



# Impact of reduced pesticide availability on control of ...



# potato cyst nematodes and weeds in potato crops



September 2008



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## **Executive summary**

A replacement to the current EU Directive (91/414) regulating the availability of Plant Protection Products (PPPs) is currently being developed in Brussels. At present a compromise statement has been published by the EU Commission introducing new criteria that will determine availability and a list of more stringent amendments proposed by the EU Parliament has also been published. From late September through till December, the proposals return to the EU for a second round of debate. Possible implications for GB potato industry arising from both the Commission and Parliament approaches were summarised in Potato Council's August Grower Gateway. ([www.potato.org.uk/department/knowledge\\_transfer/grower\\_gateway](http://www.potato.org.uk/department/knowledge_transfer/grower_gateway))

In order to provide reliable robust information that will allow levy payers / stakeholders to accurately understand the consequences of loss of plant protection products under the Commission and Parliamentary scenarios, Potato Council have commissioned ADAS to build on previous work and produce a full potato-specific impact assessment. An interim update will be published in November and full report published in January 2009 which will include assessments of a full range of pest and disease issues (e.g. blight control, slug control, sprouting management).

Potato Council consider it important to provide information that informs the European debate and this is required in good time to match the timescales of the debating process. As such two additional case studies (for weed and PCN control) are published here and will complement the full report.

In generating these case studies, the impacts on PCN and weed control have been considered on a hypothetical farm (producing 40-50ha of potatoes on a 5 year rotation) with a range of pest and disease problems (chosen to reflect GB's main challenges). Assessment of available PPPs for the exercise are based on estimates of cut-off criteria previously published by the Pesticides Safety Directorate. ([www.pesticides.gov.uk/environment.asp?id=1980](http://www.pesticides.gov.uk/environment.asp?id=1980))

### **Highlights are:**

#### **Weeds**

- The Council compromise common position would see the loss of linuron and pendimethalin with proposed Parliamentary amendments resulting in additional loss of grass control options cycloxydim and propaquizafop if accepted.
- With linuron & pendimethalin unavailable growers would need to rely on a number of alternatives (Metribuzin, Prosulfocarb, Clomazone, Rimsulfuron, gas burner or cultivation) each of which has disadvantages. Most must be used

pre-emergence and conditions are not always right for good residual activity. The exception is Rimsulfuron, which can't be used on seed. Some will require shoring up with a contact product and others (like metribuzin) will be tricky to manage on lighter land where the potential for crop damage increases considerably. Overall, new mixtures will be expensive (potentially adding £14 to £25/ha) and although good control could be achieved there is a strong likelihood that many crops of intolerant varieties (e.g. Maris Piper) would have to progress without good residual protection; the weed competition would result in a typical reduction in gross margin of £1300/ha.

- Loss of control of grass weeds, particularly couch, would affect a smaller area (say 1% by area) usually on rented land. Where this scenario occurs then growers might expect a loss in gross margin of around £600/ha.

## PCN

- The Council compromise common position would likely result in a withdrawal of some nematicides 10 years after implementation. The more stringent parliamentary approach would result in a more immediate withdrawal.
- To estimate losses is quite a challenge because nationally we have to deal with a range of infestation levels, natural decline rates, variety tolerances and nematicide efficacies. To deal with these factors we have given our hypothetical grower a range of initial populations (Pi) from 0.1 to 25 eggs per gram. Combining the effects across his hectare we would expect a loss in gross margin of £1500/ha during the first rotation, >£3000/ha at the second rotation with yields dipping below 10T/ha by the third rotation.
- A number of alternative strategies to reduce populations exist but these could be difficult for our grower to swallow. These might include extending rotations to 12 years. This assumes good volunteer control in the interim years which itself may be more of a challenge as the option to use glyphosate would disappear under new rules. Resistant varieties have been difficult to breed (especially for *pallida*). Trap cropping may help but having lost set-aside this would present a greater economic burden than previously. Other options like steam sterilisation and biological control may help in future but it is difficult to envisage how they would fill the void in the expected time periods.

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September 2008

# The impact of current proposals for replacing Directive 91/414/EEC on control of potato cyst nematodes and free-living nematodes

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## Background

As part of the development of a new European Union (EU) Thematic Strategy for Pesticides, Directive 91/414/EEC, the European regulation that governs the registration of plant protection products in the EU, is going to be replaced by a new regulation of the Commission and the Parliament which will be developed using the 'co-decision' procedure. Under the new proposals, the criteria for pesticide approvals will become hazard- rather than risk-based – a fundamental change from the approach taken to pesticide regulation up until now. Chemicals that are deemed to be of "very high concern" are likely to be excluded under the new regulation. These are likely to include: category 1 and 2 CMRs (substances that are carcinogenic, mutagenic or toxic to reproduction); POPs (persistent organic pollutants); PBTs (persistent, bio-accumulative and toxic substances) and vPvBs (substances which are very persistent and very bio-accumulative); and endocrine disrupters. The European Parliament has proposed a policy that has more stringent cut-off criteria than those agreed by the Commission.

The co-decision process, by which an agreement between the Council and Parliament will be reached, is still on-going, but a decision to move to a hazard-based system has already been taken in principle (June 2008). There is serious concern that under a hazard-based approach, there could be substantial losses of active substances available for use in UK agriculture and horticulture, with subsequent impacts on pest, disease, and weed management for key crops, both due to direct yield losses, and indirect effects due to resistance issues. These would knock-on to serious economic consequences for growers.

The aim of this case study is to evaluate the potential technical and financial impact of the current proposals on the management of potato cyst nematodes (PCN) and free-living nematodes (FLN) by UK potato growers.

## Current problems and control strategies

### **Potato cyst nematodes**

Potato cyst nematodes (PCN) are the most important potato pests in the UK. They have the capacity to cause very serious yield losses in potato. Damage can range from slight yield loss up to crop failure depending on infestation level. There are two species of PCN present in the UK. These are the white cyst nematode (*Globodera pallida*) and the golden cyst nematode (*Globodera rostochiensis*). Each species can be further subdivided into pathotypes (Kort *et al.*, 1977). For *G. pallida* the Pa2/3 pathotype is most common in the UK, with Pa1 also present in some areas. For *G. rostochiensis*, only the Ro1 pathotype is present in the UK. Pathotypes are important

as potato varietal resistance to PCN is to pathotypes not species. Over the last 30 years, *G. pallida* has come to be the dominant species in England and Wales, largely due to the historic widespread production of varieties resistant to only the Ro1 pathotype of *G. rostochiensis* and the relative ineffectiveness of current control measures in preventing long-term population increases (Trudgill *et al.*, 2003). In the most recent structured survey of PCN populations in England and Wales, 64% of potato fields sampled were found to be infested with PCN (Minnis *et al.*, 2002). Of these 67% of sites contained *G. pallida* only, 8% were *G. rostochiensis* only and 25% contained both species. The results show an increase in the incidence of PCN since previous studies were completed and confirm the perceived shift towards *G. pallida* as the predominant species.

