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Project leader:	Chris Creed, ADAS UK Ltd.
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Location of project:	Commercial grower sites in Yorkshire, Nottinghamshire and Hampshire
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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- A number of new residual and contact acting herbicides offer improved weed control in rhubarb.

Background and expected deliverables

Efficient and cost effective weed control is important in rhubarb as with other crops to prevent yield loss as a result of competition for water, space and nutrients and to enable efficient harvesting without impedance by weed growth.

In recent years, rhubarb crown size and yield has been decreasing in both forced and green pull crops, where weeds have developed resistance to currently used herbicides. Growers believe that this decrease has been caused by increased competition from weeds as well as other influencing factors. Therefore, effective weed management in rhubarb is important to maximise the yield potential of the crop by reducing competition.

The harvesting regime for green pull crops has also changed in recent years, with two to three harvests being taken from a crop through the season to provide extended supply to meet retail demands. Opportunities to apply effective post-harvest herbicides have been reduced or delayed, allowing weeds to increase in size, making control more difficult. Retailers' strict quality protocols for clean produce free of dirt and contamination mean that cultivations carried out for weed control can occasionally lead to unintentional mud splash. The cost of labour is increasing and cultural controls such as hand pulling weeds and spot treatment with knapsack sprayers is becoming prohibitively expensive when margins are tight.

Therefore new effective herbicides that can be applied safely over the crop are required, to reduce the frequency of these operations and to protect the crop from weed competition.

A high priority for investigation in this project was to provide control of 'problem weeds' such as Himalayan balsam and perennials such as docks *(Rumex spp.)* and thistles *(Cirsium arvense)*. Although there is an EAMU for glyphosate in rhubarb, the short dormant season of the crop offers few windows for treatment and since the loss of dichlobenil, perennial weed infestations have been increasing.

The aim of this project was to evaluate a selection of newer herbicides for crop safety and efficacy against a range of problem weeds in rhubarb plantations, compared with industry standards. Three principal areas were addressed, with the objective of providing information for growers on candidate herbicides which:

- Offer control of commonly-occurring annual weeds using residual herbicides;
- Control perennial weeds, often a long-term problem in rhubarb with spot and overall treatments of contact acting herbicides;
- Provide information on any adverse effects on the crop.

Summary of the project and main conclusions

Five experiments were carried out at commercial grower holdings in Yorkshire, Nottinghamshire and Hampshire. Two experiments tested a range of residual herbicides applied pre-harvest for crop safety and efficacy against annual weeds at sites in Yorkshire and Nottinghamshire. Three further experiments tested crop safety and efficacy of a range of contact herbicides applied post-harvest in Yorkshire and Hampshire.

Residual herbicide trials

These residual herbicide trials were set up in a fully randomised block design with 21 treatments including a double replicated untreated control and two grower practice controls (**Table 1**). The grower practice controls were tank mixes of Stomp Aqua (pendimethalin) and Gamit 36 CS (clomazone), and Stomp Aqua and Goltix Flo (metamitron). Apart from herbicide applications, the crop was managed as per commercial practice with other inputs such as fungicides, insecticides, fertilisers and irrigation applied as necessary.

The major weed in the Yorkshire trial was Himalayan balsam *(Impatiens glandulifera)*, and the major weeds at the Nottingham trial site were (in order of incidence); annual meadow grass (*Poa annua)*, small nettle *(Urtica urens)*, scentless mayweed *(Tripleurospermum inodorum)*, groundsel *(Senecio vulgaris)* and fat-hen *(Chenopodium album)*. Black bindweed *(Fallopia convolvulus),* black nightshade *(Solanum nigrum),* cleavers *(Galium aparine),* common chickweed *(Stellaria media),* common field-speedwell *(Veronica persica),* creeping yellow-cress *(Rorippa sylvestris),* field pansy *(Viola arvensis),* knot-grass *(Polygonum aviculare),* redshank *(Persicaria maculosa),* shepherd's-purse *(Capsella bursa-pastoris)* and annual sowthistle *(Sonachus* spp.) appeared in many plots but not as frequently.

Table 1. Treatments applied to plots in 400 L water per hectare. Yorkshire and Nottinghamshire, 2015.

Treatment no.	Treatment	Active	Rate	Approval status
1 + 2 (Untreated controls)	-	-	-	-
3 (Standard 1)	Stomp Aqua +	pendimethalin 455 g/L	3.3 L/ha	EAMU
	Gamit 36 CS	+ clomazone 360 g/L	0.25 L/ha	EAMU
4 (Standard 2)	Stomp Aqua +	pendimethalin 455 g/L	3.3 L/ha	EAMU
	Goltix Flo	+ metamitron 700 g/L	5.0 L/ha	EAMU
5	Gamit 36 CS	clomazone 360 g/L	0.25 L/ha	EAMU
6	Callisto	mesotrione 100 g/L	1.5 L/ha	Not approved on rhubarb
7	Defy	prosulfocarb 800 g/L	5.0 L/ha	Not approved on rhubarb
8	Flexidor 500	isoxaben 500 g/L	0.5 L/ha	Not approved on rhubarb
9	Sencorex WG*	metribuzin 70% w/w	1.25 Kg/ha	EAMU
10	H32	-	-	Not approved on rhubarb
11	Dual Gold	s-metalochlor 960 g/L	1.4 L/ha	Not approved on rhubarb
12	H33	-	-	Not approved in UK
13	H33 high rate	-	-	Not approved in UK
14	H34	-	-	Not approved on rhubarb
15	H35	-	-	Not approved on rhubarb
16	H33 + H34	-	-	See above
17	H33 +	-	-	See above
	Gamit 36 CS	clomazone 360 g/L	0.25 L/ha	
18	H35 +	-	-	See above
	Gamit 36 CS	clomazone 360 g/L	0.25 L/ha	
19	H36	-	-	Not approved in UK
20	H37	-	-	Not approved on rhubarb
21	H38	-	-	Not approved on rhubarb

* Note: Although Sencorex WG was used in the trials, Sencorex Flow is the form approved for use on rhubarb. Check the EAMU for the rate approved for use.

Just prior to or at bud break, the site was marked out and the residual herbicides were applied on 10 March at Yorkshire and 16 March at Nottinghamshire. The treatments were applied over the sets to the beds using an Oxford precision (OPS) knapsack sprayer and a 2m boom with 04F110 flat fan nozzles, to achieve a medium spray quality of 400 L/ha.

Phytotoxicity to the rhubarb was assessed on each plot, using a scale of 0 – 9, whereby 9 showed no effect, 7 was a commercially acceptable effect or damage, 1 was a very severe

effect and 0 was plant death. Plots were also assessed for percentage weed cover and the weed species present were also recorded. At the Nottinghamshire site, the number of weed seedlings of each species were counted at the first three assessment dates instead of percentage weed cover.

Contact herbicide trials – main trials

These trials were set up in a fully randomised block design with 18 treatments including a double replicated untreated control (**Table 2**). There were no grower practice controls, as there are currently no techniques or herbicides commonly used by all rhubarb growers, due to the difficulty of crop safety and effective application of approved contact herbicides in all situations. Apart from herbicide applications, the crop was managed as per commercial practice with other inputs such as fungicides, insecticides, fertilisers and irrigation applied as necessary.

In Yorkshire the major weeds were Himalayan balsam (*Impatiens glandulifera*). Creeping thistle (*Cirsium arvense*), common nettle (*Urtica dioica*), common wormwood or mugwort (*Artemisia vulgaris*), hedge bindweed (*Calystegia sepium*), field bindweed (*Convolvulus arvensis*), common couch (*Elytrigia repens*), curled dock (*Rumex crispus*), cleavers (*Galium aparine*) and soft brome (*Bromus hordeaceus*) appeared in many plots but not as frequently.

In Hampshire the major weeds were dandelion *(Taraxacum officinale),* fat-hen *(Chenopodium album),* field bindweed *(Convolvulus arvensis),* Canadian fleabane *(Conyza canadensis),* perennial sowthistle *(Sonchus arvensis),* scentless mayweed *(Tripleurospermum inodorum)* and common wormwood or mugwort *(Artemisia vulgaris).* Creeping thistle *(Cirsium arvense),* common nettle *(Urtica dioica),* shepherd's-purse *(Capsella bursa-pastoris),* cleavers *(Galium aparine),* black nightshade *(Solanum nigrum),* groundsel *(Senecio vulgaris)* and redshank *(Persicaria maculosa)* appeared in many plots, but not as frequently.

Table 2. Treatments applied to plots in 200 L water per hectare. Yorkshire and Hampshire, 2015.

		Treatment timing		
Treatment no.	**Treatment name**	**Timing 1 Post-harvest (1 - 2 weeks after topping)**	**Timing 2 (3-4 weeks after Timing 1)**	**Approval status**
Untreated and inter-row glyphosate treatments				
1 + 2	Untreated	-	-	-
3	Master Gly 36T inter-row	Master Gly 36T inter-row 5.0 L/ha*	-	Not approved for use in rhubarb
4	Master Gly 36T inter-row fb Stomp Aqua + Gamit 36 CS	Master Gly 36T inter-row 5.0 L/ha*	Stomp Aqua 3.3 L/ha + Gamit 36 CS 0.25 L/ha	See above and table 1.
Over the row treatments				
5	Master Gly 36T	Master Gly 36T 5.0 L/ha*		Not approved for use in rhubarb
6	Shark	Shark 0.8 L/ha		Not approved for use in rhubarb at this timing
7	H39	H39		Not approved for use in rhubarb
8	Reglone	Reglone 4.0 L/ha		Approved only for inter-row use
9	Dow Shield once	Dow Shield 0.5 L/ha		Not approved for use in rhubarb
10	Dow Shield twice	Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	See above
11	H38	H38		Not approved for use in rhubarb
12	H40	H40		Not approved for use in rhubarb
Over the row Shark followed by residual/contact herbicides				
13	Shark fb Sencorex Flow	Shark 0.8 L/ha	Sencorex Flow 1.45 L/ha	See above and table 1.
14	Shark fb H33	Shark 0.8 L/ha	H33	See above and table 1.
15	Shark fb H33 + Defy	Shark 0.8 L/ha	H33 + Defy 5.0 L/ha	See above and table 1.
16	Shark fb H33 + Sencorex Flow	Shark 0.8 L/ha	H33 + Sencorex Flow 1.45 L/ha	See above and table 1.
17	Shark fb H36	Shark 0.8 L/ha	H36	See above and table 1.

		Treatment timing		
Treatment no.	**Treatment name**	**Timing 1 Post-harvest (1 - 2 weeks after topping)**	**Timing 2 (3-4 weeks after Timing 1)**	**Approval status**
18	Shark fb H37	Shark 0.8 L/ha	H37	See above and table 1.

fb = followed by.

* Note: max individual dose under the EAMU is 4.0 L/ha, as an on-label application to stubbles or before planting or production it is 5.0 L/ha.

After the crop was harvested and then topped, the site was marked out and the contact herbicides were applied two weeks after topping on 13 May in Yorkshire, and three weeks after topping on 4 June in Hampshire. The Timing 2 treatments were applied between three to four weeks after the Timing 1 treatments, on 5 June in Yorkshire, and 29 June in Hampshire. The treatments were applied using an OPS knapsack sprayer and a 2m boom with 02F110 flat fan nozzles, to achieve a medium spray quality at 200 L/ha.

Phytotoxicity to the rhubarb was assessed on each plot. Plots were also assessed for percentage weed cover, phytotoxic effects on weeds and weed species present were also recorded.

Contact herbicides - extra trial

This trial was set up in a fully randomised block design with 5 treatments including an untreated control (**Table 3**). There was no grower practice control, as there are currently no techniques or herbicides commonly used by all rhubarb growers, due to the difficulty of crop safety and effective application of approved contact herbicides. Apart from herbicide applications, the crop was managed as per commercial practice with other inputs such as fungicides, insecticides, fertilisers and irrigation applied as necessary.

Table 3. Treatments applied to plots in 200 L water per hectare (see tables 2 and 4 for approval status of products used). Hampshire, 2015.

Treatment no.	Treatment	Active	Rate
1 (Untreated control)	-	-	-
2	Shark	carfentrazone-ethyl 60g/L	0.3 L/ha
3	Shark	carfentrazone-ethyl 60g/L	0.8 L/ha
4	Shark +	carfentrazone-ethyl 60g/L +	0.3 L/ha
	Dow Shield 400	clopyralid 400 g/L	0.5 L/ha
5	Shark +	carfentrazone-ethyl 60g/L +	0.3 L/ha
	Dow Shield 400 +	clopyralid 400 g/L + metribuzin	0.5 L/ha
	Sencorex Flow	600 g/L	1.45 L/ha

After the crop was harvested and then topped, the site was marked out and the contact herbicides were applied two weeks after topping on 13 May in Yorkshire, and three weeks after topping on 4 June in Hampshire. The Timing 2 treatments were applied between three to four weeks after the Timing 1 treatments, on 5 June in Yorkshire, and 29 June in Hampshire. The treatments were applied using an OPS sprayer and a 2m boom with 02F110 nozzles, to achieve a medium spray quality at 200 L/ha.

Phytotoxicity to the rhubarb was assessed on each plot. Plots were also assessed for percentage weed cover, phytotoxic effects on weeds and weed species present were also recorded.

Results

Crop safety of residual herbicides in outdoor rhubarb

No adverse effects were seen on the 2 year old established crop of Stockbridge Arrow planted on a sandy clay loam soil in Yorkshire. However, phytotoxic symptoms were seen in three treatments on the newly planted crop of Stockbridge Arrow in Nottinghamshire. The latter crop was planted into a sandy loam soil and a higher sensitivity to herbicides is often expected to occur on light soil types such as these. This indicates that extra care needs to be taken when selecting residual herbicides and rates of use on rhubarb in this situation.

Phytotoxic effects were seen in the plots at Nottingham treated with Sencorex WG, Callisto and H33 with the greatest effects caused by Sencorex WG applied at 1.25 kg/ha (**Figure 1**). The effect of Sencorex WG was exhibited as chlorosis along the veins of the leaves and symptoms first occurred on 6 May, seven weeks after the sprays were applied. This was two weeks after 30mm of irrigation was applied on 23 April, and the interval between occurrence and the treatment application shows the persistence of the product and its ability to re-activate

in the presence of moisture. Between the herbicide application on 10 March and 23 April, conditions were dry with the only significant rainfall occurring at the site on 3 April.

Figure 1. Effects of the application of Callisto and Sencorex on the rhubarb at 7 and 12 weeks after treatment (WAT) L-R a) Callisto – 7 WAT, b) Sencorex WG – 7 WAT, c) Sencorex WG – 12 WAT. Nottinghamshire, 2015

The effects of Sencorex WG were transient and the stronger sets had recovered 12 weeks after application, and by this point new leaves were no longer showing any chlorotic effects. However it should be noted that weaker plants were lost. Sencorex Flow was approved for use on newly established crops during the project and this risk of phytotoxicity should be taken into account when using the product. The use of lower rates may be safer in higher risk situations, especially when planting new crops on light soil types.

Callisto and H33 also showed a less severe phytotoxicity effect with an occasional early leaf showing scorch at seven weeks after treatment, but the sets recovered quickly and had grown through well by 12 weeks after treatment, with no symptoms seen at this point.

Control of commonly-occurring annual weeds using residual herbicides

Herbicides currently approved for use in rhubarb have varying weaknesses in the spectrum of annual weeds controlled. Those weeds resistant or moderately resistant to current actives include Himalayan balsam, black bindweed, mayweed, cleavers, field pansy, groundsel and charlock (Science section Appendix B). In both trials, residual herbicides were found which can control these weeds and offer better or equivalent control than the current grower standards of Stomp Aqua + Gamit 36 CS and Stomp Aqua + Goltix Flow, and significantly better control than the untreated (**Figure 2**). These five herbicides were Sencorex WG, Callisto, H32, H34 and H34 in a tank with H33.

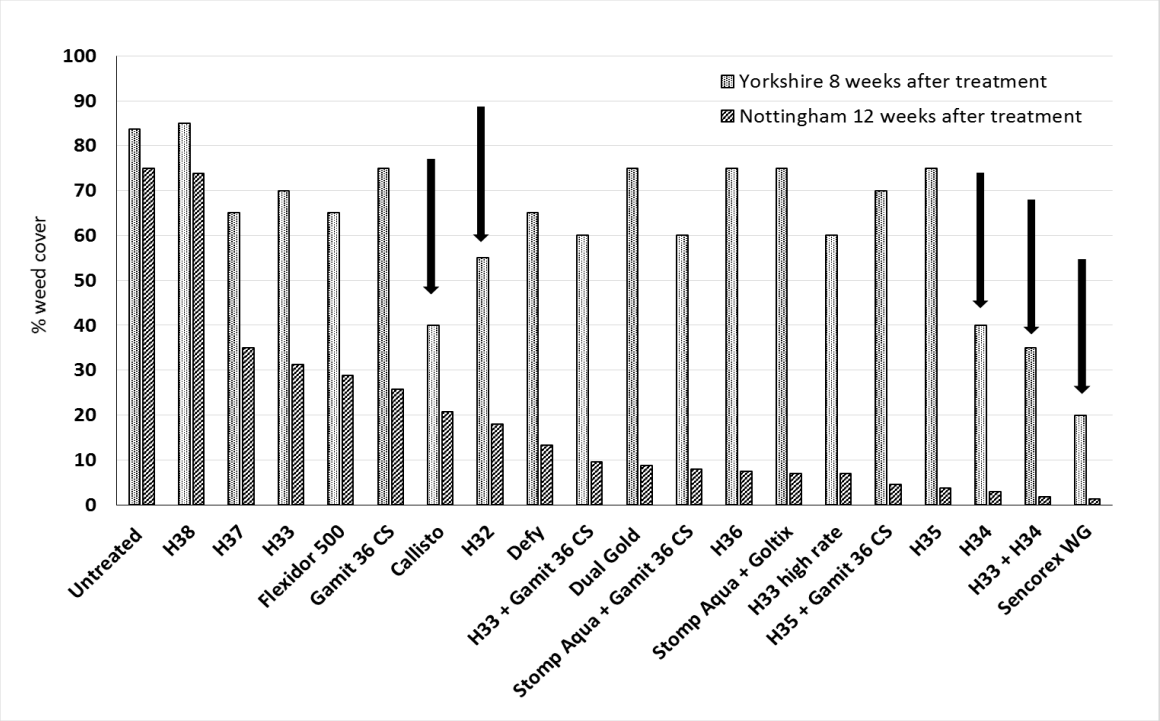


Figure 2. Mean percentage of weed cover at 8 weeks after treatment in Yorkshire and 12 weeks after treatment in Nottinghamshire. Arrows indicate those treatments that gave significantly better control than the untreated plots at both sites. 2015

Sencorex WG was the best product for overall weed control at both sites reducing weed levels by 76% in Yorkshire and by 98% in Nottinghamshire when compared to the untreated. During the project an EAMU was obtained for application of the product as the Sencorex Flow form for use on newly planted rhubarb plantations. However, due to the EAMU restrictions on use, it cannot be applied to established plantations which are going to be harvested within a period of 12 months. Therefore, options are still needed for established crops to maintain weed control during harvest in later years, and thus maintain yields through the plantation life.

Callisto (currently not approved for use on rhubarb) was the second best active for control of Himalayan balsam, reducing levels by 53% when compared to the untreated. It also gave a good reduction in a range of weeds in Nottinghamshire, reducing weed cover by 76%. Despite this, it did not appear as one of the better products for an overall reduction in the percentage of weed cover in Nottinghamshire because it doesn't control annual meadow grass or small nettle well, and these were two of the main weeds at the experimental trial site. But, if partner products are considered it could give control of a wide range of weeds in a tank-mix with Goltix, which would add control of annual meadow grass and small nettle. Callisto also has a broad weed control susceptibility list based on the label and trials data (Appendix B). It should be noted that Callisto has not been tested as a tank-mix on rhubarb, and grower experience

in crops such as maize suggest that when mixed it can increase the phytotoxicity risk. Therefore, if approved, growers should bear this in mind when using a tank-mix.

Dual Gold (currently not approved for use on rhubarb), H36 and H33 at a high rate or in a tank mix with Gamit 36 CS also gave better or equivalent control to the current grower standards in Nottinghamshire, but had no effect on Himalayan balsam. Product H33 in a tank mix with Gamit would give moderate to good control of all the annual weeds, where there are weaknesses in the current approvals except for cleavers.

Product H35 gave better control than the current standards at the Nottinghamshire site only, but was ineffective at controlling the Himalayan balsam in Yorkshire. However, it was applied after the Himalayan balsam had emerged and the mode of action of this herbicide means that it gives best control when applied pre-emergence, as it is absorbed by the subterranean parts of the plant such as the roots and hypocotyl (shoots). The product may have a greater effect if applied pre-emergence, and this approach may be worth testing in future.

Overall, an approval for Callisto or H32 would give greater or equivalent weed control where there are currently weaknesses in both geographical situations.

Crop safety of contact herbicides in outdoor rhubarb

Roundup over the row was too damaging at the rates used at both experimental sites and killed some sets. H39 over the row and Roundup inter-row were also too damaging at Yorkshire. The latter treatment may have reduced the vigour of the rhubarb because it was more difficult to apply the spray low enough to avoid drift onto the plants, as the crop is grown on ridges. Conversely, effects from Roundup applied inter-row to the crop grown on the flat in Hampshire were scored as slight by 11 weeks after treatment, whereas at the same assessment timing in Yorkshire moderate effects were still seen. Therefore Roundup between the row could be safely used depending on the situation that the rhubarb is grown in.

Dow Shield 400 (not approved for use on rhubarb) caused severe effects to the rhubarb at both sites at the rates used in the trial, causing cupping of leaves, distortion and twisting of new growth and deformed or thickened new leaves. These effects were still occurring at 11 weeks after the first applications in Yorkshire and 18 weeks after the first applications in Hampshire. Although the effects are long-lasting and set back growth by a number of weeks in the year of application, no crop death was seen in the plots. If Dow Shield 400 was applied at a lower rate, or as a spot treatment, the phytotoxic effects may be reduced, and this would be worth investigating due to the value of the product for perennial thistle control.

