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ControlInRoad
Controlling the spread of invasive species with innovative methods in road construction and maintenance

Field trials

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Controlling the spread of invasive species with innovative methods in road construction and maintenance

Field trials 2018/2019
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Executive summary

To evaluate alternative methods for the control of invasive alien plants (IAPs), field trials were conducted in 2018 and 2019.

***Ambrosia artemisiifolia* (ragweed)** was used as an example of an annual seed producing plant species. In 2018, the Electroherb™ method was tested for the first time to control ragweed. The results from this preliminary test were quite promising as Electroherb™ showed a high efficacy on ragweed where individuals were completely controlled. In 2019, a field trial was set up in Burgenland by the local road authorities. The following standard and alternative methods were tested: manual removal, mowing, Electroherb™, pelargonic acid (1x and 2x), infrared, hot foam and competitive seed mixture. All tested methods except the competitive seed mixture showed a reduction in plant density, while the treatments using Electroherb™, hot foam, infrared and pelargonic acid with two applications showed the best results. Most of the methods destroyed all plant species on the site. Hot foam, when applied with a lance represents a more targeted method, which may be an advantage on sites where valuable native vegetation exists.

***Fallopia* spp. (knotweed)** was used as a model for a rhizomatous perennial plant species. In 2018 and 2019 the Electroherb™ method was applied in three different locations in Burgenland to control *Fallopia* spp. populations. In addition, in 2019 hot foam was tested as a second alternative method in one of the three locations.

The results from the *Fallopia* spp. test showed, that during the two years a reduction in plant size could be achieved when compared to the untreated plants. The density of the plants was significantly reduced in one of the three locations, whereas in the other two locations a reduction in plant density and plant size was observed. However, no complete eradication could be achieved. In the second year, the hot foam method from Weedingtech was additionally tested. Similar results were obtained as with the Electroherb™ method. The results revealed, that both methods have potential to control *Fallopia* spp. Electroherb™ is still in the development phase. New equipment for the work on road verges is needed and investment is high. The working speed of 3 km/h is not the speed that would be required for daily maintenance of large areas, but the Electroherb™ method can be applied to hot spots of *Fallopia* spp. infestation. The hot foam method has the advantage, that it can be used on sites that vehicles cannot access, such as riversides or walls of buildings. The hot foam machines have a lance that reaches out up to 60 m. The hot foam is produced from plant oils and sugars, without palm oil, and it has been approved in Europe for the use in organic agriculture.

The results from the *Fallopia* spp. treatments are based on two years of trials. The working effort to control *Fallopia* spp. will likely decrease from year to year (because the number and viability of the remaining plants are likely to decline progressively) if the treatments using Electroherb™ or hot foam are continuously applied at least two times (in late spring and autumn) a year. The advantage of both tested alternative methods is, if small plants (below 30 cm) are treated, no plant material is cut, and therefore, no plant material can be spread to other places. After both treatments (Electroherb™ and hot foam) the plants dried out, the amount of plant waste was reduced and thus no special waste removal is required.

Both field trials represent examples for specific groups of plants (annual and perennial). The efficiency of the best alternatives can potentially be transferred to other species of these two plant groups. The results of the *Fallopia* spp. trials using Electroherb™ and hot foam may also be used against *Heracleum mantegazzianum* and other perennial plants, but the timing of the treatment needs to be adapted.

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1 Introduction

Invasive alien plants (IAPs) represent one of the main threats to biodiversity and related ecosystems and they may also have adverse impacts on human health and the economy. In this respect, roadsides play an important role in facilitating the spread of IAPs by providing a habitat for their establishment as well as serving as corridors for spread. Decision-makers considering whether to build, improve, and maintain roads are facing the need to implement preventive measures and to adapt or develop control strategies for IAPs. In the last number of years, the need for new and effective methods against IAPs has become more and more urgent.

Most of the methods to control plants have been developed for use in agriculture or for hard paved surfaces. No specific research and development has been conducted on methods to control plants on road verges. To test if such methods that have been developed for agricultural settings, are also applicable for the control of invasive plants along roadsides, different trials were conducted.

In 2018 and 2019 field trials were performed with the two plants, common ragweed (*Ambrosia artemisiifolia)* and knotweed (*Fallopia* spp.). Both plants occur regularly along roadsides throughout Europe and were identified as important IAPs that call for attention and control. Control options (manual, mechanical, or chemical) for these species are available, however, their control is still challenging due to the biological and ecological characteristics of these plants. This current study investigated the use of different methods, conventional as well as alternative ones for the control of both plants. The results provide the base for a subsequent cost-benefit analysis that was the subject of work package 5 and will be reported separately.

2 Material and Methods

2.1 Ragweed trial

2.1.1 *Field layout*

The field trial was carried out near Eisenstadt in the federal state of Burgenland, Austria (47°51'35.0"N 16°36'46.3"E). The field was prepared by the local road maintenance depot in March 2019. In total, 10 plots with a size of 3 m x 5 m were set up and each plot was sown with ragweed seeds collected in the years 2016 to 2017. The ragweed seeds were evenly spread on all plots in March 2019. In one plot, together with the ragweed seeds, *Festuca rubra* seeds (a mix of the three varieties Smaragd, Raisa and Melitta) were sown. In another plot, a grass mixture was sown, which is commonly used for the greening of road verges in Burgenland (see Table 1). In each plot, five 1.20 m x 1.20 m monitoring patches were marked. The sample sites could not be randomized because of using a tractor in the Electroherb^{TM} method. Based on the size of the tractor plus the applicator no random block design could be applied to not destroy other treatments. In each sample the number of ragweed plants was counted twice before the treatment started. The experiment had to be stopped before flowering to prevent the spread of any seed. Therefore, seeds were not counted in the experiment. The *Festuca* grass mix did not germinate due to a period of exceptionally dry weather in spring 2019. Therefore, these plots were omitted from the analysis.

2.1.2 *Treatments*

The following standard and alternative treatments were conducted, and data were compared to those of an untreated control, as shown in Table 1 (see also Figures 1 and 2).

Mowing was done as proposed by Milakovic et al. (2016) with the first mowing shortly before male flowering followed by a subsequent cut before the onset of new flowers on the re-sprouting lateral shoots. For the assessment of the effect of the different treatments a non-destructive method was used. After the treatments, the number of ragweed plants was counted at several time points in 2019 (31st of July, 7th of August, 17th of August and 6th of September; six weeks after the treatments). Figures from the final counting were used for statistical analysis.

Table 1: Overview of the treatments used in the field trial for the control of *Ambrosia artemisiifolia*, and their application dates

Treatment	**Method**	**First treatment**	**Second treatment**
Untreated control			
Removal by hand	Manual removal	23.07.2019	
Mowing	Clipping with a hedge clipper	23.07.2019	16.08.2019
Electroherb™	Zasso	23.07.2019	
Pelargonic acid (1x)	Beloukha (recommended dose)	23.07.2019	
Pelargonic acid (2x)	Beloukha (recommended dose)	23.07.2019	31.07.2019
Infrared (Brühwiler)	InfraWeeder Junior Butan B2R	23.07.2019	
Hot foam (Weedingtech)	Foamstream M600	30.08.2019	
Competitive seed mixture	HR170 (HESA, Austria)	08.03.2019 (sowing date)	
Festuca rubra seed mixture*	Varieties: Smaragd, Raisa and Melitta	08.03.2019 (sowing date)	

* This treatment could not be evaluated and was taken out of the further analysis.

Figure 1: Electroherb™ (left) and hot foam (right) used for the control of ragweed

Figure 2: Manual removal (left) and InfraWeeder (right) used for the control of ragweed

2.1.3 *Analysis*

For the analysis, the final number of ragweed plants six weeks after treatment was divided by the number of ragweed plants at the beginning of the treatments and multiplied with 100 to obtain the effectiveness of each treatment. An effectiveness of 100% means a complete control of ragweed.