Current control measures rely on rotation, limited use of resistant (or partially-resistant) potato varieties, and the use of fumigant and non-fumigant nematicides. Rotation is a critical component of control as in the absence of a host-crop, PCN field infestations will slowly decline (e.g. Whitehead, 1995). Individual field populations have individual decline rates, but average decline rates of approximately 20-30% per year are usually assumed. As very large population increases can occur when a susceptible potato crop is grown in infested soil, even if a non-fumigant nematicide is applied, having a rotation of adequate length is critical to maintaining PCN populations at manageable levels. Non-fumigant nematicides are critical to preventing yield loss as they reduce the level of root invasion by PCN larvae. Currently approved products in the UK are oxamyl (Vydate 10G), fosthiazate (Nemathorin) and ethoprophos (Mocap 10G, this product is principally used for wireworm control). The use of non-fumigant nematicides essentially allows potatoes to be grown at PCN infestations higher than would otherwise be the case, a key element in the economics of production. PCN-tolerant varieties will yield well in spite of PCN attack and derive proportionately less benefit in terms of yield protection from non-fumigant nematicides than intolerant varieties (see Trudgill, 1986). True fumigant nematicides such as 1,3-dichloropropene (Telone II) can also be applied well before planting to small areas to reduce particularly high populations of PCN and other soil pests (e.g. Minnis *et al.*, 2004), but this product has failed to achieve Annex 1 listing under 91/414/EEC and will not be available in Europe after 2008.

Apart from rotation, other cultural control measures currently used include the use of resistant varieties and trap cropping. However, very few commercially-acceptable varieties have usable resistance to *G. pallida*, though some (e.g. Maris Piper, Cara) have full resistance to *G. rostochiensis* (Ro1 pathotype). The use of trap cropping using sticky nightshade (*Solanum sisymbriifolium*), a plant in the potato family which stimulates egg hatch but which does not allow the pest to multiply, is also used commercially, but agronomic considerations limit its practicality and efficacy (see below).

### **Free-living nematodes**

Free-living nematodes (FLN) in the genera *Trichodorus* and *Paratrichodorus* are common in sandy soils which are used for potato production in the UK, most typically in Norfolk, the Vale of York, Nottinghamshire and parts of the West Midlands. High FLN populations (>1,000 nematodes/litre of soil) can be common in fields in these areas, and are now being increasingly thought of as pests capable of causing direct feeding damage to potato in their own right. However, their prime pest status is as

vectors of Tobacco rattle virus (TRV). This causes brown arcs known as ‘spraing’ in tubers of susceptible potato varieties, which severely reduce the quality and hence the value of the crop. Recent work (Dale *et al.*, 2004) has also shown that systemic TRV infection can persist through generations of vegetative propagation. In some varieties this can result in delayed plant emergence and retarded growth, reduced tuber yield, increased incidence of growth cracks and misshapen tubers and diminished dry matter content. Common weeds such as chickweed and shepherd’s purse can also act as reservoirs for TRV.

Risk assessment and control of spraing is an inexact science. Although soils can be sampled to determine the presence and level of these nematodes, both nematode and virus distribution in the field is patchy and reliable molecular tests for identifying the presence of virus in individual nematodes are still under development. Individual varieties also differ in their susceptibility to TRV. Given these uncertainties, use of nematicides to control the nematode vectors is common on soils where high nematode populations are found and/or there is a history of spraing infection in susceptible varieties.

### **Nematicide use trends**

The most recent data from official Pesticide Usage Surveys covering England, Scotland and Wales indicating the level of nematicides usage on potato are given in Table 1 (data ex <http://pusstats.csl.gov.uk/>). Surveys are done biannually.

*Table 1.* UK potato area, area treated with nematicides and % of total potato area treated with nematicides in 2002, 2004 & 2006. An estimate of % treated area by target is also given

		2002	2004	2006	Mean
UK potato area (ha)		128,100	119,100	119,600	122,267
		Area treated (ha)			
Active ingredient	Product	2002	2004	2006	Mean
aldicarb	Temik 10G	20,973	9,501	5,534	12,003
ethoprophos	Mocap 10G	1,942	2,274	14,905	6,374
fosthiazate	Nemathorin	7,246	9,704	9,563	8,838
oxamyl	Vydate 10G	6,581	11,546	9,693	9,273
1,3-dichloropropene	Telone II	760	845	1,197	934
		% area treated as % of UK total potato area			
Active ingredient	Product	2002	2004	2006	Mean
aldicarb	Temik 10G	16.4%	8.0%	4.6%	9.8%
ethoprophos	Mocap 10G	1.5%	1.9%	12.5%	5.2%
fosthiazate	Nemathorin	5.7%	8.1%	8.0%	7.2%
oxamyl	Vydate 10G	5.1%	9.7%	8.1%	7.6%
1,3-dichloropropene	Telone II	0.6%	0.7%	1.0%	0.8%
		Estimated % area treated by target			
Target	Product	2002	2004	2006	Mean
PCN (FLN) control:	*	26.6%	24.9%	20.1%	23.9%
Wireworm control:	*	2.6%	3.5%	14.1%	6.7%

\*PCN (FLN) control = sum of all usage for Temik 10G, Vydate 10G and 80% of Nemathorin usage; Wireworm control = sum of all usage of Mocap 10G and 20% of Nemathorin usage.

Broadly, c. 23% of the total UK potato area (c. 28,000 ha) is treated for PCN and/or FLN at a cost at current prices of c. £9 million (product costs only). Although the recent survey data suggests a slight downward trend in the overall area treated, there is no particular reason to suppose that this trend will continue. Aldicarb and 1,3-dichloropropene have not been listed on Annex 1 of directive 91/414/EEC and are no longer available to UK potato growers, leaving only fosthiazate, ethoprophos and oxamyl as approved actives for PCN and FLN control in the UK.

## Scenario

To assess the impact of possible changes in nematicide availability, the following scenario for an individual grower producing on their own land was devised (Table 2). Some of these parameters (as indicated in Table 2) were used as inputs to the BPC (Potato Council) PCN Model (see Elliott *et al.*, 2004) which assesses the impact of different growing scenarios on PCN population dynamics and potato yield.