Shark, Reglone and H40 initially scorched the rhubarb, but the plots treated with these contact herbicides recovered reasonably quickly to a level where the crop would be acceptable to harvest again at least 8 weeks after application. It should be noted that although Shark and Reglone are approved for use on rhubarb, they are not approved for use at this timing or application method.

The recovery from the herbicide applications varied by site and product. The plots sprayed with Shark recovered the quickest and plants appeared to be at a commercially acceptable quality at four weeks after application in both Yorkshire and Hampshire. It took slightly longer for the rhubarb to recover from Reglone and H40, with the plants at an acceptable quality by seven weeks after application in Hampshire. In Yorkshire, the crop treated with Reglone had recovered by six weeks after application, and by eight weeks for the crop treated with H40.

The Timing 2 treatments of single herbicides and tank mixes applied to the crop three to four weeks after the Timing 1 treatments also scorched the rhubarb, causing yellowing and necrosis of the leaves present at application. The crop grew through these symptoms and had recovered with no or only slight symptoms seen at seven weeks after the sprays were applied in Yorkshire, and eight weeks after the sprays were applied in Hampshire. It should be noted that if these sprays are applied one month after the first sprays as in the trials, then the crop takes a further three to four weeks to recover than those plots that only received one application of Shark, Reglone or H40.

Control of perennial weeds using overall and spot applications of contact herbicides

Control of perennial weeds is particularly troublesome in perennial crops such as rhubarb as the windows for ‘clean-up’ spray applications are limited and short. Products such as Roundup can only be safely applied when the crop is fully dormant during December and January, and in practice opportunities to spray can be few and far between in these months. Therefore herbicides that could be applied safely to the plantation outside this window would be very useful to growers. Five post-harvest applied treatments gave significant control of weeds at both trial sites, and also proved safe to the crop with no or only slight effects seen at 11 weeks after treatment, or when the crop in the trial would have been ready for harvest again.

These treatments were single applications of Shark or H40, and Shark followed by an additional application of Sencorex Flow, H36 or Sencorex Flow in a tank mix with H33. In

addition, in Hampshire, Roundup applied as a shielded application between the rows and then followed up by an application of Stomp Aqua + Gamit 36 CS gave significant weed control and was safe to the crop at this site (**Table 4**).

Shark gave the best control for a single applied product, significantly reducing weed cover to approximately 13% cover for up to 11 weeks in both Yorkshire and Hampshire. This equates to a reduction in weed cover of 84% in Yorkshire, and 48% in Hampshire when compared to the levels in the untreated plots at each site. Although Shark performed well in the contact herbicide trials, its efficacy can be variable depending on how well the weeds are growing and the temperature when it is applied. It performs best when weeds are growing well under warm conditions. In addition, during the project, Shark was applied on 10 March at 0.8 L/ha to the emerged Himalayan balsam in the residual trial area and had very little effect on the weed. Temperature on average on the day of application by the grower (11 March) was 7.5 ^{0}C, with average temperature over the seven days after application of 5.2 ^{0}C. Shark worked better when applied in Yorkshire at 11.5 ^{0}C, and temperature reached 19 ^{0}C on the day of application, with an average temperature over the seven days after application of 9.9 ^{0}C. In Hampshire, the temperature on the day and after application was even higher than these. It is also worth noting that the weeds were also growing strongly at the time of application in the contact herbicide trials.

Table 4. Mean percentage of weed cover at Timing 2 application and at the potential harvest date 11 weeks after treatment (WAT) application. Yorkshire and Hampshire, 2015

		Weed cover at dates and sites indicated (%)			
		Yorkshire		Hampshire	
Treatment Timing 1	Treatment Timing 2	5 June 4 WAT Timing 2	23 July 11 WAT Harvest	29 June 3 WAT Timing 2	26 Aug 11 WAT Harvest
Untreated	Untreated	96.2	88.8	11.7	25.4
Roundup inter-row	-	**15.5**	**38.8**	4.7	17.0
Roundup inter-row	Gamit 36 CS + Stomp Aqua	**16.2**	**22.8**	3.7	**11.5**
Roundup over row	-	**1.8**	**13.5**	4.0	50.0
Shark	-	**6.5**	**13.8**	7.3	**13.2**
H39	-	**10.2**	**35.5**	10.7	32.5
Reglone	-	**28.7**	77.5	10.0	20.0
Dow Shield 0.5 L/ha	-	**69.5**	87.5	9.5	**15.0**
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	97.5	96.8	13.0	18.0
H38	-	96.2	99.2	7.7	18.5
H40	-	**45.0**	**28.0**	11.5	**14.0**
Shark	Sencorex Flow	**19.2**	**12.0**	13.3	**8.2**
Shark	H33	**11.7**	**11.2**	9.7	17.8
Shark	H33 + Defy	**7.2**	**12.5**	10.0	14.0
Shark	H33 + Sencorex Flow	**24.2**	**13.8**	7.7	**7.0**
Shark	H36	**32.0**	**15.2**	4.7	**6.7**
Shark	H37	**14.7**	**44.0**	13.7	27.0
F probability	All treatments	<0.001	<0.001	NS	<0.001
LSD (70 d.f.)		15.88	14.73	-	9.667
F probability	Shark alone vs	0.042	<0.001	NS	0.049
LSD (26 d.f.)	Shark and follow up treatments	16.44	11.42	-	13.17

Note: Figures in **bold** are significantly different from the untreated.

In the additional trial in Hampshire, the rate of Shark at 0.3 L/ha performed as well as the higher rate of 0.8 L/ha, and therefore growers can be assured that the lower rate can be effective as long as the weed spectrum, rate of weed growth and temperature at application are considered.

H40 was the second best treatment for a single applied product at both sites, reducing weed cover significantly to 14% in Hampshire and 28% in Yorkshire at 11 weeks after spray application. This equates to a reduction in weed cover of 68% in Yorkshire and 45% in Hampshire when compared to the levels in the untreated plots at each site. Both Shark and H40 have a good range of control (see Appendix B) and although they are both contact in activity, there is an element of selectivity to their action and Shark is stronger on smooth sowthistle and fat-hen, while H40 gives good control of groundsel and mayweed. There are also differences between the desiccants Shark and Reglone, with the former being weaker on mayweed, chickweed and groundsel, while diquat is weaker on cleaver, knotgrass and small nettle. Therefore when using these contact herbicides growers need to take into account the weed spectrum, as well as timing of application with regards to speed of weed growth and temperature to select the products to get the best control.

Dow Shield 400 was the only herbicide to fully control perennial thistle with a good kill, but when applied over the crop at the rates used it gave severe crop damage causing cupping of leaves and deformation of new growth, with twisting and deformation of new leaves seen up to 18 weeks after sprays were applied. However, despite this no plant death was seen and an approval for the control of thistle would still be useful as Dow Shield may be safer to use as a spot treatment or at lower rates, and there are currently few other safe options for full control of this weed. H40 as a single spray application and Shark followed by a later application of Sencorex Flow gave good suppression of perennial thistle but did not kill it all.

Residual herbicides with some contact activity were also tested to see if they added more longevity and further control to the purely contact herbicide Shark. Of those tested Sencorex Flow and H36 added a slight reduction in weed control, Sencorex Flow reduced the weed further by 6-7% at both trial sites, while H36 gave an added reduction of 15% in weed levels at the Yorkshire site only. This is only a small extra reduction so the grower would have to decide if this was an approach worth taking. This is especially true if applied one month later than the Shark application as in the trial, as it then takes the crop a further four weeks to recover than those plots where only Shark was applied. Alternatively, applying both products in a tank-mix could be possible in practice.

Effects on the most troublesome perennial weeds were recorded and it was noted that field and hedge bindweed were initially suppressed by Shark and product H40. However, the bindweed started to grow through the initial effects after six to eight weeks and had fully recovered 11 weeks after treatment. No treatments gave long-lasting effects on the mugwort.

Shark provided good control of Himalayan balsam and a range of dicotyledon weeds in both trials but has weaknesses in chickweed, mayweed and groundsel, and growers also need to consider temperature and speed of weed growth to get good efficacy from the product. Pyraflufen-ethyl may be useful to look at in future work as it is a similar desiccant product and is suggested to have stronger activity on mayweed which can be a troublesome weed in rhubarb plantations.

Financial benefits

The production of rhubarb could become economically unviable without effective herbicides, as the increasing cost of labour is making hand-weeding a prohibitively expensive method of weed control. Therefore, growers are searching for methods to reduce their reliance on labour, and increase production efficiency. The availability of effective herbicides would permit growers to achieve this and also help to maintain yields through the life of the plantation as competition for nutrients and water from weeds is reduced. It is difficult to quantify the gain in yield from reducing weed competition but the availability of these herbicides will reduce the need for hand weeding which costs on average £2,200/ha. Where herbicide resistant weeds have developed, a crop may need weeding up to 3 times a year at a cost of up to £6,600/ha. Cultivation is an alternative method, and although lower cost at £42/ha it does not last, and in some planting configurations weeds will still be left in the row. Therefore the approval of the most promising products in the trial could reduce costs of production significantly, by c. £2,200/ha if even just one less weeding session is needed in crops where herbicide resistance to currently approved products has developed. Which over the area of rhubarb grown in the UK (505 ha) this would save the industry £1.11 million overall and maintain the profitability and viability of UK production.

Action points for growers

- Five residual herbicide treatments (Sencorex Flow, Callisto, H32, H34, and H34 in a tank mix with H33) gave better control of most commonly occurring annual broad leaf weeds than the currently approved standards for rhubarb. The weeds controlled include Himalayan balsam, and all these treatments would also increase the range of weeds controlled. H32 and Callisto controlled all broad leaved weeds in the trials except small nettle.

- An EAMU for Sencorex Flow was obtained during the trial for application pre-crop emergence in the year of establishment, and at least 12 months before harvest. This is a useful addition to the current approvals, but caution should be taken with the rate of application to new crops, as when applied at a full rate of 1.45 L/ha in the trials, severe

phytotoxicity was seen. This was exhibited as veinal chlorosis. Death of weak sets also occurred. Using lower rates may improve safety to the crop, and is advised especially on lighter soils.

- It is recommended that AHDB Horticulture investigates the possibilities of EAMUs for Callisto, Dual Gold, H33 and H34 to enable improved weed control in established plantations. These herbicides were also relatively safe to the crop.

- Shark (not approved at this application timing) and H40 significantly reduced the percentage of weed cover when applied post-harvest one to two weeks after the crop had been topped, and maintained control up to 18 weeks after application.

- Shark provided good control of Himalayan balsam and a range of dicotyledon weeds in both trials but has weaknesses in chickweed, mayweed and groundsel, and growers also need to consider temperature and speed of weed growth to get good efficacy from the product. Reglone or Retro (diquat) may be a better option in cooler temperatures and when weed growth is slow.

- Dow Shield 400 was the only herbicide to fully control perennial thistle with a good kill, but when applied over the crop at the rates used, it led to severe crop damage causing cupping of leaves and deformation of new growth, with twisting and deformation of new leaves seen up to 18 weeks after sprays were applied. However, despite this no plant death was seen and an approval for the control of thistle would still be useful as Dow Shield may be safer to use as a spot treatment or at lower rates, and there are currently no other safe options for full control of this weed.

- It would be worth investigating the possibility of an EAMU for product H40, as it gives good overall weed control, and is particularly effective on mayweeds as well as giving reasonable control of perennial thistle.

SCIENCE SECTION

Introduction

Efficient and cost effective weed control is important in rhubarb as with other crops to prevent yield loss as a result of competition for water, space and nutrients and to enable efficient harvesting without impedance by weed growth.

In recent years, rhubarb crown size and yield has decreased in both forced and green pull crops where weeds resistant to current herbicides have developed. Growers believe that this is as a consequence of increased competition from weeds amongst other influencing factors. Therefore, effective weed management in rhubarb is important to allow growers to maximise the yield potential of the crop by reducing competition. The harvesting regime for green pull crops has also changed in recent years, with two to three harvests being taken from a crop through the season to give nearly year round supply to meet retail demands. This means that opportunities to apply effective post-harvest herbicides have reduced or moved later in the season, by which time weeds have increased in size and difficulty of control. In addition, the strict requirements of retailers' quality protocols for clean produce, free of dirt and contamination, mean that cultivations carried out for weed control can occasionally lead to unintentional mud splash. Furthermore, the cost of labour is increasing, and cultural controls such as hand pulling weeds and spot treatment with knapsack sprayers is becoming prohibitively expensive when margins are tight. Further effective herbicides that can be applied safely over the crop are required, to reduce the frequency of these operations, and aid the grower in avoiding such issues.

The majority of rhubarb herbicide programmes are currently based on pendimethalin propyzamide and clomazone, and these do not provide complete enough weed spectrum efficacy and persistence. Work carried out in HDC project SF 129 gave useful information for growers on the efficacy and crop safety of clomazone (which gained an EAMU while the experiment was being carried out) and increased the weed spectrum controlled, but there were still gaps to fill. Mesotrione and metribuzin tested in the same project also showed useful activity, with the latter showing some control of Himalayan balsam *(Impatiens glandulifera).* Therefore, it was useful to revisit these products as well as test some newer materials with a view to gaining EAMUs. An EAMU was obtained for the use of metribuzin on new plantations during this project, and the information from the project will give growers guidance on its use.

This work was particularly timely with the introduction of the Sustainable Use Directive and the recent change in the EU regulations to the assessment of plant protection products by hazard in addition to risk based criteria, which has placed some residual herbicides under

threat. The recent Endocrine Disruptor review and the review of implications for the industry carried out by AHDB, highlights the future status and availability of pendimethalin and propyzamide is therefore at best uncertain. Therefore alternative sustainable options are needed to maintain weed control and guard against resistance development.

A high priority for investigation in the project was finding solutions to the control of the particular problem weeds Himalayan balsam, docks *(Rumex spp.)* and thistles *(Cirsium arvense)*, and potential replacements for products being lost. A literature search has shown that there is virtually no specific information available to rhubarb growers on the control of Himalayan balsam. Although there is an EAMU for glyphosate, the short dormant season of the crop gives few windows for treatment and since the loss of dichlobenil, perennial weed infestations are on the increase.

The aim of this project was to evaluate a selection of newer herbicides for crop safety and efficacy against a range of problem weeds in rhubarb plantations, compared with industry standards. Three principal areas were addressed, with the objective of providing information for growers on candidate herbicides which:

- Offer control of commonly-occurring annual weeds using residual herbicides;
- Control perennial weeds, often a long-term problem in rhubarb with spot and overall treatments of contact acting herbicides;
- Provide information on any adverse effects on the crop.

Materials and methods

Five experiments were carried out at commercial grower holdings in Yorkshire, Nottinghamshire and Hampshire. Two experiments tested a range of residual herbicides applied pre-harvest for crop safety and efficacy against annual weeds at sites in Yorkshire and Nottinghamshire. Three further experiments tested crop safety and efficacy of a range of contact herbicides applied post-harvest in Yorkshire and Hampshire.

Residual herbicide trials

Site 1 – Yorkshire

Work was carried out on a two year old commercial plantation of rhubarb grown on ridged beds with the variety Stockbridge Arrow (**Figure 3**). Seventy five percent of the crop was at a stage just prior to bud break on 10 March 2015, and was due for harvest on 7 May 2015. The soil is a sandy clay loam with 5.3 % organic matter. The major weed was Himalayan

balsam (*Impatiens glandulifera)*. Ground elder (*Aegopodium podagraria),* common couch *(Elytrigia repens),* curled dock *(Rumex crispus*), redshank *(Persicaria maculosa),* small nettle *(Urtica urens)* and creeping thistle *(Cirsium arvense)* appeared in many plots but not as frequently.

Full details of the soil analyses, weather at spray application, and temperature and humidity records through the duration of the trial can be found the Appendices. No residual herbicides apart from the trial treatments were applied to the project area in 2015. An overspray of Shark at 0.8 L/ha was applied to the whole trial area after the residual herbicides were applied to give them a fair test, as the Himalayan balsam had already emerged. The Himalayan balsam was at cotyledon stage at application.

Figure 3. Residual herbicide trial area in a two year old plantation with Himalayan balsam seedlings seen between the ridges. Yorkshire, 2015.

Site 2 - Nottinghamshire

At the second site, work was carried out on a newly planted crop of rhubarb grown in beds on the flat with the variety Stockbridge Arrow (**Figure 4**). The crop was planted on 9 March 2015 and a new bud was showing on the majority of sets on 16 March 2015. Rhubarb is not usually harvested in its year of planting and establishment. The soil is a sandy loam with 2.6 % organic matter. There was a wider range of problem weeds at this site with the major weeds (in order of incidence) being annual meadow grass (*Poa annua)*, small nettle *(Urtica urens)*, scentless mayweed *(Tripleurospermum inodorum)*, groundsel *(Senecio vulgaris)* and fat-hen *(Chenopodium album)*. Black bindweed *(Fallopia convolvulus),* black nightshade *(Solanum nigrum),* cleavers *(Galium aparine),* common chickweed *(Stellaria media),* common field-speedwell *(Veronica persica),* creeping yellow-cress *(Rorippa sylvestris),* field pansy *(Viola*

arvensis), knot-grass *(Polygonum aviculare),* redshank *(Persicaria maculosa),* shepherd's-purse *(Capsella bursa-pastoris)* and annual sowthistle *(Sonachus* spp.) appeared in many plots but not as frequently.

Full details of the soil analyses, weather at spray application, and temperature and humidity records through the duration of the trial can be found the Appendices. No other herbicides apart from the trial treatments were applied to the project area in 2015.

Figure 4. Residual herbicide trial area in a new plantation. Nottinghamshire, 2015.

Both sites (1 and 2)

The trials were a fully randomised block design with 21 treatments, including a double replicated untreated control and two grower practice controls (**Tables 5 and 6**). The grower practice controls were tank mixes of Stomp Aqua plus Gamit 36 CS, and Stomp Aqua plus Goltix Flo. There was four-fold replication. Each plot was 5m long and 1.7m wide at the Yorkshire site and 5m long and 2m wide at the Nottinghamshire site. Apart from herbicide applications, the crop was managed as per commercial practice with other inputs such as fungicides, insecticides, fertilisers and irrigation applied as necessary.

Table 5. Treatments applied to plots in 400 L water per hectare. Yorkshire and Nottinghamshire, 2015.

Treatment no.	Treatment	Active	Rate
1 + 2 (Untreated controls)	-	-	-
3 (Standard 1)	Stomp Aqua + Gamit 36 CS	pendimethalin 455 g/L + clomazone 360 g/L	3.3 L/ha 0.25 L/ha
4 (Standard 2)	Stomp Aqua + Goltix Flo	pendimethalin 455 g/L + metamitron 700 g/L	3.3 L/ha 5.0 L/ha
5	Gamit 36 CS	clomazone 360 g/L	0.25 L/ha
6	Callisto	mesotrione 100 g/L	1.5 L/ha
7	Defy	prosulfocarb 800 g/L	5.0 L/ha
8	Flexidor 500	isoxaben 500 g/L	0.5 L/ha
9	Sencorex WG*	metribuzin 70% w/w	1.25 Kg/ha
10	H32	-	-
11	Dual Gold	s-metalochlor 960 g/L	1.4 L/ha
12	H33	-	-
13	H33 high rate	-	-
14	H34	-	-
15	H35	-	-
16	H33 + H34	-	-
17	H33 + Gamit 36 CS	- clomazone 360 g/L	- 0.25 L/ha
18	H35 + Gamit 36 CS	- clomazone 360 g/L	- 0.25 L/ha
19	H36	-	-
20	H37	-	-
21	H38	-	-

* Note: Although Sencorex WG was used in the trials, Sencorex Flow is the form approved for use on rhubarb. Check the EAMU for the rate approved for use.

Table 6. Approval status of products used in the trials. Yorkshire and Nottinghamshire, 2015.

Product	Approval status	Application timing requirements
Stomp Aqua	EAMU	Pre-emergence of the crop in the year of harvest/ After final harvest of the crop
Gamit 36 CS	EAMU	Pre emergence or prior to bud break in the following year
Goltix Flo	EAMU	28 days before harvest
Callisto	Not approved on rhubarb, EAMU for asparagus, linseed and sweetcorn	-
Defy	Not approved on rhubarb, EAMU for celery, carrots, parsnips and alliums	-
Flexidor 500	Not approved on rhubarb, EAMU for carrots, parsnips, asparagus and squashes	-
Sencorex Flow	EAMU	pre-crop emergence in year of establishment, at least 12 months before harvest
Dual Gold	Not approved on rhubarb, EAMU for brassicas, alliums and herbs	-
H32	Not approved on rhubarb, on-label for brassicas, EAMU for baby-leaf salad	-
H33	Not approved in UK, seeking residues on celery	-
H34	Not approved for rhubarb, on-label for potatoes	-
H35	Not approved for rhubarb, on-label for grain maize and winter oilseed rape	-
H36	Not approved in the UK	-
H37	Not approved on rhubarb, on-label for forage maize	-
H38	Not approved on rhubarb, on-label for amenity grassland, forest and moorland (expires end Oct 2015)	-

All are on the approved list of active substances in the EU

Just prior to or at bud break, the site was marked out and the residual herbicides were applied on 10 March at the Yorkshire site and 16 March at the Nottinghamshire one. The treatments were applied over the sets to the beds using an OPS sprayer and a 2m boom with 04F110 flat fan nozzles, to achieve a medium spray quality at 400 L/ha. Details of weather conditions at application are included below (**Table 7**)

Table 7. Weather and crop conditions at herbicide application. 2015

Environmental parameter	Yorkshire (10 March)	Nottinghamshire (16 March)
Time of application (hh:mm)	16:15 – 18:30	11:15 – 13:15
Weather at application	Sunny and cloudy	Cloudy
Cloud cover (%)	20	90
Temperature (^{0}C)	9.4	7.6
Soil temperature at 10cm depth (^{0}C)	8.4	6.3
Soil temperature at 20cm depth (^{0}C)	7.9	5.7
Relative humidity (%)	62.4	79.7
Wind speed (mph)	1.2	2.7
Wind direction	North-west	East
Soil moisture -surface	Dry	Dry
Soil moisture –subsoil	Damp	Damp
Weather post application	Cool and dry	Cool and dry
Crop growth stage	25% at bud break	In bud

Assessments

The trials were assessed approximately two-three weeks, four-five weeks, and seven-eight weeks after the application of the treatments (WAT), on 24 March, 9 April and 7 May in Yorkshire, and 10 April, 23 April and 6 May in Nottinghamshire. An additional assessment was carried out at 12 weeks after application on 10 June in Nottinghamshire as weed emergence at this site was slower. Phytotoxicity to the rhubarb was assessed on each plot, using a scale of 0 – 9, whereby 9 showed no effect, 7 was commercially acceptable effects or damage, 1 was a very severe effect and 0 was plant death. Plots were also assessed for percentage weed cover and weed species present were also recorded. At the Nottinghamshire site the numbers of weed seedlings of each species were counted at the first three assessment dates instead of percentage weed cover. Data was analysed by ANOVA.

