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Ecoplugs containing glyphosate can be effective in preventing regrowth from *Rhododendron ponticum* stumps

Abstract

Rhododendron ponticum is a highly invasive and competitive weed on many forest sites in Britain, can act as a host for the pathogens *Phytophthora ramorum* and *Phytophthora kernoviae*, and is often very difficult to control. We therefore investigated various alternative methods of killing the stumps that are left after bushes are cleared, with the aim of preventing any further shoot regrowth.

It was found that applying one Ecoplug (a formulation of encapsulated crystalline glyphosate, marketed as Ecoplug Max® (680 g kg^{-1} glyphosate); Monsanto, 2009; or as Ecoplug Max® (720 g kg^{-1} glyphosate); Monsanto, 2016)) per 3cm of stump diameter, an equivalent of 0.068 g a.i. (grams of active ingredient) glyphosate per cm of stump diameter, can give around 80-90% control of cut rhododendron stumps. Control is likely to be as good as, but no better than, conventional sprays of liquid glyphosate, and in both cases, repeat visits to control regrowth will almost certainly still be required. Although it is recommended that Ecoplugs should be applied within two days of cutting, if at all possible, if a delay is unavoidable, our initial results suggest that Ecoplugs may have the potential to still be effective if applied up to eight weeks after cutting.

Ecoplugs may also have other advantages such as eliminating the risk of drift and operator contamination, and providing the potential for year round application, but they are likely to cost around three times more than stump spraying using conventional liquid glyphosate.

Introduction

Rhododendron (*Rhododendron ponticum* L.) is an aggressive weed that is estimated to be present in more than 3% (100,000ha) of British forests (Forestry Commission, 2016), where it can be highly competitive, both preventing woodland regeneration and destroying native flora (Edwards, 2006) (**Plate 1**).

Rhododendron also acts as a sporulating host for the fungal-like pathogens *Phytophthora ramorum* (Werres) and *Phytophthora kernoviae* (Brasier). Infected rhododendron leaves and shoots generate a large number of spores, often infecting nearby trees, and in the case of *P. ramorum* this includes in particular, larch species (European larch, *Larix decidua* (Mill.); Japanese larch, *L. kaempferi* (Lindl.) Carrière; hybrid larch, *L. x marschlinsii* (Coaz)), which normally results in potentially lethal stem cankers (Brasier and Webber, 2010). Larch also acts as a sporulating host, driving infection of other susceptible tree species in Britain (Webber *et al*, 2010).

Removal of *Rhododendron ponticum* from forest sites is therefore usually regarded as an essential part of sustainable forest management, and is a statutory requirement for woodlands infected with *P. ramorum*. Unfortunately, effective control of rhododendron can be very difficult to achieve due to its vigorous growth habit, thick, waxy leaf surfaces which discourage the absorption of foliar-acting herbicides, and due to the fact that even once absorbed, herbicides are poorly translocated around the plant (Willoughby *et al*, 2015). In addition, in the north and west of Britain where rhododendron is particularly prevalent, there are often not enough dry, wind free days in which to spray herbicides, meaning that the large scale, population level control operations that are required to prevent the recolonisation of cleared sites (Edwards, 2006) cannot be carried out.

Current recommended best practice in Britain for the control of rhododendron is to remove vegetative top growth and then spray the freshly cut stumps with the herbicide glyphosate (**Plate 2**). Stem injection of

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Plate 2: Spraying foliar regrowth from rhododendron stumps using conventional liquid herbicide.

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uncut stems can also be carried out if Phytophthora disease is not present, a technique which has the advantage of being less dependent on dry, wind free weather conditions (Edwards, 2006; Tyler *et al*, 2006). Recent work (Willoughby *et al*, 2015) has confirmed that glyphosate is effective when applied to stumps immediately after cutting. Nevertheless, some follow up foliar spraying is usually needed to eradicate rhododendron on forest sites due to poor translocation of herbicide within the treated plants, and to treat any plants that were inadvertently missed in the initial application. Rainfall after application can also reduce the efficacy of glyphosate in controlling rhododendron, although the addition of the adjuvant Mixture B NF (42.5% polyoxyethylene (3EO) C12–C15 primary alcohol plus 38.25% polyoxyethylene (7EO) C12–C15 primary alcohol; Amega, 2009) can mitigate this for foliar applications (Willoughby and Stokes, 2015).