Table 2. Parameters used to define the growing scenario for a typical potato grower

Parameter	Value used	Comment
Area grown:	40 ha	
Soil type:	Sandy loam	Input to BPC PCN model
Irrigation:	Not limiting	
PCN decline rate	22%	Input to BPC PCN model
Potato rotation	1 in 5 years	Input to BPC PCN model
Variety	Maris Piper	31% of UK maincrop in 2007
Maximum yield	50 t/ha	Input to BPC model
PCN Tolerance	Very intolerant	Input to BPC PCN model
<i>G. pallida</i> resistance	None	Input to BPC PCN model
PCN infestation	25 eggs/g on 24 ha	Input to BPC PCN model
	5 eggs/g on 8 ha	Input to BPC PCN model
	0.1 eggs/g on 8 ha	Input to BPC PCN model
PCN species mix	All <i>G. pallida</i>	Input to BPC PCN model
FLN infestation	300 <i>Trichodorus</i> /litre of soil	

## Impact of European Parliamentary amendments

The hazard trigger criteria proposed by the European Parliament in response to the Commission proposals would have the effect of immediately removing from the market all the nematicides currently approved in the UK (ethoprophos (Mocap 10G), fosthiazate (Nemathorin) and oxamyl (Vydate 10G).

### PCN

Output from the BPC PCN model using the parameters described above show that loss of nematicides for a grower with the scenario outlined above would be serious.

In the absence of nematicides, PCN populations (measured as  $P_i$ , the infestation level immediately prior to cropping) would rise to an equilibrium of about 40 eggs/g over a period of time ranging from 10 (3 crops) to 15 years (4 crops). The overall impact of this on yields and economics change for the different infestation levels over the course of 3 potato crops on a 5 year rotation are shown in Figure 1. This shows how rapidly yields will drop in the absence of nematicides, even in those areas where initial PCN populations at the start of the 3 crop cycle are as low as 0.1 egg/g.

Figure 1. Predicted yields (with and without nematicides) at different PCN infestation levels for 3 potato crops in a 5 year rotation.

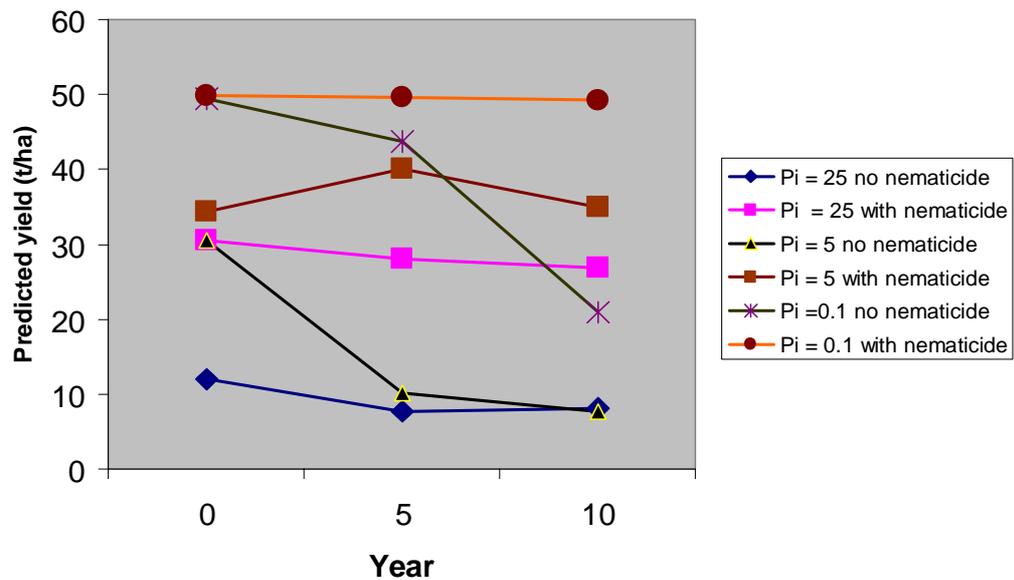
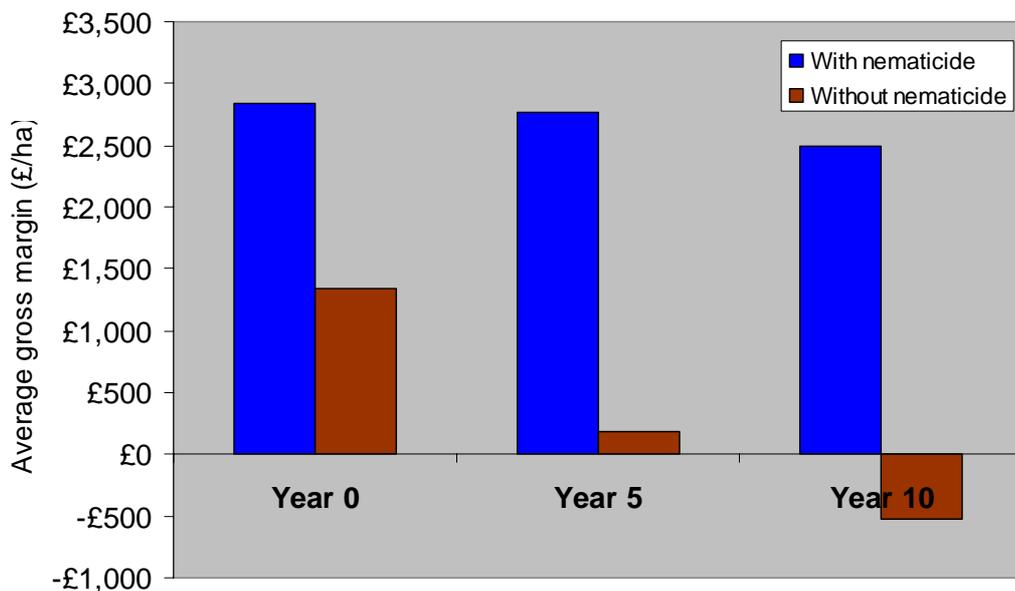


Figure 2. Effect of overall predicted yield on average gross margin (£/ha) for grower with 40 ha of potatoes.



The overall economic consequences for the grower with 40 ha as outlined above in terms of average gross margins (input cost data from Nix, 2007) indicates an immediate *c.* 50% drop in gross margin in the first crop (£2,834 £/ha to £1,344 £/ha), just break even in the second crop (£183/ha) and a loss by the third crop (-£528/ha) (Figure 2).

