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Electrical weeding in bush and cane fruit

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ADAS

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EXECUTIVE SUMMARY

In conventional horticultural production herbicides are coming under increasing pressure due to herbicide use restrictions and herbicide resistant weeds. In organic production weeding is labour intensive and increasingly expensive. The aim of this project was to test whether electrical weeding could be developed to provide a practical alternative solution for fruit growers.

It can be concluded from these trials that electrical weeding in bush and cane fruit is an effective method of weed control. Multiple electrical treatments were shown to be more effective at controlling weeds than one electrical treatment alone, with the machinery that was tested in this project. Slower travelling speeds are showing to improve efficacy of treatment, which may be due to increased contact time with the plant. This may be a more important factor for more persistent perennial weeds or weeds that are larger at the time of treatment. This aspect requires further investigation, particularly as the development of the machinery advances.

Control of creeping thistles is extremely effective using electrical treatments, but the detailed assessments on creeping thistle were restricted to one season only, which happened to be a very hot summer. This requires further investigation, including extending evaluation of the machinery to other perennial weeds such as docks and nettles.

An integrated weed management approach is required when controlling weeds in organic crops where the weed burden may be higher. Mowing is essential to ensure the weeds are at more manageable height and density before an electrical treatment is applied, especially when grasses are present. The weed control can then be more easily managed with electrical treatments alone. The electrical weeder does not disturb the soil seed bank, so it does not encouraging a further flush of weeds compared to mechanical weeders that move the soil stimulating weed emergence.

There has been no negative effects on soil health in these trials as measured by the CO_2 burst test indicating that soil microbes are present post-treatment. Further detail is required to fully understand the effect on the wider micro- and macro organisms including earthworms.

Electrical weeding is an effective and versatile option for weed control in bush and cane fruit crops. The grower has the flexibility to treat in weather conditions that a conventional sprayer would be unable to travel in, such as windy conditions and immediately after rain. These trials have shown extremely promising results for weed control and future testing can build on these initial findings and further validate the results.

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1 AIM

Bush and cane fruit producers face pressure to find effective non-chemical alternatives for weed control. In conventional production herbicides are coming under increasing pressure due to resistance developing in weeds and regulators and organisations restricting or banning the use of herbicides, given health and environmental concerns. In organic production weeding is labour intensive and increasingly expensive, both due to Brexit and the introduction of the living wage.

The aim of this project was to test whether Ubiqutek's electrical weeding technology could be developed to provide a practical solution for fruit growers by addressing the three main concerns of using electrical technology in this environment:

1) Long-term efficacy of weed control
2) Speed of weed control
3) Economics to be addressed by measuring fuel use and comparing to an alternative control method.

To this end Ubiqutek would adapt their existing technology that includes electrodes applying an electrical current to the weeds they come in contact with, to create a proof-of-concept tractor mounted solution to work in rows of bush and cane fruits. A further project aim was for Ubiqutek to identify an equipment partner to manufacture a market ready solution using Ubiqutek's core electrical transformation technology.

The project was designed at the outset to ensure that farmers input was embedded in the trial by setting it up as an Innovative Farmers field lab. The Innovative Farmers network provided opportunities for farmers to see the technology demonstrated in the field and to give direct feedback, it also allowed farmers to follow the progress of the trials.

2 MATERIALS AND METHODS

2.1 Approach

The Operational Group came together following an initial Innovative Farmers field lab on perennial weed management, which involved the electrical weeder as one of the treatments. Following this farmer-led research, it became clear that this new technology had potential and through the EIP programme there was an opportunity for further support to enable the technology to be developed towards a prototype trailed machine capable of being used in field crops. It was considered that fruit and vegetables offered the first opportunity for this technology, so the Soil Association was able, through its Farmer and Grower Board, to identify farmers interested in being involved in this Operational Group.

The resulting group represented multiple actors in the following roles:

Researcher/Technical	ADAS
Design and development	Ubiqutek
Trial coordination	Innovative Farmers network
Triallists	A.J. and C.I. Snell, Windmill Hill Farm
Growers	
Growers	A.J. and C.I. Snell, Windmill Hill Farm J&D Bevan and Son, Whitehouse Farm
Buyers	
Industry (Buyer)	Suntory/Lucozade
Other	
Environmental/NGO	Soil Association

From the operational group a steering group was formed which was chaired by the Soil Association as part of their role as project manager. The steering group included the triallist farmer, a researcher, equipment developer, industry representative, the Innovative Farmers field lab group coordinator, and the project manager. Project activities and milestones were facilitated and tracked via nine steering group meetings over the course of the project and email and phone contact between partners as necessary. Most of the meetings were held virtually, but the group found it useful to meet in person at the trial site as part of each year's trial planning.

It was determined early on that that all of the trials would take place at Windmill Hill Farm. This was partly for practical reasons regarding transport of the equipment which needed to come back and forth from Warwickshire to Herefordshire, but also because the Windmill Hill site provided both organically and conventionally grown crops for trialling.

An important part of the role of the operational group has been to ensure that other stakeholders are able to participate in the project and stay informed. This has been done by consulting with growers regarding the trial planning, inviting growers, farmers and advisors to attend our infield demos and give live feedback, and to stay informed about the project via the networks of each organisation, email newsletters, the Innovative Farmers portal, social media and presentations at industry and farming events.

2.2 Field testing year one (2018)

2.2.1 Trial location, crops and trial design

The trials were located on Windmill Hill farm, Harewood End, Herefordshire. The three 'focus' areas for treatments required crops of young and mature, conventional and organic currants. The varieties were chosen by the host farmer and recorded.

A total of four rows were required from an area of currant crop on each field ('focus area') with three alleyways in-between (Figure 1). Treatments were applied to **one side only** of an alleyway in the 0.5m wide herbicide strip at the base of the currant bushes. The ends of the selected treatment rows were marked with a flexi cane and flag. Treatments were applied to a 90m row length and then divided into three replicate sections of 30m in length each, which were also marked with a flexi cane. An untreated control area of 10m in length was marked out at the start of each row to use as a comparison to the treatments. The untreated control area was restricted to a smaller area than the treated plots so the host farmer was left with the minimum of weed burden in the field.

There were three 'focus areas', which were made up of the following crops:

I. Young conventional chuckleberries planted in polythene (*Fishpools bank field*)

II. Mature organic blackcurrants with no polythene (*Snows red barn field*)

III. Young organic blackcurrants planted in polythene (*Snows lawn field*)

A fourth focus area had been identified in a conventional mature blackcurrant crop. However the pre-emergent herbicide applied in early spring had been very successful at controlling the weeds, so it was decided that the low weed pressure in this crop would not be suitable for this trial.

