WEED CONTROL IN GLYPHOSATE TOLERANT SUGAR BEET

Author

B.J. Mitchell

Crops Research Centre,

Oak Park, Carlow

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Summary

Between 1997 and 1999 weed control trials were carried out with sugar beet tolerant to glyphosate. Glyphosate was applied at a total dose of 1620.0, 2160.0, 3240.0 and 4320.0 g a.i. ha^{-1} in two and three applications. These were compared with a standard and double standard three spray sugar beet herbicide programme. In all seasons application of the lowest dose of glyphosate, 1620.0 g a.i. ha^{-1} gave marginally better control of weeds than the standard herbicide programme. Herbicide timing was more flexible with glyphosate and only two weeds, *Polygonum convolvulus* and *Lamium purpureum* required more than one application to kill all the weeds. In most cases no significant difference in weed control was observed between the glyphosate treatments after the second and third applications but the three spray programmes were marginally better than the two spray in 1997 and 1998. In 1997 the sugar beet strain was not totally tolerant to glyphosate and a reduction in plant numbers was recorded after the

initial glyphosate application. The strain used in subsequent years was fully tolerant and no plant loss occurred even at the highest glyphosate dose. At harvest most of the root yields in the glyphosate treatments were significantly higher than the yields from the standard herbicide comparison treatments. Crop vigour was not affected by any of the treatments in 1997 but in 1998 and 1999 the two standard herbicides reduced crop vigour by 10 and 20 per cent respectively.

Introduction

In Ireland the present approach to weed control in sugar beet is the post crop emergence application of selective herbicides. As no single herbicide is capable of controlling all the weeds which are found in sugar beet a combination of three or more products is applied at very low doses at an early stage of weed and crop growth and repeated at specific intervals as required. While this approach is generally successful as long as the weeds are small and actively growing, it is expensive and can absorb as much as 15 per cent of the total beet production costs. In addition, some of these selective herbicides are not completely safe to sugar beet and under certain environmental conditions such as high temperatures or high light intensity they may damage the beet (Tenning, 1998).

The recent introduction of sugar beet strains with genetically induced resistance to the total herbicides glyphosate or glufosinate ammonium, may present the grower with the opportunity for less complex and more flexible weed control systems. Some of the immediate possible advantages of glyphosate tolerant sugar beet include eliminating the need for pre emergence herbicides treatment and less dependance on the growth stage of weeds for post emergence treatment. The crop safety factor may also be improved as the new beet strains will tolerate high glyphosate dose rates and the use of adjuvant oils will no longer be necessary. In addition, problem weeds like scutch grass, volunteer potatoes and weed beet could be controlled at no extra cost (Brants and Harms, 1998). Environmentally the benefits of glyphosate tolerant sugar beet and its effect on water and soil organisms have been clearly demonstrated in the Netherlands (Wevers 1997). The metabolic degradation of glyphosate in soil is rapid and appears to be through the cleavage of the glycyl moiety and formation of amino methyl phosphoate (AMPA) plus glyoxylate (Wells 1995).

During 1997, 1998 and 1999 trials were carried out at Oak Park with glyphosate tolerant sugar beet and the results are reported.

Methods

Site preparation

Quarter hectare sites were selected at Oak Park Research Centre. The previous crop was winter barley. The sites, free draining medium loam soil with pH ranging from 6.5 to 7.1, were ploughed to a depth of 25 cm in mid January. In mid February fertiliser (10N: 3P: 18K: 3S: 6Na: 0.3B), was applied at 1000 kg/ha with a Vicon fertiliser spreader and worked into the soil with a power harrow. In March the beet, variety Accord (1997) and Celt (1998 and 1999), was sown with an Armer Salmon four row drill to a stand of 100,000 ha^{-1} at a crop and row spacing of 25 and 55 cm respectively. An area 25 by 35 metres was left unsown in the centre of the crop for sowing the glyphosate tolerant sugar beet strains.