An additional effect of the Parliamentary amendments would be to put the herbicide glyphosate on the list of products for substitution. Although not used directly on potato, this herbicide is often used pre-harvest in cereals as a means of controlling potato groundkeepers (potatoes left in the ground from a previous potato crop). Where populations of these are high, they can act as a host-plant for PCN outside of the main potato crop in the rotation, and hence reduce the benefits of PCN decline normally expected during a break from potato cropping. The loss of glyphosate would therefore tend to make PCN problems more difficult to manage in the long-term.

## **FLN**

Assessing the economic impact of the loss of nematicides is difficult as there is no consistent relationship between nematicides use and the level of spraing control that can be achieved. The impact of damage may range from complete loss of crop quality, leading to a drop in price from (for example) £150/t for processing to £30/t for stockfeed. This potentially reduces gross margins from *c.* £2,800/ha to *c.* £550/ha.

## **Impact of European Council's common compromise position**

Under the current proposals as agreed by the European Commission, products would be candidates for substitution if the Acceptable Daily Intake (ADI), Acute Reference Dose (ARfD) or Acceptable Operator Exposure Level (AOEL) is significantly below those for the majority of approved substances, or the product meets two criteria for being a PBT. The currently approved nematicides (ethoprophos, fosthiazate and oxamyl) are all likely to fail these hazard triggers (Pesticides Safety Directorate, 2008). This means that they would remain approved for up to 10 years following the introduction of the new regulations, but some would then be removed from the market.

The impact on PCN and FLN control and the consequent economics of production would therefore be minimal for upto 10 years after the Regulation came into force assuming the companies marketing the nematicides maintained the product registrations for the full period. The impact of loss of the products thereafter (assuming no other mitigations were economically viable) would then be similar to the impact of the Parliamentary amendments outlines above – but the full effect would simply have been deferred for 10 years.

## **Mitigation**

The impending or actual loss of nematicides will focus attention on the efficacy and economic viability of alternatives. Methods which could be applied now or conceivably in the next 10 years are briefly discussed below. Most of these methods are aimed at PCN rather FLN control. None of these methods are likely to provide a

direct replacement for currently approved nematicides, and would have to be used carefully in combination in an integrated pest management (IPM) programme to ensure effective nematode control.

### ***Using clean land***

In theory, potato growers could simply switch production to land not infested with either PCN or FLN. However, soil type and the availability of irrigation limit how much land is actually available. Many larger growers already rent significant areas of land and in practice there is insufficient suitable land to enable this to be a realistic option for all growers.

### ***Longer rotations on infested land***

In principle, PCN can be effectively managed in the long-term by only growing potatoes on infested land on very long rotations. Output from the BPC PCN model using the scenario in Table 2 adjusted for rotation length indicates that PCN populations can only be held at levels (<10 eggs/g soil) that do not generally require nematicide treatment on rotations of at least 1 in 12. For the 40 ha potato grower on their own land, this is not an economically viable option as it would only permit 3 crops of potatoes on the same land in a 25 year period. It is therefore likely rotations of between 5 and 10 years would have to be used in combination with other control options. Alternatively, fields could be intensively cropped on short rotations and then taken out of potato production for up to 20 years.

Lengthening potato rotations does significantly reduce FLN populations, although there is some evidence that cropping with barley can help reduce the TRV infection load in the nematode population.

### ***Resistant varieties***

In principle, the use of resistant varieties to reduce PCN populations can be a very effective strategy, and indeed it has been a very successful approach for the control of *G. rostochiensis* in the UK as the widespread use of Ro1 resistant varieties such as Maris Piper and Cara (for purely commercial reasons) has greatly reduced the incidence of *G. rostochiensis*. However, potato breeders have found full resistance to *G. pallida* is much harder to achieve, and although some varieties are available with partial resistance to *G. pallida*, they are not generally varieties in wide demand from the market and therefore are only grown on about 8% of the potato area which may or may not be infested with *G. pallida*.

In the longer term, the use of genetically modified (GM) potatoes engineered to be resistant to PCN could offer a more durable solution. However, there is no prospect of any such varieties being available for UK commercial production in the foreseeable future.

### ***Trap cropping***

The use of trap cropping using *Solanum sisymbriifolium* (sticky nightshade) is used for PCN control (FLN are not controlled) by some growers in the UK under the trade names Foils-sis or DeCyst. The crop is grown prior to potatoes as means of reducing the PCN population before cropping. The price of seed is £285/ha and establishment costs are £70-100 /ha, making it more expensive than a conventional nematicide application. Use of *S. sisymbriifolium* can be very successful in the right

circumstances, reducing PCN populations by 65 – 75% in sandy loam soils. However, efficacy declines with increasing soil organic matter. The main issue is finding a suitable place in the rotation to grow the trap crop. Current varieties are more suited to a Mediterranean climate, and need to be sown in May/June to give 3 months of good growing weather. Attempts have been made to drill crops after winter barley and peas, but this is restricted if cereal or pea harvest is delayed. Until recently, the crop was largely grown on set-aside land, and the loss of set-aside has seen a marked reduction in the amount of *S. sisymbriifolium* grown in the UK. In the future, varieties more suited to UK conditions may become available.

If trap cropping were no longer able to use the availability of set-aside land there would be an additional cost of over £400/ha to the grower of the lost crop that would otherwise be grown on that field. Assuming the crop replaced crop was milling wheat, yielding 8.25 t/ha, the gross margin (using values from Nix 2007) would be £420/ha. This is calculated from a crop value of £82.5 t and costs for fertiliser, pesticides and seed of £260/ha. However, fertiliser prices are now much higher but grain prices have also risen. We have used Nix 2007 as a basis to ensure comparability with other financial data in this document and to provide a consistent reference.

### **Steam sterilization**

Equipment to sterilize field soil using steam is under development in the UK. However, the work rates of these machines are extremely slow, making treatment of significant areas of land impracticable. This approach would control both PCN and FLN.

Using methodology under development in Defra project FO0404 (Scenario building to test and inform the development of a BSI method for assessing GHG emissions from food) we have estimated the impacts on the carbon footprint of steam sterilization compared with nematicide treatment.

Table 1 indicates that 24% of fields are currently treated with nematicide. The market leader is ethoprophos, which is incorporated into the soil just prior to the final soil cultivation. This nematicide is applied at a rate of 100 kg/ha, with the active ingredient making up 10% ww of the product. The carbon cost of producing the nematicide, transport of product to the farm, application to the field and incorporation is approximately 100 kg CO<sub>2</sub>e per ha. On a crop yielding 44.5 t/ha this is about 1% of the total emissions per tonne of potatoes.