The data was analysed using ANOVA in the car package of the computer program R and the Dunnett test in the car package, as “post-hoc” test (https://www.r-project.org/) to compare the treatments with the control. The confidence interval of 0.95 was set. Graphics were prepared using the package ggplot2 in R.

2.2 Fallopia spp. trial

2.2.1 *Field layout*

Three different locations for the knotweed treatment with Electroherb™ were used. The locations were situated in completely different habitats. The first location was a roadside close to the Wulka river (Forchtenstein, Austria; N47° 43.42897 E16° 22.76677), the second location was a dirt road (Forchtenstein, Austria; N47° 43.465 E16° 22.77333) and the third location was a former vineyard (Schützen am Gebirge, Austria; N47° 51.55833 E16° 37.96833). In Figure 3, all three locations containing the established, perennial knotweed populations are shown. The first location was a large infestation where only a stripe of 3 m x 30 m was used for the test. The second and the third location had a size of about 40 m^2 and 100 m^2, respectively. Location 3 was later found and it took some time to obtain the permission of the owner. Therefore, location 3 was included at a later stage.

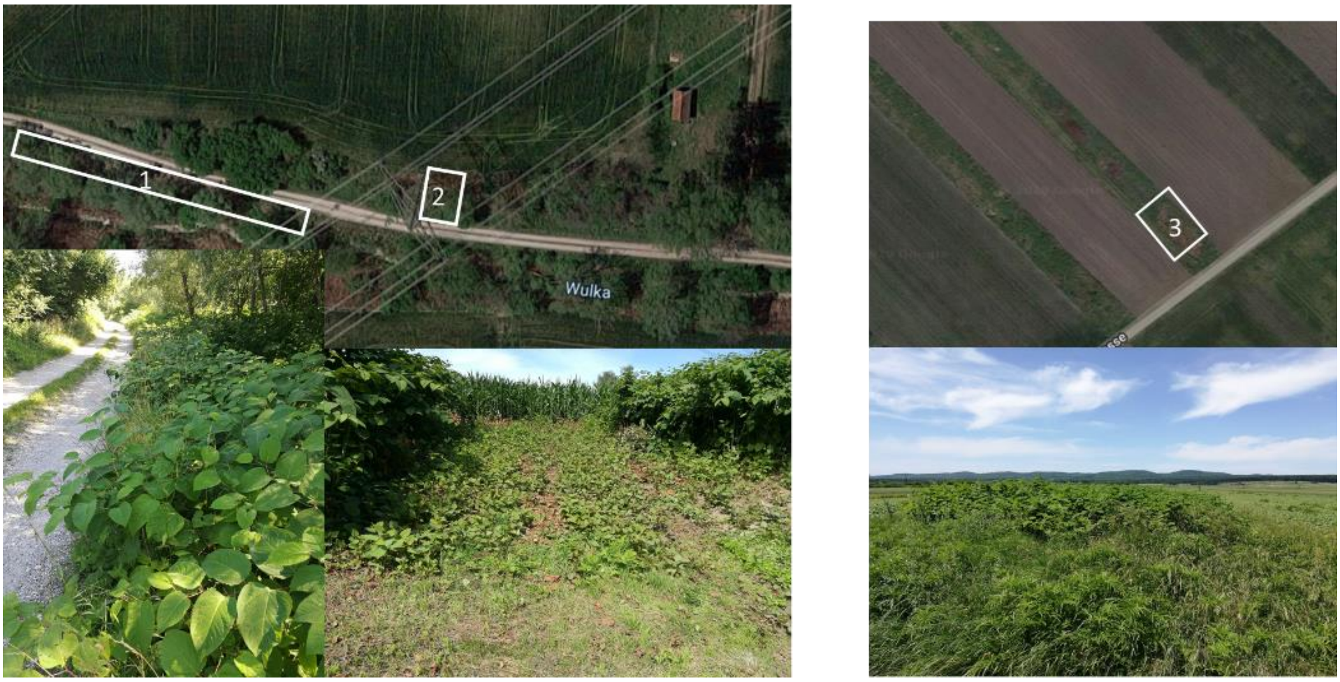

Figure 3: Knotweed populations along the river Wulka (1), and the dirt road (2) in Forchtenstein/Austria (left) and on a former vineyard (3) in Schützen am Gebirge/Austria (right)

2.2.2 *Treatments*

2.2.2.1 Electroherb™

The treatments with the Electroherb™ device were carried out in 2018 and 2019 (Table 2, Figure 4). Before each treatment, the *Fallopia* spp. populations were mulched with exception of location 2 in 2018. Mulching was necessary as the treatment with Electroherb™ is most efficient when the vegetation has a height of approximately 30 cm. The detailed application is summarized in Table 2. The mulched material was left on the field.

For the Electroherb™ application different instruments were used in both years. In 2018, a prototype was used. This prototype was further developed and a new version was used in 2019. In 2018, the populations were treated with an electricity output of 3 kW / electrode with 10 active electrodes (total power output equalled 30 kW) having a size of 12.5 cm, and equals 120 cm working width (with an applicator unit having a total width of 250 cm at a speed of 2 km/h. The first application (July) in 2019 with Electroherb™ was executed with another applicator unit. This applicator was designed for the electrophysical weed control on motorways, as it has a reduced applicator width of 120 cm. The population was treated with 3 kW per electrode, with 6 active electrodes having a size of 20 cm (which resulted in total power output of 18 kW), at a reduced driving speed of 1 km/h (Table 2). The second application (September) in 2019 was executed with another applicator unit (XPower). An area applicator with a width of 300 cm was used. This system was equipped with 24 electrodes, of which each was supplied with 3 kW (which resulted in a total power output of 72 kW) at a driving speed of 3 km/h.

Fallopia spp. plants were treated twice each year. These two treatment times are based on the physiology of the plant as recommended by Jones et al. (2018). In summer, all the resources are allocated from the rhizomes to the aboveground tissue. In autumn, the resources are transported into the rhizomes before winter dormancy begins. Treatments in late spring and fall aim to reduce the vitality of the rhizomes by reducing the accumulation of resources over the years. Location 3 was treated in 2018 only in autumn, because the location was not available at the beginning of the field trials.

Table 2: Overview of the treatments with Electroherb™ for the control of *Fallopia* spp.

Location	Year	Date of treatment/output	Date of treatment/output
1	2018	04.07. two times 30kW with 2 km/h	11.09. two times 30 kW with 2 km/h
	2019	23.07. one-time 18 kW with 1 km/h	23.09. one-time 72kW with 3 km/h
2	2018	04.07.* one-time 30 kW with 2 km/h	11.09. two times 30 kW with 2 km/h
	2019	23.07. one time, 18 kW with 1 km/h	23.09. one-time 72kW with 3 km/h
3	2018	No treatment	12.09. one time 30 kW with 2 km/h
	2019	23.07. one time 18 kW with 1 km/h	23.09. one-time 72kW with 3km/h

* not mulched before treatment

Figure 4: Zasso device in 2018 treating knotweed at location 2 (left) and the new device at location 3 in the year 2019 (right)

2.2.2.2 Hot foam

In 2019, at the location 3, the Weedingtech technology using the Foamstream M600 was tested against *Fallopia* spp. The test was performed on the same field that was used in the year before for the Electroherb™ treatment in 2018 but not in 2019 (see previous chapter). The number of stems was counted in each plot just before mulching. Five plots, each of 1 m^2 in size, were treated in total with 200 liter water to produce the foam. The hot foam was applied with a lance directly to the stems near the ground (Figure 5). The hot foam was applied on 18^{th} of September. The plots were inspected after two and four weeks and the stems in each plot were counted.

Figure 5: Application of hot foam on knotweed plants directly to the stems near the ground.