2.2.2 Trial layout

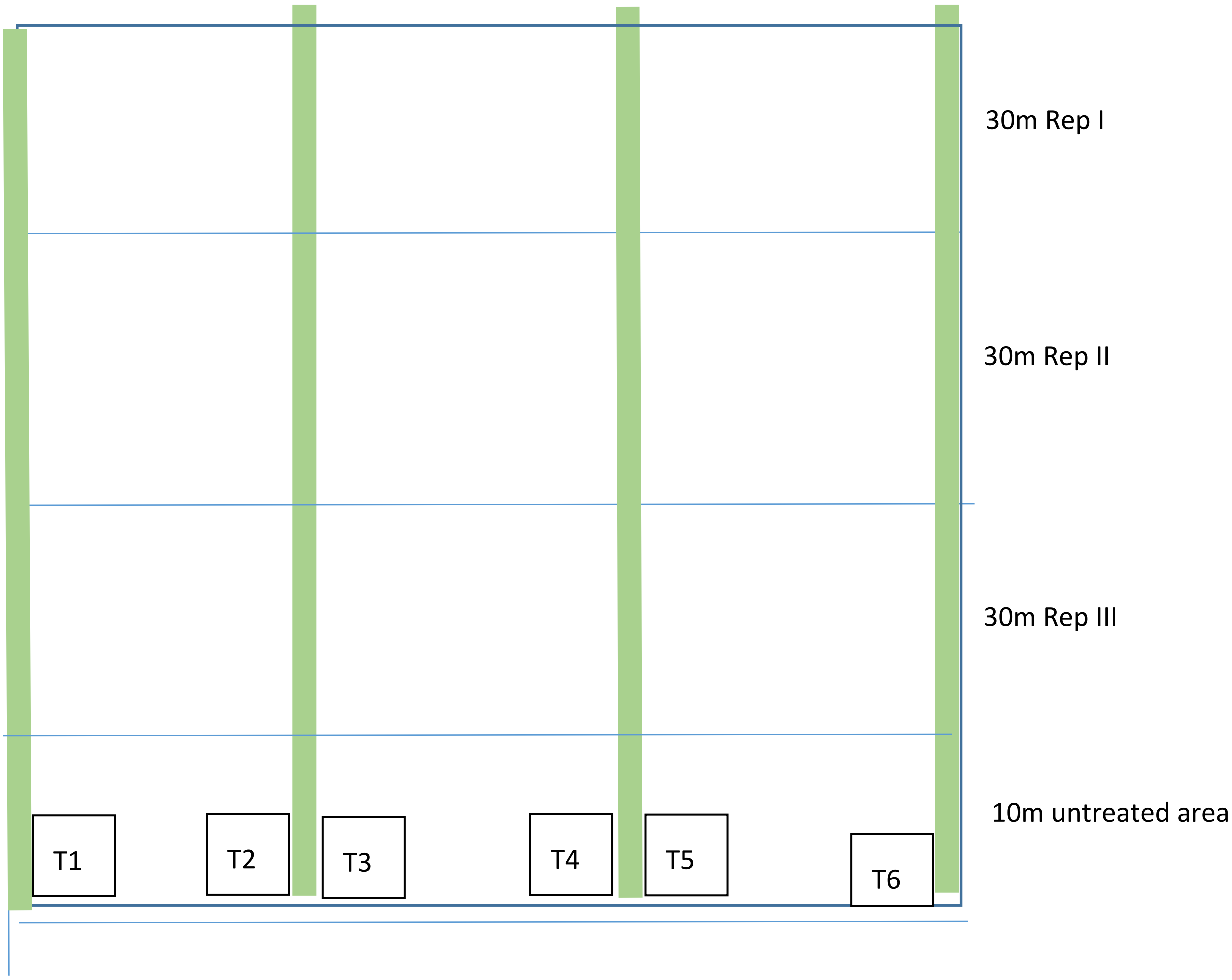

Figure 1. Trial layout. A total of four rows were required from an area of currant crop on each field, with three alleyways in-between. Treatments were applied to one side only of an alleyway.

2.2.3 Treatment list

In each of the three fields (focus areas) the following treatments (

Table 1) were applied to a length of currant row (one side of an alleyway for one treatment) measuring 100m (three replicated blocks x 30m + 10m untreated control area).

Table 1. Treatment number and timing

Treatment number	Electrical treatment application timings
T1	Speed 1 x 1 timing (Early May)
T2	Speed 1 x 2 timings (Early and Mid-May)
T3	Speed 1 x 3 timings (Early May, Mid-May, early June)
T4	Speed 1 x 1 timing (Early May)
T5	Speed 1 x 2 timings (Early and Mid-May)
T6	Speed 1 x 3 timings (Early May, Mid-May, early June)

Only one travelling speed (~3 kph) was possible for trials in 2018, so there was duplication (further replicates) with the treatments above grouping two treatments together (T1 & T4), (T2 & T5), (T3 & T6).

It was aimed that the application timings would be a minimum of two weeks apart, but were weather dependent.

2.2.4 Assessments

An assessment of weed cover (% cover) and a record of the main weed species present was done two days before the first treatment timing (2 May 2018). The crop rows for each treatment were walked and a visual assessment done. At the end of each treatment replicate a record of approximate % weed cover was made. The main weed species present was also recorded for each treatment row. The weed species were ranked from the most abundant to the least. Further assessments were then done on the following timings:

1. Two weeks post-treatment
2. One month post-treatment
3. Six months post-treatment (*where possible or relevant*)

A visual score of the weeds present giving a 0-10 rating was done (where 10 = live/healthy plants and 0= dead plants) in each treatment replicate block and untreated control area.

The chuckleberry crop was dominated by creeping thistle (*Cirsium arvense*) and it was decided to count all thistles in each block and treatment before treatment (May) and again in July. A percentage weed cover assessment were made in addition to the thistle counts.

2.2.5 Trial diary: treatment and assessment dates year one

The actual treatment and assessment dates are recorded in Table 2.

Table 2. Trial diary for treatments and assessments

Date	Activity
02/05/18	Trial plots marked out on 4 fields and pre-treatment assessments done on all fields. Photos taken. All thistles counted in all blocks in the chuckleberry crop.
04/05/18	1st electrical treatment (All blocks) (3 field sites).
16/05/18	2 week post-treatment assessment on three fields (All blocks). Photos taken
16/05/18	2nd electrical treatment (T2, T3, T5, T6) (3 field sites)
07/06/18	4 week post-treatment assessment on three fields (T1, T4). 2 week assessment on T2, T5.
07/06/18	3rd and final electrical treatment (T3, T6) (3 field sites)
28/06/18	Visual assessment of all treatments. 4 week post-treatment T2, T5, 2 week post-treatment T3, T6
05/07/18	Final assessment 4 weeks post-assessment T3, T6. All thistles counted in all blocks and plots on the chuckleberry crop.

2.3 Field testing Year two (2019)

The trial locations and design were the same as in testing year one (sections 2.1.1 and 2.1.2).

There were four 'focus areas' (fields) identified at the start of the season for testing. These were made up of the following fields/crops:

1) Young conventional chuckleberries (in polythene) - (*Fishpools bank field*)
2) Mature conventional redcurrants (no polythene) - (*Fishpools redcurrants field*)
3) Mature organic blackcurrants (no polythene) - (*Snows red barn field*)
4) Young blackcurrants in organic conversion (in polythene) - (*School field*)

2.3.1 Treatment list

In each of the four fields (focus areas) listed above the following treatments (Table 3) were intended to be applied to a length of currant row (one side of an alleyway for one treatment) measuring 95m (3m x 30m reps + 5m untreated area).

Table 3. Treatment list and applications timing year two.

Treatment number	Electrical treatment application timings
T1	**Speed 1** (2.1 kph) x 2 timing
T2	**Speed 1** (2.1 kph) x 1 timings
T3	**Speed 2** (3.2 kph) x 1 timings
T4	**Speed 2** (3.2 kph) x 2 timing
T5	**Speed 2** (3.2 kph) x 3 timings
T6	**Speed 1** (2.1 kph) x 3 timings

Application timings were weather dependent (the electrical treatments cannot be applied in the rain as it would be too dangerous), but it was aimed to be a minimum of two weeks apart. An untreated control area 5m in length was marked out at the start (and/or end) of each row to use as a comparison to the treatments. The untreated control area was reduced to 5m in year two to reduce the weed burden for the host farmer.

2.3.2 Treatment timings and travelling speeds

There were three different applications timings, of which timing two and timing three were repeated in exactly the same row as the previous treatment (e.g. T5 and T6 will have three electrical treatments over a period of approximately 6-8 weeks). For actual treatment timings see section 2.3.4.