If nematicide control was replaced with steam treatment the carbon cost would be much increased. As a basis for the calculation we have used information on a very efficient machine currently under development (HDC project CP 6: Integrated use of soil disinfection and microbial organic amendments for the control of soil borne diseases and weeds in sustainable crop production (HortLINK Project number HL0136LSF)). This involves steam treatment of the soil involves a tractor pulling the steam treatment machine very slowly across the field, as it travels across the field the steamer lifts the soil, heats it up to the required temperature and then replaces the soil. This process requires the use of diesel for heating and moving the steamer. Based on a work rate of 24 hours per ha, and a requirement of one litre of diesel per 2m length of bed this gives rise to carbon emissions of 7,000 kg/ha. Assuming the yield and all

other inputs to the potato crop are unchanged this represents an increase in the carbon emission by 80% compared with nematicide.

In relation to the total potato crop, if only 24% of the UK area of potatoes is treated, the national impact of replacing nematicide with steam treatment would be to increase the carbon emissions of by about 20%.

### ***Biological control***

Recent work in the UK at Harper Adams University has suggested that the use of a soil fungus, *Pochonia chlamydosporia*, can help to reduce PCN populations in field soil, although its efficacy may be reduced by fungicides applied for tuber-borne disease control (Tobin *et al.*, 2008). This has been under development for many years and is not currently available commercially. There are no prospects for the biocontrols of FLN.

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# **Weed and Herbicide Case study on Potatoes**

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SAC

## **Introduction**

As part of the development of a new European Union (EU) Thematic Strategy for Pesticides, Directive 91/414/EEC, the European regulation that governs the registration of plant protection products in the EU, is going to be replaced by a new regulation of the Commission and the Parliament which will be developed using the 'co-decision' procedure. Under the new proposals, the criteria for pesticide approvals will become hazard- rather than risk-based – a fundamental change from the approach taken to pesticide regulation up until now. Chemicals that are deemed to be of "very high concern" are likely to be excluded under the new regulation.

There is serious concern that under a hazard-based approach, there could be substantial losses of active substances available for use in UK agriculture and horticulture, with subsequent impacts on pest, disease, and weed management for key crops, both due to direct yield losses, and indirect effects due to resistance issues. These would knock-on to serious economic consequences for growers.

This draft report prepared for the Potato Council present a case study for an average British potato grower in response to the proposed changes in the availability of herbicides being considered by the EU. The case study assesses the potential loss of linuron and pendimethalin (PDM) as proposed by the EU Commission and the further loss of the graminicides, cycloxydim and propaquizafop, as proposed by the European Parliament. Linuron and PDM are broad-spectrum pre-emergence residual herbicides with particular activity on broad-leaved weeds and annual meadow-grass. The graminicides are used primarily for the control of couch-grass, but also other grass weeds and volunteer cereals.

## **Proposed Case Study**

We have taken an average potato grower of 50 ha with a mixture of soil types including sandy loams to clay loams growing a range of varieties including main crop Maris Piper for chipping and second earlies Estima and Saxon for pre-pack and a small area of the early variety Premiere grown under a temporary cover. He grows a small area of certified seed. He grows potatoes on a five year rotation with Winter Wheat, Winter Barley, Winter rape, Winter Wheat and Potatoes. On the light land he always has a problem with couch-grass and as he rents 5 hectares every year for seed production. On the rented land he tends to inherit couch-grass problems from time to time. Typically, the main weed problems apart from couch-grass are annual meadow grass, and range of broad leaved weeds including polygonums (e.g. black bindweed, knotgrass), fat hen, fumitory, and cleavers on the heavier soils. The above weed scenarios are typical of a British farm growing potatoes on a range of soil types although the variety mix may differ. All the weeds are competitive but bindweed, knotgrass and cleavers are particular problems at harvest as they entangle lifting equipment.

The challenges this typical British potato grower faces in terms of weed control are:

1. Variety choice. In 2007 Maris Piper accounted for 25 827 hectares, 20% of the total potato plantings in Great Britain (source Potato Council Estimate of Potato Planting by

variety, 2007). Maris Piper has a wide range of potential markets including crisping, chips, processing and pre-pack ware. If it makes pre-pack quality it attracts a premium over other white potatoes. In terms of herbicide use Maris Piper is very dependant on the use of linuron as it is not tolerant to metribuzin (e.g. Sencorex, Lexone and other generic formulations) from post emergence application and not at all on sandy soils. Application of metribuzin to Maris Piper early post emergence is likely to cause considerable crop damage. On this farm the preferred herbicide timing on all varieties is pre-emergence but this is not always possible due to weather conditions. To avoid damage to the crop the preferred residual herbicide is linuron or PDM in mix with prosulfocarb (Defy), and a contact such as diquat (e.g. Retro). The linuron or PDM is an essential partner to prosulfocarb to control the polygonums and fat hen while prosulfocarb gives effective control of annual meadow grass, fumitory and cleavers. The alternative to linuron on Maris Piper is PDM with a contact herbicide.

2. The Saxon and Estima receive prosulfocarb plus metribuzin in mix to control the fumitory and cleavers. Saxon and Estima are tolerant to metribuzin pre and post emergence so there are no limitations on timings with these varieties.

A percentage of the Saxon and Estima in this case study farm is grown on the rented land or the light soil both of which have a history of couch-grass. Couch-grass is usually more of an issue on light soils. While the diquat typically burns the tops off the couch grass the re-growth can be a problem in the second earlies, Saxon and Estima, which are not as competitive as main crop Maris Piper. Cycloxydim, (Laser) or propaquizafop (Falcon) are used to control couch-grass.

3. Occasionally on this farm, due to dry soil conditions, the residuals fail to control fumitory, bindweed and couch grass. Rimsulfuron (e.g. Titus, Tarot) applied in good time will give suppression of these key weeds.
4. The case study farm has 2 hectares of early variety Premiere grown under cover for the early punnet market. Premiere had a market share of 33% of the early market in 2007 (source Potato Council estimate potato plantings 2007). The farmer traditionally uses pre-emergence a linuron + metribuzin mix before laying down the cover as these are the only approved products for use pre-emergence on Premiere under covers.

The above is a typical British potato farm with a range of weed problems. What are his alternative weed control options and how do they reflect British use of herbicides in potatoes?