2.2.3 *Analysis*

The number of stems before each treatment was counted in 1 m^2 plots in five replications. Before the second treatment, the height of the stems was grouped in three classes; >50 cm, >20 cm, <20 cm. The data were visualized using the R package ggplot 2. The data set was checked for the interaction between treatment and location using a two-way ANOVA in package car. If the significant interaction between treatment and location was significant, each location was analysed separately applying Kruskal–Wallis Test, which is a nonparametric test. If the Kruskal-Wallis test was significant, a pairwise Mann–Whitney U-tests for multiple comparisons was performed as a post-hoc test.

2.3 *Non-target effects of Electroherb™*

The survival rate of the fruit fly *Drosophila suzukii* was tested during the field application of Electroherb™ on the ragweed trial in 2019 in order to evaluate non-targets effects.

To that end, pupae of *Drosophila suzukii* were added to grapes. The grapes were placed into the soil among the plots which were treated with Electroherb™. After the treatment the grapes were placed in a closed container and the number of hatched flies was counted. The numbers of flies hatched were compared to the numbers of flies hatched without the Electroherb™ treatment (control). The same procedure was applied in another experiment with hot water (not in this field trial). The tests were performed by Micheal Krutzler and Günter Brader (AIT Austrian Institute of Technology).

3 Results of the ragweed field trial

The ragweed plants were counted right before and six weeks after the treatments. The efficacy of the treatments was calculated in each sub-plot. An overview of the result of the different treatments on ragweed is given in Figure 6. All treatments were compared to the control. The treatments with Electroherb^{TM}, infrared, hot foam, pelargonic acid 2x, und uprooting showed a significantly higher efficiency compared to the control (P<0.001). The treatments pelargonic acid 1x, grass mix and mowing did not differ from the control.

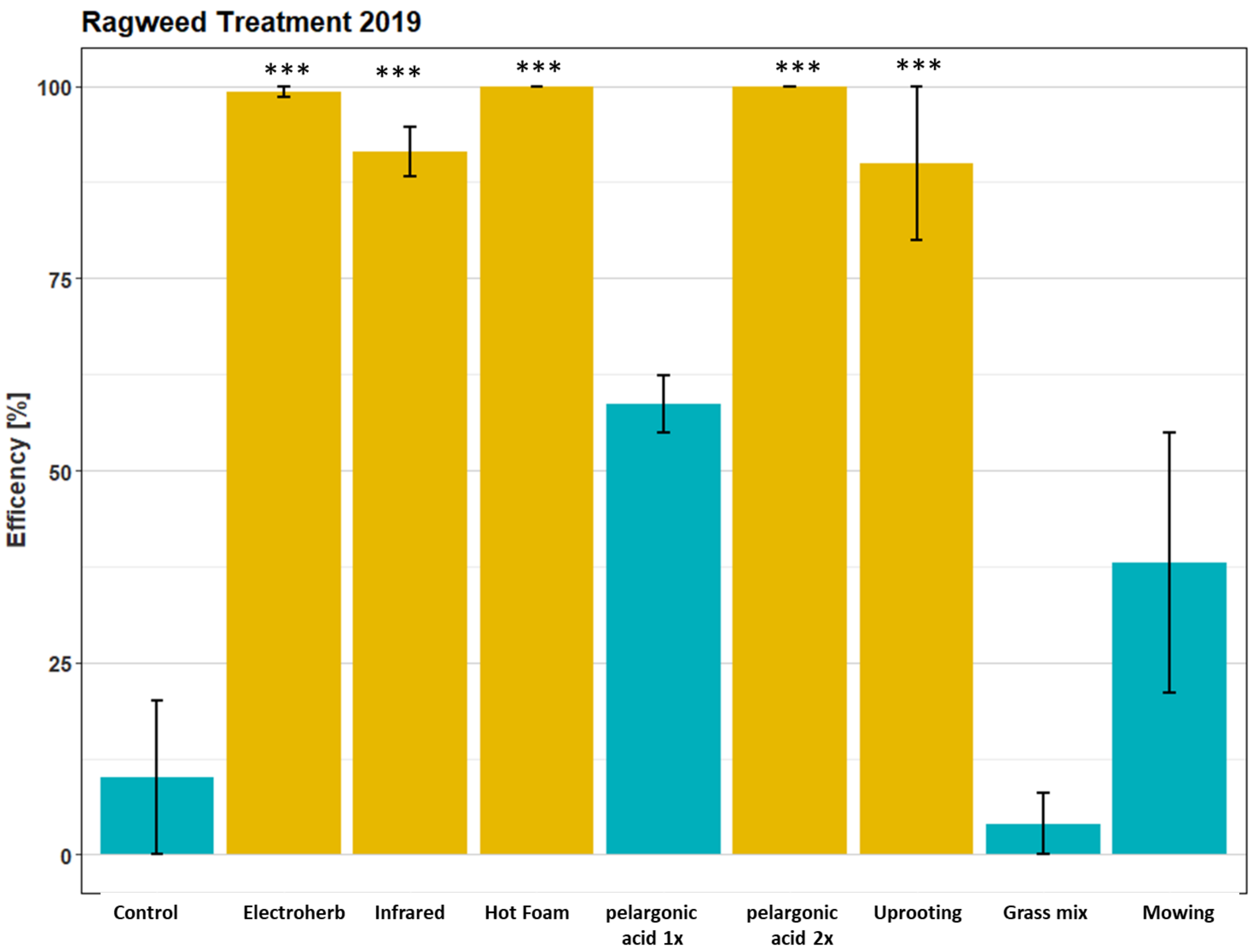

Figure 6: Results from the field trial 2019 using different methods for the control of ragweed. The results from the treatments were compared to the control. Error bars indicate the standard error. *** indicate a significance of P<0.001.

3.1.1 *Electroherb™*

The Electroherb™ treatment was highly efficient in reducing ragweed populations and showed comparable effects to the hot foam, infrared and the pelargonic acid 2x treatment (Figures 6, 7). However, it has to be considered that Electroherb™ is a treatment of the whole field, whereas hot foam and pelargonic acid can applied to individual plants and are therefore more targeted than Electroherb™. The Electroherb™ method was the fastest method because of the involvement of a tractor with a 120 cm working width.

After treatment with Electroherb™, only two surviving plants were observed three weeks after treatment. Nonetheless, the possibility exists that more seeds may have germinated after the treatment was finished. This was observed also in 2018.

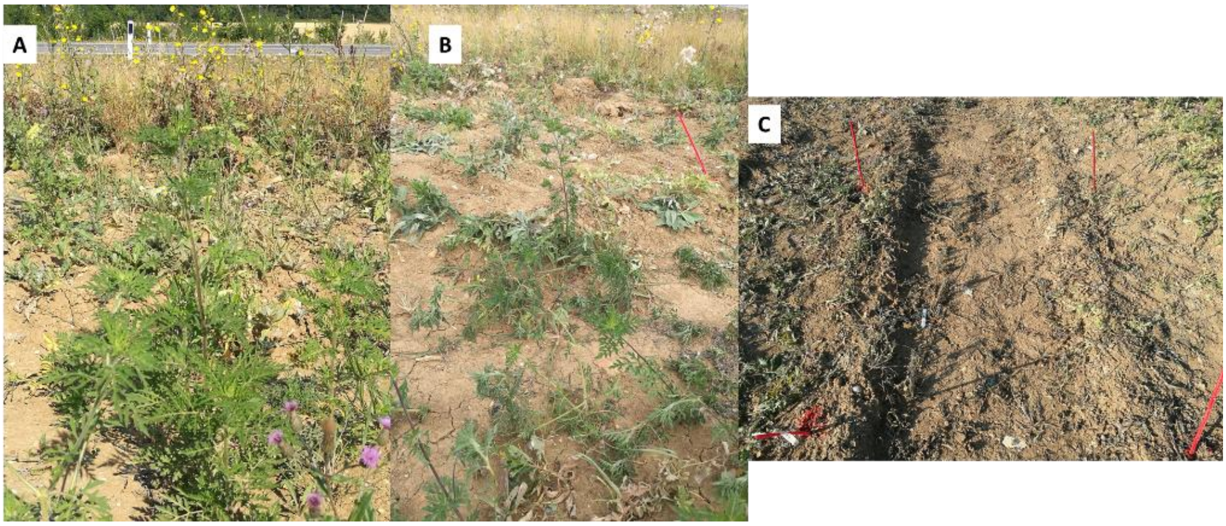

Figure 7: Treatment of ragweed using Electroherb™. Plants before treatment (A), directly after treatment (B) and one week later (C).