The crop

On May 27th in 1997, May 14th in 1998 and 14th April in 1999 the glyphosate tolerant sugar beet was sown in areas measuring 25 x 35 metres within a commercial crop of sugar beet. The 1997 beet strain was unpelletted and was therefore sown at a high drilling density whereas in 1998 and 1999 the strain was pelletted so standard sowing procedures were adhered to including an in furrow application of carbofuron (Yaltox) to minimise the risk of insect attack. To prevent any mixing of strains the seed boxes were cleaned out with a battery operated hand held vacuum cleaner after each strain was sown. All excess seeds were reboxed and returned to Monsanto. Trial design was a randomised complete block (RCB) with four replications per treatment. Each plot was four sugar beet rows, 2.5 metres wide and 13.5 metres long. The gross plot size was 37.5 metres square with half metre pathways between each replication. The trial area was protected from the main crop area with six rows of the beet variety used in the trial. Permanent markers were then put in place on the periphery of the trial.

Herbicide application

The standard herbicide treatments consisted of 15.0 g.a.i. ha^{-1} methsulfuron methyl (Debut), 208.4 g.a.i. phenmedipham plus desmedipham and ethofumesate (Betanal Progress), and 220.0 g.a.i lenacil (Venzar Flowable). The mixture was applied as a three spray programme at the normal (1N) and at twice the normal (2N) recommended dose, giving a total g a.i. of 1012.2 and 2024.4 g a.i. respectively. To comply with standard sugar beet herbicide applications 0.5 l ha^{-1} of a mineral oil, (Actipron, 970 g a.i.ha^{-1}), was included in the second and third herbicide treatments. The glyphosate used was the 360 g.a.i. L^{-1} isopropylamine salt (Roundup Biactive 360) applied at different doses as two and three spray programmes which are listed in Tables 1-5.

All the treatments were applied with an Oxford precision sprayer. The standard sugar beet herbicides were applied at a water equivalent of 120 l ha^{-1} using 00 fan jets to give a uniform spray pattern at a pressure of 2.8 bar. All the glyphosate applications were carried out using a water equivalent of 200 l/ha using 000 fan jets and a pressure of 2.0 bar. The first application (T_1) of the standard sugar beet herbicides (treatments 1 and 2), was carried out when the majority of the weeds were at the cotyledon stage, (i.e. 0.5 to 2.0 cm), and the crop was at the expanded cotyledon stage with the first true leaves just visible, (0.5 to 1.5 cm), (GS 13, EPPO code). Unless otherwise stated all subsequent treatments were applied as each new weed flush reached the (1.0 to 2.0 cm) cotyledon stage. The first glyphosate applications (T_1) were carried out when the crop had the first true leaves fully developed and the second pair 1.0 to 2.0 cm long (GS 22, EPPO code). At this time the majority of the weeds were 4.0 to 6.0 cm high. The second and third glyphosate applications (T_2 and T_3) were carried out when the crop was at the 6 to 8 leaf stage (GS 25, EPPO code) and 10 to 12 leaf stage (GS 27, EPPO code). At both stages weed size ranged from 6.0 to 14.0 cm. high.

The main weeds present in the 1997 trial in order of density were fathen, *Chenopodium album*, fumitory, *Fumaria officianalis*, red deadnettle, *Lamium purpureum*, knotgrass, *Polygunum aviculare*, bindweed, *Polygonum convolvulus*, redshank, *Polygonum persicaria*, field poppy, *Papavar rhoeas*, chickweed, *Stellaria media*, field pansy, *Viola arvensis* and field speedwell, *Veronica arvense*. Weed density was 167 plants per square metre.

In 1998 the weed flora was medium to heavy with 88 plants per square metre. The main weed species here were, in order of density, knotgrass, *Polygonum aviculare,* red deadnettle, *Lamium purpureum,* speedwell, *Veronica arvense,* fathen, *Chenopodium album,* bindweed, *Polygonum convolvulus, chickweed, Stellaria media,* willowherb, *Epilobium paviflorum*, groundsel, *Senecio vulgaris,* and a small number of cleavers, *Galium aparine.*

Weed density was heaviest in 1999 with over 300 weeds per square metre. The main weeds in order of density were bindweed, *Polygonum convolvulus*, field pansy, *Viola arvense*, red deadnettle, *Lamium purpureum*, fathen, *Chenopodium album*, knotgrass, *Polygonum aviculare*, common poppy, *Papaver rhoeas*, field speedwell, *Veronica arvense*, fumitory, *Fumaria officinalis*, corn spurrey, *Spergula arvensis*, groundsel, *Senecio vulgaris*, charlock, *Sinapis arvensis*, cleavers, *Galium aparine* and volunteer camelina, *Camelina sativa*.