There were two different travelling speeds. Speed one (T1, T2, T3) approximately 2 km/hour. Speed two (T4, T5, T6) approximately 4 km/hour. The recorded travelling speeds were 2.1 km/hour for speed one and 3.2 km/hour for speed two.

2.3.3 Assessments

Pre-treatment weed cover and species assessment

An assessment of weed cover (% cover) and a record of the main weed species present was done on the day of the first treatment timing. The selected crop rows for each treatment were walked and a visual assessment done. At the end of each treatment replicate a record of approximate % weed cover was made. The main weed species present (up to 10 species) were recorded for each treatment row and weed species were ranked from the most abundant to the least.

Post-treatment weed assessments: four occasions post-treatments

1. The day of treatment (one hour post-treatment)
2. Two weeks post-treatment
3. One month post-treatment
4. Two months post-treatment

Visual score of efficacy

A visual score of the weeds present giving a 0-10 rating were done (where 10 = live/healthy plants and 0= dead plants) in each treatment replicate and untreated control area.

2.3.4 Trial diary: treatment and assessment dates year two

The actual treatment and assessment dates are recorded in Table 4 . Field trials were due to commence at the start of May 2019 and the kit was functioning and tested in a field in Kineton on 26 April 2019. Unfortunately when the kit was in the field ready to test on 7 May 2019 there was a fault with a transformer, which had to then be sent back to the manufacturer to obtain a replacement part. These technical issues prevented the trials starting until the end of June 2019.

As the trials then started in late June 2019 the blackcurrant crop was maturing well and the fruits were forming on the bushes. A decision was made by the host grower not to treat any of the fields that had mature bushes as there potentially could have been some damage to the crop at this later growth stage resulting in fruit loss. Therefore the trial sites were reduced to one field (School's field) that had newly planted (small) bushes.

The steering group decided to try one final testing period in autumn 2019, due to the loss of trials in the spring/early summer 2019. The plan was to have two fields tested, including the newly planted blackcurrants and the chuckleberries. Testing was planned to commence again at the end of September and run for three timings (at least two weeks apart) if possible given the weather conditions and weed growth. A demonstration event was planned for the middle period of this testing programme (10 October 2019).

Table 4. Trial diary for treatments and assessments

Date	Activity
27/02/19	Trial sites agreed and four corner pegs marked
13/04/19	Trial sites clearly marked out and labelled so no herbicides would be applied
01/05/19	Pre-treatment weed assessments done on all fields. Photos taken.
07/05/19	1st electrical treatment attempted- technical issues with the kit. Testing stopped.
14/05/19	Site assessment
27/06/19	Pre-treatment weed assessment repeated. 1st electrical treatment (School field only). Fuel consumption measured Soil samples taken for Soil health testing
05/07/19	Treatment assessment (one-week post-treatment) – School field.
17/07/19	2nd electrical treatment – School field Treatment assessment – two weeks post-treatment. Further fuel consumption testing.
29/07/19	3rd assessment– School field (one-month post initial treatment)
26/09/19	Autumn testing began- Weed pre-treatment assessment (School field and Pond field) *Treatment timing one abandoned due to technical issues with the kit (low voltage)*
03/10/19	**Autumn 1st** electrical treatment timing completed
10/10/19	**Autumn 2nd** electrical testing – treatment timing two (School field) 1st Weed assessment one-week post-treatment Demo event
17/10/19	2nd weed assessment (two-weeks post treatment one/one-week post-treatment two)
01/11/19	3rd weed assessment (four weeks post 1st treatment)
21/11/19	4th and final weed assessment (two months post- 1st treatment) Field testing completed- plot canes removed

2.4 Fuel use measurement

A record of the fuel consumption was assessed on 27 June and 17 July 2019. A full tank of fuel was available at the start of the test. An area of known distance (900m long x 0.5m wide) in the surrounding field was travelled whilst the electrical treatment was running and then the amount of fuel used for a set area was calculated by topping the fuel tank back up to the top (by hand syringe or measuring cylinder). Ubiqutek carried out this assessment with ADAS staff assistance.

2.5 Soil health testing

Soil samples were taken from the field trials on 27 June 2019 for pH, **%** organic matter, nutrient analysis and microbial activity (measured by a CO_2 burst). One sample (three replicates) was taken from an electrically treated area and one (three replicates) from an untreated area in School field. Only the organic field (School field) site was sampled from and tested due to the overall cost of the soil analysis. It was considered that the organic field would also provide a good baseline for testing, as no conventional pesticides had been applied.

A second set of samples was then taken on 5 July 2019 (one-week post-treatment).

2.5.1 Sampling

A minimum of 500g of soil was required per sample, which was taken by using a hand-held soil core (18mm diameter). There were a total of nine samples:

- Three samples (reps) taken from untreated control area at the pre-treatment assessment timing
- Three samples (reps) taken 1 hour after the first electrical treatment timing
- Three samples (reps) taken one-week post-first electrical treatment timing

The samples were clearly labelled (

Table 5) by treatment number, sampling date and field name and were stored in cool boxes for transport and kept in a cold store/refrigerator until all samples had been taken. After the final collection all samples were sent to NRM for analytical requirements using the A500 soil health test. This test can measure the chemical aspects of the soil including soil pH, P, K, Mg, organic matter and the microbial activity measured as a CO_2 burst.

Table 5. Soil health test sample labelling

ADAS sample number	Location	Time of sampling
1	Untreated control rep 1	Pre-treatment assessment (27/06/19)
2	Untreated control rep 2	Pre-treatment assessment (27/06/19)
3	Untreated control rep 3	Pre-treatment assessment (27/06/19)
4	I hour post-treatment rep 1	Day of treatment – 1 hour post (27/06/19)
5	I hour post-treatment rep 2	Day of treatment – 1 hour post (27/06/19)
6	I hour post-treatment rep 3	Day of treatment – 1 hour post (27/06/19)
7	2-7 days post-treat rep 1	Post-treatment - 7 days post (05/07/19)
8	2-7 days post-treat rep 2	Post-treatment - 7 days post (05/07/19))
9	2-7 days post-treat rep 3	Post-treatment - 7 days post (05/07/19)

3 RESULTS AND OUTCOMES

3.1 Field trials year one (2018)

3.1.1 Creeping thistle count data summary in mature chuckleberries

The growth stage of the creeping thistles counted on 02 May 2018 (pre-treatment) ranged from newly emerged 2- leaf (BBCH 12) plants up to much larger plants of 50-100mm width (BBCH 31-32) (Figure 2).

Figure 2 Creeping thistles in the 'herbicide' strip at the base of the chuckleberries (left), creeping thistle example growth stage at the time of the first treatment (right)

The thistle count from the untreated control plots in both May (pre- treatment) and in July (post-all treatments) were meaned and the difference was expressed as the natural decline in thistle numbers with no treatments applied. For this particular trial there was a natural decline of 37% of thistles over the two month period which would represent the whole testing area. The weather conditions during this period of time were fairly dry and warm, resulting in natural senescence of the thistle plants and other weed species present.

The mean % reduction in the number of thistles in each treatment are shown in Table 6. These data show the mean % reduction in thistles in the treated areas of the trial compared to the untreated control plots on that particular assessment timing.

Table 6. The mean % reduction in the number of thistle plants compared to the untreated control for all treatments. The range is shown in italics.