Contact herbicide trials

Site 3 – Yorkshire

Work was carried out on a two year old commercial plantation of rhubarb grown on ridged beds with the variety Timperley Early. The crop had been topped post-harvest on 30 April (**Figure 5**) and would have been ready for a second harvest on 23 July. The soil is a sandy clay loam with 4.9 % organic matter. The major weed was Himalayan balsam (*Impatiens glandulifera)*. Creeping thistle *(Cirsium arvense),* common nettle *(Urtica dioica),* common wormwood or mugwort *(Artemisia vulgaris),* hedge bindweed *(Calystegia sepium),* field bindweed *(Convolvulus arvensis),* common couch *(Elytrigia repens),* curled dock *(Rumex crispus*), cleavers *(Galium aparine)* and soft brome *(Bromus hordeaceus)* appeared in many plots but not as frequently.

Full details of the soil analyses, weather at spray application and temperature and humidity records through the duration of the trial can be found the Appendices. No herbicides apart from the trial treatments were applied to the project area from March 2015. The Himalayan balsam was at approximately two whorls of true leaves at application.

Figure 5. Contact herbicide trial area in the two year old plantation showing the crop one week after topping. Yorkshire 2015

Site 4 and 5 - Hampshire

The second and third sites were in the same block of rhubarb in the field in Hampshire. Work was carried out on a 12 year old commercial plantation of rhubarb grown in beds on the flat with the variety Timperley Early (**Figure 6**). The crop had been topped post-harvest on 14 May and would have been ready for a second harvest on 27 August. The soil is a clay loam with 4.5 % organic matter and 15 % stones in the top 30cm soil horizon. There was a wider range of problem weeds at this site and the major weeds were (in order of incidence) dandelion *(Taraxacum officinale),* fat-hen *(Chenopodium album),* field bindweed *(Convolvulus arvensis),* Canadian fleabane *(Conyza canadensis),* perennial sowthistle *(Sonchus arvensis),* scentless mayweed *(Tripleurospermum inodorum)*, and common wormwood or mugwort *(Artemisia vulgaris).* Creeping thistle *(Cirsium arvense),* common nettle *(Urtica dioica),* shepherd's-purse *(Capsella bursa-pastoris),* cleavers *(Galium aparine),* black nightshade *(Solanum nigrum),* groundsel *(Senecio vulgaris),* and redshank *(Persicaria maculosa)* appeared in many plots but not as frequently.

Full details of the soil analyses, weather at spray application, and temperature and humidity records through the duration of the trial can be found the Appendices. No other herbicides apart from the trial treatments were applied to the project area after March 2015.

Figure 6. Contact herbicide trial in a well-established plantation three weeks after topping and at the Timing 1 herbicide application. Hampshire, 2015

Sites 3 and 4 – Trial design and treatments

The trials were a fully randomised block design with 18 treatments including a double replicated untreated control (**Tables 8 and 9**). There were no grower practice controls, as currently there are no techniques or herbicides commonly used as standard across all rhubarb growers, due to the difficultly with crop safety and effective application of currently approved contact herbicides. There was four-fold replication, and each plot was 5m long and 1.7m wide at the Yorkshire site, and 5m long and 1.8m wide at the Hampshire site. Apart from herbicide applications, the crop was managed as per commercial practice with other inputs such as fungicides, insecticides, fertilisers and irrigation applied as necessary.

Table 8. Treatments applied to plots in 200 L water per hectare. Yorkshire and Hampshire, 2015.

		Treatment timing	
Treatment no.	**Treatment name**	**Timing 1 Post-harvest (one-two weeks after topping)**	**Timing 2 (three-four weeks after Timing 1)**
Untreated and inter-row glyphosate treatments			
1 + 2	Untreated	-	-
3	Master Gly 36T inter-row	Master Gly 36T inter-row 5.0 L/ha*	-
4	Master Gly 36T inter-row fb Stomp Aqua + Gamit 36 CS	Master Gly 36T inter-row 5.0 L/ha*	Stomp Aqua 3.3 L/ha + Gamit 36 CS 0.25 L/ha
Over the row treatments			
5	Master Gly 36T	Master Gly 36T 5.0 L/ha*	
6	Shark	Shark 0.8 L/ha	
7	H39	H39	
8	Reglone	Reglone 4.0 L/ha	
9	Dow Shield once	Dow Shield 0.5 L/ha	
10	Dow Shield twice	Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha
11	H38	H38	
12	H40	H40	
Over the row Shark followed by residual/contact herbicides			
13	Shark fb Sencorex Flow	Shark 0.8 L/ha	Sencorex Flow 1.45 L/ha
14	Shark fb H33	Shark 0.8 L/ha	H33
15	Shark fb H33 + Defy	Shark 0.8 L/ha	H33 + Defy 5.0 L/ha
16	Shark fb H33 + Sencorex Flow	Shark 0.8 L/ha	H33 + Sencorex Flow 1.45 L/ha
17	Shark fb H36	Shark 0.8 L/ha	H36
18	Shark fb H37	Shark 0.8 L/ha	H37

fb = followed by.

* Note: max individual dose under the EAMU is 4.0 L/ha, as an on-label application to stubbles or before planting or production it is 5.0 L/ha.

Table 9. Approval status of products used in the trials (see table 2 for Stomp Aqua, Gamit 36 CS, Sencorex Flow and Defy). Yorkshire and Hampshire, 2015.

Product	Active ingredient	Approval status	Application timing requirements
Roundup Biactive (generic Master Gly 36T used in trial)	glyphosate 360 g/L	EAMU	Post-harvest but prior to bud break in the following year
Quit (Reglone used in trial, many generics available)	diquat 200 g/L	On label	Pre-planting, before production or emergence, or using inter-row application
Shark	carfentrazone-ethyl 60g/L	On label	Before planting or production, 1 month before planting
Dow Shield 400	clopyralid 400 g/L	Not approved in rhubarb, EAMU for leeks, salad onions, asparagus, spinach and chard	-
H33	confidential	Not approved in UK, seeking residues on celery	-
H36	confidential	Not approved in the UK	-
H37	confidential	Not approved on rhubarb, on-label for forage maize	-
H38	confidential	Not approved on rhubarb, on-label for amenity grassland, forest and moorland (expires end Oct 2015)	-
H39	confidential	Not approved on rhubarb, on-label for inter-row applications to soft-fruit crops	-
H40	confidential	Not approved on rhubarb, on-label for forage and grain maize, EAMU for sweetcorn	-

All are on the EU list of approved active substances

After the crop was harvested and then topped, the site was marked out and the contact herbicides were applied two weeks after topping on 13 May in Yorkshire, and three weeks

after topping on 4 June in Hampshire. The Timing 2 treatments were applied between three to four weeks after the Timing 1 treatments, on 5 June in Yorkshire, and 29 June in Hampshire. The treatments were applied using an OPS sprayer and a 2m boom with 02F110 flat fan nozzles, to achieve a medium spray quality at 200 L/ha. Details of weather conditions at application are included below (**Table 10**).

Table 10. Weather and crop conditions at herbicide application. 2015

	Yorkshire		Hampshire	
Environmental parameter	Timing 1 (13 May)	Timing 2 (5 June)	Timing 1 (4 June)	Timing 2 (29 June)
Time of application (hh:mm)	08:20-09:20	09:30-10:30	08:50-10:30	11:25-12:30
Weather at application	Sunny and cloudy	Sunny	Sunny and cloudy	Sunny and cloudy
Cloud cover (%)	25	5	30	25
Temperature (^{0}C)	11.5	19.9	17.2	23.3
Soil temperature at 10cm depth (^{0}C)	-	-	14.3	-
Soil temperature at 20cm depth (^{0}C)	10.4	15.5	12.8	-
Relative humidity (%)	65.6	64.8	68.3	52.8
Wind speed (mph)	0.9	2.4	4.2	4.3
Direction	West	West	West	South west
Soil moisture -surface	Dry	Dry	Damp	Dry
Soil moisture –subsoil	Damp	Dry	Damp	Damp
Weather post application	Warm and dry	Warm and dry	Warm and dry	Hot and dry
Crop growth stage (leaves per bud)	2-3 leaves	4-5 leaves	2-3 leaves	3-4 leaves

Assessments

The trial in Yorkshire was assessed before application and four weeks after the Timing 1 treatments were sprayed, and two, four and seven weeks after the Timing 2 treatments, on 8 May, 5 June, 22 June, 3 July and 23 July. The trial in Hampshire was assessed at application and one, two and four weeks after the Timing 1 treatments were sprayed, and two, four, six, eight, eleven and fifteen weeks after the Timing 2 treatments, on 3 June, 9 June, 17 June, 29 June, 13 July, 27 July, 11 August, 26 August, 15 September and 12 October.

Phytotoxicity to the rhubarb was assessed on each plot, using a scale of 0 – 9, whereby 9 showed no effect, 7 was commercially acceptable effects or damage, 1 was a very severe effect and 0 was plant death. Plots were also assessed for percentage weed cover, phytotoxic effects on weeds, and weed species present were also recorded. Data was analysed by ANOVA.

Site 5 – Trial design and treatments

The trial was a fully randomised block design with five treatments including an untreated control (**Table 11**). There was no grower practice control, as currently there are no techniques or herbicides commonly used as standard across all rhubarb growers, due to the difficulty of crop safe and effective application of currently approved contact herbicides. There was three-fold replication, and each plot was and 10m long and 1.8m wide. Apart from herbicide applications, the crop was managed as per commercial practice with other inputs such as fungicides, insecticides, fertilisers and irrigation applied as necessary.

Table 11. Treatments applied to plots in 200 L water per hectare (see tables 2 and 4 for approval status of products used). Hampshire, 2015.

Treatment no.	Treatment	Active	Rate
1 (Untreated control)	-	-	-
2	Shark	carfentrazone-ethyl 60g/L	0.3 L/ha
3	Shark	carfentrazone-ethyl 60g/L	0.8 L/ha
4	Shark +	carfentrazone-ethyl 60g/L +	0.3 L/ha
	Dow Shield 400	clopyralid 400 g/L	0.5 L/ha
5	Shark +	carfentrazone-ethyl 60g/L +	0.3 L/ha
	Dow Shield 400 +	clopyralid 400 g/L +	0.5 L/ha
	Sencorex Flow	metribuzin 600 g/L	1.45 L/ha

After the crop was harvested and then topped, the site was marked out and the contact herbicides were applied two weeks after topping on 13 May in Yorkshire, and three weeks after topping on 4 June in Hampshire. The Timing 2 treatments were applied between three to four weeks after the Timing 1 treatments, on 5 June in Yorkshire, and 29 June in Hampshire. The treatments were applied using an OPS sprayer and a 2m boom with 02F110 nozzles, to achieve a medium spray quality at 200 L/ha.

Assessments

The trial was assessed at application and two, four, six, eight, 11 and 15 weeks after treatments were sprayed, on 29 June, 13 July, 27 July, 11 August, 26 August, 15 September and 12 October.

Phytotoxicity to the rhubarb was assessed on each plot, using a scale of 0 – 9, whereby 9 showed no effect, 7 was commercially acceptable effects or damage, 1 was a very severe effect and 0 was plant death. Plots were also assessed for percentage weed cover, phytotoxic effects on weeds, and weed species present were also recorded. Data was analysed by ANOVA.

Results

Residual herbicide trials

Site 1 – Yorkshire

Five treatments significantly reduced the level of Himalayan balsam compared to the untreated control, and gave greater or equivalent control of this weed than the current standards Stomp Aqua and Gamit 36CS or Stomp Aqua and Goltix Flow at eight weeks after application (7 May). These treatments were Sencorex WG (metribuzin), coded products H33 and H34 in a tank-mix, Callisto (mesotrione), H34 and H32. At the final assessment Himalayan balsam had reached a mean of 85% plot cover in the untreated (**Figure 7 and Table 12**).

Sencorex WG was the best treatment, reducing Himalayan balsam to 20% mean cover with the remaining weed often appearing yellowed and necrotic at eight weeks post application. H34 with H33 as a tank mix, was the next best performing treatment, reducing the cover of Himalayan balsam to 35%. While Callisto and H34 alone reduced the Himalayan balsam population significantly to 40% plot cover, with H32 reducing plot cover to 55%.

The coded product H33 applied at a higher rate, or in a tank mix with Gamit 36CS (clomazone) reduced Himalayan balsam to 15 to 16% plot cover for up to four weeks. Plot cover in the untreated plots at this point (9 April) was 48%. The performance of H33 at a high rate, or in the tank mix with Gamit was comparative to the 11% plot cover in the Sencorex WG treatments at this point, but the treatments lacked longevity and control started to break down at eight weeks after application. At the final assessment H33 at the higher rate, or in a tank mix with Gamit 36CS, was just equivalent to the best tank mix of currently approved products Stomp Aqua and Gamit 36CS, which all only reduced the Himalayan balsam population by 23%, to 60% plot cover at the final assessment.

There were differences in levels of Himalayan balsam seen between the ridge and furrow in the trial, with greater weed cover in the furrow. The areas were scored separately for the first two assessments.

Visual phytotoxic effects on the Himalayan balsam were scored at four weeks after application, and the treatments Sencorex WG, H34, and H33 in a tank mix with H34 all gave symptoms of stunting, yellowing, shrivelling and necrosis to the weed. Callisto yellowed and stunted the Himalayan balsam, while those treatments containing product H33 gave varying degrees of yellowing to the weed. Flexidor 500 gave a small yellow fringe to the leaves. All treatments were safe to the rhubarb at this site, and no symptoms of phytotoxicity to the rhubarb were seen in the trial.

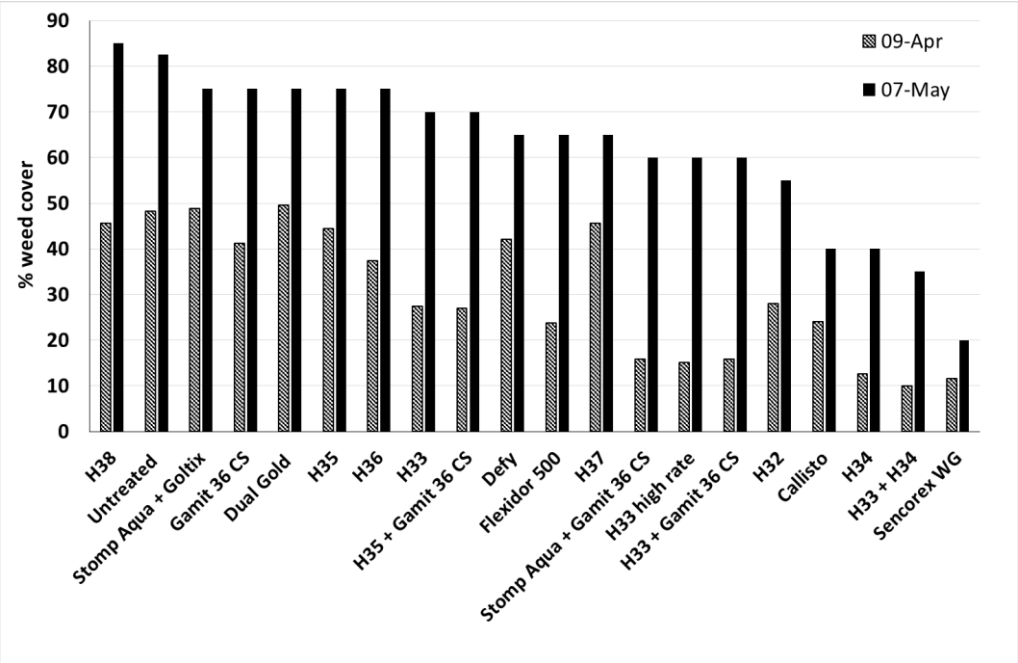


Figure 7. Mean percentage of weed cover at four and eight weeks after treatments were applied. Yorkshire, 2015

Table 12. Differences in percentage weed cover in the furrow, on the ridge and as an overall mean of the plot area, and visual phytotoxic effects on the Himalayan balsam at two, four and eight weeks after treatment (WAT). Yorkshire, 2015.

	Weed cover on assessment dates indicated (%)							Effect on Himalayan balsam (0-9*)	
	24 March 2 WAT			9 April 4 WAT			7 May 8 WAT	24 Mar 2WAT	9 April 4WAT
Treatment	Furrow	Ridge	Mean	Furrow	Ridge	Mean	Mean		
Untreated	34.1	9.4	21.8	73.8	22.8	48.2	82.5	8.8	8.7
Stomp Aqua + Gamit 36 CS	31.8	7.5	19.6	53.8	16.8	35.2	60.0	7.5	7.3
Stomp Aqua + Goltix Flow	38.8	10.5	24.6	76.2	21.2	48.8	75.0	9.0	8.3
Gamit 36 CS	28.5	8.3	18.4	70.0	12.5	41.2	75.0	8.3	7.3
Callisto	32.5	8.3	20.4	**42.5**	**5.8**	**24.1**	**40.0**	8.3	**4.5**
Defy	26.8	9.3	18.0	65.0	19.2	42.1	65.0	7.5	7.7
Flexidor 500	19.2	6.7	13.0	**34.0**	13.5	**23.8**	65.0	**5.3**	**6.7**
Sencorex WG	28.8	9.0	18.9	**17.0**	**6.3**	**11.6**	**20.0**	7.7	2.7
H32	25.0	10.3	17.6	45.0	11.0	**28.0**	**55.0**	9.0	8.3
Dual Gold	36.2	8.3	22.2	71.2	28.0	49.6	75.0	**6.5**	8.3
H33	33.8	7.0	20.4	**43.8**	11.0	**27.4**	70.0	8.0	**6.7**
H33 higher rate	18.8	7.3	13.0	**23.8**	**6.5**	**15.1**	60.0	8.3	**4.3**
H34	28.8	10.7	19.8	**18.8**	**6.5**	**12.6**	**40.0**	8.5	**4.0**
H35	35.0	11.3	23.1	73.8	15.0	44.4	75.0	7.5	9.0
H33 + H34	40.0	9.0	24.5	**15.8**	**4.3**	**10.0**	**35.0**	8.3	**4.0**
H33 + Gamit 36 CS	15.0	**4.7**	9.9	**25.0**	**6.8**	**15.9**	60.0	**5.7**	**5.3**
H35 + Gamit 36 CS	24.0	6.7	15.4	**43.8**	**10.3**	**27.0**	70.0	7.5	7.0
H36	37.5	8.3	22.9	61.2	13.5	37.4	75.0	7.3	7.7
H37	30.0	9.3	19.6	71.2	20.0	45.6	65.0	8.3	8.0
H38	21.2	9.5	15.4	**36.2**	11.0	**23.6**	85.0	7.0	8.3
F probability	NS	<0.001	NS	<0.001	0.026	<0.001	<0.001	<0.001	<0.001
LSD (83 d.f.)	-	3.689	-	29.95	12.07	19.17	24.92	2.032	1.897

Note: Figures in **bold** are significantly different from the untreated.

*9 is no effect on the Himalayan balsam, scores of 7-8 indicate a slight effect, 5-6 is a moderate effect, 3-4 is a moderately severe effect, 1-2 is a severe effect and 0 is dead.

Site 1 – Nottinghamshire

Phytotoxicity effects on the rhubarb crop were seen in plots treated with Sencorex WG, Callisto and H33 at this site. There was an increased likelihood of this occurring due to the sensitive situation of a new crop on a light sandy loam soil. Sencorex WG applied at 1.25 kg/ha caused chlorosis to occur along the veins of the leaves at seven and 12 weeks after the treatments were applied. (**Figure 8 and Table 13**) The crop was irrigated on 23 April and the first symptoms were seen at the assessment two weeks later (6 May). However, the stronger sets had recovered 12 weeks after application and by this point new leaves were no longer showing any chlorotic effects, but it should be noted that weaker plants had been lost. This indicates care needs to be taken with using Sencorex WG on light soils as it is long-acting and can be re-activated by moisture. Callisto and H33 also showed a less severe phytotoxicity effect with an occasional early leaf showing scorch at seven weeks after treatment, but the sets recovered quickly and grew through well by 12 weeks after treatment.