## **Impact of the loss of Linuron and PDM**

The majority of the GB crop of Maris Piper will receive linuron as the preferred residual. The total area of the British crop on all varieties treated with linuron in 2006 was 86,340 Hectares. This equated to 66% of the total area of potatoes grown in Great Britain (Total potato area of potatoes in 2006 was 130,758 hectares, source Potato Council estimated planting survey). The total weight of linuron by active ingredient was 101,579kg equivalent to an average application rate of 1.2lt/ha (source CSL Pesticide Usage Statistics 2006). This application rate is close to the label rate of branded linuron awaiting approval by PSD in the UK from an approval submission by Makhteshim Agan. The total area of potatoes treated with PDM in 2006 was 6697 Hectares with a total weight of active ingredient of 7703kg. This is equivalent to 5.9% of the national crop.

In our example farm the loss of linuron and PDM as a herbicide on Maris Piper will mean substitution with:-

- **Metribuzin** based products (e.g. Sencorex, Lexone or other generics), or combinations with flufenacet, e.g. Artist marketed by Bayer Crop Science. Both straight metribuzin and Artist require to be applied pre-emergence in potatoes to minimise crop damage. The flufenacet component in Artist is particularly damaging to potatoes post emergence or even at ridge cracking and should also not be applied to sandy soils. Flufenacet is very active on a range of grass weeds, including black- grass but not couch- grass. The rate of metribuzin in Artist is relatively low and will only give partial control of our farm's difficult weeds, bindweed and cleavers. (They are rated Moderately Susceptible, MS in the Bayer CS product manual.) Artist should not be used on very light soils, which is a problem for our grower with a proportion of light soils, also as stated in the Bayer CS product manual.
- **Prosulfocarb** is sold as Defy by Syngenta. Defy must also be used pre-emergence on all varieties of potatoes and will give control of cleavers and grass weeds but not couch grass. It is not a stand alone product and it would require mixing with metribuzin to broaden spectrum to control bindweed. Defy will also give some control of fumitory. This would incur additional costs of £9.3/ha.
- **Clomazone** marketed as Gamit by Belchim Crop Protection. Gamit must be used pre-emergence of the crop and is very good on cleavers control. It requires to be mixed with metribuzin to broaden weed spectrum.
- **Rimsulfuron** sold as Titus and Tarot by Makhteshim Agan UK Ltd. This is a useful post emergence product for control of bindweed, cleavers, some activity on small fumitory and useful suppression of couch-grass. It is a useful option should the pre-emergence products be ineffective *but is restricted to ware crops only*.
- **Gas burner and inter-row cultivation** the use of the gas burner or inter-row cultivation for weed control has been considered in our case study as an alternative to conventional chemical weed control. Both techniques are more expensive than the most expensive herbicide option and in the case of the gas burner considerably more, see table 1.

For our case study farm there are the issues relating to his crops under temporary cover:-

- Crops under cover. Typically our case study farm uses PDM plus linuron pre-emergence prior to covering. This gives good control of bindweed which is a problem weed, and some control of cleavers and fumitory. Alternatives are prosulfocarb + metribuzin, which is better on cleavers.

For weed control in the farm crops of second early varieties Saxon and Estima there are no restrictions on herbicide choice except where grown on the sandy soil where high rates of metribuzin should be avoided. Artist with a low rate of metribuzin, or prosulfocarb, are herbicides better suited to light soils.

**Table 1 Economics of alternative combinations to loss of Linuron and Pendimethalin and cost difference**

	£Cost/ha	Difference relative to PDM 3.3lt + linuron 1.2lt - £/ha
Linuron 1.9lt	10.21	Max rate in 2008 as recommended by industry protocols
Linuron 1.2lt. Expected New label	6.45	Unlikely to be used on its own at this rate
Metribuzin 0.75kg	24.75	- 6.45
Prosulfocarb 4.0	24.00	- 7.20
Artist 2.5kg	47.5	+16.3
Clomazone 0.25lt	27.50	
PDM 3.3	24.75	-6.45
PDM 3.3lt + linuron 1.2lt	31.20	0
PDM 3.3+ metribuzin 0.5kg	39.00	+7.80
Prosulfocarb 4.0lt+ linuron 1.2lt	34.50	+3.3
Prosulfocarb 4.0lt + metribuzin 0.5kg	40.50	+9.3
Prosulfocarb 4.0lt + Artist 1.5kg	52.50	+21.30
Prosulfocarb 4.0lt + metribuzin 0.5kg + clomazone 0.15lt	57.00	+25.80
Prosulfocarb4.0lt linuron 1.2lt+ clomazone 0.15lt	46.95	+15.75
Gas Burner	148.26	+117.06
Inter row cultivations	60.00	+ 28.8

Notes All the above herbicide combinations would require the addition of a contact herbicide such as diquat, glufosinate or cafentrazone (e.g. Retro, Basta or Shark) if applied to emerged weeds. Typically Retro at 2.0lt/ha adds another £21.00/ha to the cost of weed control.

Note we are aware that Diquat, Glufosinate, Metribuzin and Flufenacet are on the EU Commission list as molecules subject for substitution. If all these molecules were withdrawn there would be further serious consequences for the industry.

The main conclusion is that the alternatives to linuron, whether alone or in mix, will cost our case study grower and industry more. The use of the burner or inter-row cultivation, often used in organic potatoes, costs considerably more than conventional herbicides and have a higher carbon footprint.

For example the gas burner is really too expensive as a herbicide option and has environmental implications for CO<sub>2</sub> production. Gas burning of weeds using propane plus application produces approximately 380kg CO<sub>2</sub>/ha, inter-row cultivation produces 12.5kg/ha CO<sub>2</sub>/ha, (source SAC Specialists, personal communications). Conventional

herbicide application in comparison, for a single pass, would be 6.25kg/CO<sub>2</sub>, not including CO<sub>2</sub> produced as a result of herbicide manufacture.

Inter row cultivations require a minimum of two passes. Use of cultivation for weed control can be successful and safe to the crop, and is widely utilised in organic crop production. However, there are examples in the literature of trials which show an effect of cultivation for weed management on yield, assumed to be due to damage to roots/stolons (Bremner, 1966 showed yield reduction of between 7.0 and 18.7% in a three year trial and more recently from Italy (Casa & Viola, 2005) with the cultivar Desiree in organic farming suggests a yield decrease of 20.9% where hoeing was used compared with a hand weeded crop and 12.4% for hoeing + hilling (ridging). In a further review, Wulf (1997) in Germany indicated that in trials from 1993 to 1995, with various types of equipment for mechanical weed control, yields were reduced, there was less success in weed control and damage to roots and stolons.

The impact of the loss of linuron and pendimethalin on weed control is shown in Table 2, compared with alternative treatments.