Weed control was assessed throughout the growing season by counting four half square metre quadrats per plot. Weed assessments were recorded 14 to 20 days after each herbicide application and prior to crop harvest. All statistical analysis reported in this project deal specifically with the herbicide treatments excluding the untreated controls.

Results

In 1997 the first applications in both the two and three spray programmes of glyphosate gave better weed control than the standard herbicide at normal recommended rates but all treatments gave commercially acceptable weed control after subsequent herbicide applications (Table 1). Crop vigour was marginally reduced by the double dose standard herbicide. None of the glyphosate treatments had any effect on vigour but total plant numbers were reduced by 50 percent by the initial glyphosate application. This was because the beet strain used was not totally glyphosate tolerant. No adverse effects were recorded with subsequent applications. Root yields were not recorded.

In 1998 the standard herbicide applied at normal dose gave marginally better weed control than glyphosate except when the 4320 g a.i.ha^{-1} dose was applied in a two spray sequence (Table 2). The main weeds remaining after the initial glyphosate treatments were *Polygonum convolvulus* and *Lamium purpureum.* While not totally controlled, they were half the height and vigour of the untreated weeds, and were killed by a glyphosate subsequent treatment.

Crop vigour and plant number were not affected by glyphosate but both the standard herbicide treatments reduced crop vigour by 10 and 20 per cent respectively. The single dose standard returned to normal within two weeks and the double dose required four weeks to recover.

Root yield for the standard (N) and double standard (2N) herbicide treatments were 34.4 and 30.7 t/ha respectively. Root yields for the glyphosate treatments ranged from 35.9 to 41.1 t ha^{-1}. Most of the glyphosate treatment yields were significantly better (5% level), than the double dose standard (2N) herbicide but were not significantly better than the standard (N) treatment (Table 3).

In 1999 the normal dose of the standard sugar beet herbicide combination gave similar weed control to the low glyphosate dose after the initial application. All the other treatments resulted in better initial weed control. No significant weed numbers remained in any of the treated plots after the final herbicide application. As in other years, more than one spray of glyphosate was required to control bindweed, *Polygonum convolvulus,* and red deadnettle, *Lamium purpureum,* (Table 4).

Crop vigour and plant stand were not affected by glyphosate but the double dose of the standard herbicide combination reduced crop vigour by 20 per cent. This effect dissipated within two weeks of treatment.

Root yields for the standard and double dose treatments were 41.2 and 39.6 t ha^{-1} respectively. Root yield for the glyphosate treatments ranged from 42.2 to 44.6 t ha^{-1}. There was no significant yield difference, (5 % level), between the normal standard and the glyphosate treatments but the double standard dose was significantly lower then most of the glyphosate treatments (Table 5).

Discussion

The three year trial programme shows the potential for glyphosate use in tolerant sugar beet is clear in terms of flexibility, efficacy, crop safety, environment and cost. In the U.K. sugar beet growers use up to nine different herbicides over the growing season (May 1994). Because of its slow canopy development sugar beet is a poor competitor, and weeds must be removed at an early growth stage throughout the growing season in order to avoid yield losses. Uncontrolled weeds also complicate harvesting (Timmerman 1995). Glyphosate tolerant beet will provide the grower with increased flexibility in terms of timing and dose. Trials at Oak Park and elsewhere, in the UK and Holland, have indicated that high and acceptable levels of weed control can be achieved with low doses of glyphosate even when applied to advanced weeds. This was particularly noteworthy in the 1998 and 1999 trials when spraying was delayed for seven days due to adverse weather. However in such instances a second glyphosate application may be required to achieve acceptable weed control.

Crop safety is a major consideration in sugar beet production if profitable yields are to be attained. Under normal circumstances the herbicides used are safe. However, as today's technique often encourages the use of three or more products, including mineral oils, for simultaneous application, crop safety may be jeopardised. A typical example of this occurred at Oak Park in 1998 where double the normal recommended dose seriously reduced crop vigour. In fact in 1998 yields recorded in both the standard herbicide treatments were significantly lower than most of their glyphosate counterparts. Similar results were reported in Holland by Wevers in 1997 and 1998. Work with a modified sugar beet strain with tolerance to the herbicide glufosinate ammonium also showed an advantage in respect to crop safety over conventional herbicides (Butner *et al.,* 1998). In other trials, weed control programmes based on glufosinate ammonium compared to conventional treatments showed better overall weed control and were particularly effective on difficult weeds like *Polygonum aviculare*.

