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Experimental comparison of herbicide-free methods for weed management on railway tracks

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Abstract

Weed management on railway tracks is important to maintain function and operational safety, especially with regard to track stability and drainage. As the EU approval of the herbicide glyphosate expires in 2022, there is an urgent need for alternative weed management. Here, we investigated the potential of two thermal (hot water and freezing) and two mechanical approaches (manual weeding and mowing) for plant removal on tracks. Application of hot water at 10 L/m² resulted in a plant-damaging temperature of 55 °C at up to 15 cm depth in the ballast. Freezing with dry ice did not go deep and only damaged aerial parts of plant when applied at up to 10 kg/m². Mechanical measures that uprooted the plants (force of 40 - 160 N) were more effective than those removing aerial plant parts only. In sum, mechanical approaches seem most promising for herbicide-free weed management on railway tracks.

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1. Overview and motivation

Weed management is an essential part of the reliable and safe operation of railway systems. This comprises preventing the accumulation of organic material in the ballast bed, which, if improperly treated, leads to reduced drainage capacity. The latter can cause alignment errors and reduce the resilience of the track to extreme weather events (e.g. heavy rainfall). In the last decades, most European countries mainly treated the track area with synthetic

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leaf and soil herbicides to impede plant growth and maintain the operability of the track. The foliar herbicide glyphosate is widely used for effective weed control Nolte *et al.* (2018). However, because of environmental and health concerns glyphosate is expected to lose its approval in the railway sector in 2022 The European Commission (2017). These days, chemical weed management is of scientific and societal interest because of its presumed impact on the environment, human and animal health. Therefore, measures that do not rely on synthetic chemicals are needed for effective, economic, sustainable, and legally compliant weed management.

So far, weed management approaches without synthetic chemicals have been developed mostly for urban and agricultural areas Rifai *et al.* (2002), Coleman *et al.* (2019), Rask and Kristoffersen (2007). Despite some studies on the application of synthetic chemical-free weed management on railway tracks Atmatzidis and Behrendt (1995), Adolph and Tanner (2020) most of the approaches either have not been thoroughly compared or insufficiently assessed. This may be due to the complexity of application, the impact on infrastructure, or the uncertain efficiency of the different approaches in railway tracks. In addition, some empiric data disclosed uncertainties caused due to experimental variations, such as plant species, vegetation density, and the type and size of the technical equipment used for the particular experiment Nolte *et al.* (2018).

The project “Development of an Alternative Method for Vegetation Control on Railway Tracks” of the German Centre for Rail Traffic Research (DZSF) at the German Federal Railway Authority (EBA) is funded by the Federal Ministry for Digital and Transport (BMDV). The project aims at the fundamental development, or adaptation, of non-synthetic chemical-based methods for weed management on railway tracks. Then, a method, or combination of methods, shall be used to develop a prototype vehicle for testing the applicability of identified vegetation control measures in everyday condition. First, 18 alternative measures to glyphosate-based weed control were selected and evaluated theoretically for their suitability of weed control in railway track. We identified inconsistencies in published results and information gaps. When needed and possible, these were cleared by adequate experiments.

In this paper, the data of experiments using two thermal (hot water and freezing) and two mechanical approaches (manual weeding and mowing) are presented. They aim at introducing novel basic knowledge, such as the temperature in different depth-layers of the ballast bed, necessary dosages to achieve effective temperatures, and required force to uprooting plants. The experiments were done as screening and limit-test experiments (no complete series of experiments with repetitions) with the main purpose of checking plausibility and to provide some orientation in the technical implementation of the methods.

2. Methodology

Based on the general product development process acc. to Verein Deutscher Ingenieure (1993), a scheme considering product requirements and alternatives to synthetic-chemical weed management was elaborated. Scheme development considered effectiveness, technology, environmental safety and health as the criteria. Selected non-synthetic chemical methods were evaluated regarding these requirements and compared to each other.

Regarding thermal methods, we identified difficulties in the literature regarding effectiveness and energy consumption. Especially for the application of hot water, various studies addressed the dosages Astatkie *et al.* (2007), Rask *et al.* (2013), De Cauwer *et al.* (2015), Bohren *et al.* (2020). Different soils, species of weed, and plant size all led to much varying water volumes needed for weed control. Accordingly, the energy requirement also varied much. Many studies reported the treatment of young plants at the twelve-leaf stage (BBCH-stage) or less. Our own observations with plants in ballast beds revealed that sometimes the root of weeds and perennial plants grow up to 20 cm below surface. Therefore, the results of most of the published studies may recommend inappropriate measures for weed control.

In general, thermal approaches are based on destroying cell integrity. Therefore, a minimum temperature of 55 °C, at which most proteins would denature and membranes melt, is necessary to control plants with hot water Daniell *et al.* (1969), Upadhyaya and Blackshaw (2007). For weed roots, deep ballast layers must achieve this temperature. In the case of freezing (solid CO₂), we found only studies addressing energy consumption yet neither temperature or any detrimental effect on plants Coleman *et al.* (2019). For none of the temperature ranges, hot or cold, temperature gradients in soil or in the ballast bed were found.

