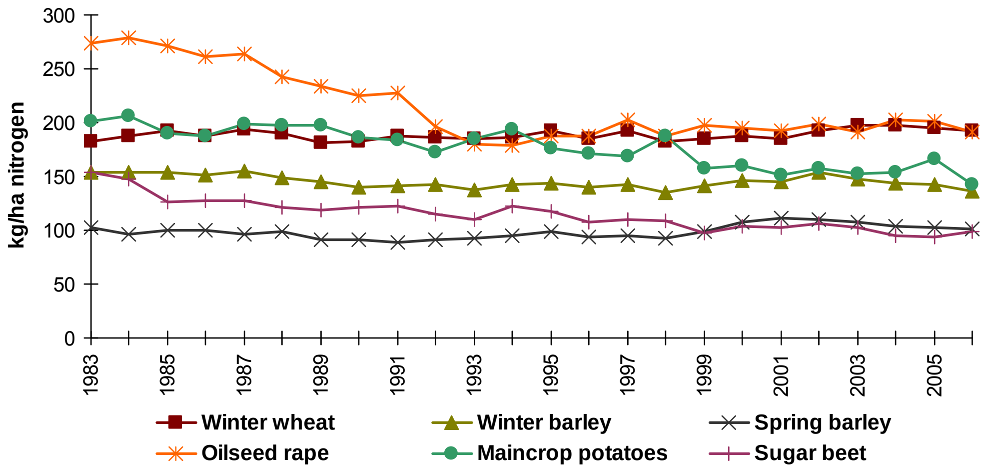

Figure 5.2.2. Nitrogen use on major arable crops grown in Britain between 1983 and 2006. (Source: BSFP)

Current nitrogen use on potatoes can be compared with recommended N rates taking account of manure applications. A wide range of organic manure types are applied to potatoes, including cattle, pig, layer and broiler/turkey, but these vary widely in nutrient content. As an example, 40 t/ha of spring-applied cattle FYM will supply around 25 kg/ha crop-available N, which can be deducted from the required nitrogen application rate. However, manure is not applied to all potato crops, in part because when applied unevenly, manures have been associated with variability in potato dry matter concentration (Potato Council, 2009). Based on an application rate of 40 t/ha of cattle FYM to one-third of the potato area, organic manure applications contribute an average of less then 10 kg/ha crop-available N. Adding this source of N to the current use of fertiliser N gives an average total N supply of around 150-160 kg/ha.

This can be compared with current N recommended rates based on potato varieties divided into four variety groups according to the degree of determinacy – this is a measure of the crops capacity to maintain leaf production after the first appearance of flowers (Potato Council, 2009). Indeterminate varieties (groups 3 and 4) require less N than determinate varieties (groups 1 and 2). Maris Piper, which accounted for 18% (by area) of the potato crop in 2010 (Potato Council, 2010), is an indeterminate variety and falls into group 3. Taking the 29 most widely grown varieties, which account for 79% of the total potato crop area, around two-thirds of the potato area is cropped with varieties in groups 2 or 3 (Table 5.2.1). The recommended N rate for these varieties ranges between 150-250 kg/ha, indicating that the current average supply of nitrogen from applied manures and fertiliser is broadly in line with current recommendations.

Table 5.2.1. Percent of total potato crop area by variety group (Potato Council, 2009; 2010)

	Variety group			
	1	**2**	**3**	**4**
Percent of total potato crop area	10	27	39	5

National nutrient balances for nitrogen and phosphate have also been calculated as part of Defra project WQ0106 (ADAS 2006). A large surplus indicates a nutrient inefficient production system with potential larger losses to the wider environment. Table 5.2.2 summarises the calculated annual surplus/ha for nitrogen and phosphate for a range of crop types using data for 2004 and an estimate for 2015.

Table 5.2.2. Calculated annual balance/ha for nitrogen and phosphate in 2004 and 2015 for selected crop types (positive values are a surplus, negative values a deficit).

Crop type	**Nitrogen surplus (kg/ha**		**Phosphate surplus (kg/ha**	
	2004	**2015**	**2004**	**2015**
Wheat	60	41	-26	-41
Barley	30	22	-1	-17
Potatoes	44	50	98	92
Sugar beet	-5	-40	-11	-31
Oilseed rape	77	87	-7	-28
Maize	51	42	42	23
Brassicas	148	154	45	23

For nitrogen, most crops have a nitrogen surplus (i.e. more nitrogen applied than removed in crop produce), some increasing and some decreasing between 2004 and 2015. The potato crop had a modest nitrogen surplus in 2004 (40 kg N/ha) but with a higher surplus (50 kg N/ha) estimated for 2015 (based on a projected yield of 42 t/ha and a fertiliser N input of 155 kg/ha).

Phosphate (P_2O_5) – The potato crop is one of very few major arable crops that can respond to fresh applications of phosphate at target soil P levels (Index 2). Therefore, within potato rotations, the potato crop is more likely to respond to P than other crops, such as cereals and oilseed rape. Because of this, high rates of phosphate are recommended and applied that are well above the amount removed in tubers (1 kg P_2O_5 per tonne of tubers). This is perfectly acceptable provided that any surplus phosphate is accounted for when fertilising following crops in the rotation.

Phosphorus is also an important potential pollutant of water, mainly through the mechanism of soil erosion and transport of P-rich sediment to surface watercourses. Significant pollution can be caused by the movement of only small quantities of P which are insignificant for P nutrient management in crop rotations. Since only very small quantities of phosphorus are lost from in-field soil P reserves, good P nutrient management practice recommends balancing.

Figure 5.2.3 shows that the average use of P to potatoes is higher than for any other of the major arable crops. Between 1983 and 2006, use of P has fallen by between 19 and 51% for the major arable crops. Large falls have been seen in all cases with the largest reductions for sugar beet (51%), oilseed rape (46%) and maincrop potatoes (40%).

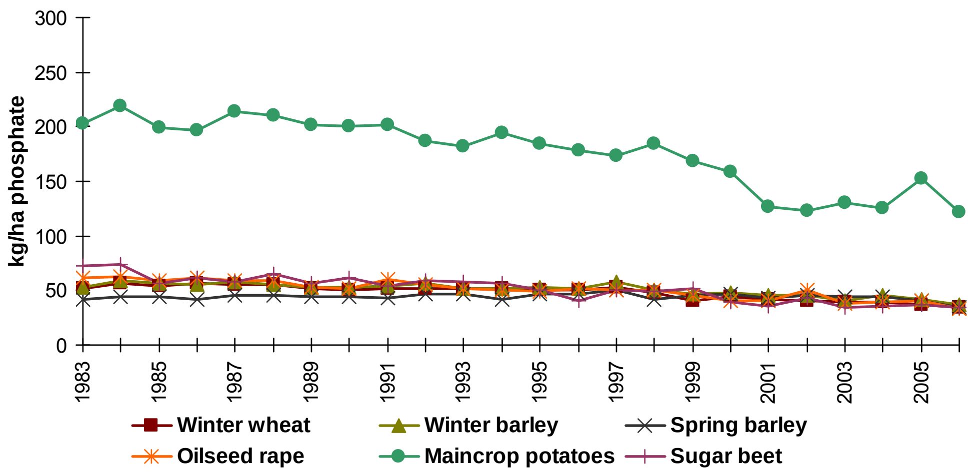

Figure 5.2.3. Phosphate use on major arable crops grown in Britain between 1983 and 2006. (Source: BSFP)

During the 1990s, use of phosphate declined from 200 kg/ha to around 170 kg/ha, and there have been further reductions since 2000 (Figure 5.2.4). This indicates that potato growers have improved their nutrient management practice. Allowing for soil P status and the contribution of manure P are the most likely causes of this trend. The current average fertiliser use is 141 kg P_2O_5/ha (BSFP 2009), which reflects recommendations applicable for the middle of RB209 Index 2, or Moderate (Lower) P status in Scotland.