	T1 & T4	**T2 & T5**	**T3 & T6**
Treatment	**One timing**	**Two timings**	**Three timings**
Mean % reduction	21.81	34.69	34.70
Range	*9.5 to 34%*	*29 to 40%*	*31 to 39%*

The results show that multiple treatment timings (T2 & T5, T3 & T6) provided a higher level of thistle control than just one treatment timing (T1 & T4). There was also a very large range of control levels across the replicates in T1 & T4, indicating that many thistles had either survived the first treatment (perhaps too small to be treated) and grown away or emerged after the first treatment. However on this occasion there was no differences in thistle control between two treatment timings (T2 & T5) and three treatment timings (T3 & T6). The range of results across the replicates was also more consistent in the treatments with multiple timings. The treatment blocks generally had an even and consistent level of thistles, however with an perennial weed they tended to be patchy.

3.1.2 Plant assessments in mature organic blackcurrants

The field of mature organic blackcurrants had been left un-mown for the trial purposes. The species present were therefore very large and fairly mature at the time of the first treatment on 02 May 2018.

The key species (main 10) present in order of abundance were: Annual grasses, nettle (*Urtica dioica*), docks (*Rumex* spp.), white clover (*Trifolium repens*), hogweed (*Heracleum sphondylium*), cleavers (*Galium aparine*), dandelions (*Taraxacum* spp.), forget-me-nots (*Myosotis arvensis*), creeping thistles (*Cirsium arvense*), scarlet pimpernel (*Anagallis arvensis*).

There was 100% weed cover (no bare ground) for all blocks (Table 7, Figure 3) on the pre-treatment assessment and all species were alive, but obviously at a range of different plant growth stages.

Table 7. The mean % weed cover for the 0.5m wide strip next to the crop pre-treatment on 02 May 2018.

	Untreated	T1 & T4	T2 & T5	T3 & T6
Mean % weed cover	100	100	100	100
Visual score*	10	10	10	10

(*10 = alive, 0= dead)

All plots were assessed again post-treatment on 16 May 2018 and 05 July 2018 and results showed no differences in any treatments, with 100% weed cover on both assessment timings.

The weed density of the un-mown strips were too thick for this particular equipment and travelling speed. The weed density was also thick in the mown organic crop, which mainly consisted of grass weed species. A thick sward of grass weeds were particularly challenging for the electrical weeding kit in trial year one, as the mechanical design of the electrodes was unsuitable for the weed level in this particular field.

3.1.3 Plant assessments in young organic blackcurrants

The field of young organic blackcurrants had been mown ahead of the trial starting. The species present were therefore much smaller and less mature at the time of the first treatment in May.

There were two main species that dominated the crop edge strips which were annual grasses and dandelions. The other species present in order of abundance were: cranesbill, plantain, clover, nettle, docks, cleavers, forget-me-nots, creeping thistles, scarlet pimpernel.

There was 95 to 100% weed cover for all blocks (

Table 8, Figure 3) on the pre-treatment assessment and all species were alive, but obviously at a range of different plant growth stages.

Table 8. The mean % weed cover for the 0.5m wide strip next to the crop pre-treatment on 02 May 2018.

	Untreated	T1 & T4	T2 & T5	T3 & T6
Mean % weed cover	95-100	95-100	95-100	95-100
Visual score*	10	10	10	10

(*10 = alive, 0= dead)

All plots were assessed again post-treatment on 16 May and 05 July 2018 and results shown no differences in any treatments, with 100% weed cover on both assessment timings. However on 16 May 2018 scorching of the grasses (Figure 4) and some knock-down of dandelions was noted. Recovery was then observed within four weeks post-treatment on all treatments.

Figure 3 Unmown mature organic blackcurrants (left) and mown young organic blackcurrants (right) showing 100% weed cover in the strip immediately below the bush and the alleyway.

Figure 4 Weed density on 16 May 2018 in the mature organic blackcurrants (left) and young organic blackcurrants (right).

3.2 Field testing year two

3.2.1 Weed assessments in organic newly planted blackcurrants

3.2.1.1 Pre-treatment assessments (spring/summer 2019)

A pre-treatment weed assessment was carried out on 01 May 2019 (Table 9) in a crop of newly established organic blackcurrants in School field. The main weed species present were swinecress (*Coronopus squamatus*), groundsel (*Senecio vulgaris),* dandelions (*Taraxacum officinale*), Scentless mayweed (*Tripleurospermum inodorum*), creeping thistles (*Cirsium arvense*), white clover (*Trifolium repens*), docks (*Rumex* spp.) and grasses. None of the rows had 100% ground (weed) cover in the strips next to the base of the bushes, as bare ground could be seen (Figure 5). The maximum weed cover was 60% (Table 9), with replicate three with the lowest weed cover.

Table 9. Pre-treatment weed assessment 01 May 2019. Percentage weed cover per treatment area and replication before any electrical treatment was applied.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Rep 1	60	50	50	60	50	40
Rep 2	20	30	30	60	50	30
Rep 3	20	40	30	30	30	30
Mean of replicates	***33.3***	***40.0***	***36.7***	***50.0***	***43.3***	***33.3***
Untreated	60	50	50	60	50	40

Figure 5. Newly established organic blackcurrants (School field). Right: Rep 2 showing the majority of the ground cover in the strip at the edge of the plastic as swinecress and mayweed, with approximately 50 % ground cover and bare ground visible.

Due to a technical issue with the electrical kit on 07 May 2019 the trial had to temporarily stop to wait for new parts to be delivered and fitted. The pre-treatment assessment was then repeated on the same trial plots on 27 June 2019, on the same day as the first electrical treatment. The weeds had grown over that eight week period and had covered the bare ground considerably (Table 10).

Table 10. Pre-treatment weed assessment 27 June 2019. Percentage weed cover per treatment and replication.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Rep 1	*90*	*90*	*85*	*100*	*100*	*100*
Rep 2	*70*	*80*	*85*	*100*	*90*	*100*
Rep 3	*80*	*90*	*85*	*100*	*90*	*90*
Mean of replicates	***80.0***	***86.7***	***85.0***	***100.0***	***93.3***	***96.7***
Untreated	*90*	*90*	*90*	*100*	*100*	*100*

3.2.1.2 Post treatment assessments

The first timing of electrical treatments was 27 June 2019. All plots were assessed one hour post-treatment and given a vigour score between 0-10 (where 10 = alive, 0=dead), all treatments (T1-T6) were given a vigour score of 5. Symptoms included brown/blackening of leaves (particularly in dock and dandelions) and the tips of the grass weeds turning black and shrivelling.

A second assessment was carried out one-week (it was considered that due to the lateness in the growing season that two weeks was too long) post-treatment on 05 July 2019.

Table 11. One-week post-treatment assessment on 05 July 2019. Level of weed control, expressed as a percentage reduction from the untreated control plots.

	Treatments					
	T1 (2.1 kph)	**T2 (2.1 kph)**	**T3 (3.2 kph)**	**T4 (3.2 kph)**	**T5 (3.2 kph)**	**T6 (2.1 kph)**
Rep 1	75	75	50	50	65	50
Rep 2	75	75	50	50	65	50
Rep 3	75	75	50	50	75	65
Mean of replicates	**75.0**	**75.0**	**50.0**	**50.0**	**68.3**	**55.0**

After just one treatment timing, treatments T1 and T2, at the slower travelling speed of 2.1 kph, gave a higher level of weed control (approximately a mean of 75% control) compared to the higher travelling speed of 3.2 kph (T3, T4, T5) (Table 11, Figure 6). However for T6, at the same travelling speed a lower level of weed control was observed (mean of 55% control). One of the electrodes was not working at treatment timing one, resulting in a striping through the treated area. It was noted that the swinecress was quite difficult to completely kill in areas of the plots where it was in very thick clumps, or where it was very small and low to the ground.