3.1.2 *Infrared*

Using infrared was effective in destroying the plants (Figure 6 and 8). However, about 20% of individuals started to re-sprout after one week (Figure 8). Some of the re-sprouts developed completely new plants (Figure 8B), while others died during the evaluation period. After the treatments 8% of all initial plants survived. All regrown and surviving plants developed male flowers at the end of the experiment (six weeks after the treatment). Therefore, a second treatment is recommended to control regrown individuals. For this experiment, a hand-hold device (Figure 2) was used because of the uneven ground, but the company Brühwiler has other wheeled models with three burning jets and a capacity to treat 300 to 500 m^2/hour. However, using these devices, the application would not be selective anymore.

Figure 8: Treatment of ragweed using infrared: (A) one week and (B) two weeks after treatment.

3.1.3 *Hot foam*

Hot foam was applied directly onto the stems (Figure 9) near the ground to well-grown plants. Every plant was treated separately because of the large size of the plants. Consequently, the time needed for the application was quite significant (about 2 min / plant). Smaller plants can be treated faster. No regrowth of the plants was observed (Figure 9C) and the roots were completely dead one week after treatment.

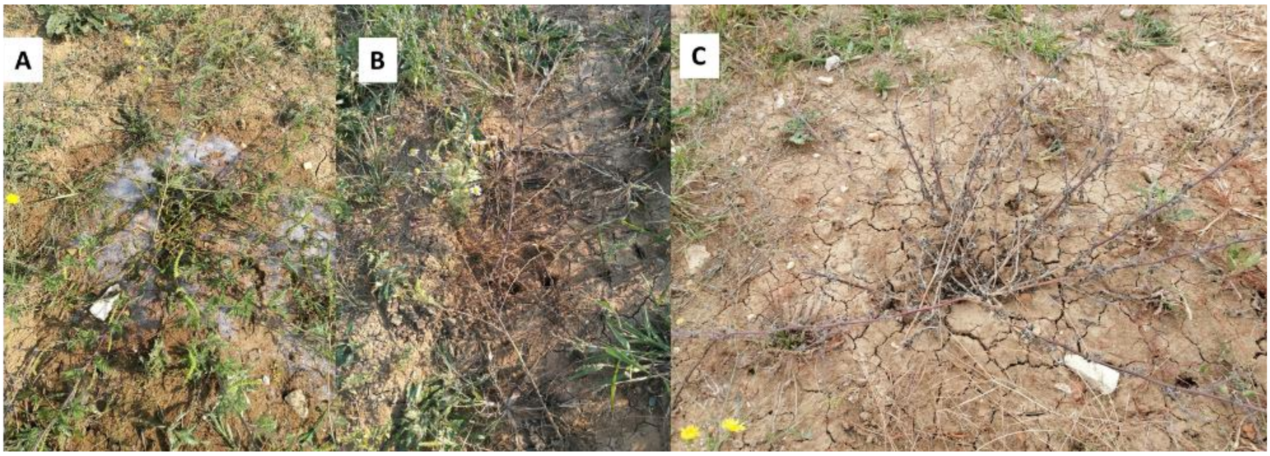

Figure 9: Treatment of ragweed using hot foam. Plants start to wilt immediately after the application (A). Individuals after 7 hours (B) and after one week (C).

3.1.4 *Pelargonic acid (Beloukha)*

The plants were affected differently after one application of pelargonic acid. In Figure 10, different symptoms are shown, (A) plants show only symptoms on the tip, (B) and (C) plants are completely killed and (D) plants starting to develop new shoots from the stem after one week after treatment. After only one application on ragweed around 40% of the plants survived and were able to flower. However, the treatment with pelargonic acid showed very good results when two subsequent applications were made (Figure 6) as all plants died.

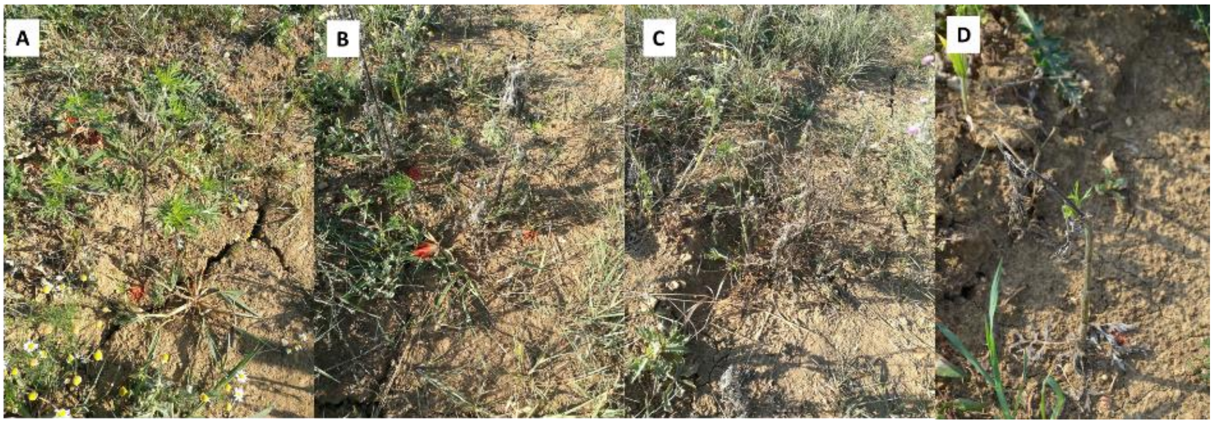

Figure 10: Non-repeated, one-time treatment of ragweed using pelargonic acid (Beloukha) after one week. The plants show different symptoms, from almost no visible effect (A) to dead plants (B) and (C) and re-sprouting from the stem (D)

3.1.5 *Uprooting*

The manual removal treatment (uprooting) was very effective (Figure 6). The plants could easily be pulled out of the ground. However, a 100%-efficiency was not obtained due to the germination of remaining seed in the ground after the treatment.

3.1.6 *Mowing*

In this experiment, ragweed was mown twice. The second mowing was carried out three weeks after the first cut (Table 1). The mowing experiment showed very variable results in the subplots (Figure 6). In one subplot, no ragweed plants were observed at all after the evaluation period. In the other four plots, more than 70% of the plants survived. These plants produced side-stems which grew near the ground (Figure 11 A and B). All green parts in Figure 11 developed after the cutting. Six weeks after treatment, these plants produced male flowers with pollen. The survival rate of the cut plants may be affected by weather conditions like heat and drought.