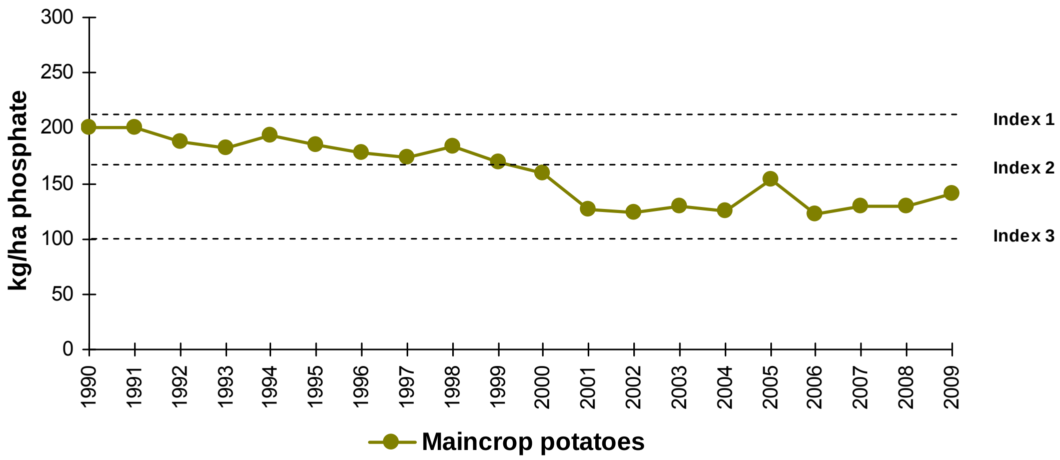

Figure 5.2.4. Phosphate use on maincrop potatoes grown in Britain between 1990 and 2009. Dotted lines indicate RB209 recommended P rates at Index 1, 2 and 3. (Source: BSFP)

Assuming that most potato land is at P Index 2 to 4, the recommended rate of P to a crop yielding 50 t/ha of tubers would be 0 kg/ha (Index 4), 100 kg/ha (Index 3) and 170 kg/ha (Index 2). However, as there is an additional supply of manure P on approximately one third of the potato area (75-125 kg/ha of available P on manure treated land, equivalent to 25-40 kg/ha available P across the whole potato area) current use of P would seem to be higher than recommended when the potato crop is considered in isolation. However, the use of higher than recommended amounts of P on potato land is acceptable practice provided that the surplus P is recognised and allowed for when fertilising following crops in the rotation.

Table 5.2.2 shows the calculated P balance for a range of crop types including potatoes. Although potatoes is the only major arable crop with positive and large P surplus (98 kg/ha in 2004, reducing to 92 kg/ha in 2015), this does not necessarily indicate a higher risk of P pollution due to potatoes than other crops. Although high P application rates will inevitably represent a greater risk than low rates, mainly due to the risk of runoff, the effect of a P surplus due to potato cropping will be minimised if this surplus is fully allowed for when fertilising following crops in the rotation. Runoff events can occur when the soil is left bare over-winter, during land preparation and via drainage ‘highways’ after ridging, resulting in soil particles with high P content entering watercourses.

Potash – Research has shown that yield responses to K are unlikely but that the removal of potash in tubers is high and needs to be replaced to maintain the soil K status. Current recommendations are based on replacing the removal of 5.8 kg/ha K_20 in each tonne of tuber yield (Potato Council, 2009) in order to maintain the target soil K Index 2. Potash is not a potential pollutant of the environment.

Between 1983 and 2006, use of K has fallen by between 3 and 35% for the major arable crops (Figure 5.2.5). The exception to this general trend has been spring barley, which has seen a marked rise in K use (34%) over the same period, possibly due to more allowance for K in baled straw. The largest reductions in K use have been for oilseed rape (35%), sugar beet (33%) and maincrop potatoes (26%).

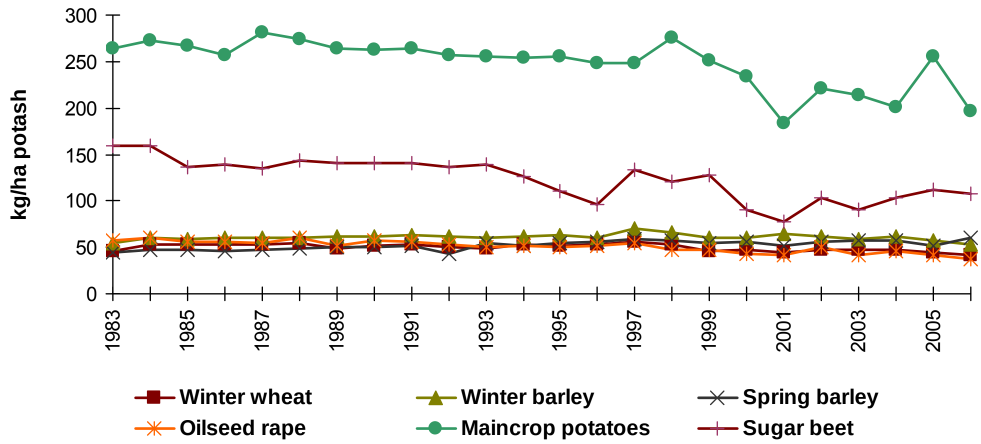

Figure 5.2.5. Potash use on major arable crops grown in Britain between 1983 and 2006. (Source: BSFP)

During the 1990s, the use of K on maincrop potatoes remained stable at around 250-260 kg/ha (Figure 5.2.6). However, since 2000 average rates have been lower but with larger fluctuations (200-250 kg/ha). The average rate of application between 2000-2009 has been 219 kg K_2O/ha (2000-2009), which reflects recommendations for K Index 2-3 (Moderate/High K status in Scotland).

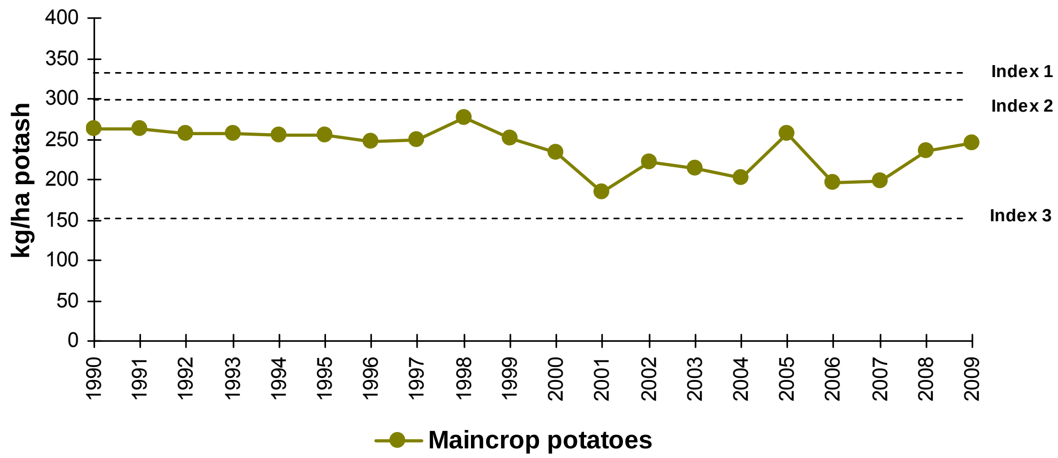

Figure 5.2.6. Potash use on maincrop potatoes grown in Britain between 1990 and 2009. Dotted lines indicate RB209 recommended K rates at Index 1, 2 and 3. (Source: BSFP)

When comparing current potash use with recommended rates, the supply of potash in manure applications must also be taken into account. Based on a typical application of 40 t/ha cattle FYM (supplying 300 kg/ha of total potash on manure treated land) on approximately one-third of the potato area, the additional supply of manure potash across the whole area of potatoes is around 100 kg K_2O/ha. Thus the average supply of fertiliser and manure potash is around 320 kg K_2O/ha (219 from fertiliser; 100 from manures), which is roughly equivalent to recommendations at soil K Index 1 (330 kg/ha). Since most potato land is likely to be at or higher than soil Index 1, this indicates that overall potash use is higher than needed. However, as for phosphate, it is difficult to assess the scope for further reductions in potash use without data for the distribution of soil Index levels used for potato cropping.

Nutrient balances have not been calculated for potash as this nutrient is not a concern for environmental pollution.

