SEARCH

Summary

Post-emergence weed control in sugar beet relies on a sequence of three to four treatments of herbicide mixtures applied when weeds, and crop, are small. The use of glyphosate in genetically modified herbicide tolerant beet would provide growers with a simpler and cheaper system. However, the ability of glyphosate to control a range of weeds at small or large growth stages also provides opportunities to manage weeds for environmental benefit. These include control of pernicious weeds, increasing invertebrate populations in the crop early in the season, reducing the risk of wind erosion, adoption of minimum tillage, and increasing weed seed production. Some of the options are mutually exclusive whilst others could be combined, certainly on a whole farm approach, to deliver benefits for both the farmer and the environment. This paper considers the published results of different management systems and the options these provide for farmers to achieve different economic or environmental outcomes.

Introduction

Approximately 20% of the world sucrose production comes from beet with the majority of the remainder from sugar cane (Anon. 2008). Europe produces over 75% of the world's beet sugar, sowing around 3.80 x 106 ha in the 2007/2008 season.

Although only 0.10 x 106 ha are grown in the UK, in 2007/8 yields were the fourth highest in the EU at 11.08 x 103 kg raw sugar/ha. Sugar beet was one of the first crops to undergo genetic modification (GM) to provide tolerance to the herbicide glyphosate (Steen & Pedersen 1993, Mannerlöf et al. 1997). Other crops with similar genetic modification, such as soya beans, were also tested around the same time (Padgette 1995). Weed control is difficult and complicated in conventional sugar beet (May 2001). Current conventional methods rely on the treatment of weeds from pre-emergence or soon after they emerge (usually at the cotyledon stage) with repeated applications (usually 3), each of mixtures of herbicides (typically 2 to 6 active ingredients), to control weeds over a range of emergence times. One of the main strengths of glyphosate is its ability to control a wide spectrum of weeds at a range of growth stages (Baylis 2000). Therefore weed control in glyphosate tolerant sugar beet would be greatly simplified compared to current conventional systems. Glufosinate-ammonium tolerant sugar beet (Rasche et al. 1995) have been developed and tested (e.g. Sweet et al. 2004) but are unlikely to be commercialised. The suitability of acetolactate synthase (ALS) herbicide tolerance in sugar beet has also been considered but not pursued at present owing to potential rotational weed control problems and the importance of this group of herbicides in cereals and other crops grown in rotation with sugar beet in various countries.

Weed control in conventional soya beans is also complicated and difficult and Genetically Modified Herbicide Tolerance (GMHT) offers similar advantages for beet. Whilst GMHT soya has been accepted since 1996 in the USA and is now grown on over 69 x 106 ha (James 2009) GMHT sugar beet was not commercialised until 2008. A major reason for this delay was that GM crops were accepted in the main countries that grow soya (e.g. North and South America) but not in the main sugar beet areas, particularly the EU. However, herbicide tolerant sugar beet now comprise 95% of the USA crop in 2009 (James 2009), making it one of the fastest adopted GM crops.

In the UK, various issues have been raised regarding the growing of GM crops, particularly gene flow. In sugar beet, which is a biennial crop and harvested before it flowers, gene flow is less of an issue than for open pollinating crops such as oilseed rape.

The change to a more environmentally benign herbicide (glyphosate) offers opportunities to reduce the negative effects of herbicide use. May et al. (2003) and Dewar et al. (2003) suggest that, whilst the environmental impact as measured under the Milieumeetlat system (Wevers 2000) for all conventional herbicide programmes used in the UK would be within acceptable limits for water organisms, some conventional treatments containing lenacil, clopyralid or paraquat and diquat could be above the limits for deeper water and or soil organisms (note: paraquat is no longer registered for use in the EU). Glyphosate scores under this system were very low, indicating no or little environmental effect. In addition, the reduction in pesticide use by adoption of a glyphosate based GMHT would be large – circa 40% (Coyette et al. 2002, Champion et al. 2003). Bennett et al. (2006) carried out life cycle analyses and suggested that GM herbicide tolerant beet would reduce environmental impacts by between 15 and 50% compared to conventional beet. The reduction depended on the impact measured, but the main effect was a reduction in CO2 emissions as a result of fewer herbicide treatments and tractor operations.

In the UK, bodies such as English Nature (English Nature 1998, 2000) and the Royal Society for the Protection of Birds (RSPB 2003) expressed concern that the high levels of weed control provided by glyphosate in GM crops would result in fields devoid of the weeds that are important for birds and wildlife. As a consequence of these concerns, the UK government set up the Farm Scale Evaluation (FSE) trials of GM crops (Firbank et al. 2003) to determine whether there was any difference in the composition of plant and invertebrate species in GM compared to conventional fields when managed for cost- effective weed control. However, there is an alternative view that the ability of glyphosate to control a wide spectrum of weed species at a range of growth stages could allow growers to manage their weeds in GMHT sugar beet for a variety of outcomes. This paper examines and discusses the various management approaches that could be used in glyphosate tolerant GM sugar beet.