Figure 8. Effects of the application of Callisto and Sencorex on the rhubarb at seven and 12 weeks after treatment (WAT) L-R a) Callisto – seven WAT, b) Sencorex WG – seven WAT, c) Sencorex WG – 12 WAT. Nottinghamshire, 2015

Table 13. Phytotoxicity scores on the rhubarb at three, five, seven and 12 weeks after treatment (WAT) application. Nottinghamshire, 2015

	Phytotoxicity scores on assessment dates indicated (0-9*)			
Treatment	10 April	23 April	6 May	10 June
	3 WAT	5 WAT	7 WAT	12 WAT
Untreated	8.7	8.8	8.3	8.8
Stomp Aqua + Gamit 36 CS	7.3	9.0	7.7	8.5
Stomp Aqua + Goltix Flow	8.7	7.5	8.3	8.7
Gamit 36 CS	8.3	7.7	8.0	8.0
Callisto	7.7	8.3	7.0	7.0
Defy	7.5	7.0	7.5	8.7
Flexidor 500	8.7	7.7	**6.7**	8.5
Sencorex WG	8.0	7.7	**5.7**	**5.0**
H32	7.7	8.3	7.5	8.3
Dual Gold	7.7	7.0	7.3	8.3
H33	8.7	7.5	**6.7**	8.0
H33 higher rate	8.3	**6.5**	8.0	8.3
H34	8.5	7.5	**6.5**	7.7
H35	8.0	8.0	7.3	8.5
H33 + H34	7.3	7.0	**6.5**	7.3
H33 + Gamit 36 CS	7.7	7.0	8.0	8.0
H35 + Gamit 36 CS	8.3	7.5	7.7	7.5
H36	8.3	8.3	8.0	8.3
H37	8.0	7.5	8.0	8.0
H38	8.7	7.3	8.0	7.7
F probability	NS	NS	<0.001	<0.001
LSD (83 d.f.)	-	-	0.8746	0.9130

Note: Figures in **bold** are below a score of 7, see below for explanation of scores.

*9 is no effect on the rhubarb, scores of 7-8 indicate a slight effect but it is commercially acceptable, 5-6 is a moderate effect, 3-4 is a moderately severe effect, 1-2 is a severe effect and 0 is dead.

All treatments except H38 significantly reduced the percentage of weed cover by at least 50% when compared to the untreated control, and seven treatments gave greater control of overall weed cover than the current standards Stomp Aqua and Gamit 36CS or Stomp Aqua and Goltix Flow at 12 weeks after application (10 June). These treatments were Sencorex WG, coded products H33 and H34 in a tank-mix, coded product H35 in a tank-mix with Gamit 36 CS, product H33 at a higher rate, and products H34, H35 and H36. (**Figure 9 and 10**, and **Table 14**).

The untreated plots had a mean of 25% weed cover (145 weeds per m^2) at seven weeks after treatment application, increasing to 75% weed cover at 12 weeks. Sencorex WG was the best product reducing weed cover to 1% at the final assessment. Product H34 and H35 also showed good weed control, reducing weed cover to 3 and 4% respectively. H35 gives good control of susceptible species applied pre-emergence, but it must be noted that it has no post-emergence activity. H33 at the higher rate, the H33 and Gamit 36 CS mix, and H36 reduced weed cover to 7% and gave control equivalent to current standards of either Stomp Aqua and Goltix, or Stomp Aqua and Gamit.

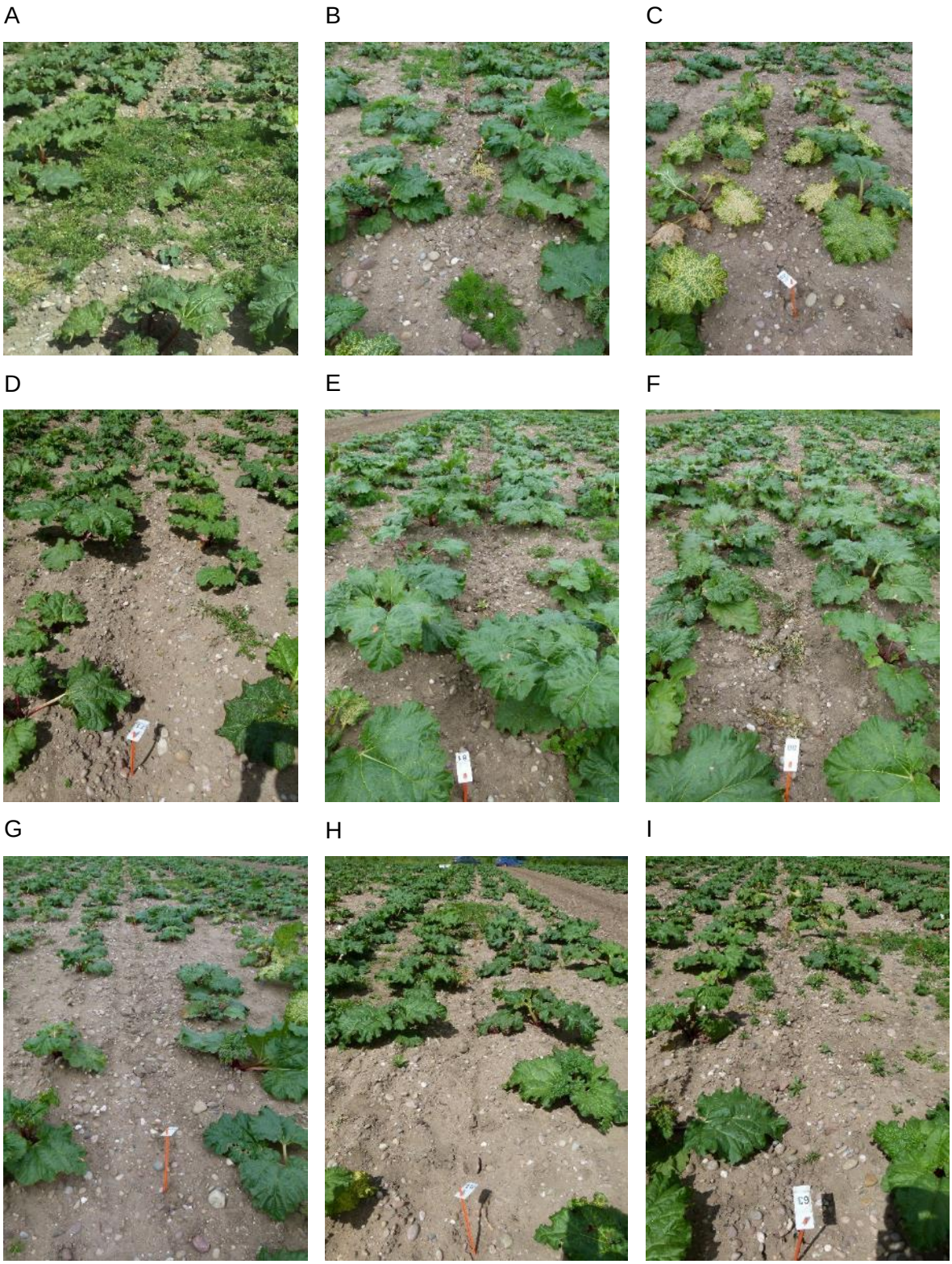


Figure 9. Levels of weeds at 12 weeks after treatment in A) Untreated; B) Stomp Aqua + Gamit 36 CS (standard); C) Sencorex WG; D) H33 + H34; E) H34; F) H35; G) H35 + Gamit 36 CS; H) H33 high rate; I) Dual Gold. Nottinghamshire, 2015.

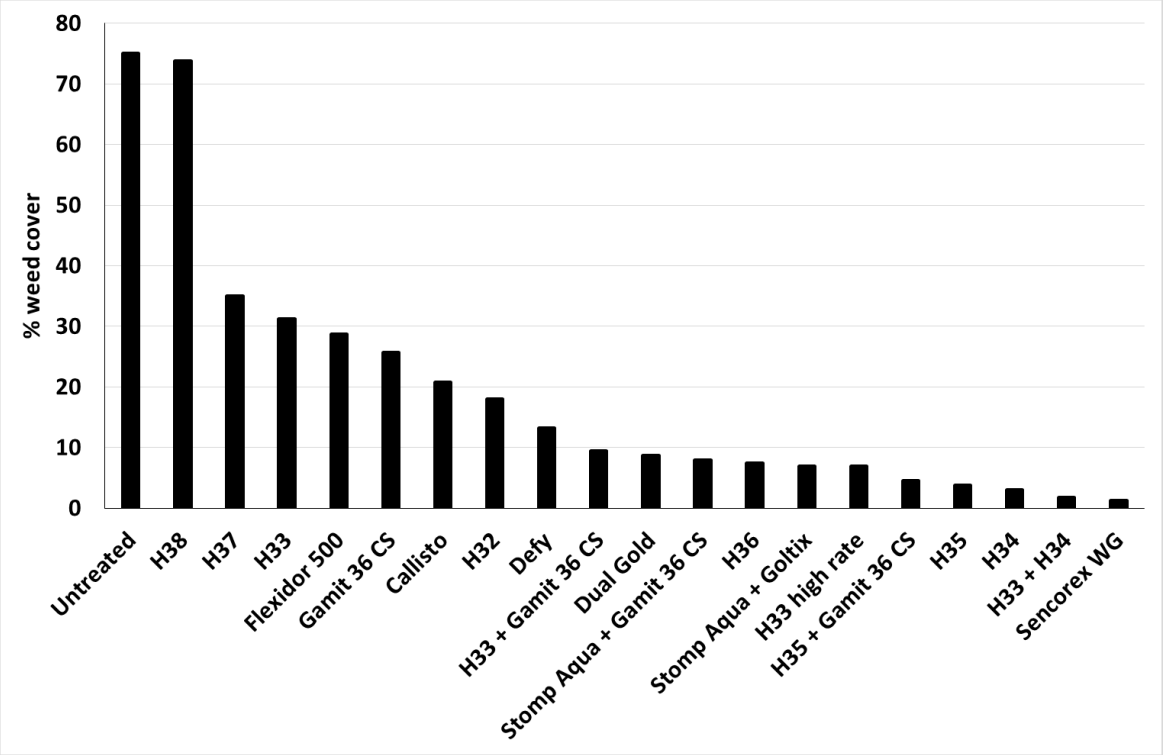


Figure 10. Mean percentage of weed cover at 12 weeks after treatments were applied. Nottinghamshire, 2015

Table 14. Mean weeds per m^2 at three, five and seven weeks after treatment (WAT) and mean percentage of weed cover 12 WAT application. Nottinghamshire, 2015

	Weeds per m^2 on assessment dates indicated			Weed cover (%)
Treatment	10 April	23 April	6 May	10 June
	3 WAT	5 WAT	7 WAT	12 WAT
Untreated	53.7	95.6	143.6	75.0
Stomp Aqua + Gamit 36 CS	**4.9**	**7.3**	**10.6**	**8.0**
Stomp Aqua + Goltix Flow	**4.9**	**4.1**	**11.4**	**7.0**
Gamit 36 CS	**12.2**	**10.6**	**33.4**	**25.7**
Callisto	**9.8**	**17.1**	**45.6**	**20.7**
Defy	**2.4**	**0.8**	**4.9**	**13.2**
Flexidor 500	**24.4**	**39.9**	**61.8**	**28.7**
Sencorex WG	**6.1**	**0.8**	**0.8**	**1.2**
H32	**9.8**	**7.3**	**16.3**	**18.0**
Dual Gold	**4.9**	**5.7**	**9.8**	**8.7**
H33	**14.6**	**30.9**	**62.7**	**31.2**
H33 higher rate	**13.4**	**4.1**	**2.4**	**7.0**
H34	**1.2**	**5.7**	**2.4**	**3.0**

	Weeds per m^2 on assessment dates indicated			Weed cover (%)
Treatment	10 April	23 April	6 May	10 June
	3 WAT	5 WAT	7 WAT	12 WAT
H35	**1.2**	**2.4**	**4.1**	**3.7**
H33 + H34	**28.1**	**0.8**	**4.1**	**1.7**
H33 + Gamit 36 CS	**3.7**	**5.7**	**4.9**	**9.5**
H35 + Gamit 36 CS	**2.4**	**0.0**	**15.5**	**4.5**
H36	**1.2**	**4.9**	**13.8**	**7.5**
H37	17.1	**17.9**	**33.4**	**35.0**
H38	33.0	**45.6**	**100.1**	73.8
F probability	<0.001	<0.001	<0.001	<0.001
LSD (83 d.f.)	23.25	24.63	37.05	12.96

Note: Figures in **bold** are significantly different from the untreated.

Callisto is worth highlighting as a useful product as it has a wide range of broad leaf weed control, except nettle and annual meadow grass. Although it did not rank as one of the top treatments due to the weed spectrum at this site, it could be partnered with Stomp Aqua or Goltix to give wider control. H32 also gave good control of all weeds except small nettle.

The major weeds occurring at this site were annual meadow grass, small nettle, scentless mayweed, groundsel and fat-hen, and differences between treatments and control of each species were recorded at seven weeks after spray application (**Table 15**). All products except Flexidor 800 gave significant control of annual meadow grass, but Gamit 36 CS, Callisto, H33 at the standard rate, and H38 did not give complete control. These products only reduced the population by 40-70%, compared to the best treatments which reduced the annual meadow grass population by at least 87%. Small nettle did not appear to be controlled by Callisto, H32 and H33 at the standard rate, but these were not significant differences due to the variability of weed in the experimental area. All products except Gamit 36 CS and H38 gave significant control of scentless mayweed.

Table 15. Mean weeds per m^2 overall, and for each of the major weed species at seven weeks after treatment application. Nottinghamshire, 2015

	Weeds per m^2					
Treatment	All species	Annual meadow grass	Small nettle	Scentless mayweed	Groundsel	Fat hen
Untreated	143.6	71.6	28.9	11.39	10.17	10.17
Stomp Aqua + Gamit 36 CS	**10.6**	**3.3**	0.0	**3.25**	0.0	**0.0**
Stomp Aqua + Goltix Flow	**11.4**	**5.7**	2.4	**0.0**	1.6	**0.0**
Gamit 36 CS	**33.4**	**22.8**	1.6	5.7	0.0	**1.6**
Callisto	**45.6**	**26.9**	18.7	**0.0**	0.0	**0.0**
Defy	**4.9**	**0.0**	0.8	**0.8**	0.0	**1.6**
Flexidor 500	**61.8**	58.6	0.0	**0.0**	0.0	**0.8**
Sencorex WG	**0.8**	**0.0**	0.0	**0.0**	0.0	**0.0**
H32	**16.3**	**0.0**	9.8	**0.8**	0.8	**0.8**
Dual Gold	**9.8**	**0.8**	0.0	**0.8**	0.8	**2.4**
H33	**62.7**	**25.2**	28.5	**0.8**	1.6	**1.6**
H33 higher rate	**2.4**	**2.4**	0.0	**0.0**	0.0	**0.0**
H34	**2.4**	**0.8**	0.0	**0.0**	0.0	**0.0**
H35	**4.1**	**0.0**	0.0	**0.0**	0.8	**0.0**
H33 + H34	**4.1**	**0.8**	2.4	**0.0**	0.0	**0.0**
H33 + Gamit 36 CS	**4.9**	**1.6**	0.0	**0.8**	0.0	**0.0**
H35 + Gamit 36 CS	**15.5**	**2.4**	10.6	**0.0**	0.0	**0.0**
H36	**13.8**	**9.0**	0.0	**0.8**	0.8	**0.8**
H37	**33.4**	**9.0**	6.5	**4.8**	2.4	**0.8**
H38	**100.1**	**43.1**	0.8	23.6	6.5	12.2
F probability	<0.001	<0.001	NS	<0.001	NS	<0.001
LSD (83 d.f.)	37.05	22.19	-	6.287	-	5.208

Note: Figures in **bold** are significantly different from the untreated.

Contact herbicide trials

Site 3 – Yorkshire

Persistent phytotoxic effects were still seen at 11 weeks after treatment (23 July) in plots treated with Dow Shield 400 (clopyralid) or Roundup (glyphosate) applied over the row, and also in plots where Roundup was applied between the rows. Dow Shield 400 caused cupping of leaves and distortion and twisting of new growth exhibited as small deformed or thickened new leaves, while Roundup caused plant death when applied over the row, and stunting and retardation of growth when applied between the rows (**Figure 11 and Table 16**). Initially severe phytotoxic symptoms were not seen on plots treated with Dow Shield 400, but the distortion of new growth developed later at eight weeks after application, and was still persisting at the final assessment. Product H40 caused a yellowing of the leaves of the rhubarb at four weeks after treatment, but the crop later recovered to a commercially acceptable standard by 11 weeks after treatment. However, although quality attributes of the crop were not assessed by ADAS as part of the trial, the grower reported that he observed that stick length of the rhubarb appeared to be 50mm shorter than in the untreated plots. This height reduction is believed to have allowed the field bindweed to grow over the rhubarb in one plot rather than under the crop.

The Timing 2 treatments of Sencorex Flow, H33, H36 and H33 tank mixed with Sencorex Flow or Defy caused yellowing of the rhubarb leaves, and also checked the growth of the crop by an additional two-three weeks when compared to applying one contact herbicide application alone. However, the crop had recovered from the symptoms by seven weeks after the application of the Timing 2 treatments.

Twelve treatments significantly reduced weed cover by at least 50% for up to 11 weeks after the first sprays were applied when compared to the levels in the untreated (89%) (**Figure 12 and Table 17**). Of these, nine treatments were safe to the rhubarb with no commercially unacceptable phytotoxic symptoms seen at the final assessment. These nine treatments were Shark (carfentrazone-ethyl), and products H39 and H40 applied as single sprays, and Shark followed by a second follow up spray of either Sencorex Flow, H33, H36, H37, H33 in a tank mix with Sencorex Flow, or H33 in a tank mix with Defy (prosulfocarb). Of these, six treatments reduced the weed cover to 15% or below.

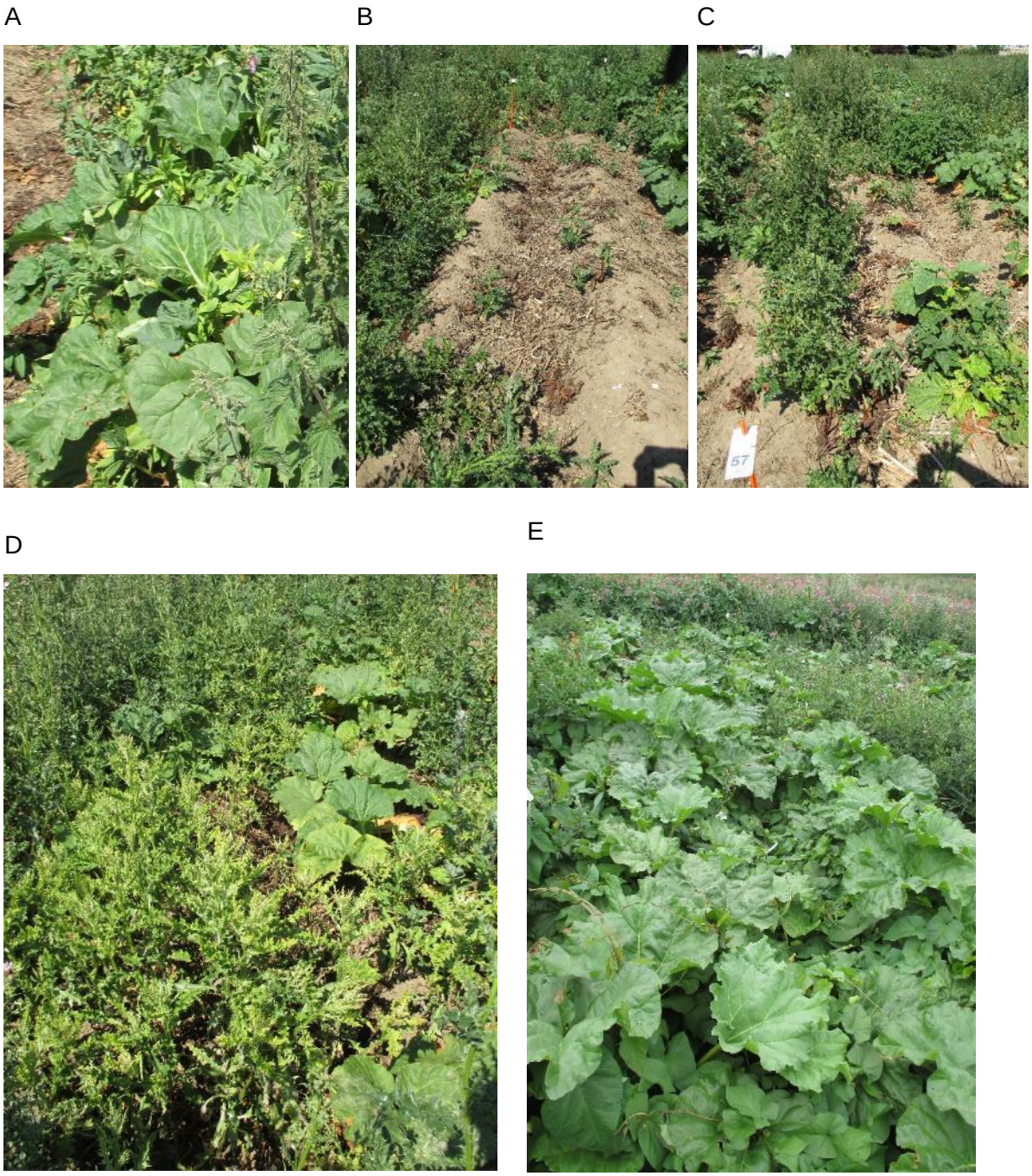


Figure 11. Effect of contact herbicides on rhubarb. A) Dow Shield at seven weeks after treatment (WAT) showing cupping of leaves; B) Roundup applied over the row at seven WAT; C) Roundup applied between the rows at seven WAT; D) H40 applied over the row at seven WAT showing yellowing; E) H40 applied over the row at 11 WAT. Yorkshire, 2015.