Conclusions

There has been a general reduction in fertiliser use between 1983 and 2006, N (17%), P (37%) and K (12%). By comparison with these average falls, fertiliser use on maincrop potatoes has shown a greater reduction N (29%), P (40%) and K (33%). The large reductions in fertiliser use on maincrop potatoes is at least in part due to this crop having more scope to reduce fertiliser use. In 1983 P and K use on maincrop potatoes was far higher than on other major arable crops, while N use was second only to oilseed rape. Therefore, despite the reductions in fertiliser use on maincrop potatoes the relative position of this crop has remained unchanged. Actual NPK fertiliser use is probably still above RB209 recommendations. The following steps are already being adopted by many potato growers to further reduce fertiliser use on potatoes:

- Autumn or winter manure applications are avoided
- Improved allowance for manure NPK
- Allowance for residues, especially P, following potatoes
- Fine tuning N use to take into account excessive canopy in previous crop, delayed skin set or if intended season length is at lower end of given ranges. Also N use may be increased if crops are planted into cold soils are slow to emerge, planting into cloddy or compacted soils, part of the N application is applied late in the season or there is evidence of pest of disease (Potato Council, 2009)
- Wide beds used to improve water availability and N use
- Cover crops are used prior to potatoes

References

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Defra (2006) Catchment sensitive farming: National N and P balances. Report for Defra project no. WQ0106 (Objective 6).

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Potato Council (2010) GB Potatoes: Market intelligence 2010-11. Publ. Potato Council, Stonleigh.

Glossary

Nitrate vulnerable zones (NVZs) – land that drains into waters affected by nitrate pollution.

5.3. Improving store efficiency

There has been significant, but relatively slow progress, to date towards increasing sustainability of potato storage operations in Great Britain. Nearly all the major markets have initiatives of their own and these vary between companies in their extent and commitment. Most measures at the retail level have, not unexpectedly, been part of wider strategies covering the potato sector as a whole or, indeed, for some of the markets, produce or products in general. However, some multi-national companies have led the way in sustainability initiatives (eg Pepsico/Walkers carbon footprinting of crisps; Carbon Trust, 2008) and are now leading the adoption of carbon footprinting systems such as the Cool Farm Tool (eg Pepsico and McCain – Hillier *et al* 2009; Hillier, 2010).

Tesco have also been using carbon footprinting as a measure of sustainability and storage forms over 50% of this footprint in late-stored crops (Nelson, 2010). Other supply chains, such as Produce World/Solanum supplying Waitrose, have also had a clear focus on sustainability issues for some time (Bowen, 2003) and have been working steadily towards producing a more cohesive, sustainable approach to the supply of their market. Their approach has been across a wider spectrum of issues than simply energy use. Examples of initiatives include the removal of the use of CIPC sprout suppressant in their supply chain in 2010 (Faulkner, 2010) in favour of ethylene use, to minimise post-harvest residues.

Firms such as Marks and Spencer have had their company-wide Plan A initiative and associated with this, there are examples such as the WarmStor™ development at their main potato supplier, Manor Fresh Ltd at Holbeach, Lincs, which have addressed concerns in potato storage (Potato Review, 2009). In this instance, a new store with a specially-designed positive ventilation system was created to improve the efficiency of the warming process used to bring crops up to a higher temperature (~9C) from the normal storage level of 3C, to minimise the risk of bruising during the packing process. This system was nominated for a Potato Innovation award at the Potato Europe event held at Emmeloord, the Netherlands in September 2009 (Potato Europe, 2009).

A further example where positive ventilation has been introduced as a design feature on a new storage complex is at Co-operative Farms, Coldham, Cambridgeshire (Burgess & Cunnington, 2010) in order to optimise the efficiency of the storage process.

Airflow efficiency in storage is frequently compromised (BPC, 2007) and yet this must be addressed much more extensively if optimal store performance is to be achieved in GB storage. In particular the wider adoption of positive ventilation in box storage is the only real solution to address the inefficiencies of these systems (Cunnington, 2008; Cunnington, 2010). Some companies have adopted an alternative, low energy approach such as the passive upward flow stores installed by IMA, although there is limited public information on their performance to date.

A three year study of 33 industry stores on energy use, carried out by Farm Energy and Sutton Bridge Crop Storage Research (Swain, 2010) illustrated the challenge. Stores commonly had as much as a three fold difference in their comparative use of energy per tonne of crop stored. Very few of the stores were using positive ventilation so it is likely that significant gains in efficiencies are available across the industry as a whole. In addition, factors like air leakage from stores have seldom been taken into account adequately and there is likely to be further scope for efficiency improvements on this score too. In addition to British Standard 5502 which provides a baseline requirement for the insulation of agricultural buildings (Anon, 2007), other environmentally-focused assessment standards such as BREEAM (operated by the former government-run Buildings Research Establishment) are now available for building design in industry (BRE, 2011) which might be adopted to ensure a higher standard of construction and long term life of a store. Techniques such as computational fluid dynamics (CFD) modelling are also now starting to become more widely available and cost-effective for use in agriculture and could be utilised to ensure stores are designed for optimal energy utilisation.

Crop temperature selection in the fresh sector has been dominated in recent years by a need to keep blemish disease and sprouting suppressed (Cunnington & Pringle, 2008) but these stores have had very high demands for energy. Swain (2006) cited potato stores in the fresh sector within the top 10 users of energy in food supply chain. However, with changing emphases in relation to energy use and issues such as acrylamide risk (Food Standards Agency, 2011), there are strengthening arguments to move to slightly warmer temperatures for this market. There is a risk of slightly less attractive skin quality but, with new varieties and providing the consumer can be fully informed of the benefits, changes are likely to be seen in the next few years.

Inverters – electronic speed control devices for use on ventilation fans, compressor and pumps – are being increasingly adopted in new storage installations (Cunnington *et al*, 2010) and these have offered a great deal of potential to reduce energy consumption, although their use has to be managed carefully to ensure crop quality is not compromised. Warwick HRI and FEC (Anon., 2007) estimated that a 9% reduction in energy use was achievable through optimisation of ventilation and cooling in store, equivalent to *c.* 9 GWh per annum. A further advantage of inverters is that electricity supply line capacities can be lowered significantly through their use, as they permit 'soft-starting' of equipment which greatly reduces the maximum current demand. Uptake of inverter technology in stores in the potato processing sector is closely linked with the need to apply potato sprout suppressant more effectively (McGowan *et al,* 2009) but is currently only estimated at around 20% (Harris, 2011).

The use of renewable energy sources for potato storage is limited. It is not currently possible to match renewable generation patterns to the demand from potato stores and therefore there is no significant, direct use of renewable generation in effect. However, there are instances within the industry where new storage complexes have been built that have featured, primarily, wind turbine generation albeit linked to the National Grid. This enables a site to generate electricity to the equivalent or, in many cases, in excess of that used in the stores to *offset* the consumption (and cost) of electricity. The viability of installations on a small to medium scale has been improved by the introduction of more favourable tariff structures (McGovern, 2009), although the loss of some sources of grant assistance with the closure of Rural Development Agencies will also prevent some developments from coming to fruition. Long standing examples of wind turbine installations associated with potato storage would include those at Abbey Growers and McCain Foods at Whittlesey, Cambs. More recent examples include a new pre-pack store at Luffness Mains in East Lothian (Fletcher, 2010[30]). The Co-operative Group also have a multi-turbine

[30] *New building aims to reduce carbon footprint. Scottish Farmer,* www.thescottishfarmer.co.uk/arable *accessed 30 November 2010*

complex on their farm at Coldham, Cambridgeshire, which has been recently expanded (Co-Operative, 2011).

Other sources of renewable energy which are potentially well suited to storage include solar photovoltaic, which is likely to be best suited to remote, rural locations where connection to the National Grid is difficult or expensive (Anon, 2007) and ground source heat pumps (GSHP) which use the ground as a heat sink, since the ground temperatures below a depth of *c.* 2 metres remain largely constant. A trial GSHP installation was investigated in a Defra-funded project in collaboration with Warwick HRI, Farm Energy, Potato Council and HDC (Swain, 2009). The test system was successfully used to provide heating to an adjacent tomato packhouse. However, at the present time, there are only isolated examples of these types of systems in commercial use in potato stores.