Figure 6. Post-treatment assessment on 05 July 2019. Left: Untreated control area, Right: T2 at a travelling speed of 2.1 kph.

A second electrical treatment was applied to treatments T1, T4, T5 and T6 on 17 July 2019 and weather conditions surrounding the treatments were generally dry and warm. These plots were assessed on 29 July 2019 (effectively one-month post-timing one and two weeks post-timing two) (Table 12). The level of weed control with two timings of electrical treatment compared to one timing alone was much higher, with a mean of 88.5% control from a speed of 2.1 kph (T1 & T6) and 89% control from a speed of 3.2 kph (T4 & T5). Therefore, after just two electrical treatments there was no clear difference in the travelling speeds tested at this assessment timing.

A third treatment timing was initially planned for these trials but due to the late starting date for treatment timing one it was too late in the plants natural growing season to include a third timing. Therefore T1 and T6 are the same, and T4 and T5 are the same.

Table 12. One-month post timing one and two-week post-timing two assessment on 29 July 2019. Level of weed control, expressed as a percentage reduction from the untreated control plots.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Speed	**2.1 kph**	**2.1 kph**	**3.2 kph**	**3.2 kph**	**3.2 kph**	**2.1 kph**
Timings	**Two**	**One**	**One**	**Two**	**Two**	**Two**
Rep 1	90	60	50	95	95	85
Rep 2	90	60	30	85	85	85
Rep 3	90	60	20	85	90	90
Mean of replicates	***90***	***60***	***33***	***88***	***90***	***87***

3.2.1.3 Creeping thistle assessment

There was a distinctive patch of creeping thistles in a crop row next to the trial area (approximately 20m in length) so a count of total number of thistles was done on 27 June 2019 and the patch was electrically treated at a travelling speed of 2.1 kph. The patch was re-assessed on 05 July 2019. There was a 77.3% reduction in thistles, with just one treatment timing (Figure 7). The weather conditions on 27 June 2019 were warm and dry and the subsequent two weeks before assessment were also warm, which appears to be beneficial for higher levels of weed control post-electrical treatment.

Figure 7. Control of creeping thistle with just one electrical treatment timing (27 June 2019). Left: Alive thistle (bottom- one electrode was not working so no electricity had been conducted) and dead thistles (top). Right: Very high levels of control of creeping thistle.

3.2.1.4 Autumn treatments

Due to the late start of the spring trials one final trial was carried out in autumn 2019 to test the kit further and obtain additional data. The trial plots had remained in the ground, so the trial continued on top of the plot that were treated in June and July 2019. Trial plots were assessed on 26 September 2019 ahead of an autumn electrical treatment (Table 13). There were fewer weeds present than in spring 2019, mainly due to the effective electrical treatments in the summer. An interesting observation was that one side of crop on ground that was the most shaded had more weeds present than the side that had less shading. The crop rows ran east-west, so the northern side of the rows was in the shade for the majority of the day and it was obvious that more moisture was present and more grass was green on that side (Figure 8). The main weed species were grasses, which in some areas had spread from the central mown grass strip between the crop rows. Other weeds included clover, creeping thistles, dandelions, mayweed and docks (in the strip at the base of the bushes and in the mown grass strip between rows).

Table 13. Pre-treatment assessment on 26 September 2019. Percentage weed cover per treatment and replication.

	Previous treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Speed	**2.1 kph**	**2.1 kph**	**3.2 kph**	**3.2 kph**	**3.2 kph**	**2.1 kph**
Timings	**Two**	**One**	**One**	**Two**	**Two**	**Two**
Rep 1	75	40	75	40	60	60
Rep 2	75	40	75	40	60	60
Rep 3	75	40	75	40	60	60
Mean of replicates	***75***	***40***	***75***	***40***	***60***	***60***

	
Left: more grass on the shaded edge of the crop row.	Right: Northern side of the crop row (on the left of the photo) had more grass than the southern edge (right in the photo) where the previous electrical treatments were still visible.

Figure 8. Pre-treatment assessment 26 September 2019.

The first electrical treatment for the autumn was applied on 03 October 2019. The treatment was attempted on 26 September 2019 but a technical issue with the voltage flow resulted in the kit requiring some further maintenance. Ground conditions were very wet at this time which may have resulted in some of the technical problems encountered. The second electrical timing was 10 October 2019. On the first timing (03 October) all treatment strips (T1-T6) had one electrical treatment and the travelling speeds varied from the summer trials (Table 14). On the second timing (10 October 2019) T3-T6 had a treatment, at the varied travelling speeds (Table 14). Weather conditions were generally wet pre- and post- both October treatments.

Table 14. The revised autumn treatment list for School field (Young blackcurrants in organic conversion (in polythene)) treatments.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Speed	**2.1 kph**	**3.2 kph**	**2.1 kph**	**3.2 kph**	**3.2 kph**	**2.1 kph**
Timings	**One**	**One**	**Two**	**Two**	**Two**	**Two**

After just one electrical treatment the slower travelling speed of 2.1 kph gave the highest mean level of weed control of 70% control, compared to that of 47% at the higher speed of 3.2 kph (Table 15).

Table 15. Post-treatment assessment on 10 October 2019 (One-week post timing one). Level of weed control, expressed as a percentage reduction from the untreated control plots.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Speed	**2.1 kph**	**3.2 kph**	**2.1 kph**	**3.2 kph**	**3.2 kph**	**2.1 kph**
Timings	**One**	**One**	**Two**	**Two**	**Two**	**Two**
Rep 1	75	40	75	40	60	60
Rep 2	75	40	75	40	60	60
Rep 3	75	40	75	40	60	60
Mean of replicates	***75***	***40***	***75***	***40***	***60***	***60***

The post-treatment assessment on 17 October 2019 (two weeks post timing one and one week post timing two) showed that the two electrical treatments (T3-T6) gave a higher levels of weed control compared to one pass only (Table 16), again with the slower travelling speed showing the highest control.

Table 16. Post-treatment assessment on 17 October 2019 (Two-weeks post timing one & one week post timing two). Level of weed control, expressed as a percentage reduction from the untreated control plots.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Speed	**2.1 kph**	**3.2 kph**	**2.1 kph**	**3.2 kph**	**3.2 kph**	**2.1 kph**
Timings	**One**	**One**	**Two**	**Two**	**Two**	**Two**
Rep 1	50	40	70	50	75	75
Rep 2	50	40	70	50	75	75
Rep 3	50	40	70	50	75	75
Mean of replicates	***50***	***40***	***70***	***50***	***75***	***75***

The trial plots were re-assessed for a final time on 07 November 2019 (five weeks post-treatment timing one and on-month post timing two). The levels of weed control was extremely difficult to assess at this assessment. The results tend to show that weed control had significantly reduced at this assessment timing (Table 17), with no clear differences visible between any treatment timings or speeds. However, this is likely due to the time of year of treating and assessment as there had been some growth through late September and October, but the plants were naturally dying back after this period. The weather conditions were colder and wetter. This was therefore not the ideal time of year to be testing the machinery, as it was very difficult to compare to an untreated control area that was not actively growing. Autumn control had been effective when the plants were still actively growing in late September early October.

Table 17. Post-treatment assessment on 07 November 2019 (Five weeks post timing one & one-month post timing two). Level of weed control, expressed as a percentage reduction from the untreated control plots.

	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Speed	**2.1 kph**	**3.2 kph**	**2.1 kph**	**3.2 kph**	**3.2 kph**	**2.1 kph**
Timings	**One**	**One**	**Two**	**Two**	**Two**	**Two**
Rep 1	15	10	15	10	15	15
Rep 2	15	10	15	10	15	15
Rep 3	15	10	15	10	15	15
Mean of replicates	***15***	***10***	***15***	***10***	***15***	***15***

At the same time as the demo event on 10 October 2019 the host farmer used a mechanical weeder in the same field on crop rows adjacent to the trials. The weeder had a rotovating wheel that moved the soil surface, effectively uprooting and burying any weeds.