Table 16. Phytotoxicity scores on the rhubarb at four, six, eight and 11 weeks after treatment (WAT) Timing 1 applications. Yorkshire, 2015

		Phytotoxicity scores on assessment dates indicated (0-9*)			
Treatment Timing 1 (13 May)	Treatment Timing 2 (5 June)	5 June 4 WAT	22 June 6 WAT	3 July 8 WAT	23 July 11 WAT
Untreated	Untreated	9.0	8.6	9.0	8.8
Roundup inter-row	-	**5.7**	**4.5**	**5.0**	**6.5**
Roundup inter-row	Gamit 36 CS + Stomp Aqua	**3.5**	**4.0**	**3.7**	**4.5**
Roundup over row	-	**2.3**	**2.0**	**2.7**	**3.5**
Shark	-	7.5	7.7	8.5	8.7
H39	-	**5.7**	7.5	8.5	9.0
Reglone	-	**6.7**	7.7	8.7	9.0
Dow Shield 0.5 L/ha	-	7.0	7.7	7.5	**6.3**
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	8.5	8.5	7.3	**5.7**
H38	-	8.7	8.7	8.7	9.0
H40	-	**6.3**	**6.7**	7.5	8.3
Shark	Sencorex Flow	7.0	**6.3**	**6.5**	8.7
Shark	H33	7.7	**6.0**	**6.3**	8.0
Shark	H33 + Defy	8.0	**6.3**	7.0	8.5
Shark	H33 + Sencorex Flow	7.7	**6.0**	**6.5**	8.5
Shark	H36	7.5	**6.7**	**6.7**	8.5
Shark	H37	7.3	7.7	8.7	8.7
F probability		<0.001	<0.001	<0.001	<0.001
LSD (70 d.f.)		1.085	1.498	1.210	1.532

Note: Figures in **bold** are below a score of 7, see below for explanation of scores.

*9 is no effect on the rhubarb, scores of 7-8 indicate a slight effect but it is commercially acceptable, 5-6 is a moderate effect, 3-4 is a moderately severe effect, 1-2 is a severe effect and 0 is dead.

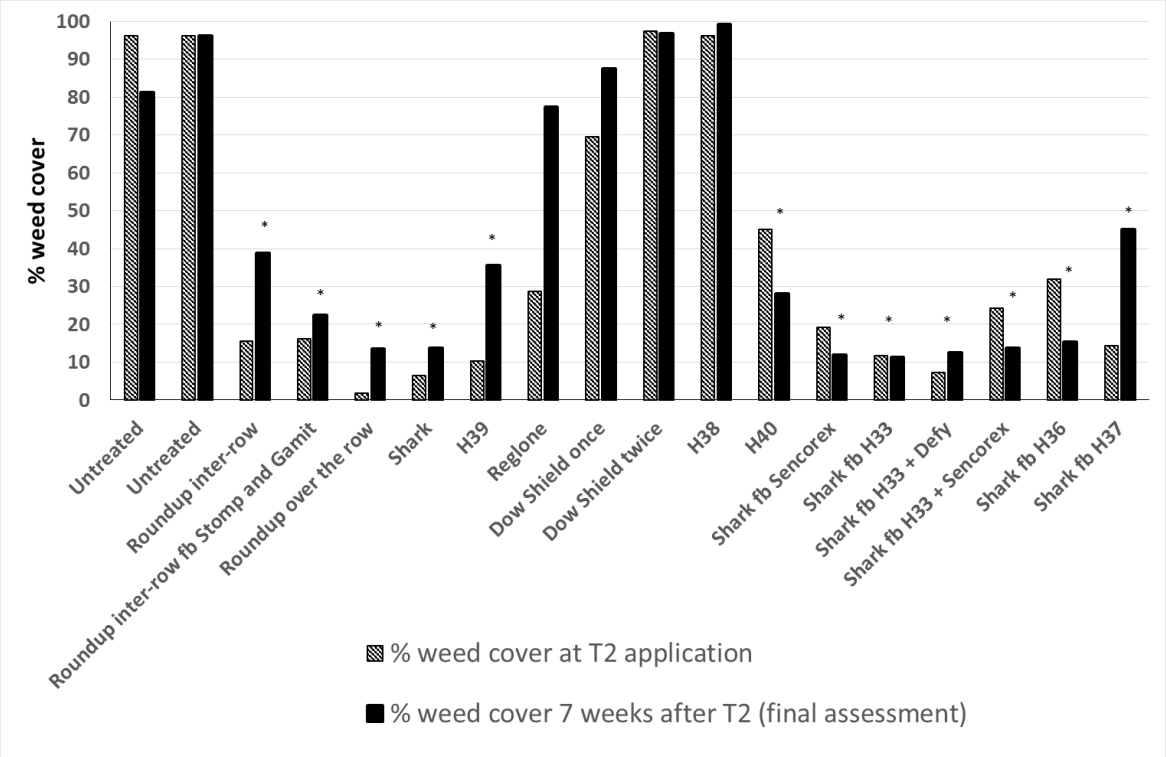


Figure 12. Mean percentage of weed cover at four and 11 weeks after the first treatments were applied. Yorkshire, 2015

Table 17. Mean percentage of weed cover at four, six, eight and 11 weeks after treatment (WAT) application. Yorkshire, 2015

		Weed cover at dates indicated (%)			
Treatment Timing 1 (13 May)	Treatment Timing 2 (5 June)	5 June 4 WAT	22 June 6 WAT	3 July 8 WAT	23 July 11 WAT
Untreated	Untreated	96.2	95.6	99.4	88.8
Roundup inter-row	-	**15.5**	**17.5**	**21.3**	**38.8**
Roundup inter-row	Gamit 36 CS + Stomp Aqua	**16.2**	**15.0**	**17.5**	**22.8**
Roundup over row	-	**1.8**	**3.2**	**4.3**	**13.5**
Shark	-	**6.5**	**8.2**	**13.3**	**13.8**
H39	-	**10.2**	**14.5**	**40.8**	**35.5**
Reglone	-	**28.7**	**40.0**	**80.0**	77.5
Dow Shield 0.5 L/ha	-	**69.5**	**74.5**	83.8	87.5
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	97.5	100.0	100.0	96.8
H38	-	96.2	98.8	100.0	99.2

H40	-	**45.0**	**47.5**	**56.3**	**28.0**
Shark	Sencorex Flow	**19.2**	**15.0**	**14.8**	**12.0**
Shark	H33	**11.7**	**9.0**	**16.3**	**11.2**
Shark	H33 + Defy	**7.2**	**6.7**	**23.0**	**12.5**
Shark	H33 + Sencorex Flow	**24.2**	**15.5**	**17.5**	**13.8**
Shark	H36	**32.0**	**20.2**	**34.8**	**15.2**
Shark	H37	**14.7**	**16.2**	**35.2**	**44.0**
F probability	All treatments	<0.001	<0.001	<0.001	<0.001
LSD (70 d.f.)		15.88	14.52	17.23	14.73
F probability	Shark alone vs	0.042	NS	NS	<0.001
LSD (26 d.f.)	Shark and follow up treatments	16.44	-	-	11.42

Note: Figures in **bold** are significantly different from the untreated.

Compared to applying just Shark alone, the addition of the Timing 2 applications of residual herbicides with some contact activity did not give a further significant reduction in general weed levels, but did improve control of Himalayan balsam. Plots followed up with Sencorex Flow, H33, H36, H33 in a tank mix with Sencorex Flow, and H33 in a tank mix with Defy gave significantly more suppression of Himalayan balsam, with nearly full control of the weed in these plots. (**Table 18**).

Table 18. Phytotoxicity scores to show effect of the treatments on the Himalayan balsam at four, six, eight and 11 weeks after treatment (WAT) Timing 1 applications. Yorkshire, 2015

		Effect on Himalayan balsam on assessment dates indicated (0-9*)			
Treatment Timing 1 (13 May)	Treatment Timing 2 (5 June)	5 June 4 WAT	22 June 6 WAT	3 July 8 WAT	23 July 11 WAT
Untreated	Untreated	9.0	8.8	9.0	8.7
Roundup inter-row	-	**1.7**	4.3	4.5	5.3
Roundup inter-row	Gamit 36 CS + Stomp Aqua	**0.5**	**1.5**	2.7	4.0
Roundup over row	-	**0.3**	**0.7**	**0.7**	2.3
Shark	-	**1.5**	2.0	**1.5**	2.5
H39	-	2.5	3.5	4.0	5.0
Reglone	-	4.5	5.3	6.5	7.7
Dow Shield 0.5 L/ha	-	7.3	7.7	8.3	8.0
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	8.3	7.7	8.0	8.5
H38	-	8.7	9.0	9.0	9.0
H40	-	3.0	**1.5**	2.3	3.0
Shark	Sencorex Flow	**1.5**	**0.3**	**0.0**	**0.0**
Shark	H33	**1.3**	**0.5**	**0.3**	**0.3**
Shark	H33 + Defy	**1.7**	**0.3**	**0.0**	**0.7**
Shark	H33 + Sencorex Flow	2.0	**0.7**	**0.0**	**0.0**
Shark	H36	2.3	**1.5**	2.0	**1.5**
Shark	H37	2.4	2.3	3.4	2.6
F probability	All treatments	<0.001	<0.001	<0.001	<0.001
LSD (70 d.f.)		1.104	1.681	1.690	2.275
F probability	Shark alone vs	NS	NS	<0.001	0.02
LSD (26 d.f.)	Shark and follow up treatments	-	-	1.424	1.850

Note: Figures in **bold** are below a score of 2 which indicates a very severe effect

*9 is no effect on the Himalayan balsam, scores of 7-8 indicate a slight effect, 5-6 is a moderate effect, 3-4 is a moderately severe effect, 1-2 is a severe effect and 0 is dead.

Dow Shield 400 was the only treatment to control perennial thistle well with a good kill, but at the rates used it was damaging to the rhubarb when applied over the crop. H40 as a single application, and Shark with a Sencorex Flow follow up gave good suppression of perennial thistle but did not kill it all. No treatments gave full control of perennial nettle, but Roundup and H39 gave strong suppression. However, Roundup was too damaging whether applied

over the crop or between the rows with a shielded lance. H39 set back the growth stage of the rhubarb, but it had recovered to a commercially acceptable standard by eight weeks after treatment.

Site 4 – Hampshire

This trial was assessed for a further seven weeks compared with the Yorkshire trial, and the damaging phytotoxic effects of Dow Shield 400 and Roundup applied over the row were still persisting at a moderate to severe level at 18 weeks after treatment (12 October). Again, Dow Shield caused cupping of leaves, and distortion and twisting of new growth exhibited as small deformed or thickened new leaves, while Roundup caused plant death when applied over the row, and stunting and retardation of growth when applied between the rows (**Figure 13 and Table 19**). The severe distortion of new growth caused by Dow Shield 400 appeared at two weeks after the herbicide was applied at this site, which was earlier than the initial symptoms were seen in Yorkshire. Product H40 caused a yellowing of the leaves of the rhubarb at one week after treatment, but the crop later recovered to a commercially acceptable standard (score >7) by six weeks after treatment.

A

B

C

D

E

Figure 13. Effect of contact herbicides on rhubarb. A) Dow Shield 400 at 15 weeks after treatment (WAT) showing deformed new growth; B) Roundup applied over the row at seven WAT; C) Roundup applied between the rows at seven WAT; D) H40 applied over the row at two WAT showing yellowing of rhubarb and thistle; E) H40 applied over the row at seven WAT. Hampshire, 2015.

Table 19. Phytotoxicity scores on the rhubarb at three, seven, 11 and 15 weeks after treatment (WAT) Timing 1 applications. Hampshire, 2015

		Phytotoxicity scores on assessment dates indicated (0-9*)			
Treatment Timing 1 (4 June)	Treatment Timing 2 (29 June)	29 June 3 WAT	27 July 7 WAT	26 Aug 11 WAT	15 Sept 15 WAT
Untreated	Untreated	7.2	8.7	9.0	9.0
Roundup inter-row	-	**4.5**	**5.7**	8.3	8.7
Roundup inter-row	Gamit 36 CS + Stomp Aqua	**4.3**	**5.3**	7.5	7.7
Roundup over row	-	**1.5**	**1.7**	**2.3**	**2.5**
Shark	-	7.0	8.3	9.0	9.0
H39	-	**5.3**	**6.5**	7.7	8.0
Reglone	-	**6.7**	7.3	8.5	9.0
Dow Shield 0.5 L/ha	-	**6.0**	**5.5**	**5.5**	**5.7**
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	**6.3**	**5.7**	**5.3**	**5.5**
H38	-	**6.3**	7.3	8.5	8.7
H40	-	**6.5**	8.3	8.5	8.7
Shark	Sencorex Flow	**6.7**	**5.5**	7.5	8.3
Shark	H33	7.0	**6.0**	7.5	8.3
Shark	H33 + Defy	7.3	**5.3**	7.7	8.3
Shark	H33 + Sencorex Flow	**6.7**	**5.5**	7.3	8.5
Shark	H36	**6.7**	**5.7**	7.5	8.7
Shark	H37	**6.5**	8.0	9.0	9.0
F probability		<0.001	<0.001	<0.001	<0.001
LSD (70 d.f.)		1.152	1.028	1.123	1.031

Note: Figures in **bold** are below a score of 7, see below for explanation of scores.

*9 is no effect on the rhubarb, scores of 7-8 indicate a slight effect but it is commercially acceptable, 5-6 is a moderate effect, 3-4 is a moderately severe effect, 1-2 is a severe effect and 0 is dead.

At the final assessment on 12 October the mean weed cover in the untreated plots was 29%. This was 18 weeks after the first contact treatments were applied and 15 weeks after the second follow up treatments were applied. Weed incidence levels and species were variable across the trial but the use of replication and blocks took account of this variability.

Eight treatments significantly reduced weed cover by at least 40% for up to 18 weeks after the first sprays were applied, and up to 15 weeks after the second sprays were applied, when

compared to the levels in the untreated (29%) (**Figure 14 and Table 20**). Of these, seven treatments were safe to the rhubarb with no commercially unacceptable phytotoxic symptoms seen at the point of harvest, 12 weeks after treatment. These seven treatments were; Shark (carfentrazone-ethyl), and product H40 applied as single sprays, Roundup applied inter-row followed by a second follow up spray of Stomp Aqua in a tank mix with Gamit 36 CS, and Shark followed by a second follow up spray of either Sencorex Flow, H36, H33 in a tank mix with Sencorex Flow, or H33 in a tank mix with Defy (prosulfocarb). These treatments reduced the weed cover to 17% or below at 18 weeks after the first applications.

Roundup gives good weed reduction until eight weeks after treatment), but is too damaging to the rhubarb when applied over the row, killing some sets. In addition, this loss of canopy allowed further weed to re-establish, and it reached greater levels than seen in the untreated plots at 69% plot cover at 18 weeks after treatment. Roundup was also applied as an inter-row treatment, and this was safer to the crop and gave some weed reduction (22% at 18 weeks after treatment), but this was still not as good control as obtained with Shark or H40.

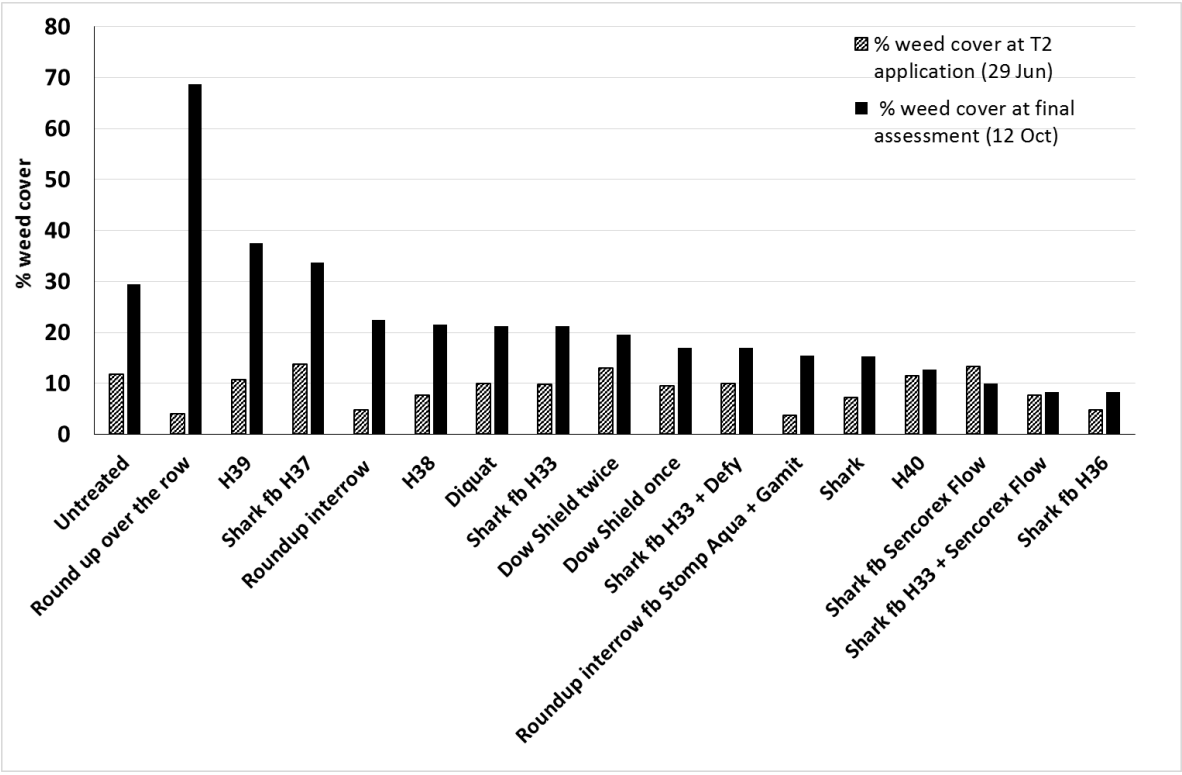


Figure 14. Mean percentage of weed cover at three and 18 weeks after the first treatments were applied. Yorkshire, 2015

Table 20. Mean percentage of weed cover at three, seven, 11 and 18 weeks after treatment (WAT) application. Hampshire, 2015

		Weed cover at dates indicated (%)			
Treatment Timing 1 (4 June)	Treatment Timing 2 (29 June)	29 June 3 WAT	27 July 7 WAT	26 Aug 11 WAT	12 Oct 18 WAT
Untreated	Untreated	11.7	18.6	25.4	29.4
Roundup inter-row	-	4.7	12.0	17.0	22.5
Roundup inter-row	Gamit 36 CS + Stomp Aqua	3.7	**6.5**	**11.5**	**15.5**
Roundup over row	-	4.0	13.7	50.0	68.8
Shark	-	7.3	12.0	**13.2**	**15.2**
H39	-	10.7	21.3	32.5	37.5
Reglone	-	10.0	15.0	20.0	21.2
Dow Shield 0.5 L/ha	-	9.5	12.3	**15.0**	**17.0**
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	13.0	14.3	18.0	19.5
H38	-	7.7	13.3	18.5	21.5
H40	-	11.5	11.7	**14.0**	**12.7**
Shark	Sencorex Flow	13.3	**5.7**	**8.2**	**10.0**
Shark	H33	9.7	12.5	17.8	21.2
Shark	H33 + Defy	10.0	**7.3**	14.0	**17.0**
Shark	H33 + Sencorex Flow	7.7	**6.0**	**7.0**	**8.2**
Shark	H36	4.7	**6.3**	**6.7**	**8.2**
Shark	H37	13.7	22.5	27.0	33.8
F probability	All treatments	NS	<0.001	<0.001	<0.001
LSD (70 d.f.)		-	7.272	9.667	11.91
F probability	Shark alone vs	NS	0.008	0.049	0.053
LSD (26 d.f.)	Shark and follow up treatments	-	8.76	13.17	16.75

Note: Figures in **bold** are significantly different from the untreated.

The follow up treatments of Sencorex Flow, H33, H36 and H33 tank mixed with Sencorex Flow or Defy caused yellowing of the rhubarb leaves, and also checked the growth of the crop by an additional two to three weeks when compared to applying one contact herbicide application alone. However, the crop had recovered from the symptoms by eight weeks after the application of the follow up treatments. These follow up applications were included to see if an additional application of a residual herbicide with some contact activity gave further

longevity of control in addition to the initial Shark spray. However, these follow ups did not give any further significant reductions in general weed levels compared to Shark alone. Sencorex Flow reduced the weed levels 4-6% more than Shark alone, but as aforementioned this was not a significant reduction.

The main weed present in all plots was dandelion and while no treatment killed them, their growth stage was retarded by a number of treatments and flowering was either delayed or stopped. The treatments that showed a moderate effect and had retarded growth of the dandelions the strongest at 15 weeks after the first treatments were applied were; Shark followed by a further application of Sencorex Flow, product H40 and two applications of Dow Shield 400 applied at 0.25 L/ha and then 0.5 L/ha.

No treatments gave long-lasting effects on the mugwort or the field and hedge bindweed, but there was some initial suppression of bindweed by Shark and product H40. However, the bindweed started to grow through the initial effects after six-eight weeks and had fully recovered 11 weeks after treatment.

Site 5 – Hampshire

This trial considered the effects of tank-mixes of the most effective products in the trials and also rates of 0.3 L/ha and 0.8 L/ha of Shark. Shark scorched the leaves of the rhubarb to start with, but as at Sites 3 and 4, the crop recovered quickly and had reached a commercially acceptable level of appearance by six weeks after application. There was no difference in the level of scorch or rate of recovery between 0.3 L/ha or 0.8 L/ha of Shark. Where Dow Shield had been included in the tank-mix, the herbicide gave the typical distortion and stunting of new growth seen in the earlier trials, and this was still persisting at the final assessment 15 weeks after application. The addition of Sencorex Flow to Shark and Dow Shield did not add any further phytotoxicity effects, as it is the Dow Shield that causes the most severe effects (**Table 21**)

Table 21. Phytotoxicity scores on the rhubarb at four, six, eight and 15 weeks after treatment (WAT) application. Hampshire, 2015

	Phytotoxicity scores on assessment dates indicated (0-9*)			
Treatment	27 July 4 WAT	11 Aug 6 WAT	26 Aug 8 WAT	12 Oct 15 WAT
Untreated	9.0	9.0	9.0	9.0
Shark 0.3 L/ha	**5.3**	7.7	8.7	9.0
Shark 0.8 L/ha	**6.0**	7.7	8.0	8.3
Shark 0.3L/ha + Dow Shield 0.5 L/ha	**5.0**	**5.7**	**6.0**	**6.0**
Shark 0.3L/ha + Dow Shield 0.5 L/ha + Sencorex Flow 1.45 L/ha	**4.0**	**5.3**	**5.3**	**6.0**
F probability	<0.001	0.005	<0.001	<0.001
LSD (14 d.f.)	0.4861	1.702	1.140	0.972

Note: Figures in **bold** are below a score of 7, see below for explanation of scores.