Conclusions

Improved store efficiency has formed a key part of wider sustainability initiatives developed by major potato packers, retailers and food processors. These initiatives have identified the importance of storage in terms of the crops overall carbon footprint. Storage improvements have not been restricted to energy use and have also seen companies working to improve crop quality, for example through the use of positive ventilation, or remove the use of chemicals used to suppress sprouting in storage.

The conditions under which potatoes have previously been stored are coming under increasing challenge and this is likely to drive further change. In the fresh sector the drive to keep blemish disease and sprouting suppressed has led to high energy demands. There are also now increasing concerns relating to the presence of acrylamide in potatoes stored under these conditions. Therefore, there is a strengthening argument to move to slightly warmer temperatures.

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5.4. Reducing waste – anaerobic digestion

Overview of anaerobic digestion

Anaerobic digestion (A.D.) is recognised as being an important biological technology for future sustainable waste management, and the production of biogas for heat and electricity generation. Modern systems are often designed such that beneficial use can be made from the heat produced by the engine cooling water and exhaust system.

The production and processing of potatoes, along with the disposal of associated waste products (peelings, outgrades, and dirty water) provides significant opportunities for A.D., whilst helping to minimise waste from the potato supply chain. The process of A.D. uses anaerobic bacteria, in a closed, controlled environment, to breakdown organic materials into a stable fertiliser and usable biogas (Figure 5.4.1). Owing to their high carbohydrate content, approximately 20% (Potato Council, 2010) potatoes are valued as a feed stock for A.D., particularly when used in combination with animal manures. Waste-water from washing and processing potatoes also form a useful co-substrate for other feedstock, ensuring that there is a high enough water content for the digestion process; the optimum total solids content of a feedstock is between 6-8%, but higher total solids can be accommodated . Furthermore, although fats give the highest biogas yields, carbohydrates show the fastest biogas conversion rates (Steffen *et al.,* 1998).

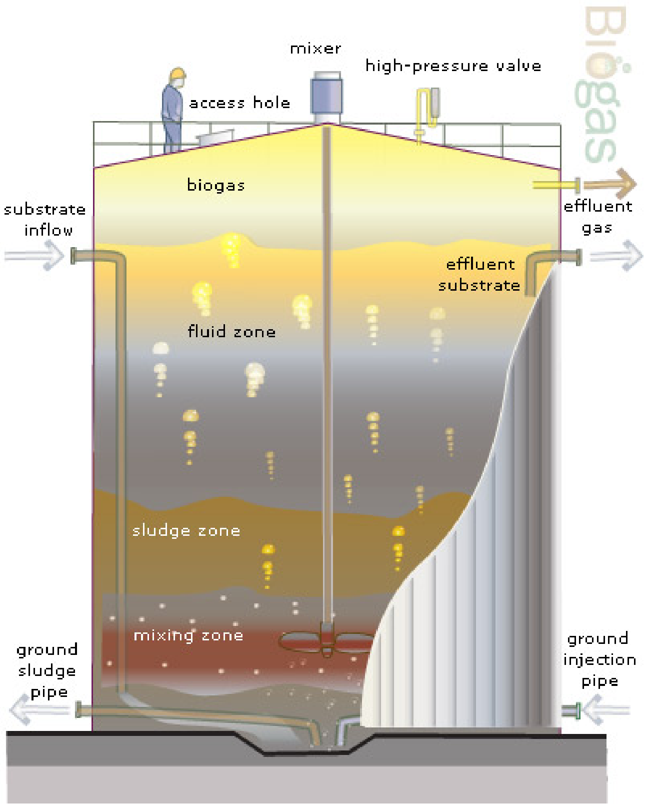

Figure 5.4.1. A Diagram of the process of A.D. (Source: Renewable Energy Association, 2009[31])

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[31] http://www.r-e-a.net/biofuels/biogas/anaerobic-digestion accessed 20 January 2011

Social, environmental and economic benefits of anaerobic digesters

Social benefits

- Create a cleaner environment
- Create local employment
- Provide diversification for rural businesses such as farms
- Achieves the "Proximity Principle" i.e. treating wastes close to their source is sustainable.
- Potential to supply 'free' heat to local residences and businesses

Environmental benefits

- Development of a benign and safe waste management system
- Reduce pollution risk of organic putrescible wastes
- Use of digestate as a fertiliser reduces the need for artificial fertilisers
- Control of pathogenic bacteria and viruses
- Production of renewable energy
- Reduction of greenhouse gas emissions
- Carbon neutral process.
- Can significantly reduce the odour emissions of the feedstock
- Can reduce carbon footprint by replacing fossil fuel derived energy

Economic benefits

- Charging a gate fee for the treatment of wastes
- Provide 'free heat'
- Production and sale of biogas for electricity, heat or fuel
- Production and sale (or use on farm) of fibre and liquid fertilisers
- Payments via the Feed in Tariff Scheme or provision of Renewable Obligation certificates
- In the future payments are possible from the Renewable Heat Incentive
- Improve the efficiency of farming practices by offsetting fertilizer and energy bills.
- Because A.D. is a closed system all the inputs and outputs can be accounted for. A mass and energy balance can therefore be calculated for any AD system.
- At current renewable energy electricity market prices, there is an opportunity to make £10 to £20 from only one tonne of organic waste.

(Renewable Energy Association, 2009[32]; Defra, 2010[33]).

Legislation

Despite extensive use of A.D. technology in continental Europe and elsewhere, there has been limited uptake in the UK, with only 25 single on-farm and 12 centralised A.D. plants in operation in 2009. These plants use food and farm waste with 60 more planned or under construction (DECC, 2010).

The Government recognises that A.D. has great potential to contribute to UK climate change and wider environmental objectives. It is therefore encouraging growth in the use of A.D., through research, development and environmental incentives. Key actions include research to optimise the A.D. process, including £1 million for a new small scale A.D. development unit to better understand the economics of A.D. throughout its lifecycle; optimise the use of available feedstocks for A.D., including assessing the impacts of energy crop production; and demonstrate the agronomic and economic value of digestate (Defra, 2010).

Government incentives to increase the uptake of A.D. include:

- Renewable Obligation Certificates (ROCs),
- Feed In Tariffs (FITs) Renewable
- Heat Incentive (RHI) (from April 1st, 2011),
- The Renewable Transport Fuel Obligation (RTFO),

Although the Renewables Obligation is available for all sizes of installations, it has encouraged mainly centralised renewable electricity generation. Therefore the Government has now also introduced feed-in tariffs for small-scale low-carbon electricity generation, so as to provide support for installations up to 5MW. Electricity from A.D. plants will receive 9.0p/kWh. An additional tariff for farm scale A.D. will provide 11.5p/kWh for plants below 500kW (Defra, 2010).

The use of waste potatoes as a feedstock for A.D. fits with Defra's aims of creating 'win-win' scenarios through this technology by using food and animal wastes rather than specially grown feedstocks so as to avoid any negative environmental impact. (Defra, 2010).

Research into the potential of potatoes as a feedstock for anaerobic digesters

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[32] *Renewable energy technologies* http://cogeneration.net/renewable-energy/ accessed 20 January 2011

[33] Accelerating *the Uptake of A.D. in England: an Implementation Plan.* http://www.defra.gov.uk/environment/waste/ad/documents/implementation-plan2010.pdf accessed 31 January 2011

Previously, materials such as potatoes, which have a high soluble carbohydrate content, have been considered more suited to the production of ethanol rather than conversion for biogas. However scientific research provides strong evidence for the potential of using potatoes as a feedstock for A.D.

Bogue and Badger (1984) reported the yield of ethanol from potato as being approximately 0.42 l/kg total solids (TS), giving a total gross energy yield of 2.6kWh/kg TS, whereas the energy in methane produced from potato was reported as 4.1 kWh/kg TS. As the gross energy of potato is 4.3kWh/kg TS, this gives a gross energy conversion efficiency of 60% for ethanol production compared with 95% for biogas (Bogue and Badger, 1984).