Left: Crop area that had been mechanically rotavated showing new seedling emergence.

Right: Crop area that had electrical treatments showing very few weeds emerging and virtually a weed-free strip.

Figure 9. Observation on 12 December 2019.

Trial plot area was observed again for a final time on 12 December 2019. The area that had been mechanically rotovated had a flush of new weed seedling emerging, due to the soil disturbance of that technique. However, in the trial plot area that had only had electrical treatments with no soil disturbance the soil surface was virtually free of weeds (Figure 9).

3.3 Fuel use assessment

To evaluate the economic aspects of electrical weeding compared to other conventional weed control options an assessment of fuel consumption was carried out on 27 June 2019 and 15 June 2019 (Table 18). In both cases the same procedure was followed with the exception that in June the fuel was measured by volume and in July it was measured by weight. In both instances the tractor was always refuelled in the same location to ensure the fuel level measurement was consistent across all re-fill scenarios. A visual feature in the tractor filling neck was used as the fill point and diesel from the same batch was used for both trials.

Strips measuring 3 x 900m were marked out (one for June (single side operation) and two for July (single and dual sided operation)). All strips were broadly similar in terms of vegetative load at the point at which they were identified on the 27 June 2019.

For the June trial the tractor was filled and driven along the first of the 900m trial strips and back to the filling point loaded with the equipment but without the power take off (PTO) running. The fuel consumed was then volumetrically measured and recorded as the baseline motive fuel cost. The tractor returned to the start of the first test strip, the driver engaged the power take off drive but kept the electrical weeding equipment off. The first 900m test strip was re-driven. At the end the power take off was 'disconnected' and the tractor returned to the filling point. The fuel consumed was volumetrically measured to give the additional fuel cost as a result of loading the transmission with the electrical weeding equipment (baseline transmission). The final test in the June trial was to return to the start of the first test strip, re-engage the power take off drive, enable the equipment and drive the 900m test strip treating all the way. At the end of the 900m the equipment and power take off was shut down and the tractor returned to the fill point where the final volumetric fuel measurement was made. By taking away the motive and transmission fuel cost the fuel use for the treatment cycle could be calculated as could the cost per hectare.

In July, other than measuring fuel use by weight the only difference was that two electrical treatment cycles were measured. In addition to single side operation trial both the baseline motive and baseline transmission fuel use values were calculated on test strip two. The third test strip was used solely for the dual sided operation fuel use trial.

The PTO only test was performed to provide a comparison to herbicide spraying in which a PTO is used to spray. From the data it is clear to see that the fuel consumption using electricity is like that of the PTO/herbicide. A conclusion can be made that the fuel costs between the two technologies are comparable, although electricity does not then have the added consumable cost of the spray.

Table 18. Fuel use measurements and results (June and July 2019)

Measurement - June	Units	Tractor	PTO	Electricity
Distance travelled	m	900	900	900
Width treated	m	0.5	0.5	0.5
Area travelled	m²	450	450	450
Area travelled	ha	0.045	0.045	0.045
Time	hr	0.40	0.45	0.40
Diesel used	l	1.0	2.0	1.9
Diesel per hectare	l/ha	22.2	44.4	41.1
Cost diesel	€/L diesel	0.6	0.6	0.6
Cost diesel per ha	€/ha	13.3	26.7	24.7

Measurement - July	Units	PTO	Electricity	Electricity
Distance travelled	m	900	900	900
Width treated	m	0.5	0.5	1
Area travelled	m²	450	450	900
Area travelled	ha	0.045	0.045	0.090
Time	hr	0.37	0.47	0.50
Diesel used	l	1.7	1.8	2.6
Diesel per hectare	l/ha	38.6	39.7	28.7
Cost diesel	€/L diesel	0.6	0.6	0.6
Cost diesel per ha	€/ha	23.1	23.8	17.2

3.4 Soil health testing results

The microbial activity in the soil was measured by a CO_2 burst test in an untreated trial area compared to an electrically treated area, one hour post-treatment and one-week post-treatment. The results were generally consistent between trial replicates. The mean results per treatment (Table 19) show there was no different between the CO_2 level in the untreated control area and the one-hour post electrical treatment, as they were both recorded as moderate (CO_2 burst is measured in mg/kg, with the following ranges: low 15-25, moderate 25-45, high 75-105. The whole scale ranges from very low >15 to very high 105-123). The results for the one-week post treatment showed a higher level of CO_2. This may be due to the fact that plant material treated in the plots had died back and was releasing carbon into the soil below, potentially increasing microbial activity.

Table 19. Results of the soil health test assessing the level of microbes in the soil by a CO_2 burst test.

Sample tested	CO_2 burst Category
Untreated rep 1	*moderate*
Untreated rep 2	*moderate*
Untreated rep 3	*moderate*
Mode Untreated	**moderate**
Treated rep 1	*moderate*
Treated rep 2	*high*
Treated rep 3	*moderate*
Mode treated	**moderate**
Post-7 days rep 1	*high*
Post 7 days rep 2	*high*
Post 7 days rep 3	*high*
Mode post-7 days	**high**

4 OVERVIEW OF MACHINE DEVELOPMENT

4.1 Treatment system development, year one

The bush and cane fruit weeding platform was an iterative development starting with a simple concept based around a single mechanical housing affixed using a rear mounted 3 point linkage to an agricultural vehicle. Internally the enclosure housed the mechanical / electrical conversion, control and distribution systems (comprising a belt driven 40KVA alternator, single phase (230VAC – 5kVAC) 6.5KVA transformer, E-Stop and treatment applicators and two manually adjustable (height / protrusion) electrode treatment booms). In this instance the high voltage treatment system was connected between all the active electrodes and the 2 earth return jockey wheels (Figure 10).

Figure 10. Year one equipment build and test.

Testing noted low efficacy largely as a result of: the single transformer architecture (one transformer feeding all applicators simultaneously) and intermittent electrode contact resulting from the fixed beam approach (tractor roll had a dramatic effect on electrode height especially at the boom ends); the difficulty of having the treatment applicators behind the driver and not in line of sight; damage caused by the earthing wheels especially in soft / water soaked areas.

Single transformer architectures present technical challenges when multiple applicators are in contact with separate weeds simultaneously. Under such circumstances one weed (treatment circuit) will drag the transformer output down as it transitions through the breakdown phase and current in that treatment circuit increases. This drag down reduces the voltage available / presented to the rest of the applicator array and reduces the treatment voltage available to other weeds also in contact with applicator electrodes unless the tractor unit can counter the load passed back from the electrical chain into the mechanical one. A reduction in treatment voltage increases the time required for breakdown to occur which on a moving platform increases the likelihood of a no treatment scenario.

Owing to the belt drive approach (which offers benefits in protecting the tractor transmission system against mechanical shock resultant from sudden and significant electrical events), the increase in mechanical loading resultant from drag down caused slippage in the belt drive and so the tractor unit was unable to counter the issue of reducing treatment voltage effectively.

4.2 Treatment system development, year two

Year two would focus upon: moving the treatment electrodes forward of the driver; reducing the array position variability (height / mechanical slip); changing to a multiple transformer architecture; minimising the effect of tractor roll on weed / electrode contact; and improving the mechanical / electrical power transmission path to eliminate belt slip.