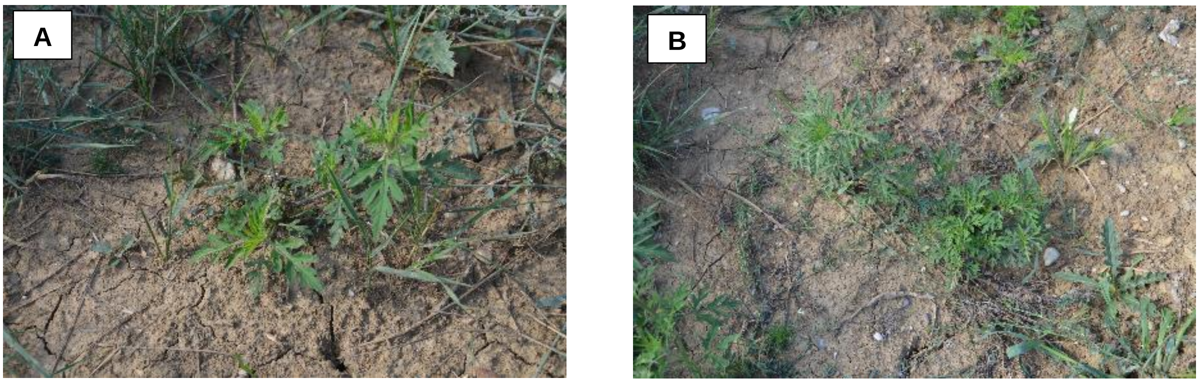

Figure 11: Treatment of ragweed using mowing. Plants one week (A) and two weeks after treatment (B). All visible green stems are developed after the treatment.

3.1.7 *Competitive seed mixture*

The results from the one-year trial in 2019 showed, that the competitive seed mixture (grass mix) was not able to prevent the growth of ragweed (Figure 6). Because of the long dry period in spring the seeds of the grass mix did not germinate well and therefore, did not compete with ragweed.

4 Results of *Fallopia* spp. field trials

4.1 Results from the field trials 2018

In 2018, Electroherb™ was tested on *Fallopia* plants for the first time. When the plants got in contact with the Electroherb™ applicator, the plants started to wilt immediately (Figure 12).

At the end of the vegetation period of 2018, the number of shoots was counted. Location 1, which was treated in 2018 twice in spring and autumn, showed also the lowest number of shoots (10 shoots/m^2). Location 2 showed the highest number of shoots with 110 shoots/m^2, but it was also the site with the highest density of plants and the smallest plants at the beginning of the trial. Because location 3 was treated only once in 2018, the number of stems were not counted in autumn 2018.

The treated plants in all three locations showed in late autumn still green leaves, whereas the untreated plants showed discoloured leaves, indicating that the plant started the winter dormancy. The green colour of the leaves indicate that the plants were still photosynthetically active and tried to recover from the treatment. But with the first frost in mid-November the green plants died off and the accumulated resources in the leaves could not be transported to the rhizomes. Whether this effect also occurs without winter frost cannot be said.

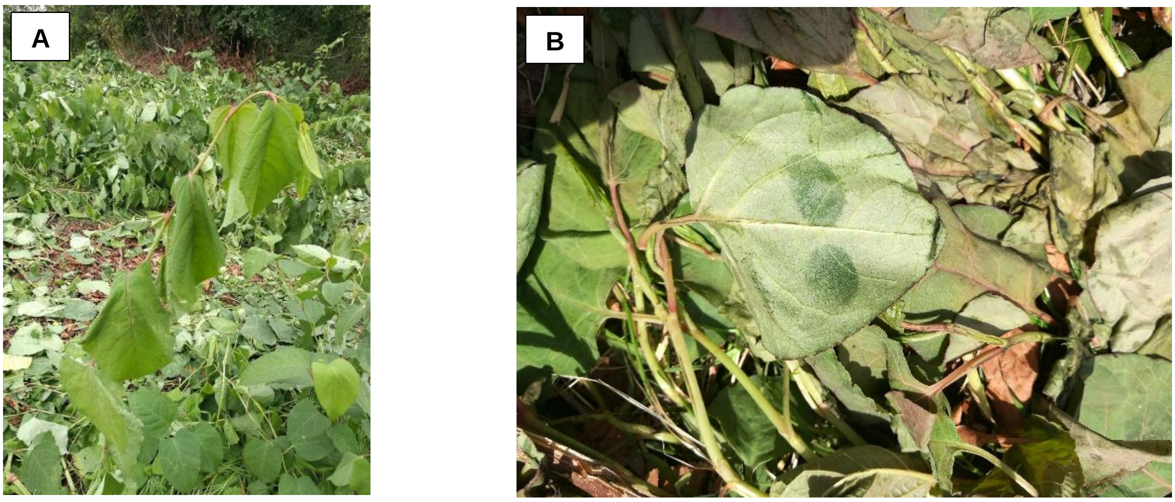

Figure 12: (A) Wilting symptoms of knotweed directly after the treatment with Electroherb™. (B) the thumb pressure test immediately after application shows destroyed, water-soaked tissue.

4.2 Results from the field trials 2019

4.2.1 *Number of stems after the first treatment 2019*

Before the treatments in 2019, numbers of stems were counted just before mulching at all three locations (number of stems before treatment). The stems at the locations were counted on the 22th and 23th of July, on the 23th of July the plants were mulched and one day after mulching the treatment with Electroherb™ was performed. For the analysis of the first treatment in 2019 the number of stems was counted just before the second treatment on 14th and 15th September. Because in the two-way ANOVA the interaction between treatment and location was significant (P<0.001) all the locations had to be analysed separately. Thus, the Kruskal- Wallis Test was used as nonparametric test for more than two groups. As a post-hoc test the Mann–Whitney U-tests for multiple comparisons was applied, when the Kruskal- Wallis Test showed a significance.

In Figure 13, the median number of stems before and after the first treatment are summarized. The three locations showed different numbers of stems at the beginning of the first treatment in 2019. The results demonstrate that after the treatment no significant differences between the control (only mulched) and the Electroherb™ treatment were found in any location.

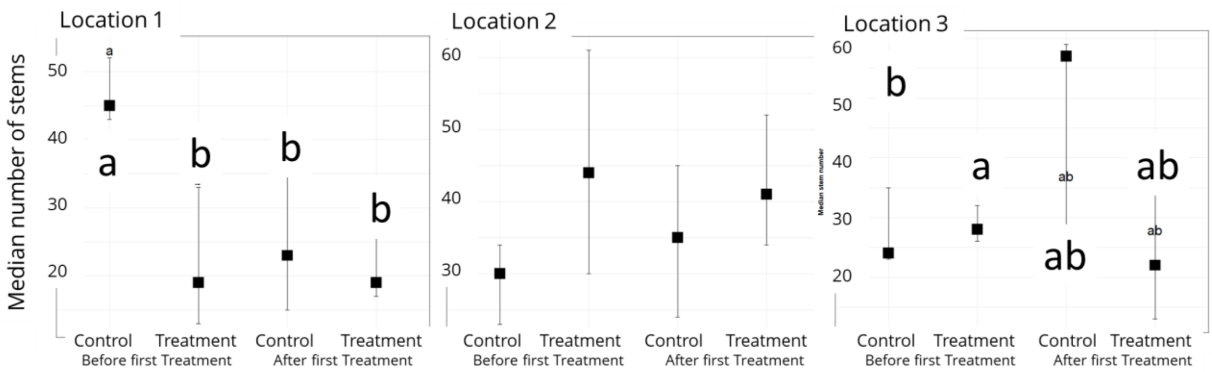

Figure 13: Median number of stems per m^2 in the locations compared to the control (only mulching). Error bars indicate the 95% confidence intervals for the median with the percentile method and the different letters indicate the significance (P<0.05) in the Mann–Whitney U-tests for multiple comparisons. Only letters are added if the treatments gave significantly different results.

4.2.2 Fallopia *spp. plant size after the first treatment 2019*

By comparing the plant size (Figures 14 & 15), it was observed that in all locations the total number of larger plants (>50 cm) was lower on the treated site. In location 2, which is a dirt road, the high number of total *Fallopia* plants was due to the high number of small plants.