A 2004 laboratory study by Kaparaju and Rintala examined the possible use of potato tuber and its industrial by-products (potato stillage and potato peels) on farm-scale co-digestion with pig manure. Results showed that the highest methane yields were achieved by a feedstock of 80% pig manure to 20% potato waste, in a continuously stirred tank at a temperature of 35°C. The results suggest that the methane yields and process performance for potato tuber would be similar to that of its industrial residues. Thus, co-digestion of potatoes and/or its industrial by-products with manures on a farm scale level would generate renewable energy and provide a means of waste treatment for industry (Kaparaju and Rintala, 2004).

A pilot study conducted by Parawira et al (2004) examined the biomethane production from potatoes on their own and in conjunction with sugar beet leaves from two-stage A.D. This study obtained the highest methane yield was produced from a mix of 40% potato and 60% sugar beet leaves.

Some issues do exist when using potatoes in A.D., depending on the type of potato feedstock that is used, considerable pre-treatment may be required including removal of non-degradable components (woods, plastic, stones etc) and the homogenisation of the feedstock. Also there can be pH reduction inside the digester, as well as the poor-degradation of cellulose material and inhibition by pesticides (Steffen et al., 1998[34]).

Overall, research shows that there is considerable potential for the use of potato wastes and other semi-solid agricultural residues for A.D. Where these residues have a dry matter of below 25%, as is the case for potatoes, A.D. provides an effective mechanism for exploiting their energy potential, which is otherwise difficult to achieve. Methane derived via A.D. has proved to be competitive with heat (via burning), steam and ethanol production in efficiency, cost and environmental impact of the conversion of waste streams to energy forms (Parawira et al, 2004).

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[34] *Feedstocks for A.D.* Institute for Agrobiotechnology Tulln, University of Agricultural Sciences Vienna, http://www.adnett.org/dl_feedstocks.pdf accessed 20 January 2011

On- farm Anaerobic Digesters

Typical, on farm, installations range from 125kW to 2mW electrical output. The size of A.D. plants varies; plants are normally quoted on the potential electrical output. Typical capital costs are in the range £500,000 to £7 million. Costs vary greatly and depend on the type of feedstock used. For example, if maize is the predominant feedstock, then considerable storage will be required. Typical feedstocks include, maize, sugar beet, grass, food waste, vegetable waste and animal manures.

Ray Williams of ADAS is currently working on an AD plant for a large potato grower where the feedstocks under investigation include, potato haulm, potato waste and mustard (grown as break crop after potatoes and ploughed in for its fertiliser value). The resultant digestate will be separated into solid and liquid. The liquid will be cleaned up using a reed-bed system and stored in a purpose built reservoir, and irrigated onto crops. The solid material will be composted and used as a fertiliser and soil improver. Heat from the plant will be collected and used to heat a greenhouse for raising plants for other enterprises on the farm. Investigations are also underway to use the heat to power the potato store refrigeration system, through the use of an absorption chiller.

Absorption chillers use heat instead of mechanical energy to provide cooling. A thermal compressor consists of an absorber, a generator, a pump, and a throttling device, and replaces the mechanical vapor compressor.In the chiller, refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber. This solution is then pumped to the generator. There the refrigerant re-vaporizes using a waste steam heat source. The refrigerant-depleted solution then returns to the absorber via a throttling device. The two most common refrigerant/ absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water.

Compared with mechanical chillers, absorption chillers have a low coefficient of performance (COP = chiller load/heat input). However, absorption chillers can substantially reduce operating costs because they are powered by low-grade waste heat. Vapor compression chillers, by contrast, must be motor or engine-driven. (Renewable Energy Institute).

The planned A.D. developments should also consider both the carbon savings that the system will make and the possible addition of a rainwater harvesting system that will enable additional water to be added to the feedstocks (where required) and increase the quantity of water available for irrigation. ADAS believes that this approach provides the most sustainable solution by considering both the inputs and outputs of the system and maximising the value of both in terms of revenue and the environment.

Case studies

Some large potato producers within the UK have already begun using potato waste for biogas production. The section below provides three examples of where potato growers and manufacturers are successfully using A.D. to generate biogas for heat and electricity generation and utilizing the resultant digestate for soil conditioning.

McCain

In 2008 McCain constructed an anaerobic digestor for its Whittlesey French fry factory. Wastewater from the potato chip plant is pumped into a lagoon, where bacteria feed on the starch in the water and produce about 300 cubic feet of biogas a minute. The biogas is then stored and used to produce electricity through a gas burning generator. The turbine produces 1.2 megawatts of electricity (about one-tenth of the energy the plant uses). New technology has been used to remove hydrogen sulphide from the gas prior to burning at a much lower cost than pervious systems (Potato Pro, 2008[35]; Byrne, 2008[36]).

Branston Ltd

Branston Ltd, situated near Lincoln Ltd is one of the UK's largest potato buyers, packers and distributors, with around 150,000 tonnes being produced at the Lincoln site. The company received a grant from the Rural Development Programme for England (RDPE) to part fund a new A.D. plant and water recycling facility at the site. The A.D. plant uses 'out of grade' potatoes, which are unfit for consumption, to generate 300 kW of electricity for use on site. The solid residue left at the end of the process is used as a soil conditioner or to fuel an existing biomass boiler. The project will save Branston over 40% on electricity and 60% on water at the site, as well as taking one HGV load of waste off the road each day (Defra, 2010).

Worth Farms

Situated near Holbeach in Lincolnshire, Worth Farms produces 200,000 tonnes of potatoes a year. Of these approximately 15,000 tonnes are not saleable. To help meet part of the farm's annual energy requirement of 1.5 -1.7 megawatts (mW) Mr Worth, the farm owner, has invested £3 million in an A.D. project. The digestor will convert potato (55%) and green waste (45%) feedstocks into approximately 1MW of electricity, other products from the digester include heat and fertiliser. It is projected that the plant will save the farm around £150,000 a year in fertiliser costs and have a total payback period of three years (Harris, 2008[37]).

The photographs below (Figure 5.4.2) show examples of on-farm anaerobic digesters and spreading of digestate.

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[35] *McCain food applies new technology for biogas production.* [Online]. http://www.potatopro.com/Lists/News/DispForm.aspx?List=813b91f5%2Df5b5%2D46ec%2D95e2%2D463829ed0100&id=1955 accessed 31 January 2011

[36] McCain Foods invests in biogas project at UK plant. Food Production Daily.com, http://www.foodproductiondaily.com/Processing/McCain-Foods-invests-in-biogas-project-at-UK-plant accessed 31 January 2011

[37] *Banking on a Biogas Project.* [Online]. http://www.thebioenergysite.com/articles/215/banking-on-a-biogas-project accessed 31 January 2011

Figure 5.4.2. On-farm anaerobic digester plants courtesy of F.L.I Ltd and spreading on digestate ADAS library

Conclusions

As fuel costs continue to increase the viability of A.D. is improved. Viability of these facilities is further improved through the increased cost of waste disposal, which A.D. also helps to reduce. Alongside these drivers are increased commercial interest and legislation relating to carbon footprinting, which may be improved through the adoption of A.D.

Despite the apparent potential A.D. viability is at present marginal and it is essential that a detailed assessment of the costs are completed. In these considerations, the payment or costs attached to the feedstock is often of primary concern. Feedstocks are an area of further research in order to assess the potential to use other potato products as feedstock. These alternate feedstocks may include potato haulm and in some cases mustard (which is used as a break crop).

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Parawira, W. et al (2004) Anaerobic batch digestion of solid potato waste alone and in combination with sugar beet leaves. *Renewable Energy,* 29 1811–1823.

5.5. Use of wind turbines

UK wind potential

Being the windiest of all the European countries, the UK has great potential for wind generation (BWEA, 2010[38]).