Currently used herbicide programmes can cost between £125 and £200 ha^{-1} depending on the weed flora. At current prices a glyphosate based weed control programme cost approximately £30 ha^{-1} including the control of problem weeds such as *Elymus repens, Circium arvense* and *Solanum spp.* Therefore, on a cost basis, the introduction of sugar beet genetically engineered to tolerate glyphosate could benefit both the producer and consumer. In addition there is ample evidence that the total amount of active ingredient can be reduced in glyphosate tolerant beet. Trials reported by Madsen and Jensen in 1995 and Brant and Harms in 1998 indicated that reductions of 25 to 75 per cent of active ingredient could be achieved with glyphosate tolerant beet compared to the standard herbicides. This reduction was not evident in the Oak Park trials, where the active ingredient value of the mineral oil was not considered. If the active ingredient value of the added mineral oil were included in the calculation of the total dose the overall herbicide reduction would be similar to that reported elsewhere. Furthermore it is not unusual for a beet grower to apply up to 2.5 kg a.i. ha^{-1} in a season if problem weeds like *E. repens* or *C. arvense* are present. Trials have shown that excellent control of annual and perennial weeds in sugar beet can be obtained with glyphosate (Moll, 1997). This could have considerable economic and environmental benefit compared with current chemical weed control practices.

Conclusions

- In 1997 the genetically modified beet strain was only 50 per cent tolerant to glyphosate but in the two subsequent years the strain was completely tolerant to all of the glyphosate doses applied.
- At all dose rates glyphosate controlled a wide range of weed species but in all trials *Lamium purpureum* and *Polygonum convolvulus* required a second application for total weed control where the lowest glyphosate dose was applied.

- All the glyphosate treatments, applied as two or three spray programmes, gave total control of the weeds present which ranged in height from 8.0 to 16.0 cms. at application.
- Crop vigour was not affected by any of the glyphosate dose rates but the standard beet herbicides reduced crop vigour by 10 to 20 per cent.
- Crop yield in the glyphosate treated plots was equal to and in some cases better than the standard three spray herbicide programme.
- In all instances where the overall weed control was commercially acceptable, the monetary cost and the amount of chemical active ingredient applied was significantly lower for the glyphosate programme than the standard sugar beet herbicide programme.
- As glyphosate has a significantly lower toxicity value and practically no residual properties in mineral soil it would be much more environmentally acceptable than the presently applied sugar beet herbicides.
- As dictated by protocol all the genetically modified sugar beet trial crop was destroyed in situ by repeated rotavation and ploughing.

Table 1: **Effect of standard beet herbicides and glyphosate on annual weeds in a glyphosate tolerant sugar beet crop 1997**

Product	**Dose g a.i./ha**	**No of Sprays**	**Total dose g a.i./ha**	**Weed counts plants/m^{2}***		
				T_1	**T_2**	**T_3**
Standard (1N)	337.4	3	1012.2	31	0	9
Standard (2N)	674.8	3	2024.4	8	0	0
Glyphosate	540.0	3	1620.0	21	5	7
Glyphosate	720.0	3	2160.0	11	0	3
Glyphosate	1080.0	3	3240.0	4	1	1
Glyphosate	1440.0	3	4320.0	2	0	0
Glyphosate	720.0	2	1440.0	10	12	5
Glyphosate	1080.0	2	2160.0	5	12	3
Glyphosate	2160.0	2	4320.0	1	6	3
Untreated	00.0	0	00.0			167

* *T_1 = Weed counts recorded 14 days after initial herbicide application*
T_2 = Weed counts recorded 14 days after final herbicide application
T_3 = Weed counts recorded 14 days prior to crop harvest

Table 2: Effect of standard beet herbicides and glyphosate on annual weeds in glyphosate tolerant sugar beet crop 1998