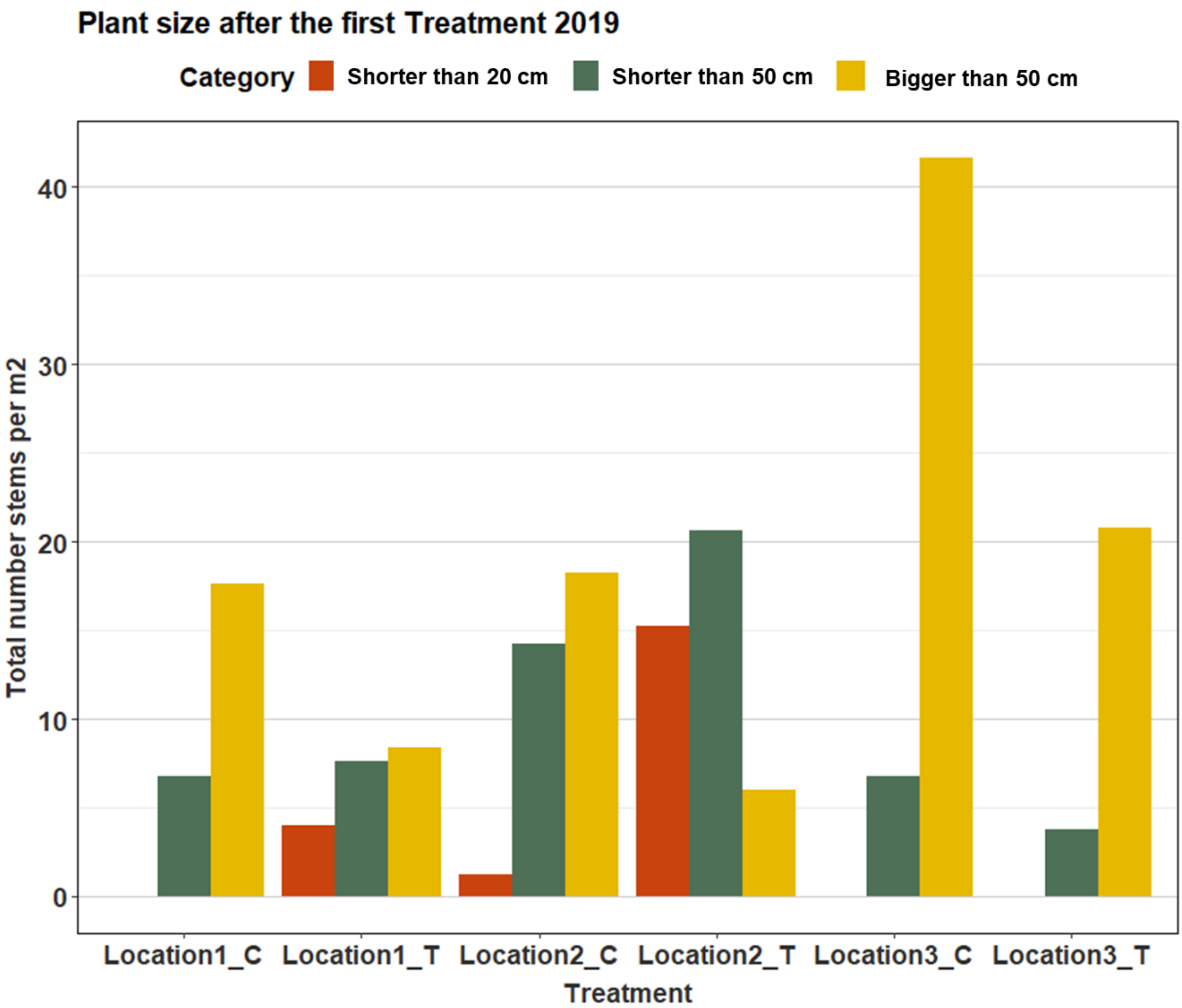

Figure 14: Distribution of the different plant size categories among the locations and treatments (C = control, T = treatment with Electroherb™).

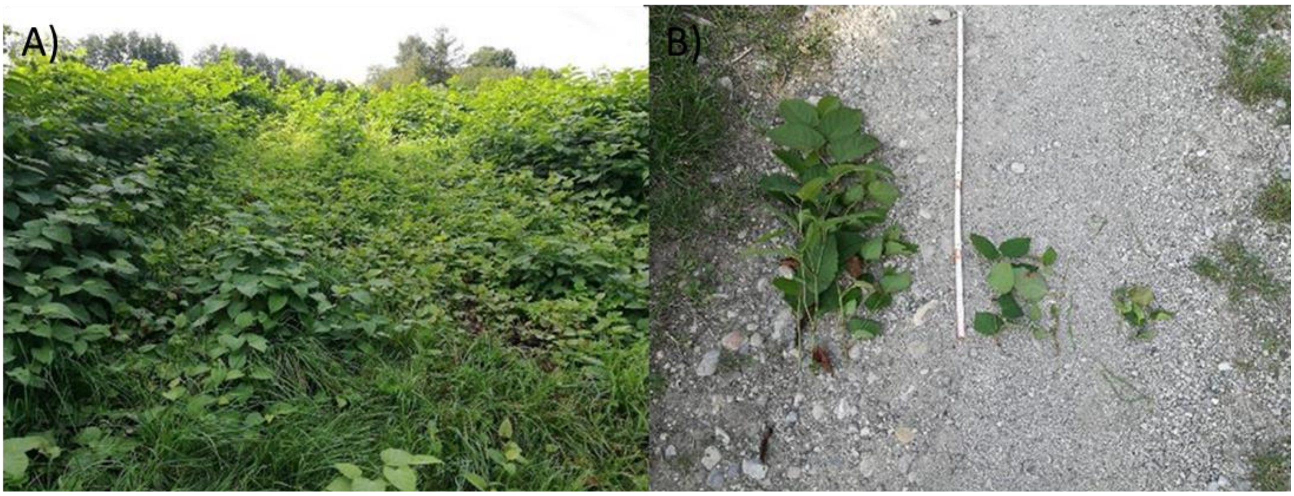

Figure 15: Differences in plant size at location 2. (A) view (dirt road), (B) size of the *Fallopia* plants, left control, right Electroherb™ treatment.

Figure 15 shows the differences in plant size between the control and the treatment in location 2. Comparing all locations together (no significant interaction between location and treatment) the treated plants are much smaller compared to the control plants (Figure 16). A smaller plant means also less photosynthesis and less accumulation of nutrients, which could be transported to the rhizomes.

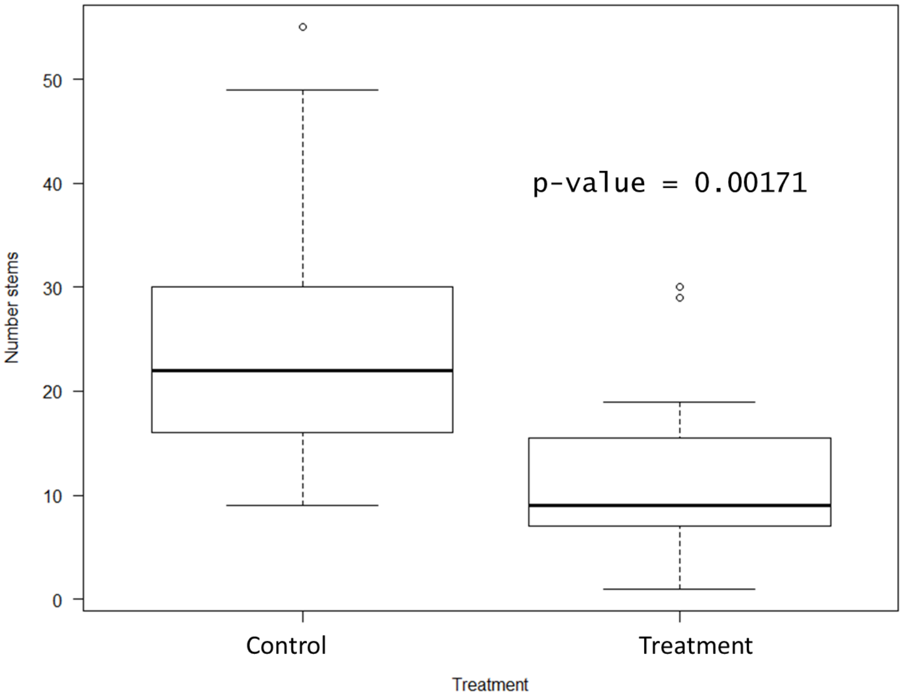

Figure 16: Number of stems >50 cm between control and treatments among all locations.