*9 is no effect on the rhubarb, scores of 7-8 indicate a slight effect but it is commercially acceptable, 5-6 is a moderate effect, 3-4 is a moderately severe effect, 1-2 is a severe effect and 0 is dead.

Only the treatments where Dow Shield was included in the tank mix, significantly reduced the percentage of weed cover from 46.7% in the untreated to 15 to 18.3% at the final assessment, 15 weeks after treatment (**Table 22**). Shark did not significantly reduce the percentage of weed cover in the plots in this trial due to the weed spectrum present in the trial area. There was a greater percentage of mayweed present throughout this trial, which is moderately resistant to Shark, and therefore the inclusion of Dow Shield here increased weed control and percentage weed reduction. The rate of Shark of 0.3 L/ha performed as well as the higher rate of 0.8 L/ha, and therefore growers can be assured that the lower rate can be effective as long as the weed spectrum, rate of weed growth and temperature at application are considered.

Table 22. Mean percentage of weed cover at four, six, eight and 15 weeks after treatment (WAT) application. Hampshire, 2015

	Weed cover on assessment dates indicated (%)			
Treatment	27 July 4 WAT	11 Aug 6 WAT	26 Aug 8 WAT	12 Oct 15 WAT
Untreated	22.0	35.0	46.7	46.7
Shark 0.3 L/ha	15.0	25.0	36.7	36.7
Shark 0.8 L/ha	14.0	26.0	28.3	31.0
Shark 0.3L/ha + Dow Shield 0.5 L/ha	16.0	**15.7**	**17.7**	**18.3**
Shark 0.3L/ha + Dow Shield 0.5 L/ha + Sencorex Flow 1.45 L/ha	**8.3**	**13.0**	**16.0**	**15.0**
F probability	0.056	0.021	0.089	0.080
LSD (14 d.f.)	8.32	12.38	25.83	24.14

Note: Figures in **bold** are significantly different from the untreated.

Discussion

The aim of this project was to evaluate a selection of newer herbicides for crop safety and efficacy against a range of problem weeds in rhubarb plantations, compared with industry standards. This was with the objective of providing information for growers on candidate herbicides on crop safety and efficacy under the following areas:

- Provide information on any adverse effects on the crop from residual herbicides tested in the trials;
- Offer control of commonly-occurring annual weeds using residual herbicides;
- Provide information on any adverse effects on the crop from contact herbicides tested in the trials;
- Control of perennial weeds, often a long-term problem in rhubarb with spot and overall treatments of contact acting herbicides.

Results from the 2015 trials are discussed against these objectives below.

Crop safety of residual herbicides in outdoor rhubarb

No adverse effects were seen on the two-year old established crop of Stockbridge Arrow planted on a sandy clay loam soil in Yorkshire. However, phytotoxic symptoms were seen in three treatments on the newly planted crop of Stockbridge Arrow in Nottinghamshire. The latter crop was planted into a sandy loam soil, and a higher sensitivity to herbicides is often expected to occur on light soil types such as these. This indicates that extra care needs to be taken when selecting residual herbicides and rates of use on rhubarb in this situation.

Phytotoxic effects were seen in the plots in Nottinghamshire treated with Sencorex WG, Callisto and H33 with the greatest effects caused by Sencorex WG applied at 1.25 kg/ha. The effect of Sencorex WG was exhibited as chlorosis along the veins of the leaves, and symptoms first occurred on 6 May, seven weeks after the sprays were applied. This was two weeks after 30mm of irrigation was applied on 23 April, and the interval between occurrence and the treatment application shows the persistence of the product and its ability to re-activate in the presence of moisture. Between the herbicide application on 10 March and 23 April conditions were dry with the only significant rainfall occurring at the site on 3 April.

The effects of Sencorex WG were transient and the stronger sets had recovered 12 weeks after application, and by this point new leaves were no longer showing any chlorotic effects,

but it should be noted that weaker plants were lost. Sencorex Flow was approved for use on newly established crops during the project and this risk of phytotoxicity should be taken into account when using the product. The use of lower rates may be safer in higher risk situations, especially when planting new crops on light soil types.

Callisto and H33 also showed a less severe phytotoxicity effect with an occasional early leaf showing scorch at seven weeks after treatment, but the sets recovered quickly and had grown through well by 12 weeks after treatment with no symptoms seen at this point.

Control of commonly-occurring annual weeds using residual herbicides

Currently approved herbicides for rhubarb leave weaknesses in the spectrum of annual weeds controlled. Those weeds resistant or moderately resistant to current actives include Himalayan balsam, black bindweed, mayweed, cleavers, field pansy, groundsel and charlock (Appendix B). Residual herbicides were found in both trials which can give control of these weeds and gave control better than or equivalent to the current grower standards of Stomp Aqua + Gamit 36 CS and Stomp Aqua + Goltix Flow, and significantly better control than the untreated (**Figure 15**). These five treatments were Sencorex WG, Callisto, H32, H34 and H34 in a tank mix with H33.

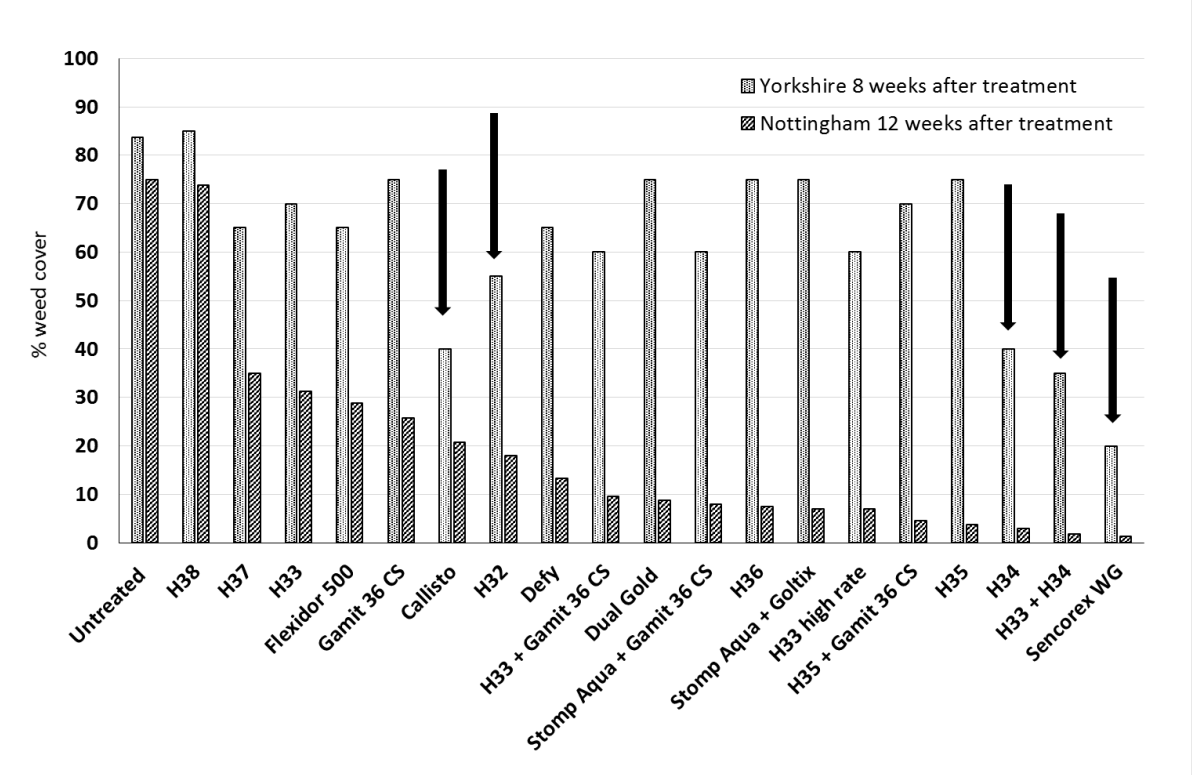


Figure 15. Mean percentage of weed cover at eight weeks after treatment in Yorkshire and 12 weeks after treatment in Nottinghamshire. Arrows indicate those treatments that gave significantly better control than the untreated plots at both sites. 2015

Sencorex WG was the best product for overall weed control at both sites, reducing weed levels by 76% in Yorkshire and by 98% in Nottinghamshire when compared to the untreated. During the project an EAMU was obtained for application of the product as the Sencorex Flow form for use on newly planted rhubarb plantations. However, due to the EAMU restrictions on use it cannot be applied to established plantations which are going to be harvested within a period of 12 months. Therefore, options are still needed for established crops to maintain weed control during harvest in later years, and thus maintain yields through the plantation life.

Callisto was the second best active for control of Himalayan balsam, reducing levels by 53% when compared to the untreated, and also gave a good reduction in a range of weeds in Nottinghamshire, reducing weed cover by 76%. Despite this, it did not appear as one of the better products for an overall reduction in the percentage of weed cover in Nottinghamshire because it doesn't give good control of annual meadow grass or small nettle, and these were two of the main weeds at the experimental trial site. But if partner products are considered, it could give control of a wide range of weeds in a tank-mix with Goltix, which would add control of annual meadow grass and small nettle. According to the label and trials data, Callisto also has a broad weed control susceptibility list (Appendix B). It should be noted that Callisto has not been tested as a tank-mix on rhubarb, and grower experience in crops such as maize suggest that when mixed it can increase the phytotoxicity risk. Therefore, if approved, growers should bear this in mind when using a tank-mix.

Dual Gold, H36 and H33 at a high rate or in a tank mix with Gamit 36 CS also gave better or equivalent control to the current grower standards in Nottinghamshire, but had no effect on Himalayan balsam. Product H33 in a tank mix with Gamit would give moderate to good control of all the annual weeds where there are weaknesses in the current approvals, except for cleavers.

Product H35 gave better control than the current standards at the Nottinghamshire site only, but was ineffective at controlling the Himalayan balsam in Yorkshire. However, it was applied after the Himalayan balsam had emerged and the mode of action of this herbicide means that it gives best control when applied pre-emergence, as it is absorbed by the subterranean parts of the plant such as the roots and hypocotyl (shoots). The product may have a greater effect if applied pre-emergence, and this approach may be worth testing in future. In trials on a range of vegetables including courgettes in AHDB Horticulture project CP 77 SCEPTRE, work by Knott. C (2014) also showed that this herbicide is best used pre weed emergence.

Overall, an approval for Callisto or H32 would give greater or equivalent weed control where there are currently weaknesses in both geographical situations

Crop safety of contact herbicides in outdoor rhubarb

Roundup over the row was too damaging at the rates used at both experimental sites and killed some sets. H39 over the row and Roundup inter-row were also too damaging at the Yorkshire site. The latter treatment may have reduced the vigour of the rhubarb because it was more difficult to apply the spray low enough to avoid drift onto the plants as the crop is grown on ridges. As conversely, effects from Roundup applied inter-row to the crop grown on the flat in Hampshire were scored as slight by 11 weeks after treatment, whereas at the same assessment timing in Yorkshire moderate effects were still seen. Therefore Roundup between the row could be safely used depending on the situation that the rhubarb is grown in.

Dow Shield 400 caused severe effects to the rhubarb at both sites at the rates used in the trial, causing cupping of leaves, and distortion and twisting of new growth exhibited as small, deformed or thickened new leaves. These effects were still occurring at 11 weeks after the first applications in Yorkshire, and 18 weeks after the first applications in Hampshire. Although the effects are long-lasting and set back growth by a number of weeks in the year of application, no crop death was seen in the plots. If Dow Shield 400 was applied at a lower rate, or as a spot treatment the phytotoxic effects may be reduced, and this would be worth investigating due to the value of the product for perennial thistle control.

Shark, Reglone and H40 initially scorched the rhubarb, but the plots treated with these contact herbicides recovered reasonably quickly to a level where the crop would be acceptable to harvest again at least eight weeks after application. The recovery from the herbicide applications varied by site and product. The plots sprayed with Shark recovered the quickest and plants appeared to be at a commercially acceptable quality at four weeks after application in both Yorkshire and Hampshire. It took slightly longer for the rhubarb to recover from Reglone and H40, with the plants at an acceptable quality by seven weeks after application in Hampshire. In Yorkshire, the crop treated with Reglone had recovered by six weeks after application, and by eight weeks for the crop treated with H40. However, although quality attributes of the crop were not assessed by ADAS as part of the trial, the grower reported that he observed that stick length of the rhubarb appeared to be 50mm shorter than in the untreated plots. This height reduction is believed to have allowed the field bindweed to grow over the rhubarb in one plot rather than under the crop, and growers should be mindful of this possible effect.

The follow up treatments of single herbicides and tank mixes applied to the crop three to four weeks after the Timing 1 treatments also scorched the rhubarb, causing yellowing and necrosis of the leaves present at application. The crop grew through these symptoms and had recovered with no or only slight symptoms seen at seven weeks after the sprays were applied in Yorkshire, and eight weeks after the sprays were applied in Hampshire. It should be noted that if these sprays are applied one month after the first sprays as in the trials, then the crop takes a further three to four weeks to recover than those plots that only received one application of either Shark, Reglone or H40.

Control of perennial weeds using overall and spot applications of contact herbicides

Control of perennial weeds is particularly troublesome in perennial crops such as rhubarb as the windows for 'clean-up' spray applications are limited and short. Products such as Roundup can only be safely applied when the crop is fully dormant during December and January, and in practice opportunities to spray can be few and far between in these months. Therefore herbicides that could be applied safely to the plantation outside this window would be very useful to growers. Five post-harvest applied treatments gave significant control of weeds at both trial sites, and also proved safe to the crop with no or only slight effects seen at 11 weeks after treatment, or when the crop in the trial would have been ready for harvest again.

These treatments were single applications of Shark or H40, and Shark followed by an additional application of Sencorex Flow, H36 or Sencorex Flow in a tank mix with H33. In addition, in Hampshire, Roundup applied as a shielded application between the rows and then followed up by an application of Stomp Aqua + Gamit 36 CS gave significant weed control and was safe to the crop at this site (**Table 23**).

Shark gave the best control for a single applied product in the main trials, significantly reducing weed cover to approximately 13% cover for up to 11 weeks in both Yorkshire and Hampshire. This equates to a reduction in weed cover of 84% in Yorkshire, and 48% in Hampshire when compared to the levels in the untreated plots at each site. Although Shark performed well in the contact herbicide trials, its efficacy can be variable depending on the weed spectrum present, how well the weeds are growing and the temperature when it is applied. It performs best when weeds are growing well under warm conditions, as demonstrated in work by Agostineto *et al.* (2015). In addition, during the project Shark was applied on 10 March at 0.8 L/ha to the emerged Himalayan balsam in the residual trial area

and had very little effect on the weed. Temperature on average on the day of application by the grower (11 March) was 7.5 ^{0}C, with average temperature over the seven days after application of 5.2 ^{0}C. Shark worked better when applied in Yorkshire at 11.5 ^{0}C, and temperature reached 19 ^{0}C on the day of application, with an average temperature over the seven days after application of 9.9 ^{0}C. In Hampshire, the temperature on the day and after application was even higher than these. It also worth noting that the weeds were also growing strongly at the time of application in the contact herbicide trials.

Table 23. Mean percentage of weed cover at Timing 2 application and at the potential harvest date 11 weeks after treatment (WAT) application. Yorkshire and Hampshire, 2015

		Weed cover at dates and sites indicated (%)			
		Yorkshire		Hampshire	
Treatment Timing 1	Treatment Timing 2	5 June 4 WAT Timing 2	23 July 11 WAT Harvest	29 June 3 WAT Timing 2	26 Aug 11 WAT Harvest
Untreated	Untreated	96.2	88.8	11.7	25.4
Roundup inter-row	-	**15.5**	**38.8**	4.7	17.0
Roundup inter-row	Gamit 36 CS + Stomp Aqua	**16.2**	**22.8**	3.7	**11.5**
Roundup over row	-	**1.8**	**13.5**	4.0	50.0
Shark	-	**6.5**	**13.8**	7.3	**13.2**
H39	-	**10.2**	**35.5**	10.7	32.5
Reglone	-	**28.7**	77.5	10.0	20.0
Dow Shield 0.5 L/ha	-	**69.5**	87.5	9.5	**15.0**
Dow Shield 0.25 L/ha	Dow Shield 0.5 L/ha	97.5	96.8	13.0	18.0
H38	-	96.2	99.2	7.7	18.5
H40	-	**45.0**	**28.0**	11.5	**14.0**
Shark	Sencorex Flow	**19.2**	**12.0**	13.3	**8.2**
Shark	H33	**11.7**	**11.2**	9.7	17.8
Shark	H33 + Defy	**7.2**	**12.5**	10.0	14.0
Shark	H33 + Sencorex Flow	**24.2**	**13.8**	7.7	**7.0**
Shark	H36	**32.0**	**15.2**	4.7	**6.7**
Shark	H37	**14.7**	**44.0**	13.7	27.0
F probability	All treatments	<0.001	<0.001	NS	<0.001
LSD (70 d.f.)		15.88	14.73	-	9.667
F probability	Shark alone vs	0.042	<0.001	NS	0.049
LSD (26 d.f.)	Shark and follow up treatments	16.44	11.42	-	13.17

Note: Figures in **bold** are significantly different from the untreated.

In the additional trial in Hampshire, the rate of Shark at 0.3 L/ha performed as well as the higher rate of 0.8 L/ha, and therefore growers can be assured that the lower rate can be effective as long as the weed spectrum, rate of weed growth and temperature at application are considered.

H40 was the second best treatment for a single applied product at both sites, reducing weed cover significantly to 14% in Hampshire and 28% in Yorkshire at 11 weeks after spray application. This equates to a reduction in weed cover of 68% in Yorkshire, and 45% in Hampshire when compared to the levels in the untreated plots at each site. Both Shark and H40 have a good range of control (see Appendix B) and although they are both contact in activity, there is an element of selectivity to their action and Shark is stronger on smooth sowthistle and fat-hen, while H40 gives good control of groundsel and mayweed. There are also differences between the desiccants Shark and Reglone, with the former being weaker on mayweed, chickweed and groundsel, while diquat is weaker on cleaver, knotgrass and small nettle. Therefore when using these contact herbicides growers need to take into account the weed spectrum, as well as timing of application with regards to speed of weed growth and temperature to select the products to get the best control.

Dow Shield 400 was the only herbicide to fully control perennial thistle with a good kill, but when applied over the crop at the rates used it gave severe crop damage causing cupping of leaves and deformation of new growth, with twisting and deformation of new leaves seen up to 18 weeks after sprays were applied. However, despite this no plant death was seen and an approval for the control of thistle would still be useful as Dow Shield may be safer to use as a spot treatment or at lower rates, and there are currently few other safe options for full control of this weed. H40 as a single spray application and Shark followed by a later application of Sencorex Flow gave good suppression of perennial thistle but did not kill it all.

Residual herbicides with some contact activity were also tested to see if they added more longevity and further control to the purely contact herbicide Shark. Of those tested Sencorex Flow and H36 added a slight reduction in weed control, Sencorex Flow reduced the weed further by 6-7% at both trial sites, while H36 gave an added reduction of 15% in weed levels at the Yorkshire. site only. This is only a small extra reduction so the grower would have to decide if this was an approach worth taking. This is especially true if applied one month later than the Shark application as in the trial, as it then takes the crop a further four weeks to

recover than those plots where only Shark was applied. Alternatively, applying both products in a tank-mix could be possible in practice.

Effects on the most troublesome perennial weeds were recorded and it was noted that field and hedge bindweed were initially suppressed by Shark and product H40. However, the bindweed started to grow through the initial effects after six to eight weeks and had fully recovered 11 weeks after treatment. In Hampshire. the main weed present in all plots was dandelion and while no treatment killed them, their growth stage was retarded by a number of treatments and flowering was either delayed or stopped. The treatments that showed a moderate effect and had retarded growth of the dandelions the strongest at 15 weeks after the first treatments were applied were; Shark followed by a further application of Sencorex, H40 and Dow Shield 400 applied twice. No treatments gave long-lasting effects on the mugwort.

Shark provided good control of Himalayan balsam and a range of dicotyledon weeds in both trials but has weaknesses in chickweed, mayweed and groundsel, and growers also need to consider temperature and speed of weed growth to get good efficacy from the product. Another potato desiccant, pyraflufen-ethyl may be useful to look at in future work as it is a similar desiccant product and is suggested to have stronger activity on mayweed which can be a troublesome weed in rhubarb plantations.

Conclusions

- Five residual herbicide treatments (Sencorex Flow, Callisto, H32, H34, and H34 in a tank mix with H33) gave better control of commonly occurring annual broad leaf weeds than the currently approved standards for rhubarb. The weeds controlled include Himalayan balsam, and these treatments would also increase the range of weeds controlled.

- An EAMU for Sencorex Flow was obtained during the trial for application pre-crop emergence in the year of establishment, and at least 12 months before harvest. This is a useful addition to the current approvals, but caution should be taken with the rate of application to new crops, as when applied at a full rate of 1.45 L/ha in the trials severe phytotoxicity was seen. This was exhibited as chlorotic veins, and death of weak sets also occurred. Using lower rates may improve safety to the crop, and is advised especially on lighter soils.

- It is recommended that AHDB horticulture investigate the possibilities of EAMUs for Callisto, Dual Gold, H33 and H34 to enable improved weed control in established plantations. These herbicides were also relatively safe to the crop.
- Shark (not approved at this application timing) and H40 significantly reduced the percentage of weed cover when applied post-harvest one to two weeks after the crop had been topped, and maintained control up to 18 weeks after application.