The system developed for year two utilised the same electrode mechanisms but improved on the initial implementation providing enhanced mechanical / electrical performance through a PTO coupled alternator mounted in rear unit which also housed the control and safety systems. The new front unit supported the applicator arrays / electrodes and high voltage conversion elements. Although developed for dual sided working the year two machine was assembled electrically for single sided trial use and included 4, 3 phase (415VAC - 5kVAC) 3kVA transformers which provided 12 individual treatment / return pairs. The earth return wheels used in the first generation machine were replaced with pneumatic tyre equivalents and the return portion of the electrical circuit was moved to electrodes on the treatment array.

Electrode deployment was simplified owing to the single array structure with integrated bush lifter on the outer most end and a manual pulley arrangement for completing raising and lowering actions (Figure 11).

Figure 11. Year two equipment open day demonstrations

Whilst a significant improvement on the initial build the second generation variant suffered from electrode skip and array bounce. The bounce (whole treatment array) occurred naturally as a result of the tractors movement across a working field and was a function of the gravity only type deployment mechanism. This bounce resulted in skipping (electrodes bouncing up and away from their intended ground contact position). Notably skipping increased (impacting the achieved efficacy) with decreasing levels of vegetative cover as the electrode running surface became more randomised (lumps of earths / small stones / etc.). Given the revised electrode architecture (treatment electrode on the front array carrier and the return electrode situated on the rear array carrier) when electrodes of any electrical pair skipped, either the front, rear or both simultaneously, treatment would be interrupted as a complete electrical circuit was no longer available for the current to flow around the treatment circuit. Notably the limited dynamic (whilst moving) adjustability (height and pitch) of the treatment array position / orientation with respect to the ground was a major factor in the efficacies recorded as this limited the drivers ability to adjust the arrays height and pitch in relation to the ever changing field surface.

Restrictions on being able to dynamically position the electrode array resulted in the bush lifter digging in and wrapping around the underside of the electrode array on several occasions, lifting the outer treatment electrodes clear of the herbicide strips being treated. In addition the lack of an electrode lock mechanism required a separate mechanical restraint structure to be installed to stop each and every electrode swinging freely during transportation.

Introducing the three phase electrical distribution system generated cross phase arcing issues because of the proximity of electrodes at differing electrical potentials. Whilst the electrodes of any single phase were laterally isolated from those of the other two, as much a practically possible, there was a practical limit owing to the array size to which physical isolation could be achieved.

Finally and from an operability perspective the primary operator hand trigger (energy on / off) was difficult to hold / use whilst simultaneously driving a tractor within the planting confines of commercial berries. In a similar manner the cab control box, to which the hand trigger attached, was difficult to securely locate within the reach of the driver and without compromising access to the other levers and switches already present in the cab.

4.3 Treatment system development, year three

The third development of the bush and cane fruit weeding platform aimed to: 1) improve efficacy; 2) address the practical deployment issues noted during the year two trials. Principally the development resolved the following:

1) Full hydraulic deployment (array up / down, array in / out, electrode height, electrode pitch;
2) Dual sided operation;
3) Structural bush lifter;
4) Footswitch energy on / off control;
5) Means of extending primary safety circuit to additional cut out / sensing switches;
6) Cab mounted control panel (E-stop, safety reset, on / off key, Hydraulic controls);
7) Option for operator feedback, instructions, touch screen control, power monitoring.

Figure 12. Year three equipment field testing

The year three trial equipment offered a more practical in-field platform (Figure 12) , with all aspects of the machines deployment and management being controlled by the driver through two human machine interfaces, (the control panel and footswitch). The hydraulically adjustable top-link was not however, a permanent feature of the machine owing simply to the significant variance in ram size required by differing front link mechanisms / designs. But the hydraulic and control system design ensured fitting one of the correct length was a simple process, (only two hydraulic quick-fit connectors), once the ram was physically inserted in place of the standard fixed top-link. It could then be controlled through the control panel without any additional configuration.

The machine enabled, through a single control panel, full and independent (left / right) hydraulic control over array deployment (up / down), electrode height adjustment (150 mm) implemented as a function of the primary array up / down controls and array extension (in / out) to accommodate planting width variance (200 mm per side). Both arrays were fitted with structural bush lifters. Once authorised energy on / off was controlled through a foot switch which the driver could position in a location which was best suited for the existing tractor controls.

Electrically the entire machine was redesigned to ensure that all control elements were in one of three, easy to remove Ingress protected electrical enclosures. This ensured the addition or removal of electrical functions could be achieved simply by replacing or modifying the circuits in an existing box. The boxes themselves were interconnected by cables which included spare circuits to ensure future improvements could be implemented in a cost-effective manner.

Summer trials of the machine indicated improved control and in-row usability however the equipment was more susceptible to shock loading the tractor transmission when subjected to a significant electrical load. Because the number of active transformers had doubled the effective electrical loading increased by four times meaning there was less motive reserve in the tractors transmission to absorb the increase. This was especially evident in the saturated soils especially when encountering large weeds (docks / thistle) which naturally absorb significant amounts of treatment energy and resulted in several spiralled power take off shafts. This was eventually (post trials, October 2019) resolved using a slip-clutch which allowed the tractor transmission to continually drive even if the instantaneous (shock) electro-mechanical load appeared as a significant breaking force at the equipment end of the power take of shaft. Using more capable power take off shaft resulted in stalled tractors and a safety system resets.

4.4 Key system specifications

Table 20 Key systems specifications for the electrical weeding kit tested

Parameter	***Value***
Output voltage (Vrms)	5000 per phase
Power system input voltage (Vrms)	415 (3 phase)
Number of transformer outputs / Power per output (KVA)	24 / 1
Nominal outputs per side	12
Electrode width (mm)	70
Electrode array width (mm)	704
Maximum system width (mm)	2685
Minimum system width (mm)	3091
Estimated System weight, front / rear / cables / panel (kg)	1250 / 450 / 10 / 2

5 CONCLUSIONS

The trials were challenging at times due to technical issues with the machinery, but as this was a proof-of-concept trial is was expected that issues may occur and would require resolving during the testing periods. The project team worked together to ensure the maximum amount of testing could be delivered to produce as much data as possible within the project duration.

The main conclusions from these trials is that electrical weeding in bush and cane fruit is an effective method of weed control. Multiple electrical treatments are more effective at controlling weeds than one electrical treatment alone, with the machinery that was tested in this project. Slower travelling speeds are showing to improve efficacy of treatment, which may be due to contact time with the plant. This may be a more important factor for more persistent perennial weeds or weeds that are larger at the time of treatment. This aspect requires further investigation, particularly if the machinery development advances.

Control of creeping thistles is extremely effective using electrical treatments. The detailed assessments on creeping thistle were restricted to one season only, which happened to be a very hot summer, so this requires further investigation. This can also be extended to other perennial weeds such as docks and nettles.

In the organic blackcurrant crops tested there were lots grasses (mainly creeping bent) in the strip at the base of the blackcurrants that were creeping in from the central pathway. It can be concluded from these trials that mowing is essential to ensure the weeds are at more manageable height and density before an electrical treatment is applied. The weed control can then be more easily managed with electrical treatments alone. This would be an ideal integrated weed management approach.

The electrical weeder does not disturb the soil seed bank, so it does not encourage a further flush of weeds when compared to mechanical weeders that move the soil. However, an integrated weed management approach could use both machines; a flush of weeds could be stimulated by the mechanical treatment that could then be treated by an electrical treatment to ultimately reduce the weed seed bank.

The results from these trials indicate that fuel consumption is no higher than a conventional tractor that may be used for mowing or mechanically treating weeds or a tractor-mounted conventional sprayer. Therefore electrical treatments would be comparable to other weed control options.