Besides the smaller plants in the Electroherb™ treatments (Figure 17 A) it was observed, that the plants which were only mulched showed fresh shoots coming out from the mulched stems (Figure 17 B). This was not observed in the Electroherb™ treatments. In the Electroherb™ treated sites, the new stems started to re-sprout from the rhizomes.

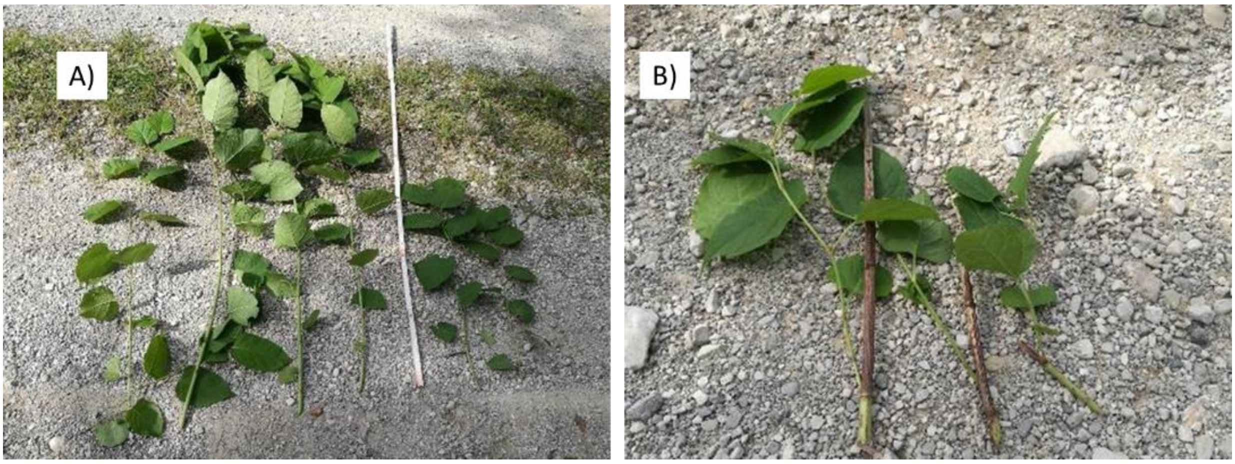

Figure 17: A) Differences in plant height in location 1 between control (left) and Electroherb™ treatment (right). B) Fresh shoots emerging from mulched stems in the control treatment

4.2.3 *Number of stems after second treatment*

The second treatment with Electroherb™ at all three locations was performed on 23th of September. The locations were mulched one week before the treatment.

In addition to the Electroherb™ method, the hot foam method using the Weedingtech Foamstream M600 device was also tested, because good results had been observed in preliminary trials (Figure 18). The treatment was only tested in location 3 in autumn 2019 at the same site where Electroherb™ was applied in the year 2018 in autumn but not in 2019. The site was mulched at the same day as for the treatment with Electroherb™.

The number of stems were counted two and four weeks after the treatment (Table 3). Because the interaction between the treatment and the locations were significant for the Electroherb™ method, each location was analysed separately with the Mann–Whitney U-test (Table 3). After two weeks the number of stems was significantly reduced in all three locations. After four weeks a low number of stems in the control plots were observed and in most of the control plots no plant stems were visible.

For example, in the location 3, a median of 21.2 stems/m^2 was counted after two weeks in the control plot, while only less than one stem/m^2 was found after four weeks. This observation indicates that the control plants had already began to hibernate.

On the treated site (location 3) 2 and 3.6 stems/m^2 were found after two and four weeks, respectively. It can be assumed that the treatment stimulated the rhizomes to form new plants, which will die with the first frost and consequently, less resources are accumulated into the rhizomes. This may have a negative effect on shoot budding in next spring. However, if the effect is the same without winter frost cannot be said.

The treatment in location 3 using hot foam gave the same significant result as the treatment with Electroherb™. Because the method was tested only once in one location, no conclusion about the effectiveness can be drawn.

Table 3: Median number of stems/m^2 of *Fallopia* spp. after the second treatment of Electroherb™ in autumn 2019 two and four weeks after the treatment. The data was analysed using the Mann–Whitney U-test in the R package car. Ns means not significant. The treatments were analysed against the corresponding control.

Treatment	Location	N	Median number of stems two weeks after treatment	Standard deviation	P-value	Median number of stems four weeks after the treatment	Standard deviation	P value
Control	1	5	3	0.71		0.6	0.89	
Electroherb™	1	5	0	0	0.006	0.8	1.30	ns
Control	2	5	7.8	2.68		4.0	1.87	
Electroherb™	2	5	1.8	1.92	0.015	4.8	1.59	ns
Control	3	5	21.2	7.56		0.8	1.30	
Electroherb™	3	5	2	1.00	0.011	3.6	2.88	ns
Hot foam	3	2	1	1.41	0.0003	4.8		ns

Figure 18: Knotweed plants four (left) and five (right) weeks after the hot foam treatment

4.3 Non-target effects of Electroherb™

This experiment was conducted to find out, if the electricity produced by Electroherb™ can affect insects. This preliminary test may provide first information on potential undesired, non-target effects by the Electroherb™ technology on insects, such as ground beetles, and soil organisms in general.

The number of hatched flies in the Electroherb™ trial, comparing the Electroherb™ and no treatment of grapes, was much higher compared to the treatment with hot water (Figure 19). The results demonstrate that insects and soil organisms are presumably less affected by Electroherb™ than by hot water. Hot water directly heats the upper layers of the soil and therefore, organisms living near the ground will be most likely killed. However, these are preliminary results from one experiment. Different soil organisms and species need to be analysed in order to better understand non-target effects of the Electroherb™ method.