An alterative option might be to use Ecoplugs (formulated as Ecoplug Max® (680 g kg^{-1} glyphosate); Monsanto, 2009; or as Ecoplug Max® (720 g kg^{-1} glyphosate); Monsanto, 2016)), which are an encapsulated formulation of crystalline glyphosate currently used in the UK to prevent resprouting from cut stumps after tree felling, particularly on railway embankments and beneath utility lines (**Plates 3 and 4**). Recent research has found that Ecoplugs can also be effective in killing standing trees (Willoughby *et al*, 2017 *in prep.*) without significantly increasing the risk of infection by *Heterobasidion annosum* (Fr.) Bref. compared to conventional harvesting (Tubby *et al*, 2017 *in prep.*), although they are currently only approved for use on cut stumps. Potential advantages of Ecoplugs over traditional herbicide spraying for the treatment of cut stumps are that the need for handling liquid product is eliminated, and there is virtually no risk of any non target drift or contamination even in windy conditions. Unlike conventional liquid sprays, it is also claimed that Ecoplugs can be used in any weather conditions, as they are not affected by wash off caused by rainfall (Monsanto, 2009). In addition, although the manufacturers currently recommend applications are made no more than two days after initial felling (Monsanto, 2009), if Ecoplugs could be shown to be effective if used after longer delays, this would allow greater operational flexibility compared with conventional spraying.

Ecoplugs are likely to be more expensive to purchase and apply than conventional liquid formulations of glyphosate, around £1.20 $stump^{-1}$ as opposed to around £0.35 $stump^{-1}$ for conventional stump treatment, based on an extrapolation of the costs of chemical thinning of standing trees as determined by Saunders (2016). However, if they proved to be more effective than conventional sprays, hence reducing the need for follow up treatment, or if dose rates of Ecoplugs could be reduced without affecting efficacy, then the relative difference in costs would be reduced.

Therefore, in the work reported here, three experiments were carried out to test the efficacy of Ecoplugs at various application rates compared to cut stump treatment of rhododendron with conventional liquid herbicides, and to determine if the efficacy of Ecoplugs was affected by rainfall or a delay in application after cutting.

Plate 3: Ecoplug before insertion (left), drill bit used to create holes (middle), Ecoplug after insertion into hole drilled in tree stump showing cracked case which allows release of crystalline glyphosate (right).

Table 1: Experiment site details

EXPERIMENT NUMBER	1	2	3
Site name	Strathgarve	Tarlogie	Glengarry
Experiment type	Rate response	Time since cutting	Rainfastness
Grid ref	NH 405616	NH 756833	NH 305005
Elevation (m above sea level)	100	50	120
Overstorey vegetation	50-year-old Norway spruce [2] / birch [3]	64-year-old Norway spruce [2] / Scots pine [4]	23-year-old Sitka spruce [5] / birch [3]
Soil type	Indurated podzol	Indurated podzol	Peaty surface water gley
Mean annual rainfall (mm)	1,042	737	1,648
Growing degree days >5°C	1,130	1,194	1,186
Windthrow hazard classification	2	3	3
Treatment date [1]	28-29 Mar 2012	12 Apr 2012	28-29 Feb 2012

Notes:

1. All treatments were made to freshly cut stumps on these dates, except for the delayed treatments in Experiment 2 (DEP-1, DEP-4, DEP-8, DEP-012, **Table 3**).
2. *Picea abies* (L.) H. Karst.
3. *Betula pendula Roth*, *Betula pubescens Ehrh.*
4. *Pinus sylvestris* L.
5. *Picea sitchensis* (Bong.) Carrière

Table 2: Treatment details, Experiment 1, rate response

TREATMENT CODE	TREATMENT NAME	DETAILS
O	**Control**	Vegetative top growth cut, but with no follow up herbicide treatment.
HS	**Herbicide solution**	Conventional application of 20% Roundup ProBio® [1] (360 g l^{-1} glyphosate; Monsanto, 2013) in water, applied by saturation spraying of freshly cut stumps and basal bark with the dilute solution plus blue marker dye using a Cooper Pegler® CP3 knapsack sprayer fitted with a flood jet nozzle.
EP-1	**Ecoplug single [2]**	One single Ecoplug (as Ecoplug Max® [3] (680 g kg^{-1} glyphosate); Monsanto, 2009) inserted in the centre of the stump.
EP-S	**Ecoplug standard [2, 4]**	1 Ecoplug (as Ecoplug Max® [3] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter.
EP-R	**Ecoplug reduced [2]**	1 Ecoplug (as Ecoplug Max® [3] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 6cm diameter of stump. Equivalent of 0.034 g a.i. glyphosate per cm of stump diameter.