There has been no negative effects on soil health in these trials as measured by the CO_2 burst test indicating that soil microbes are present post-treatment. Further detail is required to fully understand the effect on the wider micro- and macro organisms.

Electrical weeding is an effective and versatile option for weed control in bush and cane fruit crops. The grower has the flexibility to treat in weather conditions that a conventional sprayer would be unable to travel in, such as windy conditions and immediately after rain. These trials have shown extremely promising results for weed control and future testing can build on these initial findings and further validate the results.

6 OUTCOMES

6.1 Future needs

The field trials tested in 2018 and 2019 have resulted in a number of key questions for future testing requirements. These include:

1) **Speed of travel**, which would be most effectively be tested on a field scale basis and not just within smaller field plots. These trials have indicated that a slower travelling speed is more effective, but results were limited to one field year and the two travelling speeds tested were very close together.

2) The **number of passes** required for the highest level of weed control. This may best be assessed directly by a grower loaning the machinery and testing from the very beginning to the very end of their normal growing season. They would then have the flexibility to apply a treatment whenever they planned and would not be restricted by trial design or movement of machinery from a different geographic location. This could still be monitored and assessed in conjunction with a project team, but would be more of a farmer-led approach.

(3) **Integration of electrical weeding with other weed control methods**. These could include a combination of chemical and non-chemical control options. The timing of mowing and or mechanical treatments in conjunction with the electrical treatment to achieve maximum weed control should be investigated.

(4) **Benefits of no soil movement**- Anecdotal evidence of the benefits of no soil movement from the electrical weeder compared to a mechanical weeder were observed in year two, but no data were collected. This requires further investigation to quantify the theory, requiring seedling emergence assessments and longer term benefits.

(5) **Weather conditions** around the time of treatments were not formally recorded in these trials, but only observed and reported. Detailed temperature and rainfall records could be taken, pre-, during and post-treatments to help interpret the trial results from specific treatments. Variation of control may be expected in different temperatures and moisture levels as they will have an effect on general plant growth. The moisture levels within the plant cells may have an effect on the efficacy of the movement of the electrical current through the plant tissues, which has not been investigated in this project.

(6) **Soil biology** – More detailed investigation on the soil microbes, insects and other species such as earthworms could be assessed to ensure electrical treatments were having no detrimental effects. Studies were limited to soil microbes in only one season in this project.

(7) **Other crops –** the potential for this technology to be used in other crops needs further investigation. From these trial results it is easy to see that other fruit crops could use this method. The method of application would need to be adapted for other horticultural and arable crops such as row crops including vegetables and cereals, but the electrode design may require minimal adaptations. There is a huge potential to extend this technology into grassland weed control, but perhaps using a system similar to a weed wiper bar, but applying an electrical current rather than glyphosate. This would be especially valuable if glyphosate were to be lost to the industry due to political reasons or herbicide resistance in the future.

6.2 How the project built bridges between research and the agricultural industry

Using the Innovative Farmers model gets farmers working directly with researchers to collaborate in designing the on farm trial. The triallist and other growers are involved in the on farm trial design meetings to ensure that their input is incorporated. By opening the trial up via the public field lab demonstration events there is also an effective feedback loop between the researcher and the farmers.

6.3 The additional benefits that have arisen from the delivery of the project

The potential for this technology to be used in other crops is vast. Attendance at the demo events from growers of crops other than blackcurrants demonstrates the interest from UK growers. It is easy to see that other fruit crops could use this method, which may include orchards and vineyards in the UK and other perennial tree fruit crops or vines worldwide. The method of application would need to be adapted for other horticultural and arable crops such as row crops including vegetables and cereals, but the electrode design may require minimal adaptations. There is a huge potential to extend this technology into grassland weed control, but perhaps using a system similar to a weed wiper bar, but applying an electrical current rather than glyphosate. This would be especially valuable if glyphosate were to be lost to the industry due to political reasons or herbicide resistance in the future.

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8 APPENDIX

8.1 Dissemination events and materials

8.1.1 In field demonstration events

	Event	**Attendees**
	Electrical Weeding for Bush and Cane Fruit Year 1 in field demonstration and planning meeting, 14/11/17	13
	Electrical Weeding for Bush and Cane Fruit Year 1 in field demonstration meeting, 16/05/18	24
	Electrical Weeding for Bush and Cane Fruit Year 2 in field demonstration meeting, 10/10/19	17

8.1.2 Dissemination events

Event	Participation
World Agritech Summit, London, 2018	A. Diprose, Ubiqutek - presentation
Oxford Real Farming Conference 2018	R. Diprose, Ubiqutek - presentation, facilitated by Jerry Alford, Soil Association
World Agri-Tech Innovation Summit in San Francisco, 2018	A. Diprose, Ubiqutek - presentation
Innovative Farmers Network Day, 2018	Jerry Alford - workshop panelist
ADAS Crop protection and Crop Physiology teams planning meeting, 2018	Lynn Tatnell, ADAS
Lucozade Ribena Suntory (LRS) Blackcurrant Grower Conference, 2018	Harriet Prosser, LRS - presented
Welsh Organic producers meeting, 2019	Jerry Alford
Oxford Real Farming Conference 2019	Lynn Tatnell, ADAS – Presenter and panelist
Innovative Farmers top fruit field lab meeting, 2019	Soil Association, Ben Raskin, Soil Association
Telford Energy and Rural Business, 2019	Soil Association, stall
Groundswell 2019	Lynn Tatnell, ADAS - panelist, Jerry Alford, Soil Association
The Changing Face of Weed Management - 2019	Organised by Soil Association and Royal Agricultural University, Lynn Tatnell, ADAS – Presenter and panelist, Jerry Alford, Soil Association, S. Jelley, Ubiqutek
AHDB blackcurrant grower Knowledge Exchange event - 2019	Harriet Prosser, LRS

8.1.3 Press and print dissemination

Media	Item title
Direct Driller Magazine: Issue 8, p22-23, January 2020	Innovative Farmers - Farmer led research answering farmer's questions
Organic Farming Magazine: Issue 132, p12-13, Winter 2020	Electric weeding
Innovative Farmers 2020 Field Lab Guide, p11-12, January 2020	Can electrical weeding effectively control weeds in bush and cane fruit farms?
BBC Farming Today: 21/10/19 Future of weed control; electric weeder; pink apples	Future of weed control; electric weeder; pink apples
Horticulture Week, 01/11/2019	Can electrical equipment replace sprays to tackle weeds?
Waitrose Magazine, December 2019	Weed Zapper offers hope for eco farmers
AHDB Grower Magazine, Jun/July 2018	Electric Avenues
The Fruit Grower: July 2018, p41-43	Electricity takes charge against weeds
ADAS Technical Update (March 2018)	Alternative weed control in bush and cane fruit: Electrical weeding
Farmers Weekly - 08/06/18	Grower-led trials tackle key challenges for arable farms

AHDB Grower

The Fruit Grower

BBC Farming Today

8.1.4 Social media

The trial and events have been disseminated by partners via social and email newsletters, some examples follow:

Innovative Farmers @IFarmers · Oct 11

Here's a close up of the #electrical weeding machine in action. The aim of the project was to achieve fast moving effective zapping of weeds (perinnial or otherwise) to act as a viable alternative to herbicide or mechanical weeding. innovativefarmers.org/field-lab?id=1...

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Lynn Tatnell
@lynntatnell1

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Please come and view electrical weed control in bush & cane fruit at our Herefordshire demo day eventbrite.co.uk/e/electrical-w ..., @ADASGroup @RootWave @SoilAssociation @IFarmers @AntSnell #IWM

7:54 am - 18 Apr 2019

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