- Shark provided good control of Himalayan balsam and a range of dicotyledon weeds in both trials but has weaknesses in chickweed, mayweed and groundsel, and growers also need to consider temperature and speed of weed growth to get good efficacy from the product. Reglone or Retro (diquat) may be a better option in cooler temperatures and when weed growth is slow.

- Dow Shield 400 was the only herbicide to fully control perennial thistle with a good kill, but when applied over the crop at the rates used it gave severe crop damage causing cupping of leaves and deformation of new growth, with twisting and deformation of new leaves seen up to 18 weeks after sprays were applied. However, despite this no plant death was seen and an approval for the control of thistle would still be useful as Dow Shield may be safer to use as a spot treatment or at lower rates, and there are currently no other safe options for full control of this weed.

- It would be worth investigating the possibility of an EAMU for product H40, as it gives good overall weed control, and is particularly effective on mayweeds as well as giving reasonable control of perennial thistle.

Further work

The work has highlighted a number of promising herbicides for weed control as both pre and post-harvest applications. But, gaps in control of field and hedge bindweed, and mugwort still remain. Shark and H40 suppressed bindweed but the effects were variable and did not last. It would be useful to test product H40 in tank mix with other contact herbicides such as Buctril (bromoxynil) and Starane 2 (fluroxypyr) at different rates and timings to see if more persistent and consistent control of bindweed and mugwort can be gained without damage to the rhubarb. Starane 2 may also add better control of dandelions

Since the trial was commissioned other promising contacts have come to light, for example pyraflufen-ethyl has recently been approved on potatoes and was not tested in the trial but could also be worth considering in further work as it is a similar desiccant product to Reglone and Shark but is reported to be stronger on mayweed than these products.

Knowledge and Technology Transfer

Rhubarb grower association meeting and trial viewing, E. Oldroyds & Sons, Yorkshire. – 7 May 2015

Grower meeting and presentation of results, Glassford-Hammond Farming, Nottinghamshire. – 25 November 2015

Glossary

ANOVA = analysis of variance

LSD = least significant differences

OPS = Oxford precision sprayer

WAT = weeks after treatment

References

Agostineto, C.A., Ansolin, H.H. and de Carvalho, B. (2015). Spray temperature and spray volume influence on the efficacy of carfentrazone-ethyl and saflufenacil to control morning-glory. Communications in Plant Sciences Vol 5:Issue 3-4:45-49

Knott, C. (2014). 1.8 Courgette transplants: evaluation of herbicides for control of weeds and crop safety (field trial, Lincs; ABC). Annual report for project CP 077

Appendices

Appendix A: Site diaries

Site 1 – Residual trial – Yorkshire

Soil analysis

Soil type: Sandy clay loam

Organic matter: 5.3%

pH: 6.9

P: Index 4 K: Index 3 Mg: Index 3

Previous cropping

2014: Rhubarb (1st year)

2013: Winter barley

2012: Winter wheat

2011: Savoy cabbage

2010: Cauliflowers

Field operations

2013

Autumn/winter 2013 - Field prepared for planting (plough, press and power harrow)

Pre-planting - Applied 13.5 tonnes/ha of shoddy

2014

2 January – Field planted with rhubarb, variety Stockbridge Arrow

13 January - Ridged with potato ridger

14 January – Applied herbicides; Stomp Aqua 3.3l/ha + Gamit 36CS 0.25l/ha in 200l/ha water

3 March – Applied fertiliser; 375 kg/ha Muriate of Potash (to supply 225 kg K_2O/ha)

15 December – Applied herbicides; Roundup Biactive 4.0l/ha + Kerb Flo 3.0l/ha in 200l/ha water

2015

20 February – Applied herbicide; Shark 0.33l/ha in 200l/ha water

10 March – Experimental herbicides applied by ADAS

19 March – Applied fertiliser; 360 kg/ha Ammonium Sulphate (to supply 75 kg N/ha)

Site 2 – Residual trial – Nottinghamshire

Soil analysis

Soil type: Sandy loam

Organic matter: 2.6%

pH: 7.1

P: Index 4 K: Index 1 Mg: Index 2

Previous cropping

2014: Various vegetable crops (Garden of Innovation demonstration plots)

2013: Parsnips

2012: Sugar beet

2011: Savoy and green cabbage

Field operations

February – Field prepared for planting (plough, press and power harrow)

9 March – Field planted with rhubarb, variety Stockbridge Arrow

Post-planting (March) – Subsoil and fertilised with 335 kg/ha Muriate of Potash (to supply 200 kg K_2O/ha)

16 March – Experimental herbicides applied by ADAS

Irrigated five times through 2015 including once with 30mm on 23 April during trial duration

Site 3 – Contact trial – Yorkshire

Soil analysis

Soil type: Clay loam

Organic matter: 4.9%

pH: 6.9

P: Index 3 K: Index 2- Mg: Index 4

Previous cropping

2014: Rhubarb (1st year)

2013: Winter wheat

2012: Winter wheat

2011: Cauliflowers

2010: Cauliflowers

Field operations

2013

Autumn 2013 - Field prepared for planting (subsoil, plough, and power harrow)

Pre-planting - Applied 16.9 tonnes/ha of shoddy

10 November – Field planted with rhubarb, variety Timperley Early

2014

4 January – Applied herbicides; Stomp Aqua 3.3l/ha + Gamit 36CS 0.25l/ha + Retro 2.5l/ha in 200l/ha water

3 March – Applied fertiliser; 335 kg/ha Muriate of Potash (to supply 200 kg K_2O/ha)

15 December – Applied herbicides; Roundup Biactive 4.0l/ha + Kerb Flo 3.0l/ha in 200l/ha water

2015

14 February – Applied herbicides; Stomp Aqua 3.3l/ha + Gamit 36CS 0.25l/ha + Retro 2.5l/ha in 200l/ha water

18 March – Applied fertiliser; 330 kg/ha Ammonium Sulphate (to supply 70 kg N/ha)

30 April – Rhubarb topped after harvest

13 May – Experimental herbicides applied by ADAS – Timing 1

5 June – Experimental herbicides applied by ADAS – Timing 2

Site 4 and 5 – Contact trials – Hampshire

Soil analysis

Soil type: Clay loam

Organic matter: 4.5%

pH: 6.4

P: Index 5 K: Index 4 Mg: Index 4

Previous cropping

2000 - 2014: Rhubarb

Field operations

2014

December – Applied herbicides; Roundup biactive 4.0l/ha + Kerb Flo 3.0l/ha in 200l/ha water

2015

February – Applied fertiliser; variable rate lime by GPS map (maintenance dressing).

February – Applied herbicides; Stomp aqua 3.3l/ha + Gamit 36CS 0.25l/ha in 200l/ha water

March – Applied fertiliser; 370 kg/ha Ammonium Nitrate (to supply 100 kg N/ha)

14 May – Rhubarb topped after harvest

May – Applied fertiliser; 370 kg/ha Ammonium Nitrate (to supply 100 kg N/ha)

4 June – Experimental herbicides applied by ADAS – Timing 1

29 June – Experimental herbicides applied by ADAS – Timing 2

August - Applied fertiliser; 370 kg/ha Ammonium Nitrate (to supply 100 kg N/ha)

Appendix B: Susceptibility of weeds to approved products, and herbicides tested in SF 161 in rhubarb crops

Note: This data is compiled from on-label recommendations and limited trials data including SF 161, and should be treated with caution and as a guide only, as susceptibilities may vary from site to site due to local resistances and historical rotations.

Key: S=Susceptible (good kill) M= Moderately Susceptible (some kill, strong suppression of survivors) MR = Moderately resistant (poor kill but useful suppression) R=Resistant, blank = no information available

	Established crops – approved products				*Approved for use 1 month before production or planting*	*Approved pre crop emergence in establish-ment year*	*Established crops – best experimental products – Residuals*								*Contacts - Best experimental*	
BROAD LEAVED WEEDS	***Clomazone*** **Gamit 360g/L 0.25 L/Ha**	***Metamitron*** **Goltix flo 700g/l 5L/ha x2**	***Pendimethalin*** **Stomp Aqua 400g/L 3.3 L/Ha**	***Propyzamide*** **Kerb Flo 400 g/L apply before 31st December 4.25 L/ha**	***Carfentrazone-ethyl*** **Shark 60g/L 0.3 L/ha**	***Metribuzin*** **Sencorex Flow 600g/L 1.15 L/ha**	***mesotrione*** **Callisto 100g/L 1.5 L/ha**	***Prosulfocarb*** **Defy 800g/L 5.0 L/ha**	***S-metalochlor*** **Dual Gold 1.4 L/ha**	**H32**	**H33**	**H33 high rate**	**H35**	**H36**	**H40 0.75 L/ha**	***clopyralid*** **Dow Shield 400 0.25 + 0.5 L/ha**
AM Grass	MS	S	MS	S	R	S	MS	MS	S	S	MS	S	S	S	S	R
Black bindweed	MR	MR	MS	S	S	MS	S		R		MS	MS		MR	S	MS
Black nightshade	MS		MS	S	S	R	S	S	MR	R	MR	MS		MS	S	MR
Charlock	R		R	R	S	S	S		MR	R	S	S			S	R
Cleavers	S	R	MR	S	S	R	MS	MS	R	MS	R	MR		S	S	R
Common chickweed	S	S	S	S	MR	S	S	S	MS	S	S	S	S	MS	MS	MR
Common fumitory	R	S	MS	MS		S	S		S		MR	MS			S	R
Common orache	MR	S	S	S	S	S	S				S	S			S	

	Established crops – approved products				*Approved for use 1 month before production or planting*	*Approved pre crop emergence in establish-ment year*	*Established crops – best experimental products – Residuals*								*Contacts - Best experimental*	
BROAD LEAVED WEEDS	***Clomazone*** **Gamit 360g/L 0.25 L/Ha**	***Metamitron*** **Goltix flo 700g/l 5L/ha x2**	***Pendimethalin*** **Stomp Aqua 400g/L 3.3 L/Ha**	***Propyzamide*** **Kerb Flo 400 g/L apply before 31st December 4.25 L/ha**	***Carfentrazone-ethyl*** **Shark 60g/L 0.3 L/ha**	***Metribuzin*** **Sencorex Flow 600g/L 1.15 L/ha**	***mesotrione*** **Callisto 100g/L 1.5 L/ha**	***Prosulfocarb*** **Defy 800g/L 5.0 L/ha**	***S-metalochlor*** **Dual Gold 1.4 L/ha**	**H32**	**H33**	**H33 high rate**	**H35**	**H36**	**H40 0.75 L/ha**	***clopyralid*** **Dow Shield 400 0.25 + 0.5 L/ha**
Common poppy	**R**	**S**	**S**	**R**		**S**	**R**			**S**	**S**	**S**	**S**			**R**
Corn buttercup																
Corn marigold		**S**	**S**				**S**			**R**						**S**
Corn spurrey		**S**				**S**	**S**			**S**						
Crane's bill	**S**	**S**	**MS**				**MR**	**S**	**S**		**MS**	**S**				
Creeping thistle	**R**	**R**	**R**		**S (from seed)**	**MR/MS**									**MR**	**S**
Dandelion	**R**	**R**	**R**		**MR**	**MR**			**R**						**MS**	**MS**
Fat-hen	**MS**	**S**	**S**	**S**	**S**	**S**	**S**		**MS**	**S**	**S**	**S**	**S**	**S**	**MS**	
Field/hedge bindweeds	**MR**	**R**	**R**	**R**	**MR**	**MR**	**MS**		**R**		**MR**				**MS**	**MR**
Field forget-me-not	**MR**	**S**	**MS**			**S**	**S**	**S**		**S**						
Field pansy	**R**	**MS**	**MS**		**S**	**S**	**S**	**R**	**MR**	**MS**	**MR**	**MS**			**S**	
Fool's parsley	**S**						**S**				**MR**	**MS**		**MS**		
Groundsel	**S**	**S**	**R**	**R**	**MR**	**S**	**S**	**MR**	**S**	**S**	**MS**	**S**	**S**	**MS**	**S**	**S**

	Established crops – approved products				*Approved for use 1 month before production or planting*	*Approved pre crop emergence in establish-ment year*	*Established crops – best experimental products – Residuals*								*Contacts - Best experimental*	
BROAD LEAVED WEEDS	***Clomazone*** **Gamit 360g/L 0.25 L/Ha**	***Metamitron*** **Goltix flo 700g/l 5L/ha x2**	***Pendimethalin*** **Stomp Aqua 400g/L 3.3 L/Ha**	***Propyzamide*** **Kerb Flo 400 g/L apply before 31st December 4.25 L/ha**	***Carfentrazone-ethyl*** **Shark 60g/L 0.3 L/ha**	***Metribuzin*** **Sencorex Flow 600g/L 1.15 L/ha**	***mesotrione*** **Callisto 100g/L 1.5 L/ha**	***Prosulfocarb*** **Defy 800g/L 5.0 L/ha**	***S-metalochlor*** **Dual Gold 1.4 L/ha**	**H32**	**H33**	**H33 high rate**	**H35**	**H36**	**H40 0.75 L/ha**	***clopyralid*** **Dow Shield 400 0.25 + 0.5 L/ha**
Hemp-nettle (Day nettle)	MR	S	S		S	S	S							S	S	
Henbit Dead-nettle			S		S	S	MS				MS	MS			S	
Himalayan balsam	MR	R	R		S (summer)	S	MS	MR	R	MS	R	MR	R	R	S	R
Knotgrass	MS	S	S	S	S	S	S		R	S	MR	MS	R	S	S	
Mayweeds	MR	S	R	R	MR	S	S	MR	S	S	MS	S	S	S	S	S
Mugwort	R	R	R	R	MR	MR					MR				R	MR
Pale persicaria	MS				S	S	S		R	MS	MR	MS			S	MR
Parsley piert			S							R						
Red dead-nettle	S	S	S	R	S	S	S	S	S		MS	MS	S	S	S	R
Redshank	MS	S	MS	S	S	S	S		R	MS	MR	MS	R	MR	MS	MR
Scarlet pimpernel		S	S	R		S	S			R					S	R
Shepherds-purse	S	S	R	MS	S	S	S		MS	MS	S	S	S	S	S	
Small nettle	R	S	S	S	S	S	MR	MS	MS	MS	MS	S	MS	MS		R

	Established crops – approved products				*Approved for use 1 month before production or planting*	*Approved pre crop emergence in establish-ment year*	*Established crops – best experimental products – Residuals*								*Contacts - Best experimental*	
BROAD LEAVED WEEDS	***Clomazone*** **Gamit 360g/L 0.25 L/Ha**	***Metamitron*** **Goltix flo 700g/l 5L/ha x2**	***Pendimethalin*** **Stomp Aqua 400g/L 3.3 L/Ha**	***Propyzamide*** **Kerb Flo 400 g/L apply before 31st December 4.25 L/ha**	***Carfentrazone-ethyl*** **Shark 60g/L 0.3 L/ha**	***Metribuzin*** **Sencorex Flow 600g/L 1.15 L/ha**	***mesotrione*** **Callisto 100g/L 1.5 L/ha**	***Prosulfocarb*** **Defy 800g/L 5.0 L/ha**	***S-metalochlor*** **Dual Gold 1.4 L/ha**	**H32**	**H33**	**H33 high rate**	**H35**	**H36**	**H40 0.75 L/ha**	***clopyralid*** **Dow Shield 400 0.25 + 0.5 L/ha**
Smooth sowthistle	**MS**	**S**	**R**	**S**	**S**	**S**			**S**	**MS**	**S**	**S**		**S**	**MS**	**S**
Speedwells	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**R**	**MR**	**S**	**S**	**S**	**MR**
Sun spurge		**S**			**MS**	**S**										
Volunteer oilseed rape (1)	**R**		**MS**	**MS**	**S**	**S**	**S**		**MS**		**MS**	**S**		**S**	**S**	
Wild radish					**S**	**S**	**S**		**R**		**S**	**S**			**S**	

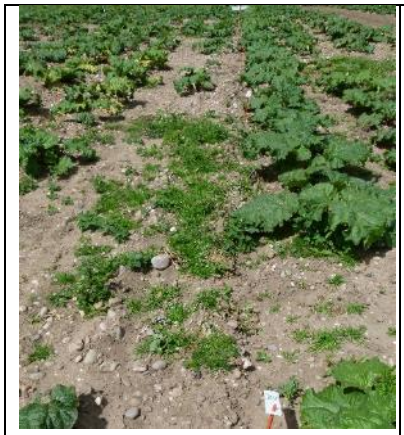
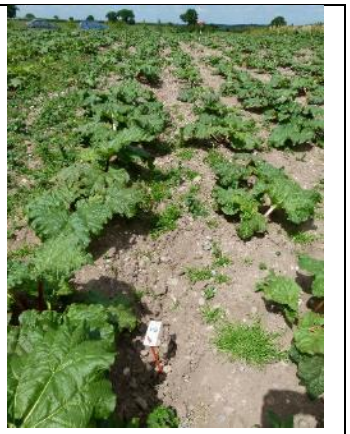
Appendix C: Plot photographs

Site 1: Photographs taken four weeks after treatment. Yorkshire, 2015.

		
Sencorex WG (top of photo) compared with Stomp Aqua + Gamit 36 CS	Sencorex WG	H33 + Gamit 36 CS (Note: control broke down at 8 weeks)

Site 2: Photographs taken 12 weeks after treatment. Nottinghamshire, 2015.

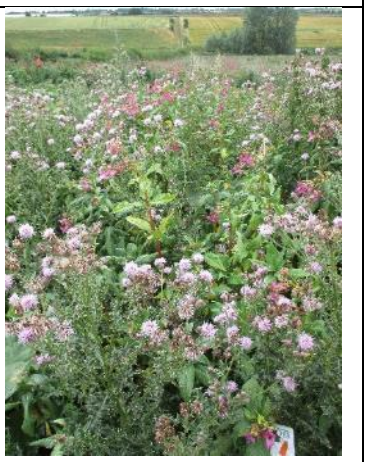
(Note: with the exception of Sencorex WG, crop losses are not treatment related).

				
Untreated	Stomp Aqua + Gamit 36 CS	Stomp Aqua + Goltix Flo	Gamit 36 CS	Callisto
				
Defy	Flexidor 500	Sencorex WG	H32	Dual Gold

				
H33	H33 higher rate	H34	H35	H33 + H34
				
H33 + Gamit 36 CS	H35 + Gamit 36 CS	H36	H37	H38

Site 3: Photographs taken 11 weeks after the first treatment applications. Yorkshire, 2015.

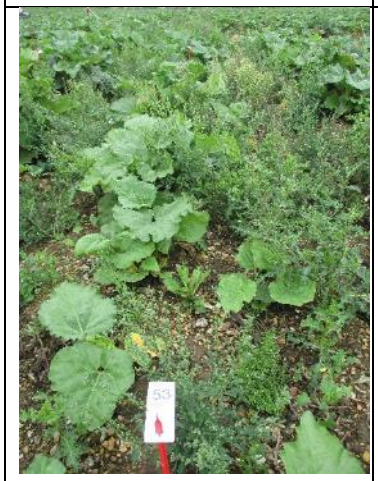
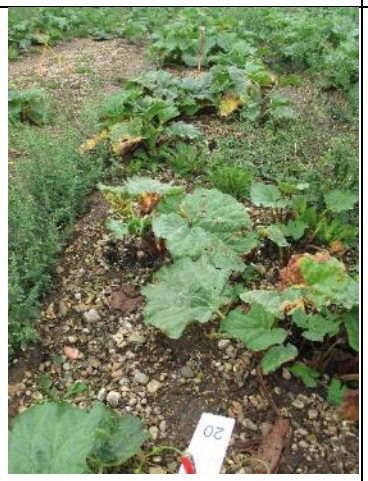
Fb = followed by

				
Untreated	Roundup inter-row	Roundup inter-row fb Stomp Aqua + Gamit 36 CS	Roundup over the crop	Shark
				
H39	Reglone	Dow Shield applied once	Dow Shield applied twice	H38

				
H40	Shark fb Sencorex Flow	Shark fb H33	Shark fb H33 + Defy	Shark fb H33 + Sencorex Flow
				
Shark fb H36	Shark fb H37			

Site 4: Photographs taken 11 weeks after the first treatment applications. Hampshire, 2015.