Notes:

1. Roundup ProBio® has now been replaced in the UK market by the identical product Roundup ProActive® (360 g l^{-1} glyphosate; Monsanto, 2015).
2. Applied by drilling the calculated number of 13mm diameter x 30mm deep holes, evenly spaced around the circumference of the stump (except for EP-1 which had a single hole drilled into the centre of the stump), then the Ecoplugs were inserted into the holes and hammered into place.
3. Note that since carrying out this research the formulation of Ecoplug Max® has changed from a plug containing 0.300g of 689 g kg-1 glyphosate (Monsanto, 2009) to a plug containing 0.283g of 720 g kg^{-1} glyphosate (Monsanto, 2016), but as this results in exactly the same amount of active ingredient per plug being applied (i.e. 0.204 g plug-1 a.i. glyphosate), our conclusions and recommendations relating to the use of Ecoplug Max® remain unchanged.
4. The 'standard' Ecoplug rate in this work was taken to be that recommended on the product label (Monsanto, 2009) for the majority of woody weed species, which is half the absolute maximum rate permitted.

Materials and methods

Three experiments were established in the Highlands of Scotland at: Strathgarve, eight miles west of Dingwall; Tarlogie, four miles south of Dornoch; and Glengarry, just south of Invergarry (**Table 1** for site details). Each experiment consisted of a randomised block design with five replicate blocks, with each treatment occurring once in each block. Every treatment plot contained six *Rhododendron ponticum* stumps and was separated from adjacent plots by a buffer strip at least 2m wide. Each site had different experimental treatments (**Tables 2-4** for details).

Rhododendron plants were cut as close to ground level as possible using chainsaws and the residues removed from the site and burnt. All herbicide applications, apart from the delayed treatments (DEP-1, DEP-4, DEP-8, DEP-012, **Table 3**), were made within 24 hours of cutting and there was no rainfall for at least six hours after every herbicide treatment.

Survival of each stump, and the number of live shoots regrowing from each stump, were assessed at the end of the first, second and third full growing seasons (i.e. in the autumn/winter) after treatment.

Statistical analysis was carried out using SAS® (SAS, 2011). Data were analysed separately for each experiment and for each year within each experiment. Survival was analysed using a generalised linear model with a binomial error and logit link function. Number of live shoots were analysed as a standard Analysis of Variance, and data transformation to normalise variance was not required. Where there was a significant ($P<=0.05$) effect of treatment, pairwise tests were carried out by comparing differences in least square means (with Bonferroni adjustments for multiple comparisons) to identify which treatments differed from each other at the $P<=0.05$ significance level.

Table 3: Treatment details, Experiment 2, time since cutting

TREATMENT CODE	TREATMENT NAME	DETAILS
O	**Control**	Vegetative top growth cut, but with no follow up herbicide treatment.
HS	**Herbicide solution**	Conventional application of 20% Roundup ProBio® [1] (360 g l^{-1} glyphosate; Monsanto, 2013) in water, applied by saturation spraying of freshly cut stumps and basal bark with the dilute solution plus blue marker dye using a Cooper Pegler® CP3 knapsack sprayer fitted with a flood jet nozzle.
EP-S	**Ecoplug standard** [2,3]	1 Ecoplug (as Ecoplug Max® [4] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter. Applications made immediately after stump severance.
DEP-1	**Delayed Ecoplug application – 1 week** [3]	1 Ecoplug (as Ecoplug Max® [4] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter. Applications made 1 week after stump severance.
DEP-4	**Delayed Ecoplug application – 4 weeks** [3]	1 Ecoplug (as Ecoplug Max® [4] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter. Applications made 4 weeks after stump severance.
DEP-8	**Delayed Ecoplug application – 8 weeks** [3]	1 Ecoplug (as Ecoplug Max® [4] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter. Applications made 8 week after stump severance.
DEP-12	**Delayed Ecoplug application – 12 weeks** [3]	1 Ecoplug (as Ecoplug Max® [4] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter. Applications made 12 weeks after stump severance.