Currently wind power is used to generate 2.2% of the UK's electricity. Wind provides more of the UK's energy than any other renewable energy source and is the fastest growing form of renewable energy (BWEA, 2010; Renewable Energy Association, 2009). Indeed wind power features significantly in the Government's renewable energy strategy, which sets the target for 15% of all of the UK's energy to come from renewable sources by 2020. It is estimated that a further 33GW of wind generated power will be needed to meet this target (BWEA, 2010). The 'Building a low carbon economy' report proposes that wind power (both on and offshore) has the potential supply 30% of the UK's energy by 2020- (Committee on Climate Change, 2008[39])

A 2.5MW wind turbine can generate an average of 6.5 million units of electricity per year (enough to power 1,400 houses) (BWEA, 2010). Actual wind generation potential depends on a number of factors including the height of the turbine, the surface of the land around it, and the average wind speed for the site. Table 5.5.1 below summarises the potential electricity generation from different size turbines depending on the site suitability.

Wind turbines are available in a range of sizes from 100W to 3MW (Renewable Energy Association, 2010). The different sizes make wind turbines a suitable source of renewable power generation for many sites including farms.

Table 5.5.1. Wind generation capacity from different size turbines (Little, 2009[40])

Suitability Class	2MW Turbines	2.75MW Turbines
Poor	0 - 2.5 GWh	0 - 3.3 GWh
Medium	2.5 - 3.8 GWh	3.3 - 5.1 GWh
Good	3.8 - 5.1 GWh	5.1 - 6.8 GWh
Very Good	5.1 - 7.2 GWh	6.8 - 9.7 GWh

ADAS has generated a tool which enables the easy assessment of any given site to generate wind power. Such a tool is of value to potato growers who may have an

[38] *Onshore wind* http://www.bwea.com/onshore/index.html accessed 02 February 2011

[39] Building a low-carbon economy –The UK's contribution to tackling climate change: The First Report of the Committee on Climate Change December 2008. http://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf accessed 02 February 2011

[40] *How much energy can a wind turbine produce?* http://aplus.adas.co.uk/Services/energy/How-much-energy-can-a-wind-turbine-produce.aspx accessed 02 February 2011

interest in erecting wind turbines. The tool includes the ability to assess the technical feasibility of a proposed site in relation to (Lancaster, 2009[41]):

- Wind speed
- Proximity to National Park, Area of Outstanding Natural Beauty, Site of Special Scientific Interest
- Proximity to housing and airports
- Flood risk
- Toppling distance from roads, footpaths, water ways, rail lines, boundaries?
- Gradient of land

Use of alternative energy sources are seen as important in helping growers to counter rising energy prices, which have outpaced the rise in market value of potatoes over the last few years. The impact on individual growers will depend on their particular reliance on energy. Producers carrying out more post harvest operations and storing for longer will see the greatest net cost increase (Potato Council, 2006[42])

The potato industry has shown considerable support for wind energy generation. Large processing companies including McCain and PepsiCo are incorporating wind into their sustainability commitment. In 2008 McCain constructed three wind turbines at its Whittlesey production plant. McCain estimates that the turbines will produce enough energy to cut their energy bills by 60% and their CO_2 emissions by 23,000 tonnes (Atwood, 2007[43]). In their 2010 Sustainable Farming Report PepsiCo stated that they are encouraging their potato growers to invest in renewable energy technology, including wind, enabling farms to be powered by green energy and therefore reducing greenhouse gas emissions (PepsiCo 2010[44]).

In their 2006 Energy Status Report, the Potato Council examined the potential of wind and solar power to be used in potato stores. Whilst the report highlighted that renewable technologies work most economically when the load factor of the application they are supplying is high, it concluded that it is feasible to use these technologies in potato stores as all the load factor is low, it does have the advantage of not being as time critical as some other applications. That is to say, the thermal

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[41] *Why food businesses should be looking at wind power as a renewable energy source?* http://aplus.adas.co.uk/Services/energy/why-food-businesses-should-be-looking-at-wind-power-as-a-renewable-energy-source.aspx accessed 02 February 2011

[42] Energy Status Report *http://www.potato.org.uk/secure_downloader.php?index_id=91&secdoc_id=506* accessed 02 February 2011

[43] *McCain's potato chip factory to be run on wind power.* The Independent. http://www.independent.co.uk/news/business/news/mccains-potato-chip-factory-to-be-run-on-wind-power-461622.html accessed 20 January 2011

[44] *Passionate about growing PepsiCo UK sustainable farming report 2010* http://www.pepsico.co.uk/farming accessed 02 February 2011

inertia of the store is such that cooling can be delivered in sporadic bursts without leading to undue risk to the crop. It is possible to envisage systems which rely on wind and solar energy for instance to provide energy for cooling without being too sensitive to the erratic availability of these energy sources (Potato Council, 2006).

Wind turbines are just one of a range of renewable technologies that are worthy of consideration, others include:

Photovoltaic (P.V.) panels - these are often suited to being sited on large potato stores or other buildings. A typical potato store could house panels capable of producing approximately 250kW peak of electricity. PV has found favour because of its simplicity in operation and the payments made via the Feed in Tariff. There are a wide range of companies willing to supply, fit and maintain PV panels at no cost in exchange for supplying low cost electricity (often around 1p/kWhr) and sharing revenues from generation back into the grid. Issues to consider are:

- orientation of the roof – ideally within 10 degrees of due south
- potential for shading from surrounding structures
- geographic location – in general the further south the better
- capability of the building structure to carry the additional weight
- potential to use generated electricity on site
- matching of output to predicted use
- capability of the grid to accept generation and the cost of connection
- the potential to recover the cost of installation – commonly 10 years
- potential to sell the green energy via a power purchase agreement rather than accept the 3p/unit as a guaranteed minimum – can expect to get around 5.5p/unit
- Calculate percentage of output that can be used on site rather than feed into the grid i.e. feeding into the grid at say 3p/unit or ideally use to replace bought in electric at say 8 – 10p/unit

Hydro - possibly not suited to the majority of potato farms or sites unless they have sufficient free flowing water supplying a suitable head of water.

Biomass as a fuel - this can provide an alternative heating system for offices and other onsite building. Biomass boilers can be fuelled by waste crop residue such as oilseed rape straw. Interest has been stimulated by increasing energy cost and the planned funding via the renewable heat incentive. Typical feedstocks include woodchip (clean virgin wood only), dry crop residues and some animal wastes (mainly poultry litter). It is possible to use such systems to produce electricity, but care needs to be taken to ensure that efficiencies are maintained. It is of paramount importance to determine the quality; quantity and cost of the feedstock over a considerable period (no less than 5 years). The cost of the feedstock will have a significant effect on the viability.

Ground/air source heat pumps - this technology also has the potential for heating on farm buildings. In essence ground source heat pumps give around 300% increase in energy in to out. That is to say that for every 1 kW of electricity in, up to 3.5kW of heat can be created. Such systems can be described as a refrigerator working in reverse. Ground source offer the best potential as the ground at depth has a consistent temperature of around 12 deg C. However capital costs may limit the use of this technology. To reduce capital costs air source may be considered. This system may be ideal for potato growers if they have reservoirs or lagoons because the heat can be collected from them. ADAS believe that when the Renewable Heat Initiative is announced that these systems will be the preferred technology. Ideally P.V. panels could be used to power the system to improve returns.

Conclusions

The use of renewable energy on farms will become increasingly important in helping to offset rising fuel and energy costs and help to meet greenhouse gas reduction targets. However, in order to be successfully implemented a full feasibility assessment is required to consider all aspects of renewable energy. Specifically, consideration should be given to the planning implications before investing. To aid this process tools are now available, which assist in determining site suitability for wind turbines helping to ensure that all factors are properly considered. Using more than one renewable technology in combination can help increase their overall efficiency and output.

5.6. Other examples

Voluntary Initiative (VI)

VI schemes have been supported by UK farmers for the past 10 years. Schemes include National Register of Sprayer Operators (NRoSO) and the National Sprayer Testing Scheme (NSTS). The advantage of these schemes is that they allow the UK government to provide practical and proportionate solutions to reduce the risks associated with pesticide use whilst avoiding an increase in the administrative burden placed on farmers[45]. VI is likely to play an increasingly important role in meeting the challenge raised by the Sustainable Use Directive (2009/128/EC).