## Economic aspects

May (2003) discussed the various ways that GMHT sugar beet would have an impact on the economics of growing sugar beet in the UK. He suggested that the total farm savings from growing glyphosate tolerant compared to conventional beet would be approximately €200/ha (ca €22/t raw sugar). Kniss et al. (2003) suggested that would be greater in the US at around €270/ha (ca €30/ha) but this depended on the relative yield performance of the varieties. In both cases the degree of economic saving would be affected by any price premium applied to the technology and so they worked on figures similar to those in other commercialised GM crops in the USA. A review of May’s figures in 2009 (May 2009) indicated that the savings would then be nearer to €150/ha, mainly as a result of higher technology fees. The economic cases would vary according to country. Most of the EU countries pay a similar price for conventional herbicides but labour costs vary. In some countries, e.g. Turkey and India, labour costs are low and savings would likely be very much lower than those suggested by Kniss et al. (2003) and May (2003).

## Potential management options using GMHT Management for cost-effective weed control

The ability of glyphosate to control most weed species at a range of growth stages in tolerant sugar beet has been tested extensively. Wevers et al. (2005) suggest that high levels of control of most weeds can be achieved if a first application of glyphosate is applied no later than 10 days after the cotyledon stage of the first flush of weeds. A second or third application of glyphosate may be required to complete weed control depending upon the range of weed species and their times of emergence. They also report that the selectivity of glyphosate between weeds and GMHT beet is superior to most current herbicide programmes and that yield improvements of between 2 and 5% could be achieved. When weather conditions are such that selectivity of conventional herbicides is reduced, the difference could be increased to 10% (May 2000). Another potential benefit of controlling all weeds is the reduction in the weed seed bank and possible less weed competition in subsequent crops.

In the UK Farm Scale Evaluations glyphosate was applied according to a putative label based on delivering cost-effective weed control. The evaluations concluded that, used in the manner suggested by the label, there would be fewer weeds present and less weed seed rain in GM compared to conventional sugar beet fields (Heard et al. 2003a & b).

Increased weed numbers and invertebrates early season

It has long been understood that weeds must be controlled before the crop reaches the 6 to 8 true leaves stage to prevent competition (Scott et al. 1979) but that later emerging or low growing species are not always competitive. The early treatment of weeds in conventional beet is driven by the poor weed control activity of current conventional herbicides (May 2001). With GMHT it is possible to delay weed control until later in the season rather than when weeds are at the cotyledon to two true leaves stage. Dewar et al. (2003) reported the results of such an approach, but suggested that, whilst weeds could be controlled at very large growth stages such as those occurring just before the crop closes in the row, competition with the crop would already have occurred To reduce this effect, they adopted a spatial approach to weed treatment, controlling those weeds growing in the crop row early (at the 2-4 leaves stage) but leaving the weeds between the rows (i.e. those more distant from and therefore less competitive with the crop) until just before the crop canopy covered. This approach still provided good weed control, with little weed seed returned to the soil, and gave at least as good crop yield as conventional treatments. An additional benefit from leaving weeds for such a long time in the inter-row early in the season was that they increased numbers of invertebrates present (Dewar et al. 2000a, 2003). In these studies, numbers of beetles within two important groups were increased where weeds were left by management of the glyphosate sprays – carabids 3 fold and staphylinids 7 fold.

Prevention of erosion

Around 25% (Tzilivakis 2005) of the UK sugar beet crop is grown on light sand or peat land that is at risk of some wind erosion. Whilst most soil movement is local (within field), some crops are at risk of severe damage if strong winds occur early in the season. Such high risk fields are usually sown with cover crops of barley before the sugar beet is drilled to protect the young beet seedlings. Broad-leaved weeds are particularly difficult to control in this situation because both the barley and beet need to be preserved. The barley is killed with a graminicide once the beet are established and at less risk of wind damage (May 2001). The use of GMHT would allow the cover crop to be controlled at the same time as the broad-leaved weeds at no extra cost, in terms of herbicide, labour or machinery.

### Increase in autumn seed return

The approaches described above tend to reduce the number of weed seeds produced in sugar beet crops and this was one of the concerns of English Nature (1998, 2000) and RSPB (2003). May et al. (2005) showed that the techniques used by Dewar et al. (2003) could be modified to allow more weeds to remain in the beet and set viable seeds. To achieve this, glyphosate was either applied early (at 10 to 20% cover down the rows) without further treatment or, where additional treatment was required, applied as an over-the-row application only, leaving the spatially separated, less competitive weeds in the inter-row to survive and produce seeds. Seed rain was increased to between 1900 and 4200 seeds/mÇ in the managed GM herbicide tolerant plots compared to 250 seeds/mÇ in the conventionally treated ones.