Notes:

1. Roundup ProBio® has now been replaced in the UK market by the identical product Roundup ProActive® (360 g l^{-1} glyphosate; Monsanto, 2015).
2. The 'standard' Ecoplug rate in this work was taken to be that recommended on the product label (Monsanto, 2009) for the majority of woody weed species, which is half the absolute maximum rate permitted.
3. Applied by drilling the calculated number of 13mm diameter x 30mm deep holes, evenly spaced around the circumference of the stump, then the Ecoplugs were inserted into the holes and hammered into place.
4. Note that since carrying out this research the formulation of Ecoplug Max® has changed from a plug containing 0.300g of 689 g kg^{-1} glyphosate (Monsanto, 2009) to a plug containing 0.283g of 720 g kg^{-1} glyphosate (Monsanto, 2016), but as this results in exactly the same amount of active ingredient per plug being applied (i.e. 0.204 g $plug^{-1}$ a.i. glyphosate), our conclusions and recommendations relating to the use of Ecoplug Max® remain unchanged.

Table 4: Treatment details, Experiment 3, rainfastness

TREATMENT CODE	TREATMENT NAME	DETAILS
O	**Control**	Vegetative top growth cut, but with no follow up herbicide treatment.
HS-D	**Traditional herbicide solution dry**	Conventional application of 20% Roundup ProBio® [1] (360 g l^{-1} glyphosate; Monsanto, 2013) in water, applied by saturation spraying of freshly cut stumps and basal bark with the dilute solution plus blue marker dye using a Cooper Pegler® CP3 knapsack sprayer fitted with a flood jet nozzle.
HS-W	**Traditional herbicide solution wet** [2]	Conventional application of 20% Roundup ProBio® [1] (360 g l^{-1} glyphosate; Monsanto, 2013) in water, applied by saturation spraying of freshly cut stumps and basal bark with the dilute solution plus blue marker dye using a Cooper Pegler® CP3 knapsack sprayer fitted with a flood jet nozzle, followed immediately by simulated rainfall.
EP-W	**Ecoplug standard wet** [2,3,4]	1 Ecoplug (as Ecoplug Max® [5] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter, followed immediately by simulated rainfall.
EP-D	**Ecoplug standard dry** [3,4]	1 Ecoplug (as Ecoplug Max® [5] (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump. Equivalent of 0.068 g a.i. glyphosate per cm of stump diameter.

Notes:

1. Roundup ProBio® has now been replaced in the UK market by the identical product Roundup ProActive® (360 g l-1 glyphosate; Monsanto, 2015).
2. Simulated rainfall applied by saturating the stump and above ground basal bark with water immediately after herbicide treatment with water using a Cooper Pegler knapsack sprayer fitted with a floodjet nozzle.
3. The 'standard' Ecoplug rate in this work was taken to be that recommended on the product label (Monsanto, 2009) for the majority of woody weed species, which is half the absolute maximum rate permitted.
4. Applied by drilling the calculated number of 13mm diameter x 30mm deep holes, evenly spaced around the circumference of the stump, then the Ecoplugs were inserted into the holes and hammered into place.
5. Note that since carrying out this research the formulation of Ecoplug Max® has changed from a plug containing 0.300g of 689 g kg-1 glyphosate (Monsanto, 2009) to a plug containing 0.283g of 720 g kg-1 glyphosate (Monsanto, 2016), but as this results in exactly the same amount of active ingredient per plug being applied (i.e. 0.204 g plug-1 a.i. glyphosate), our conclusions and recommendations relating to the use of Ecoplug Max® remain unchanged.

Results

Figures 1-5 show the effects of the different treatments on stump survival and regrowth over three growing seasons. For survival, although statistical analysis was based on transformed data, untransformed means are presented in **Figures 2, 4 and 6** for clarity. In general, results for survival and shoot regrowth showed similar trends, and most impacts were apparent by the end of the first growing season.

In Experiment 1 (**Figures 1-2**), which examined the effects of different rates of Ecoplug use, after three growing seasons all herbicide treatments appeared to reduce stump survival by around 55-80% compared to the untreated control (O), although pairwise comparisons indicated that these were not statistically significant in the majority of cases (**Figure 1**). All herbicide treatments reduced shoot regrowth compared to the control, but there were no significant differences between the herbicides. Ecoplugs (treatments EP-1, EP-R and EP-S) were equally as effective as conventional liquid glyphosate (treatment HS), and reducing the rate of Ecoplug use apparently had no effect.