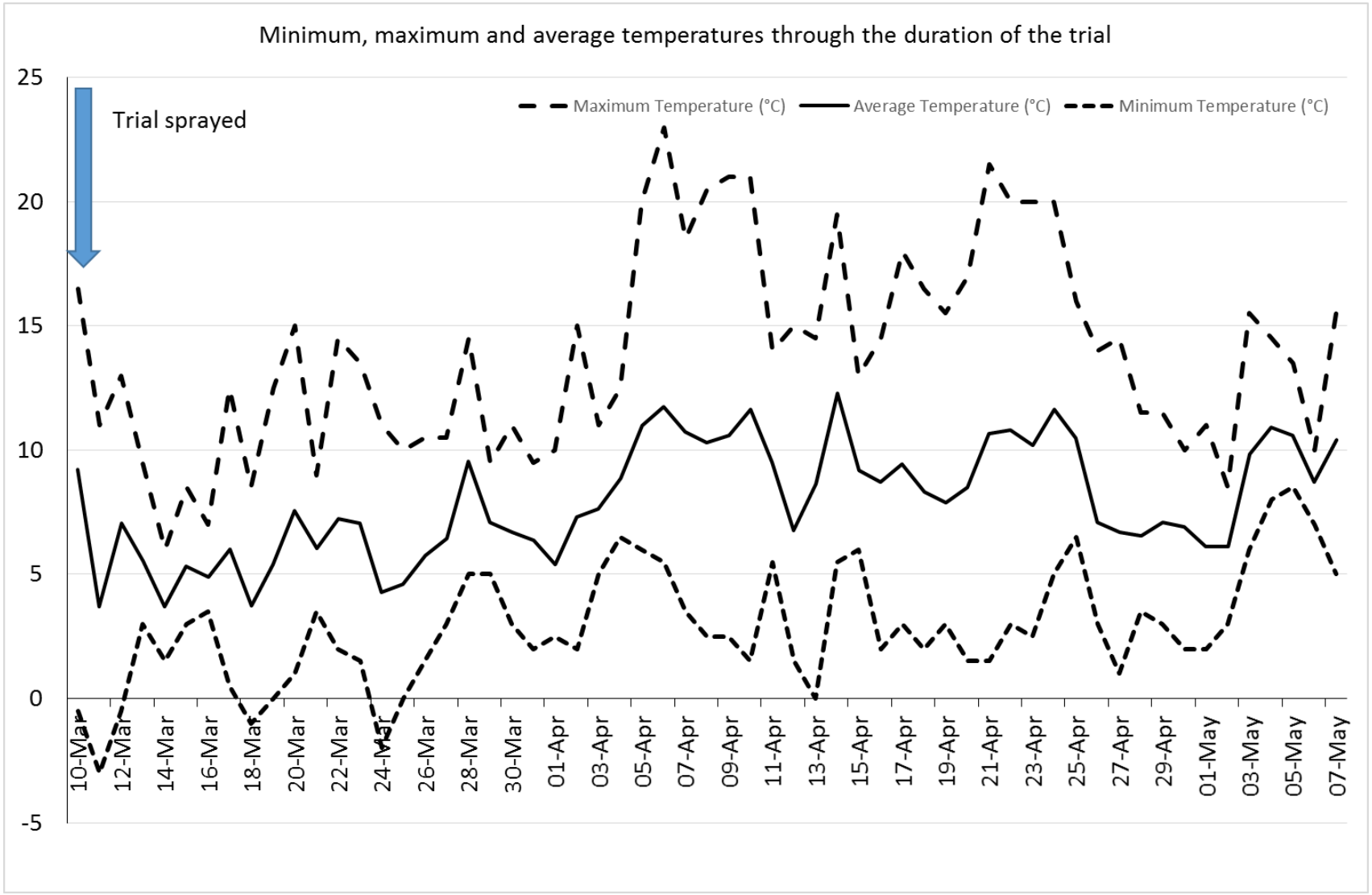
Fb = followed by

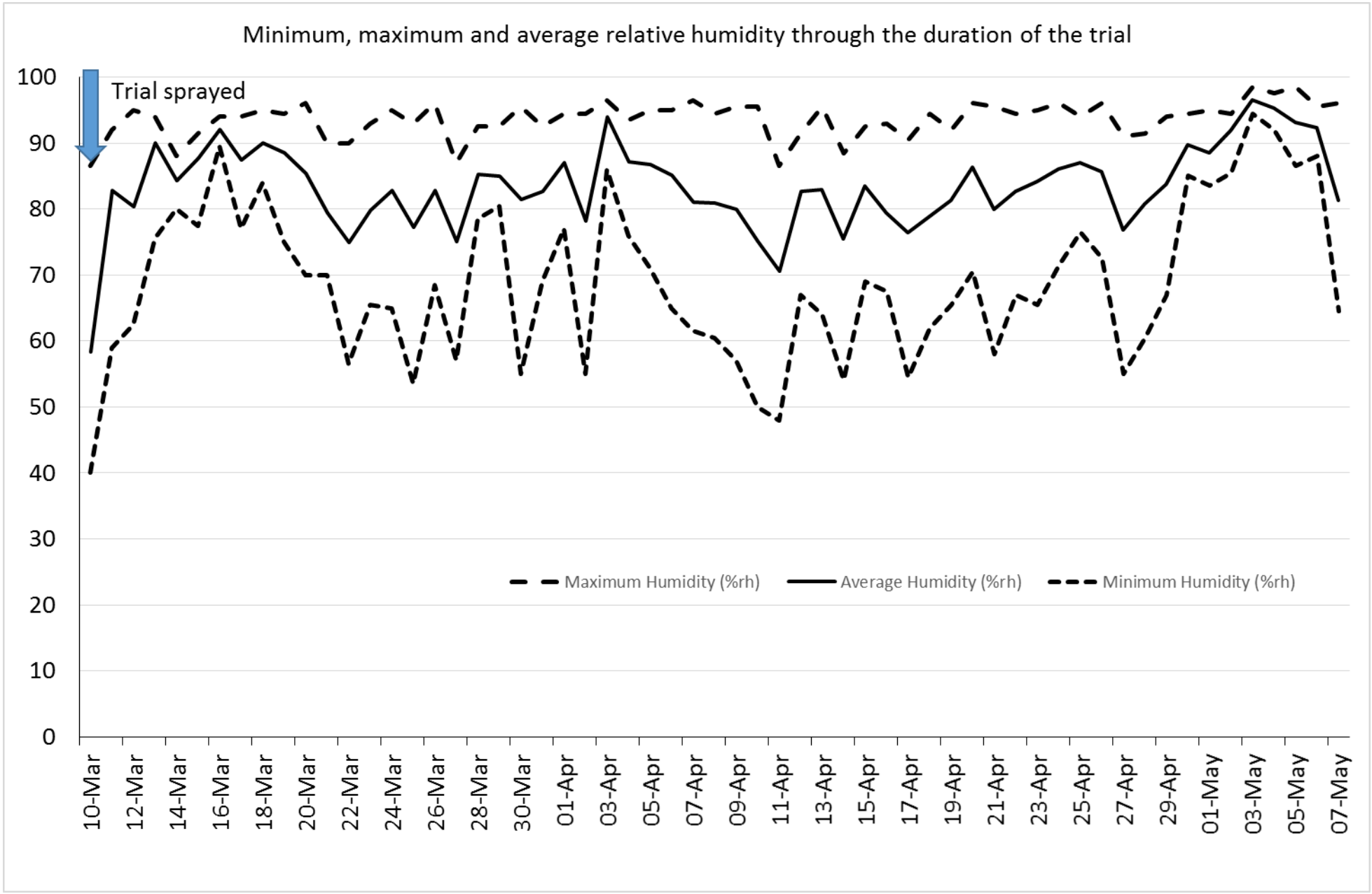
				
Untreated	Roundup inter-row	Roundup inter-row fb Stomp Aqua + Gamit 36 CS	Roundup over the crop	Shark
				
H39	Reglone	Dow Shield applied once	Dow Shield applied twice	H38

				
H40	Shark fb Sencorex Flow	Shark fb H33	Shark fb H33 + Defy	Shark fb H33 + Sencorex Flow
				
Shark fb H36	Shark fb H37			

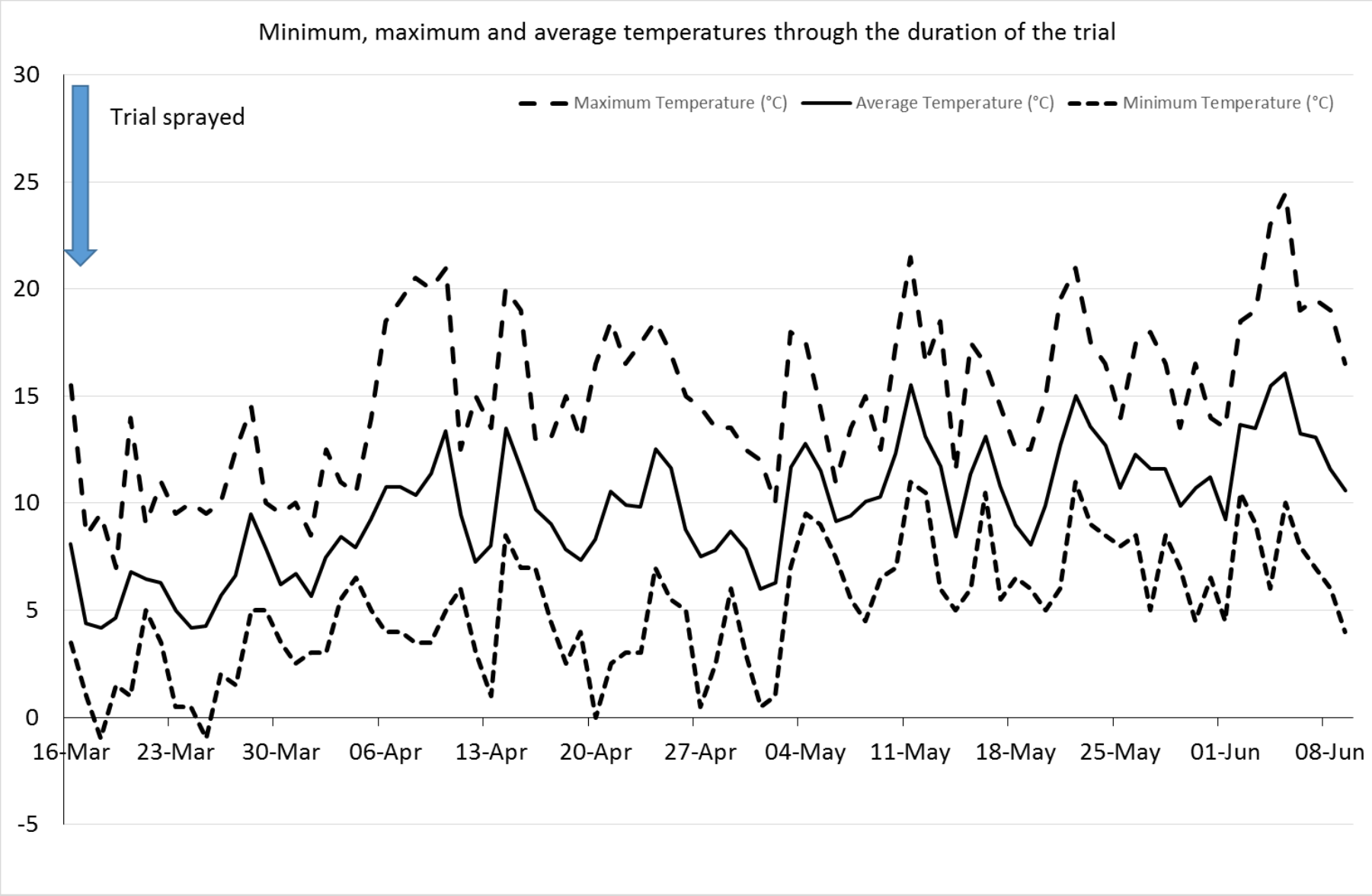
Appendix D: Temperature and humidity details for trial sites

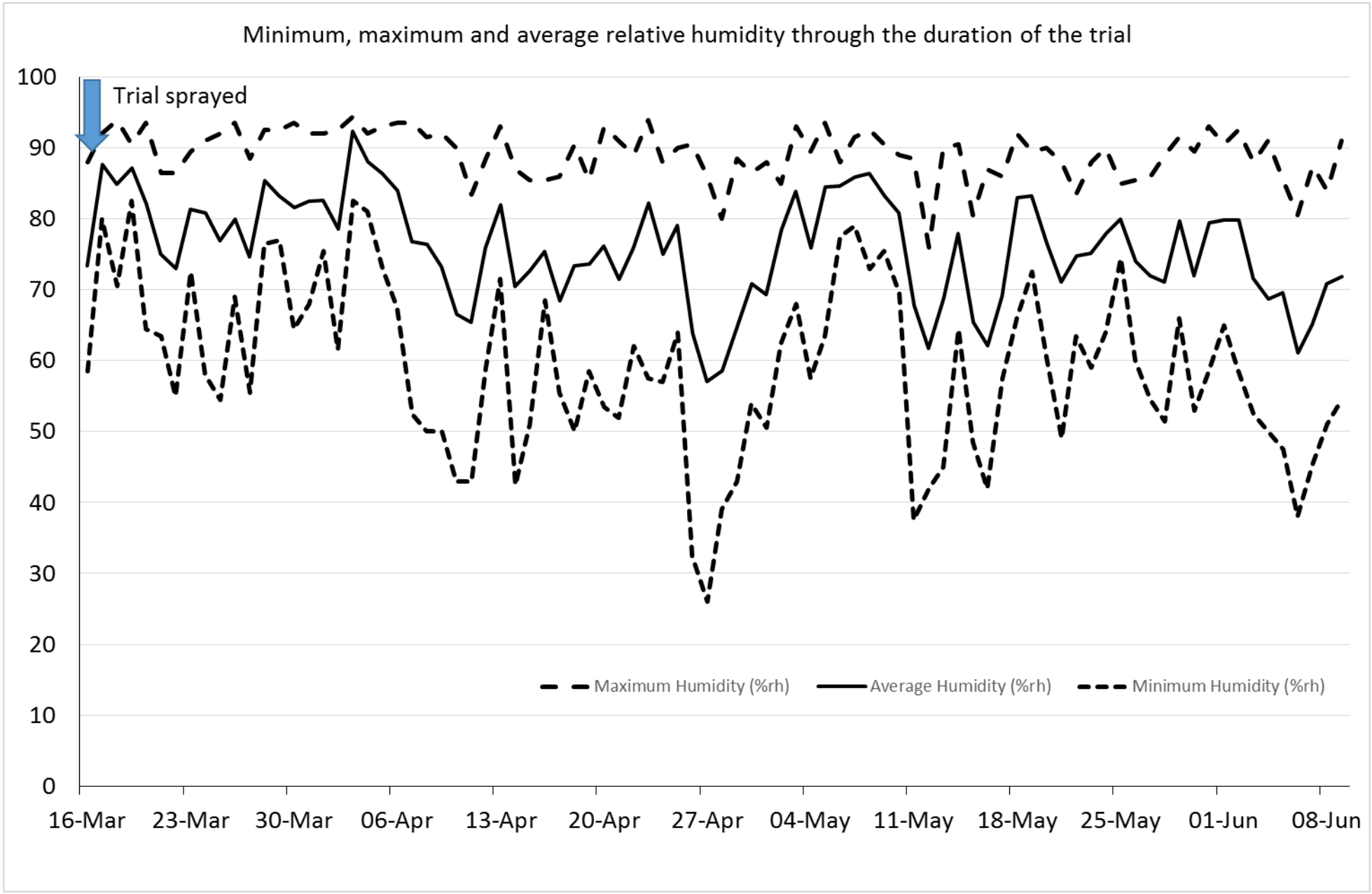
Site 1: Residual trial. Yorkshire, 2015



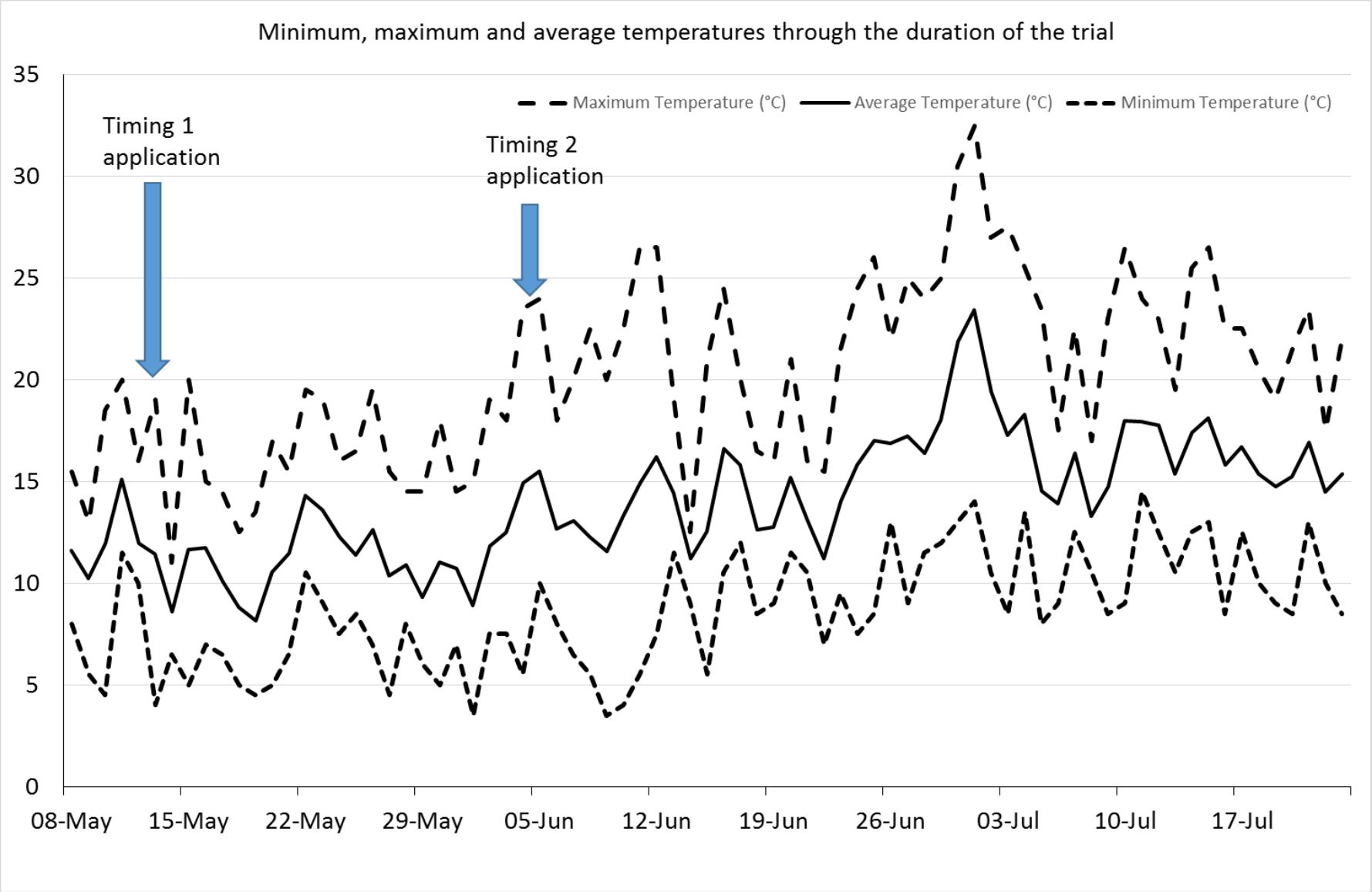


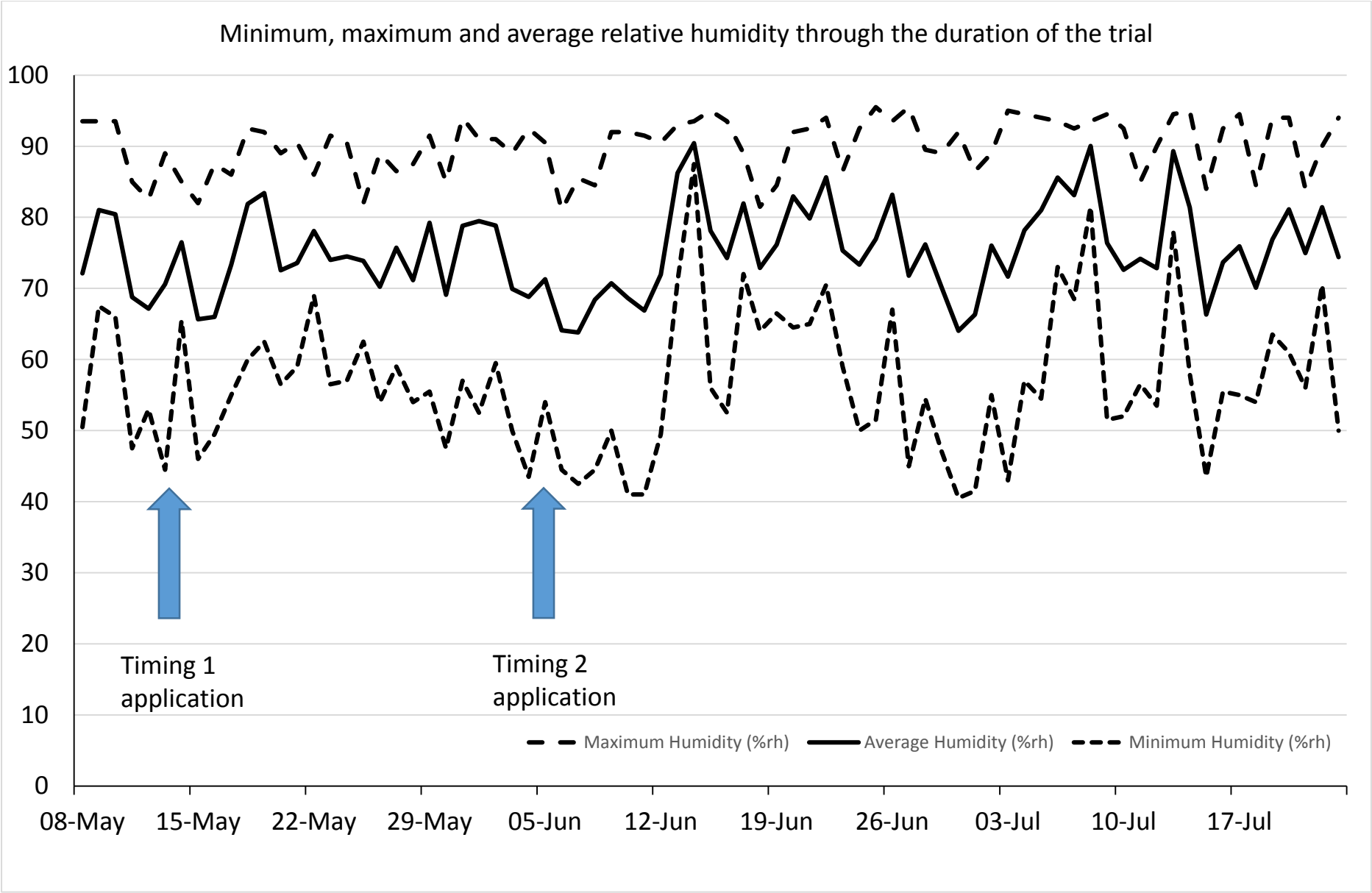
Site 2: Residual trial. Nottinghamshire, 2015





Site 3: Contacts trial. Yorkshire, 2015





Site 4 and 5: Contacts trials. Hampshire, 2015