NRoSO is a register of spray operators that uses a programme of Continuing Professional Development (CPD) to ensure ongoing training (http://nroso.nptc.org.uk/). Membership of NRoSO currently stands at approximately 80% and accounts for approaching 90% of the cropped area. The scheme is open to anyone with the appropriate National Proficiency Tests Council (NPTC) PA certificate(s) of competence or was born before 31 December 1964 who may apply under 'Grandfather Rights'. Typically, potato growers have had PA1 (foundation unit) and PA2 (boom sprayer – mounted, trailed or self propelled) certificates. However, a number of products are applied at planting e.g. nematicides and soil fungicides, which are applied as granular formulations. Therefore staff operating planters should also have PA4 (pesticide granular applicator – mounted or trailed) and P12 (application of pesticides to material as a continuous process via conveyor, roller tables and other moving equipment). In order to address this gap in NPTC training the Potato Treater Group (under the auspices of the Potato Council and chaired by Dr Stuart Wale) have persuaded NPTC to offer a new training module (PA-SC special category equipment) specifically for planter operators.

NSTS provides annual checks of machines to ensure that they are safe for both the operator and the environment. In 2009/2010 the NSTS checked 13,800 sprayers that covered 89.2% of the UK sprayed area (http://www.nsts.org.uk/). The NSTS confirms best practice and is a required element of major crop assurance and supermarket protocols.

The Metaldehyde Stewardship Group[46] (MSG) has been set up to 'promote and encourage best practice use of metaldehyde slug pellets in agriculture, minimise environmental impact and in particular, protect water'. The group includes Lonza (the principal manufacturer of the active ingredient) and key slug pellet formulators. Activities of the MSG include provision of additional training for those who took a PA2 or PA3 (broadcast or boom sprayer mounted or trailed) after June 1994. Slug pellet usage has been reduced, with a limit of 210 g metaldehyde per hectare from 1 August through to 31 December and a legal maximum of 700 g metaldehyde per hectare per calendar year. These changes are likely to have had a larger effect on the way that cereal and oilseed rape crops are managed than potato crops for a number of reasons. The limit of 210 g metaldehyde between 1 August and 31 December is primarily aimed at autumn sown crops, where slug pellets may be

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[45] http://www.voluntaryinitiative.org.uk/_Attachments/resources/1377_s4.pdf accessed 9 February 2011
[46] http://www.pelletsarepesticides.co.uk/include_pellets.asp?sec=788&con=794 accessed 9 February 2011

applied to protect crops at establishment. By comparison, most potato crops are harvested soon after this period of restriction starts. Unlike cereal crops a significant proportion of molluscicide applications to potatoes use the active ingredient methiocarb (43% by area of treated ware potato crops). The rate at which slug pellets are applied to potato crops is also significantly lower than in wheat or oilseed rape crops (178 g a.i. per hectare of ware potatoes compared with 305 and 300 g a.i. per hectare wheat and oilseed rape, respectively).

Agrochemical led initiatives

There are a number of industry led stewardship schemes that relate specifically to the potato industry. These include the Syngenta Best Use Guidelines for application of the nematicide/insecticide Nemathorin[47] for soil pest control. In addition to the guidelines there have been training initiatives including workshops for operators involved with Nemathorin and the fungicide Amistar. Similarly Bayer CropScience have produced a best practice guide for their nematicide/insecticide Mocap 10G[48] as do DuPont for their nematicide Vydate[49].

While it could be argued that agrochemical industry led stewardship schemes are in the best interests of these companies, the training elements and best practice guides improve production. Industry stewardship schemes may therefore be seen as complementary to VI schemes and their role has been extolled by Potato Council director Dr Rob Clayton[50].

Potato Council led initiatives

Potato Council led 'Fight Against Blight!' works on the basis of 300 blight scouts drawn from the industry on a voluntary basis. Data provided by scouts to provide the industry with a blight incident reporting service (www.potato.org.uk/blight). Analysis of samples allows for identification of blight strains, which is essential for effective control. Data on blight outbreaks complements forecasts based on weather data and comprehensive grower advice leaflets.

Potato Council funded monitoring by Fera of peach-potato aphid (*Myzus persicae*) provides growers with information on the first aphids found in a region and also when the index value of a region exceeds a given threshold (http://aphmon.csl.gov.uk/levy/index.cfm). Monitoring is important because of the ability of this species of aphid to transmit virus diseases of potatoes.

A new Maximum Residue Limit (MRL) of 10 mg/kg for the sprout suppressant chlorpropham (CIPC) were established when this chemical received European Annex I clearance under Directive EC/91/414. Concern that the industry would be able to

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[47] http://www.syngenta-crop.co.uk/news-viewer.aspx?id=30 accessed 9 February 2011
[48] http://www.bayercropscience.co.uk/pdfs/2667_BCS_Mocap10G_Guide_v3.pdf accessed 9 February 2011
[49] http://sandbox.genius.de/eventpage/ressources/pdf/04%20Wilbert%20Flier%20Vydate.pdf accessed 9 February 2011
[50] http://www.bayercropscience.co.uk/pdfs/2611%20BCS%204SPots%20Spring%2009%20v2.pdf accessed 9 February 2011

adhere to the new MRL led to the establishment of a Potato Council led stewardship group[51]. This cross-industry group seeks to promote uptake of existing knowledge on CIPC, further R&D as well as to implement and develop a code of best practice.

The British Potato Council played a major role in the development of the Safe Haven certification scheme. The scheme continues to be supported by the Potato Council and provides the industry with protection from imported diseases such as ring rot[52]. Approximately two thirds of the Scottish seed area is currently covered by the scheme and increasing numbers of seed and ware potato growers in other areas are actively seeking out certified supplies.

European initiatives

ENDURE brings together a network of researchers from 10 European countries (http://www.endure-network.eu/what_is_endure). The aim of ENDURE is to establish a community of researchers in crop protection, provide short-term solutions to specific problems, develop a holistic approach to sustainable pest management and to inform plant protection policy changes. Between 2007 and 2010 ENDURE developed a network of excellence in a range of fields of study related to crop protection.

EuroBlight is a potato late blight network for Europe (http://www.euroblight.net/EuroBlight.asp). EuroBlight has a range of activities from establishing protocols and guidelines to test host plants, the pathogen and fungicides. EuroBlight is also actively involved in monitoring and forecasting. In the UK this has led to development of Blight Watch, which takes traditional Smith Periods used to calculate the risk of potato blight infection and combines this with local weather data to provide risk assessments down to individual postcode level. This service operates in conjunction with the Potato Councils ‘Fight Against Blight!’ service (see above).

Other initiatives

A number of initiatives have been led by potato packers and processors. Greenvale AP has developed water saving technology in order to reduce water used to wash potatoes (see Section 3.1). Branston Potatoes have recently built a new prepared food factory that is based on the philosophy of low carbon = low cost (see Section 5.4).

Conclusions

There are a large number of voluntary, agrochemical industry, Potato Council and European led initiatives, which the potato industry participate in. These initiatives provide a number of benefits to the industry itself through for example improved

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[51] http://www.potato.org.uk/ref.html?podlet_id=142&did=2547 accessed 9 February 2011

[52] http://www.potato.org.uk/media_files/seed/safe_haven_09.pdf accessed 9 February 2011

health and safety and well as to the environment, through measures taken to reduce the impact of pesticides. These benefits are typically achieved without substantially increasing the administrative burden on farmers.

6. The contribution of GB potatoes to social and economic sustainability

Economic sustainability

Potatoes make an important contribution to the economic sustainability of UK agriculture. The farm gate value of UK potato production (based on average figures for 2007-2009) is £699 million (Table 6.1). Whilst this is considerably lower than for wheat or vegetables, when examined on a per hectare basis it can be seen that the value of potato production is second only to that of vegetables (including protected crops).

Table 6.1. Value of crop production (Defra, 2010[53])

Crop	**Value of production (£million)** 2007-2009 average	**Area of production** ('000 ha)	**Value** £ per ha
Winter wheat	£1,720	1 908	901
Winter Oil Seed Rape	£506	620	816
Sugar Beet	£204	121	1,685
Vegetables	£1,075	120	8,958
Potatoes	£699	144	4,854

As such potatoes are a high value crop for farmers and this is reflected in the average gross margin per hectare, relative to other arable crops, (Table 6.2). Growing potatoes can be important to maintaining the viability of smaller family farms and as such contributes to the social fabric of the countryside.