In Experiment 2 (**Figures 3-4**), which examined the effects of delaying herbicide application after cutting, after three growing seasons all herbicide treatments had reduced stump survival by around 80-90% compared to the untreated control (O), but there were no significant differences between herbicides. For shoot growth, all herbicide treatments significantly reduced regrowth compared to the untreated control at all assessment dates. At the end of the first growing season, delaying Ecoplug application for 12 weeks (treatment DEP-12) significantly reduced efficacy compared to the other herbicide treatments, but this effect was not evident by the end of the third growing season. In other words, delaying application of Ecoplugs by 12 weeks (treatment DEP-12) reduced the speed, but not the overall level of kill. By the end of the third growing season Ecoplugs that had been applied as recommended immediately after cutting (treatment EP-S) appeared to have slightly higher efficacy than the conventional application of liquid herbicide (treatment HS), but there were no other differences between herbicide treatments.

Plate 4: Ecoplugs inserted into holes drilled into a tree stump.

In Experiment 3 (**Figures 5-6**), which examined the effects of artificial rainfall on herbicide rainfastness as indicated by efficacy, after three growing seasons all herbicide treatments again reduced stump survival by around 80-90% compared to the untreated control, but there were no significant differences between treatments. Similarly, all herbicides reduced shoot regrowth compared to the untreated control, but otherwise there were no significant differences between treatments. In other words, artificial rainfall appeared to have no effect on herbicide efficacy, and Ecoplugs were equally as effective as conventional liquid herbicide in killing stumps and reducing regrowth.

"Delaying the application of Ecoplugs had no impact on efficacy in our work, except when we waited 12 weeks before application which reduced the initial speed of kill, but did not affect the overall level of control as measured after three growing seasons"

Discussion

These experiments suggest that Ecoplugs can be equally as effective as the spraying of conventional liquid glyphosate as a method of killing cut rhododendron stumps, and preventing subsequent shoot regrowth.

Applying one Ecoplug (as Ecoplug Max® (680 g kg^{-1} glyphosate); Monsanto, 2009) per 3cm diameter of stump, an equivalent of 0.068 g a.i. glyphosate per cm of stump diameter, in late winter/early spring gave 80-90% control of treated rhododendron stumps after three growing seasons.

These levels of efficacy would normally be taken as indicating that the target plants are between 'moderately susceptible' and 'susceptible' to the herbicide treatment (Chemicals Regulation Directorate, 2010). Reducing the application rate to one Ecoplug per 6cm diameter of stump, an equivalent of 0.034 g a.i. (grams of active ingredient) glyphosate per cm of stump diameter, did not appear to result in lower efficacy in our work, however this treatment was only tested on one site, and as efficacy even at higher rates was only moderate, currently it is recommended that the use of this reduced rate should not be adopted without further research.

Although not statistically significant, given that up to 45% of treated stems apparently survived the treatments where only one Ecoplug was applied regardless of stump size, this application rate should not be adopted without further research.

In one of our experiments, the highest rate tested (one Ecoplug per 3cm diameter of stump) appeared to give slightly better overall control of rhododendron after three growing seasons than conventional application of liquid glyphosate. However, this rate was still only half that recommended on the Ecoplug Max® product label (Monsanto, 2009) for the most difficult to control woody species. The maximum permitted product rate (two Ecoplugs per 3cm diameter of stump) should therefore be tested on cut rhododendron stumps to see if this improves overall levels of control, and hence reduces the need for costly follow up treatments.

Delaying the application of Ecoplugs had no impact on efficacy in our work, except when we waited 12 weeks before application, which reduced the initial speed of kill, but did not affect the overall level of control as measured after three growing seasons. Delays in spraying stumps after cutting with conventional liquid glyphosate are thought to result in reduced efficacy, although correct product selection, accurate application and optimising timing may be more important factors affecting the successes of many operational treatments (Willoughby, 1999). Current recommendations are to spray immediately after cutting for