Product.	**Dose g a.i./ha**	**No of Sprays**	**Total dose g a.i./ha**	**Weed counts plants/m^{2}***		
				T_1	**T_2**	**T_3**
Standard (1N)	337.4	3	1012.2	6	4	3
Standard (2N)	674.8	3	2024.4	1	3	0
Glyphosate	540.0	3	1620.0	21	1	1
Glyphosate	720.0	3	2160.0	14	0	0
Glyphosate	1080.0	3	3240.0	13	0	0

Product.	Dose g a.i./ha	No of Sprays	Total dose g a.i./ha	Weed counts plants/m^2*		
				T_1	T_2	T_3
Glyphosate	1440.0	3	4320.0	5	0	0
Glyphosate	720.0	2	1440.0	14	0	10
Glyphosate	1080.0	2	2160.0	10	0	5
Glyphosate	2160.0	2	4320.0	5	0	1
Untreated	00.0	0	00.0			88

* T_1 = *Weed counts recorded 14 days after initial herbicide application*
T_2 = *Weed counts recorded 14 days after final herbicide application*
T_3 = *Weed counts recorded 14 days prior to crop harvest*

Table 3: **Effect of standard beet herbicides and glyphosate on root yield and vigour in a glyphosate tolerant sugar beet crop 1998**

Product	Dose g a.i./ha	No of Sprays	Total dose g a.i./ha	Crop yield t/ha	Crop vigour* 1-10
Standard (1N)	337.4	3	1012.2	34.4	9.0
Standard (2N)	674.8	3	2024.4	30.7	8.0
Glyphosate	540.0	3	1620.0	36.9	10
Glyphosate	720.0	3	2160.0	36.7	10
Glyphosate	1080.0	3	3240.0	36.7	10
Glyphosate	1440.0	3	4320.0	39.6	10
Glyphosate	720.0	2	1440.0	35.9	10
Glyphosate	1080.0	2	2160.0	41.1	10
Glyphosate*	2160.0	2	4320.0	00.0	0.0
Untreated	00.0	0	00.0	23.4	10
LSD +/-				5.4	1.8

* *Crop vigour score 10 = No reduction. 1 = Severe reduction*
Not harvested

Table 4: **Effect of standard beet herbicides and glyphosate on annual weeds in glyphosate tolerant sugar beet crop 1999**

Product	Dose g a.i./ha	No of Sprays	Total dose g a.i./ha	Weed counts plants/m²*		
				T_1	T_2	T_3
Standard (1N)	337.4	3	1012.2	80	7	1
Standard (2N)	674.8	3	2024.4	37	1	0
Glyphosate	540.0	3	1620.0	83	2	0
Glyphosate	720.0	3	2160.0	35	1	0
Glyphosate	1080.0	3	3240.0	18	0	0
Glyphosate	1440.0	3	4320.0	8	0	0
Glyphosate	720.0	2	1440.0	39	20	0
Glyphosate	1080.0	2	2160.0	15	5	0
Glyphosate	2160.0	2	4320.0	3	1	0
Untreated	00.0	0	00.0			339

* *T_1 = Weed counts recorded 14 days after initial herbicide application*
T_2 = Weed counts recorded 14 days after final herbicide application
T_3 = Weed counts recorded 14 days prior to crop harvest

Table 5: **Effect of standard beet herbicides and glyphosate on root yield and vigour in a glyphosate tolerant sugar beet crop 1999**

Product.	Dose g a.i./ha	No of Sprays	Total dose g a.i./ha	Crop yield t/ha	Crop vigour* 1-10
Standard (1N)	337.4	3	1012.2	41.2	9.0
Standard (2N)	674.8	3	2024.4	39.6	8.5
Glyphosate	540.0	3	1620.0	42.2	10
Glyphosate	720.0	3	2160.0	43.0	10
Glyphosate	1080.0	3	3240.0	44.6	10
Glyphosate	1440.0	3	4320.0	43.3	10
Glyphosate	720.0	2	1440.0	43.5	10
Glyphosate	1080.0	2	2160.0	44.4	10
Glyphosate*	2160.0	2	4320.0	43.5	9.0
Untreated	00.0	0	00.0	7.3	10
LSD +/-				3.2	2.1

* *Crop vigour score 10 = No reduction. 1 = Severe reduction*

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