**Table 2. Grass weed and Broad leaved weed spectrum from herbicide options applied Pre-emergence**

	Metribuzin 075kg	Linuron 1.9lt	PDM 3.3lt	PSC 4.0lt	PSC 4.0lt + linuron 1.2lt	PSC 4.0lt + Metribuzin 0.75	PDM 3.3lt+ Metribuzin 0.5kg	Artist 2.5kg	Rim- sulf- uron 50 gm
AMG	****	****	****	****	****	****	****	****	R
A. Nettle	****	****	NI	****	****		****	**	R
B. Bindweed	**	****	NI	**	****	***	***	**	***
Chickweed	****	****	****	****	****	****	****	****	****
Charlock	****	****	NI	****	****	****	****	**	****
Cleavers	***	*	*	****	****	****	***	****	****
Creeping Thistle	**	**	R	**	**	****	**	*	*
Deadnettle	****	***	***	****	****	****	****	****	****
Fat hen	***	****	***	**	****	****	****	****	NI
Fumitory	****	*	**	***(*)	****	****	***	****	**
Groundsel	****	***	NI	****	****	****	****	****	NI
Knotgrass	***	**	****	**	***	****	****	****	R
Mayweed	****	***	**	*	****	****	****	****	****
Pansy	***	****	***	*	****	****	****	****	*
Redshank	****	****	**	**	****	****	****	****	**
Poppy	****	****	***	*	****	****	****	NI	NI
S. Purse	****	****	**	****	****	****	***	**	NI
Speedwells	****	****	****	****	****	****	****	**	NI
V rape	****	***	****	**	***(*)	****	****	**	****

\* <40% control, \*\* 40-65%, \*\*\* 65-95%, \*\*\*\* >95% control, NI – no information, R – resistant

Note: PSC = prosulfocarb. Note that with potential reduction in application rate of linuron to 1.2lt/ha reduced persistence and control of some key weeds can be expected. This reduction in yield will appear as the expected label rate of Linuron for the 2009 cropping year. It is dependant on PSD approving the label on the dossier submitted by Makhteshim Agan UK Ltd.

The main weeds where the loss of linuron will have most impact is the control of fat hen and bindweed; both can be very competitive weeds in potatoes. However substituting with pre-emergence use of straight metribuzin or prosulfocarb+ metribuzin or Artist picks up on

all of the weeds where linuron is weak such as fumitory, cleavers and knotgrass. Most of the weeds to which PDM is weak such as mayweeds and fumitory will be picked up by metribuzin and prosulfocarb mixes.

Reviewing the literature on the effects of the potential loss of linuron and PDM on weed control in potatoes highlights the lack of recent studies.

An area that also needs some consideration is the effect of potentially poor weed control in potatoes, and indeed in other parts of the case study rotation, are weeds as hosts of some of the common potato diseases. A brief review of some of the studies is given below.

## **Effect of Treatments on Yield: Examples from some weed control trials**

### ***Broad-leaved Weeds***

1. A series of trials have been undertaken at Terrington EHF in 1974 and 1975 which showed no significant difference in marketable yield of potatoes between metribuzin applied pre- or post-emergence, linuron pre-emergence and the use of cultivations. There is no indication of weed levels, and there was no untreated comparison. (copies of trial reports for series PT.1/29 'Weed control techniques' from ADAS Terrington report of trials: 1974 and 1975).
2. A further series of trials undertaken at Terrington EHF in years 1987, 1988 and 1989 (copies of ADAS interim trial reports) compared metribuzin applied pre-emergence or post-emergence, amongst a wide range of mixture and timing combinations, with PDM pre-emergence alone (at high dose of 2400g ai/ha) in 1987 and PDM + cyanazine (1600 + 750g ai/ha) in the other two years, plus untreated plots. Note the high rate of PDM used is higher than currently recommended and cyanazine is no longer available.

Despite weed levels of 11-50% weed cover in June there was no significant difference in yield between untreated plots and those treated with metribuzin post-emergence or with pendimethalin treatments, although untreated yields tended to be lower.

On two out of three years, PDM based treatments tended to be lower yielding than metribuzin treatments, and in one case, lower than untreated yields. Trial reports commented on phytotoxic effects from PDM in 1987. In one year metribuzin pre-emergence was significantly higher yielding than the other treatments.

3. A trial from DANI, Northern Ireland, in 1997 (Mercer et al., 1999, *Annals of Applied Biology* 134 (Supplement) p30-31) compared a range of treatments at high and low doses. Amongst the treatments were paraquat combinations with metribuzin, rimsulfuron and linuron. There were no significant differences in yield between the treatments, although all gave significantly higher yield than the untreated plots. In this case weed levels were high, at about 240g dry matter/ m<sup>2</sup>. The treatments giving the best control of broad-leaved weeds and annual grasses was paraquat + linuron (leaving about 11g dry matter/m<sup>2</sup>, compared with about 25g for the other treatments).
4. Trials at ESCA in 1985 showed PDM improving yield over untreated plots by about 25% with a 28% ground cover of broad-leaved weeds (ESCA Report of Weed Control Trials, 1985), and various herbicides increased yield by 90% over untreated plots with

about 38% ground cover of weeds (ESCA Trial Report: Potato Herbicides Trial E149, 1986).

In conclusion, the yield response of potatoes to broad-leaved weeds tends to be very variable, depending on soil moisture, soil type, weed seed bank, when the weeds emerge, etc, etc, but in general there is a yield response to broad-leaved weed control ranging from a few percent to more than 50%.

There is a limited amount of comparative weed control yield data for the herbicides and individual weeds discussed in this case study, but in general the differences between herbicide treatments are non-significant so long as weeds are controlled reasonably well, and early. The 1974/5 series suggests cultivations can also produce yields similar to herbicide treatments. However, other texts do suggest that yields can be depressed if later cultivations damage the stolons. The series at Terrington in 1987-89 may suggest that PDM, at the higher doses used then, may not be as safe to the crop as other herbicide treatments, but this is based on very limited data that we have available.

## Impact of the loss of Graminicides

The loss of the graminicides, cycloxydim and propaquizafop (Laser and Falcon) on our example farm and nationally would have a significant effect locally where crops are grown on land of unknown history, and where there is grass in the rotation.

The total usage of Laser on potatoes in 2007 was approximately 1500lt, (personal communication from BASF) equating to 666ha, while that of Falcon was 670 litres, (personal communication from Makhteshim Agan). This equates to approximately 450 Ha, the two together equating to 1116 Ha or 0.9% of the total national potato area treated with a graminicide. The alternative to the graminicides are good attention to couch-grass control in preceding crops and fallows with glyphosate. Couch-grass levels in potatoes could potentially become more of a problem as the options for control in the rotation diminish. There is less set-aside and we may see the loss of the pre-harvest glyphosate option in cereals. (This recommendation has been lost in some Baltic states and Denmark and is on the list of products on the EU Parliament substitution list). This will put pressure on the use of rimsulfuron, the only alternative treatment. However rimsulfuron is not as active as the graminicides, only giving moderate control, (accepted circa 50%), nor can it be used on seed crops, a particular problem for our case study farm and the wider industry, (reference product labels).