### Mitigation areas

If the aim is to provide weed seeds for birds in the autumn or refugia for invertebrates, these could be achieved by leaving weedy uncropped areas in fields. Pidgeon et al. (2005) suggest that as little as 1% of fields may need to be left this way to mitigate for the differences observed in seed production between GMHT and conventional sugar beet in the Farm Scale Evaluations (FSE).

### Minimum tillage

Minimum tillage can provide a number of advantages compared to ploughing (Blevins et al. 1977, Edwards 1975, 1978, Wild 1988) but most sugar beet fields in the UK are ploughed in the autumn or spring prior to sowing beet. One of the main reasons for this is to control weeds, especially perennial and grass weeds. The use of glyphosate tolerant beet would allow such weeds to be controlled in the beet and possibly encourage a wider adoption of minimum tillage. Petersen et al. (2002) showed that the use of GMHT in minimum tillage systems for sugar beet is also compatible with the use of cover crops to reduce erosion and nutrient leaching during the previous autumn. However, to date, no other studies have been published where minimum and inversion tillage in GMHT sugar beet have been compared for environmental impact and effects on soil structure.

### Control of weed beet (conventional) and volunteer potatoes

Some weeds are either very difficult (e.g. weed beet) or expensive (volunteer potatoes) to control in conventional sugar beet. Glyphosate tolerant sugar beet would allow both to be controlled at the same time as normal weeds for no extra cost. Where weed beet are present, there would be a need to prevent seed return or pollen release from any bolters of the GMHT beet (Sweet et al. 2004). Bolters can be controlled in conventional crops by selective height application with glyphosate or other herbicide, or by repeated cutting above the crop to destroy the flower spikes, so controlling pollen flow to neighbouring fields or to areas with conventional weed beet flowering at the same time. Successful pollen receipt depends on density of source and distance of recipient. 70% of the UK sugar beet area has weed beet present (May 2005). Dewar et al. (2000b) showed that where volunteer potatoes were controlled with glyphosate in HT sugar beet, potato cyst nematode numbers could be reduced. They suggested that this could be used in a programmed approach to potato cyst nematode control, which in some circumstances could reduce the amount of nematicide applied to potato crops.

Discussion and Conclusions

A high level of weed control in sugar beet will reduce the number of weed seeds returned to the seedbank. This will have less rotational benefit to the farmer where beet is grown in rotation with winter crops and autumn germinating weeds predominate, than where the rotation includes spring cropping with spring germinating species. The reduction of weeds in the seedbank will have particular agronomic importance in following spring crops where weed control is difficult, such as where few or no effective herbicides are registered for use.

In Europe, sugar production is limited by a tonnage quota so the increased yields possible where a two or three spray programme of glyphosate is applied would proportionately reduce the area of crop sown. This would decrease the total amount of inputs (pesticide, energy, labour) to grow this quota, thus reducing the environmental effect of sugar beet which, like all crops, is negative when considering inputs (Tzilivakis et al. 2005). However, in the case of beet grown in rotation with winter crops, the ‘footprint’ is positive as good habitats are provided for wildlife before, during and after the beet (Evans et al. 2004, Vickery & Atkinson 2003).

Reduction of seed return in beet could have long term consequences for the arable seed bank. These have been declining for the last 100 years (Robinson & Sutherland 2002). Where agricultural fields are considered important for wildlife, as in the UK, this is considered an adverse effect, but in other countries, such as the USA, where the ratio of non-cropped to cropped land is higher, this is of lesser consequence.

The technique of leaving weeds uncontrolled until late in the season (as demonstrated by Dewar et al. 2003) does not alleviate this problem. However, it does increase the number of invertebrates present at a time when birds are feeding their chicks and searching for protein (e.g. skylarks, Alauda arvensis). Some of the invertebrates recorded by Dewar et al. (2003) tend to be nocturnal but some birds (e.g. lapwing Vanellusa vanellus) often feed at night. The extra weeds present can also provide food and cover for birds and mammals as well as invertebrates. Such an approach could also provide alternative food for birds such as skylarks (Champion pers. comm.) and reduce the amount of damage they do to the young beet crop.

Weeds present early in the season can, depending on their density and size, help prevent erosion on light soils, especially from wind. This technique could replace the barley cover crop technique used on light soils, because it is simple and has no extra cost, and it could encourage erosion protection on a greater number of fields than at present. Where weed populations were too low to provide erosion control, the use of GMHT with cover crops such as barley could provide easier and cheaper weed management than with conventional beet.