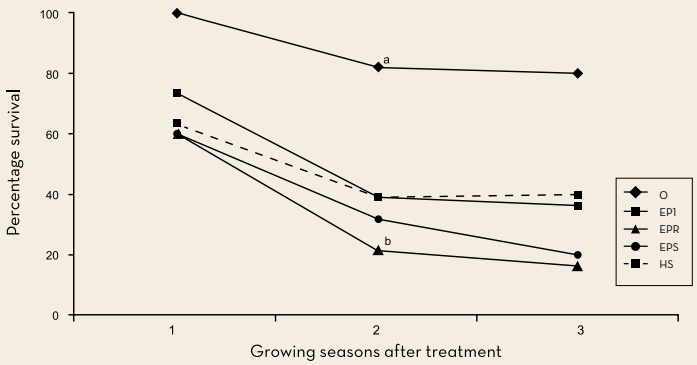

Figure 1: Experiment 1, rate response, effect of treatments on stump survival over three growing seasons

Notes

Lettering (a,b) indicates significant differences between treatments, within growing season (pairwise comparisons, Bonferroni adjustments). Lettering only provided for growing seasons and treatments where pairwise comparisons indicated statistically significant (P<=0.05) differences.

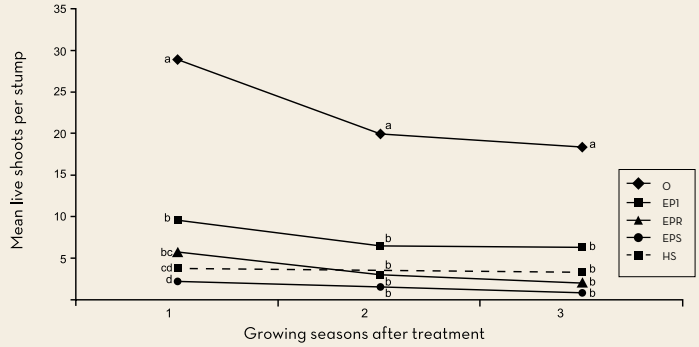

Figure 2: Experiment 1, rate response, effect of treatments on shoot regrowth from treated stumps over three growing seasons

Notes

Lettering (a,b,c,d) indicates significant differences between treatments, within growing season (pairwise comparisons, Bonferroni adjustments). Lettering only provided for growing seasons and treatments where pairwise comparisons indicated statistically significant (P<=0.05) differences.

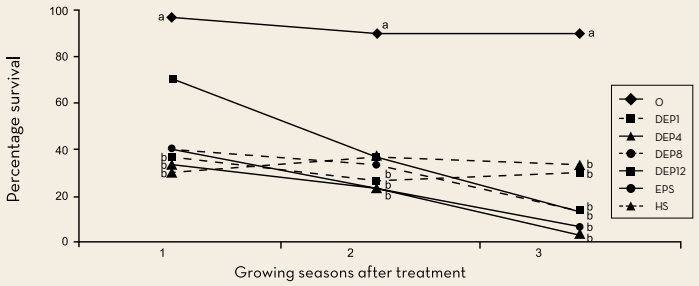

Figure 3: Experiment 2, time since cutting, effect of treatments on stump survival over three growing seasons

Notes

Lettering (a,b) indicates significant differences between treatments, within growing season (pairwise comparisons, Bonferroni adjustments). Lettering only provided for growing seasons and treatments where pairwise comparisons indicated statistically significant (P<=0.05) differences.

rhododendron (Edwards, 2006), and as soon as possible (Monsanto, 2013; 2015) and no longer than one week after cutting (Willoughby and Dewar, 1995) for other woody species. Although the manufacturer's currently recommend Ecoplugs are applied no more than two days after initial felling (Monsanto, 2009), it has been speculated that because the act of drilling the reservoir for the plugs exposes fresh, uncalloused plant material through which the herbicide might be absorbed, that longer delays after cutting may be possible. The option to delay applications would provide greater operational flexibility, and might help to reduce overall costs. However, despite there appearing to be some potential to delay the application of Ecoplugs for up to eight weeks without having any impact on efficacy, because we made no direct comparisons, we are not able to confirm whether or not Ecoplugs are less affected by a delay after cutting than when conventional liquid glyphosate is used.

As in the work on standing trees reported by Willoughby *et al* (2017 *in prep.*), in our work on rhododendron, artificial rainfall had no effect on any treatment, but this may be because not enough water was applied. Future research should therefore test the effects of heavier simulated rainfall, up to an equivalent of 50mm hour^{-1}, which Willoughby *et al* (2017 *in prep.*) suggest is likely to be reflective of very heavy rainfall events as experienced in the north and west of Britain. Although it is logical to assume that Ecoplugs will not be affected by rainfall after application, and that they can therefore be applied in all weather conditions (Monsanto, 2009), given the lack of any effect of artificial rainfall on conventional glyphosate treatments either in our work, we were not able to confirm this assumption.