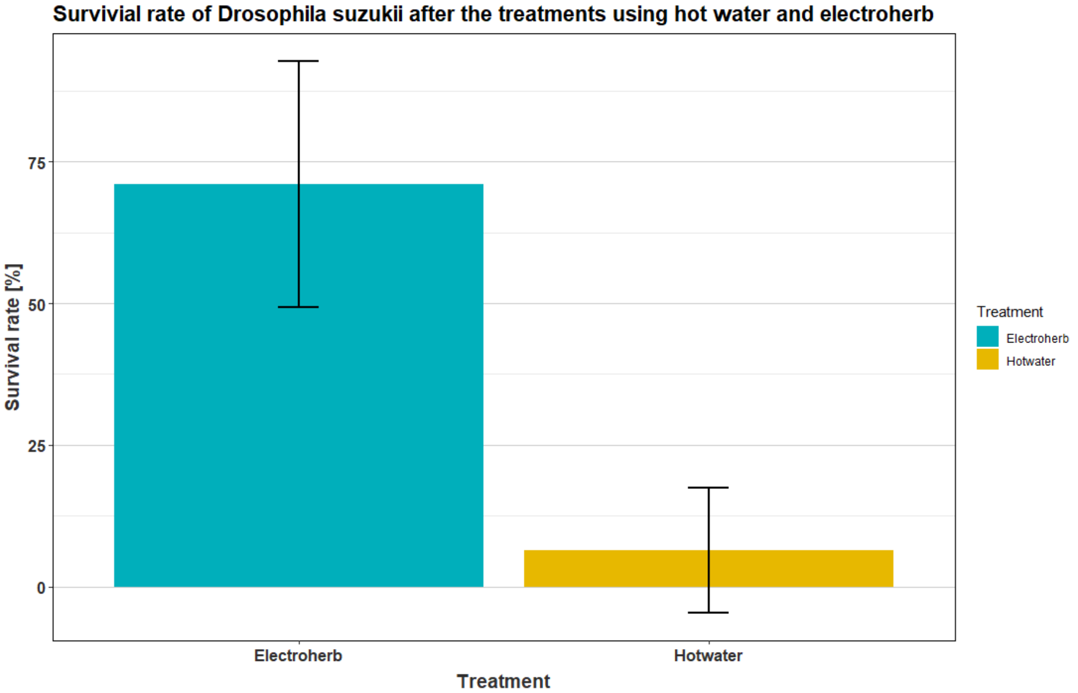

Figure 19 Survival rate of *Drosophila suzukii* pupae after the application of Electroherb™ or hot water. Data was produced by Michael Kurtzler and Günter Brader (AIT Austrian Institute of Technology). Error bars indicate the standard error.

5 Discussion

As the Electroherb™ technique at the beginning of the project was still in development, the aims of the field trials were:

1. to test the Electroherb™ technique on different plant species
2. to compare different (standard and alternative) methods in one field trial.
3. to test the Electroherb™ technique on two plant species which had shown to respond well to the treatment

In 2018, the Electroherb™ method was tested for the first time to control three different IAPs (annual: ragweed, perennial: knotweed, tree: black locust). As no information about the necessary voltage and the time of application was known, different settings were tested. The treatment of ragweed was very successful as the plants died off and did not re-sprout. In the case of knotweed, the positive effect was seen in 2019 resulting in a size reduction of plants compared to the control. However, the Electroherb™ did not prevent the production of new sprouts of black locust. Thus, only ragweed and knotweed were used in the field trials.

Electroherb™ and seven additional methods were tested on ragweed in one field trial in 2019. The field was prepared by the road authorities of Burgenland for this purpose. As for the Electroherb™ method a tractor is needed, no randomized design could be applied. With the required working width of the tractor plus the applicator, the blocks were too small to use this treatment in a random block design. Therefore, several samples from each plot were used for the analyses. The type of statistical analyses and conclusions to be made from such a type of "replicated, pseudo-randomized" experimental design might be limited, and future tests should be performed to confirm results. However, the ANOVA analysis clearly showed statistic differences among the treatments ($P < 0.001$). Comparing the treatments to the control site the best treatments were Electroherb™, infrared, hot foam, pelargonic acid 2x and uprooting. Using these treatments more than 90% of the plants died. With the standard method mowing only 38% of the plants died. This means 62% of the remaining plants were able to produce pollen and seeds. The problem of mowing ragweed is that the plants produces new sprouts, which are growing just near the surface and are problematic for a subsequent mechanical treatment. Therefore, other methods need to be used to control the spread of ragweed. The obtained data from the one-year field trial shows, that different methods can control ragweed without re-sprouting. Future tests are recommended to confirm these findings, and also to test the treatments under different environmental or climatic conditions.

For the knotweed trial in 2019, Electroherb™ was applied in three different locations. The locations showed completely different conditions for knotweed in regard to soil, light and also *Fallopia* development stages. Statistical tests showed a significant interaction between treatments and locations and therefore, locations were analysed individually. Sampling was made on replicated, 1x1 m squared, approximately equidistant patches by counting live individuals. Owing to the overall small size of the fields, no blocks were made. The choice of sampling squares followed the representative occurrence of plants (knotweed typically is of very different size and age and their distribution across space is uneven and patchy). Therefore, the sampling patches may have followed a "pseudo-random" distribution. However, in this project tests were carried out using the conditions available, i.e. employing natural stands of vegetation within fields. The data obtained provide relevant indications and represent a good basis for further testing and confirmation. Ideally, field tests with small plots growing the IAPs under controlled conditions should be performed.

6 Conclusions

6.1 Ragweed trial

In the field trial, different standard and alternative methods for the control of *A. artemisiifolia* were tested. The tested alternative methods infrared, hot foam, Electroherb™ and pelargonic acid (2x) delivered very satisfactory results, equivalent or even better than the tested standard methods. The results are based on one-year field trials and must be proven in other locations. The tested methods can be recommended for future tests for the control of ragweed and for other annual herbaceous plant species.

All alternative methods, except Electroherb™, can be applied as a spot treatment to ragweed so that other plants will not be affected, and no space will be left open for new invasions. Mulching must be done at the right time, before ripe seeds are developed. If the plants are mulched later, the chance is high that the seeds are transported with the mowing equipment. The danger of unwanted seed dispersal by these methods like Electroherb™, hot foam etc. is less dramatic compared to mulching. However, the seeds are not affected by methods like Electroherb™ and hot foam. In frame of working speed, Electroherb™ can work at 3-5 km/h. For the application in the road sector special equipment needs to be developed to work in road verges.

6.2 **Fallopia** *spp. trial*

The Electroherb™ method was tested on *Fallopia* spp. at different locations over two years. Already after the first year, a reduction of plant size was observed compared to untreated sites. The best results could be achieved when the plant size was about 30 cm for the Electroherb™ treatment ensuring the optimal contact of the applicator with all plants. If the plant height is lower than 30cm, mulching of the sites is not necessary. As it was shown by Jones et al. (2018), no treatment was able to eradicate *Fallopia* spp. within three years, but the use of glyphosate two times a year showed to interfere with the source-sink transition causing the greatest reduction in stem density. This knowledge was used for the application of Electroherb™ to produce as much as possible damage to the plant. Because already small amounts of remaining, vital *Fallopia* spp. rhizomes are able to produce green plants, the aim was to restrict the nutrient flow to the rhizomes and therefore, to reduce the viability of the plants. Consequently, by steadily and repeatedly applying methods like Electroherb™, hot foam or herbicides, it is expected to achieve a reduction of stem density over the years. The results from 2019 showed that the plant size was significantly reduced at all locations. Smaller plants are photosynthetically less active than bigger plants and therefore, less resources can be transported to the rhizomes which make them less vital.

The Electroherb™ device might require specific adjustments when using it on sites, which are not easy to reach. Preliminary results showed also that Electroherb™ harms soil organisms to a lower extent than hot water.

6.3 Applicability for other IAPs

It can be assumed that the proposed alternative methods tested in this study can also be used in the same way for the control of other annual and perennial IAPs. In particular, the alternative methods pelargonic acid, hot foam, infrared and Electroherb™ are presumably also effective against other annual herbaceous IAPs like *Impatiens glandulifera* or *Erigeron annuus*. However, efficacy studies are hardly available. Similar to the perennial *Fallopia* spp., multiple treatments may be necessary to contain other perennial IAPs species (e.g. *Heracleum* spp., *Solidago* spp.) with pelargonic acid. This may also apply to Electroherb™, where two to three treatments in the growing season should be sufficient to control and reduce populations. The control of the *Fallopia* spp. by hot foam was promising as the stems were completely damaged and no re-sprouts were produced as with mowing or mulching. However, the applicability for other perennial IAPs (e.g. *Lupinus polyphyllus*, *Gunnera tinctoria*, *Asclepias syriaca*) is fairly difficult (also due to the absence of any studies), since the efficacy of thermal methods depends e.g. on the location of the vegetation cone, leaf structure, characteristics of the root system which differs between the respective plant species. Further studies on the efficacy of the tested methods on other perennial IAPs are needed. Furthermore, woody species (shrubs trees) are an important plant category along roadsides. Woody species were not included in this study. Further tests should focus on the application of alternative methods on this plant category including e.g. thermal control methods for juvenile woody species.

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