Where weed seed return is important, late emerging weeds or those growing between the rows could be left to provide this resource as suggested by May et al. (2005). This would not only produce more seeds for the seedbank but, if coupled with no-tillage after harvest, leave more weed seeds for birds, mammals and invertebrates to eat during the autumn and winter following beet harvest. The benefits of such an approach need to be weighed against the agronomic disadvantages of more weeds emerging in subsequent spring crops. However, in a rotation dominated by winter crops, the technique would pose relatively low risk of compromising the agronomy of the rotation.

If beet quotas can be grown on a smaller area using GMHT compared to conventional treatments, this could provide more than adequate mitigation areas to produce seeds for environmental benefits as suggested by Pidgeon et al. (2007). However, this would only provide localised improvements to the weed seed bank and the concentrated feeding area could become a focal point for predators. With the changes in the EU agricultural policy to reward farmers for improving the environment rather than paying them to produce agricultural products, there is already a change to beet fields in the UK with more headlands being devoted to wildlife than was the case a few years ago. The other reason for this change is that sugar yields from headlands are not profitable (Sparkes et al.1998).

Much of the sugar beet in the UK (circa 80%) is preceded by winter wheat (Jaggard pers. comm.). The majority of winter wheat stubbles that are left overwinter are sprayed with glyphosate before they are cultivated or sown with a following crop. If the following crop was glyphosate tolerant sugar beet, there would be less need for this herbicide in the autumn prior to beet or as a pre-harvest spray in the preceding winter wheat. The cereal stubbles prior to beet are important for wildlife (Gillings et al. 2005). The benefit of any reduction of glyphosate treatment to the stubbles would very much depend on the level of weeds that result. If the cereal crops are generally devoid of weeds, it is likely that the benefit to birds and mammals would be minimal. The aftermath of beet harvest is also important for birds (Winspear 2003), especially for pink footed geese in North Norfolk, UK (Gill 1996).

Adoption of minimum tillage would bring its own recognised benefits. However, a potential drawback may result from the need to control large overwintering weeds relatively early in the life of the crop in order to prevent weed competition. This treatment is likely to be much earlier than the timings suggested by Dewar et al. (2003) or May et al. (2005) (Dewar pers. comm.).

Whilst adoption of GM glyphosate tolerant beet would easily control any weed beet present, care would be required to ensure that problems do not arise from creation of HT tolerant weed beet. On one level, to prevent infestation in the sown field would require GM bolters in the crop to be removed before they shed seed. This would be relatively easy with the low levels of bolting in current varieties. However, if gene spread to neighbouring weed beet growing in non-GMHT beet fields was to be prevented, it would be necessary to remove bolters before they produced pollen. This would entail more visits to the field and be more costly to the grower. The best method of preventing such pollen flow would be provision of suitable isolation distances between GMHT and non-GMHT beet. Alternatively, contractual or permit of use obligations could be used to ensure control was undertaken. Breeders already take care to ensure seed crops are grown away from areas where weed beet is present.

As well as a possible reduction in potato cyst nematode populations, control of volunteer potatoes in GMHT beet would be much cheaper than the application of clopyralid, which is currently used to control volunteer potatoes in the UK. However, timing of treatment is unlikely to be compatible with the approaches suggested by Dewar et al. (2003) and May et al. (2005).

Although many opposed to the introduction of GMHT crops fear that glyphosate's ability to provide high levels of weed control would adversely affect the environment, it is precisely this aspect of the herbicide that would provide a wide range of opportunities to actually enhance the farmed environment whilst giving economic benefits to farmers.

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## Figures

**Table: Summary of main environmental targets and techniques achievable with glyphosate herbicide tolerant sugar beet.**

| *Target* | *Application technique for glyphosate* |
|---|---|
| Provision of weeds to reduce bird grazing on young beet | Delay first glyphosate application until crop past 2 true leaves stage |
| Increase weed presence early season for wind erosion control | Delay first glyphosate application until crop has 4 to 6 true leaves |
| Protein food for bird chicks in spring | Leave inter-row weeds until later in season |
| Provide early season cover for birds | Leave inter-row weeds until later in season |
| Increased seed rain in autumn to provide food for birds and replenish soil seedbank | Leave inter-row and non competitive weeds by spatial and temporal management of weed control inputs |
| Reduced $CO_2$ emissions | Apply single maximum dose of glyphosate at 4 to 6 true leaves stage of sugar beet |
| Control of problem weeds such as weed beet and potatoes | Apply a sequence of glyphosate sprays that includes one post 8 true leaves of the crop. |

Figure 1.
Summery of main enivironmental targets and techniques achieveable with glyphosate herbicide tolerant sugar beet.

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# 1111

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11th October 2011

economic, weed, management;, environmental, benefits;, herbicide, tolerant, sugar, beet, genetically, modified;

## Comments

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