### ***Grass Weeds – Impact on yield***

The information we have found is limited to the effects of couch-grass on yield. Couch is very competitive, starting at emergence (Zimdahl, R. 2002, *Weed-Crop Competition – a review*, 2<sup>nd</sup> edition, Blackwell Publishing, p51). He concluded that there was a critical period of competition as such and that control is needed as soon as possible. Further studies have shown that 10% yield loss can be expected from 25 shoots/m<sup>2</sup> with an economic threshold of between only 0.04 and 0.2 shoots /m<sup>2</sup> (Baziramakenga R & Leroux GD, 1994, Critical Period of quackgrass (*Elytrigia repens*) removal on potatoes (*Solanum tuberosum*), *Weed Science* 42:526-533). The rhizomes can also cause difficulties at harvest, clogging up machinery.

In Canadian research (Ivany, JA (1986). *Canadian J of Plant Sc* 66, 185-187) on hand-weeding couch grass trials from 1978-1981 the mean yield from four hand weeded trials was 20.5t/ha. Where no weeding took place, this reduced to 4.6t/ha. The couch population at 6 weeks after emergence was 56-326 g/m<sup>2</sup>. The yield response depended on degree of

infestation and how long it was left to compete. Early removal was most beneficial. There was no significant difference between weeding at 2, 4 and 6 weeks.

## Weeds as hosts to pests and diseases

Leaving weeds in the crop could provide a host for pests and diseases of potatoes and, aside from aphids, examples include:

1. Host range for *Colletotrichum coccodes* includes: fat hen, creeping thistle, field bindweed, shepherds purse, couch-grass, (Raid RN, Pennypacker SP 1987, Weeds as hosts for *Colletotrichum coccodes*. Plant Disease 71: 643- 646), & oilseed rape( Chesters, CGC & Hornby D 1965. Studies on *Colletotrichum coccodes* II. Alternative host tests and tomato fruit inoculations using a typical tomato root isolate. Transactions of the British Mycological Society 48, 583-594).
2. Host range of *Rhizoctonia solani* include shepherds purse, creeping thistle, couch-grass, crane's-bill, rye-grass, mayweed, knot-grass, redshank, black nightshade and chickweed. (Jager G, Hekman W and Deenan A,1982. The occurrence of *Rhizoctonia solani* on subterranean parts of wild plants in potato fields. Netherlands Journal of Plant Pathology 88, 155-161).
3. Oilseed rape is a key host for *Erwinia* (also calabrese and possibly wild brassicas - personal communication I Toth). (Toth, I et al. (2006) What has genomics ever done for us? - A study of *Erwinia* and blackleg disease. Proc CPNB 2006, 230-244).
4. Nematodes and TMV: Nematodes and TMV host plants- especially mayweeds, chickweed and fat hen in paper. Probably also knot-grass and shepherds purse in spoken paper. (MFB Dale, DJ Robinson, J Wishart (2006) Development of Diagnostic procedures to assess the distribution of Tobacco Mosaic Virus in fields. Proc CPNB 2006, 279-284).

## What are the financial impacts to the case study farm and the industry?

The financial loss to the industry of linuron and PDM in terms of broad leaved control would be minimal as there is sufficient product substitution to metribuzin or co formulations with flufenacet as Artist. On Maris Piper, or other varieties not tolerant to post emergence use if metribuzin, the impact of missing the pre-emergence timing is difficult to quantify. In a worst case scenario, for example in a wet spring, the yield loss of no residual application could be 20%, (Report on European Agriculture of the Future, The Role of plant Protection Products). On an average national yield of 44.5t/ha in 2007, (source Potato Council), this equates to a loss of 9t/ha which with an average price in 2007 of £142.71, (source Potato Council) is a loss to our case study farm of £1284.39/ha.

The impact of changing from linuron @ 1.9lt/ha based herbicide programme to using metribuzin @ 0.75kg/ha is £14.50/ha, table 1. Assuming that 66% of the potato industry that received linuron in 2006 switched to metribuzin, at these rates, then extra cost to the GB potato industry is £1.2M, (using 2008 Potato Council planting census figures).

The loss of the graminicides, although used on a much smaller area than linuron, will have a bigger impact, especially on seed crops where no product substitution is possible. There are no figures to break down the use of graminicides on seed crops. The impact on yield of

couch grass from literature ranges from 10% to 77%. At a 10% yield loss and an average national yield of 44.5t/ha and an average price /tonne of £142.71 the loss is £635/ha. At anything approaching 77% yield penalty the impact will be up to nearly 8 times as great! On seed crops with a generally higher value the yield loss will be greater than ware, especially as they tend not to be as competitive as ware crops.

## Conclusions

The loss of PDM will be felt less than the potential loss of linuron. Linuron is cost effective and it has a wide take up within the GB potato industry and for other root crops; notably carrots where there are even fewer herbicide options than in potatoes. Growers know how to use linuron and the product is safe on the common variety Maris Piper, pre and post emergence. Linuron has a wide weed spectrum and any gaps are covered by tank mixing with prosulfocarb.

Metribuzin either alone or in mix with flufenacet as Artist offer good alternatives to linuron and PDM but require a higher management input with an early pre-emergence application. Although this is the preferred timing to avoid damage to the developing crop, weather conditions often do not make this possible and an early post-emergence application inevitable.

Linuron and PDM are often used in potatoes under temporary covers. Metribuzin is an alternative and has a label recommendation for use, and Artist is a useful option.

Alternative non chemical options such as inter row cultivations are often used in organic crops requiring at least two passes, the second of which can cause crop damage. The gas burner is really too expensive as a herbicide option and has environmental implications for CO<sub>2</sub> production. Gas burning of weeds using propane plus application produces approximately 380kg CO<sub>2</sub>/ha, inter-row cultivation produces 12.5kg CO<sub>2</sub>/ha, (source SAC Specialists, personal communications). Conventional herbicide application in comparison, for a single pass, would be 6.25kg/CO<sub>2</sub>, not including CO<sub>2</sub> produced as a result of herbicide manufacture.

A recent report suggests that should the loss of herbicides continue beyond those in this case study the Industry is likely to see a decline in yields of 20%. (Report on European Agriculture of the Future, The Role of plant Protection Products).