[53] Agriculture in the UK 2009 tables and charts http://www.defra.gov.uk/evidence/statistics/foodfarm/general/auk/latest/excel/index.htm accessed 1 February 2011

Table 6.2. Crop Gross Margins (Nix, 2010)

Crop	Gross Margin £/ha
Winter Wheat (milling)	606
Spring wheat	454
Winter Barley (malting)	478
Winter Oil Seed Rape	319
Sugar Beet	1,018
Onions	2,651
Maincrop Potatoes	3,461

Labour

By comparison with combinable and other crops such as sugar beet, the growing of potatoes is by far the most labour intensive (Table 6.3). As such potatoes make an important contribution to the rural economy. Potatoes also provide further employment opportunities once the crop has been harvested through packing and processing.

Table 6.3. Labour hours per ha (Nix, 2010)

Crop	Labour hours per ha
Maincrop potatoes	74
Winter cereals	9
Sugar Beet	26

Public subsidies and market management

In 1996 the Potato Marketing Scheme was abolished ending forty years of institutional control over the British potato market. The result has been greater market volatility but an increased focus on markets and supply chain links. Today the market for potatoes is increasingly reliant on contracts for processing and dedicated supply chains for the fresh market, driven by the large retailers.

This high degree of efficiency and market focus also reflects the fact that potatoes have not been directly supported through EC farm subsidies in the way that cereals and oilseeds have been. As such, the public cost of potato production, as with the vegetable sector is very limited. More recently, potato growers have effectively been supported through area based direct support payments (Single Payment Scheme) but this is modest relative to the value of the crop and the sector is not dependent on this form of income.

Another aspect of the potato market has been the significant amount of specialisation and restructuring of the production sector over the past 50 years. This has included a substantial fall in growers (Figure 6.1). This is consistent with a fairly static market in terms of consumption and despite the 56% drop in area, production has remained at around 6 million tonnes as yields have risen, driven mainly by improved crop protection, fertilizer regimes, varieties, and irrigation. This means that the scale of economic activity in the supply chain has largely been retained. Further, as already noted, this has allowed land to be released for other uses such as food or energy production or delivering other ecosystem services.

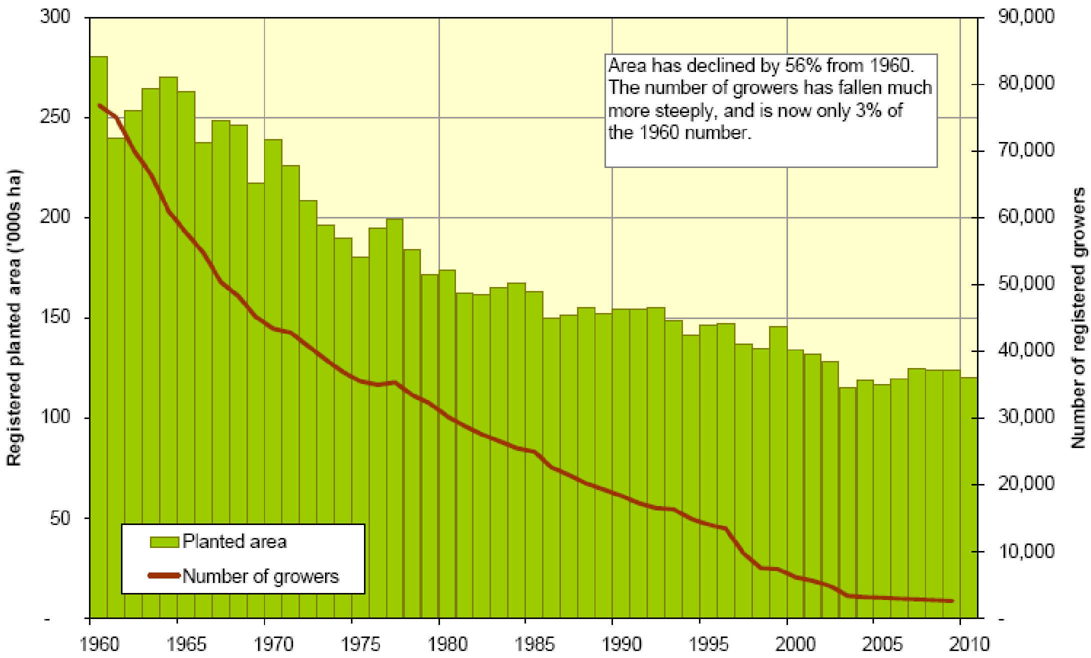

Figure 6.1. Registered planted potato area and growers between 1960 and 2010.

Trade and food security

Potatoes are of economic significance at an international scale. In terms of production, potatoes were the sixth largest commodity in 2008, (after sugar cane, maize, paddy rice, wheat, and cow's milk) with total production at 325,558,724 million tonnes. (ADHB, 2010) The UK is the twelfth largest producer of potatoes in the world, with total production of 5,946,100t in 2008 (Potato Council, 2010).

Potatoes are a key staple food in the UK, with average consumption in 2007 of 92.8 kg/capita/year (Potato Council, 2010). Figure 6.2 shows that potatoes and potato products have the largest share of the carbohydrates market in Great Britain. In 2010 fresh potatoes, frozen potato products and crisps constitutes approximately three quarters of the carbohydrate products sold in Great Britain, whilst this is slightly less than the 2007 figure the market value of the economic share of potatoes has grown from 79.6% to 82%.

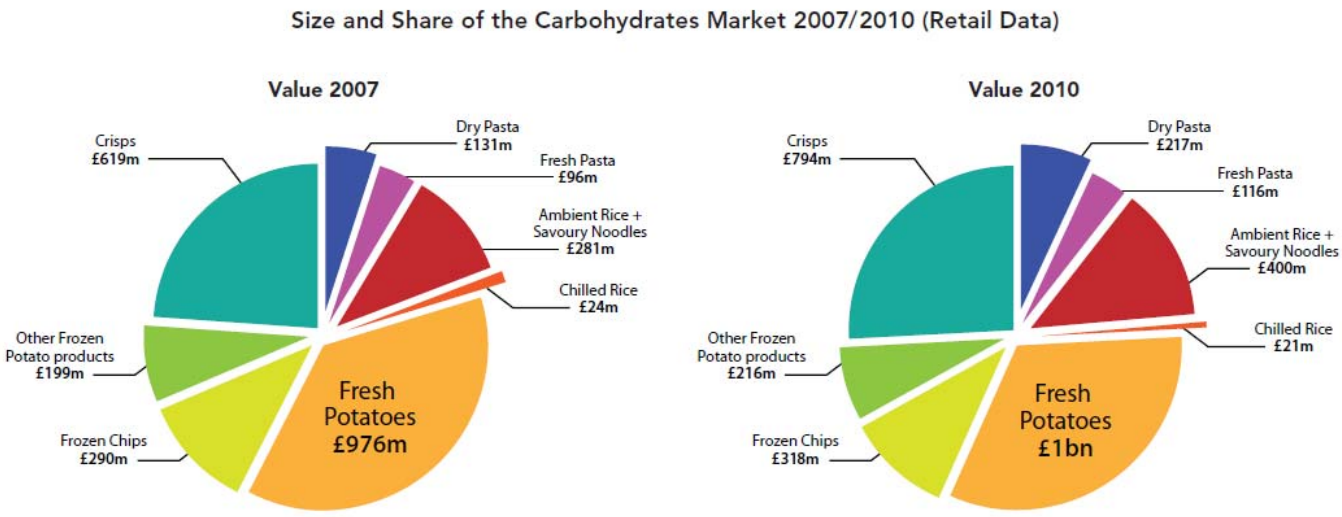

Figure 6.2. Size and value of the carbohydrates market in Great Britain in 2007/2010. (Potato Council, 2010)

Figure 6.2 also highlights the consumer value of the crop at over £3 billion before consideration of multiplier effects. In addition, the potato processing sector is estimated to employ 11,000 people (BRASS, 2005).

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