Conclusions

Our results suggest that applying one Ecoplug (formulated as Ecoplug Max® (680 g kg-1 glyphosate); Monsanto, 2009; or as Ecoplug Max® (720 g kg-1 glyphosate); Monsanto, 2016) per 3cm diameter of stump, an equivalent of 0.068 g a.i. glyphosate per cm of stump diameter, can give 80-90% control of cut rhododendron stumps. Control is likely to be as good as, but no better than, sprays of the surface of the cut stumps using a conventional liquid glyphosate such as Roundup ProActive® (360 g l-1 glyphosate; Monsanto, 2015) at a rate of 20% Roundup ProActive® in water. In both cases, repeat visits to control subsequent regrowth will almost certainly still be required.

Ecoplugs should always be applied to stumps within two days of cutting if possible. However, if a delay is unavoidable, our results suggest they may still be effective if applied up to eight weeks after cutting. This is unlikely to be the case with sprays of conventional liquid glyphosate

Ecoplugs may also have other advantages such as eliminating the risk of drift and operator contamination, and providing the potential for year round application, but using them may be around three times more expensive than cut stump spraying using conventional liquid glyphosate.

Further research is required using higher Ecoplug application rates, greater quantities of artificial rainfall, and comparing the effect of delaying treatment after cutting on both Ecoplugs and conventional liquid glyphosate formulations.

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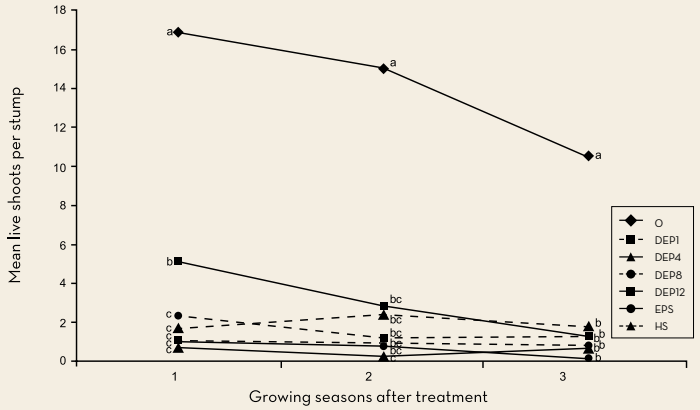

Figure 4: Experiment 2, time since cutting, effect of treatments on shoot regrowth from treated stumps over three growing seasons

Notes

Lettering (a,b) indicates significant differences between treatments, within growing season (pairwise comparisons, Bonferroni adjustments). Lettering only provided for growing seasons and treatments where pairwise comparisons indicated statistically significant (P<=0.05) differences.

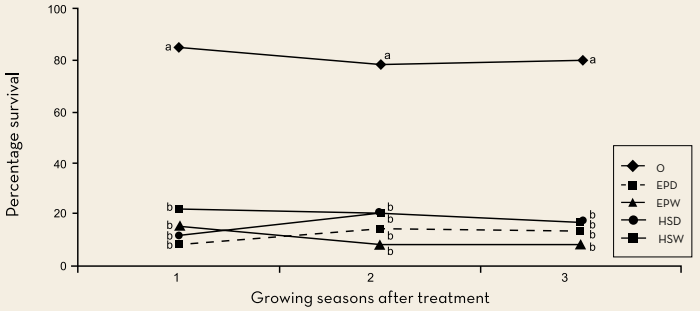

Figure 5: Experiment 3, rainfastness, effect of treatments on stump survival over three growing seasons

Notes

Lettering (a,b) indicates significant differences between treatments, within growing season (pairwise comparisons, Bonferroni adjustments). Lettering only provided for growing seasons and treatments where pairwise comparisons indicated statistically significant (P<=0.05) differences.

Figure 6: Experiment 3, rainfastness, effect of treatments on shoot regrowth from treated stumps over three growing seasons

Notes

Lettering (a,b,c) indicates significant differences between treatments, within growing season (pairwise comparisons, Bonferroni adjustments). Lettering only provided for growing seasons and treatments where pairwise comparisons indicated statistically significant (P<=0.05) differences.

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