Despite the general use of mechanical methods (manual weeding and mowing) for weed management on railway tracks Below *et al.* (2003), there essentially is any report on the effects and parameters that would allow further

development of the few reported methods. Published experiments neither addressed the force or speed needed to tear out the plants. Same was true for cutting for which there is essentially no data available so far. Thus, we decided to perform experiments relating thermal and mechanical methods to fill the identified gaps.

The experiments with hot water and freezing were done in two ways. First, the temperature of the applied medium in the ballast was recorded. The aim was to see, whether the amount of medium applied and the temperature measured at a certain time and at specific depths in the ballast bed would correlate. To do so, Euro-boxes (40 x 30 x 12 cm) made of HDPE were filled with ballast to imitate track condition and stacked to the regular thickness of a ballast bed (40 cm) Lichtberger (2010) (Fig. 1a). Thermometers were placed at even intervals in the centre of the boxes, starting from the surface down to the very bottom, to record temperature profile.

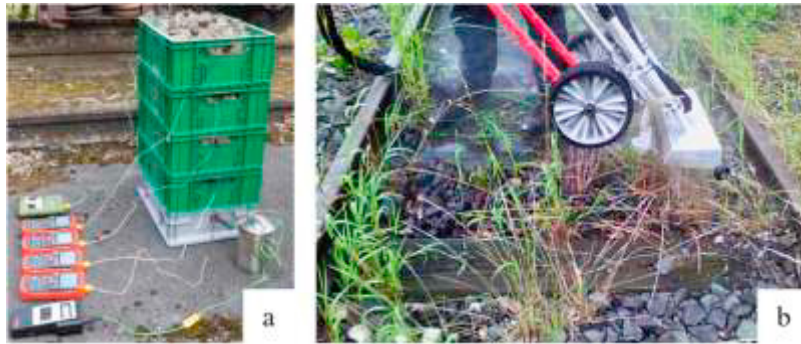


Fig. 1. Track-imitating experimental setup for temperature measurement at different depth (a) and treatment of a track section with hot water (b)

Additional experiments were performed on temporarily or permanently closed railway tracks. To evaluate the effectiveness of approaches, we examined the vegetation and growth of plants on the selected tracks before, during, and after the experiments. To do so, the track section in question was divided into areas with seemingly uniform vegetation. Track areas were treated with different volumes of appropriate medium (Fig. 1b). For comparability, the quantities of the medium used were standardised to area (application rate/m² treated ballast area without sleepers) in all experiments shown.

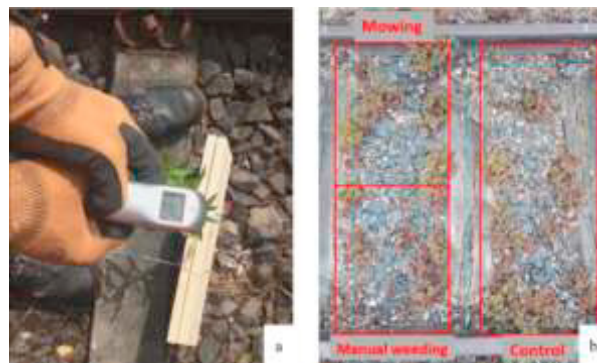


Fig. 2. Device for measuring force to uprooting weeds (a) and mechanical treatment of track sections (b)

In the experiments relating mechanical methods, a tool consisting of two wood boards to measure the required force needed to uproot plants was developed. Using the device, plants were clamped between the boards and pulled with a force as uniform as possible by means of a steel cable attached to a hand scale (Fig. 2a). The other experiments of manual weeding and mowing were carried out directly on track. Like in the temperature experiments, to-be-treated plots were defined and monitored for 7 times monthly up to this point. For this purpose, the plants were manually weeded in one part of plot (completely removed) and cut off (mowed) in another. The removed vegetation was weighted after the treatment. Re-emerged plants were photographed monthly and will be removed and documented

on an ongoing monthly basis throughout the three-year project period (Fig. 2b).

3. Results and discussion

3.1. Hot water treatment

Application rates of 5, 10, and 20 L/m² were used to measure the temperature distribution in ballast. Additionally, three different ways of hot water application (surge, surge-split, and sprayer) were tested. It was considered that water application might be split in several nozzles to achieve the desired operational speed of 20 km/h to avoid traffic disturbance. Water was applied at an initial temperature of 95–98 °C from 20 cm height, mimicking the installation of the nozzles on a vehicle. The experiments were performed at dry day at ambient temperature (29 °C).

Table 1. Experimental plan and results – Hot water.

Experiment	Application rate (L/m ²)	Form of application	Maximum temperature (°C) at 15 cm depth (rating)
1	5	Surge	47 (ineffective)
2	10	Surge	68 (effective)
3	10	Surge – Split (2x5L)	67 (effective)
4	20	Surge – Split (2x10L)	63 (effective)
5	10	Sprayer	46 (ineffective)
6	20	Sprayer	38 (ineffective)

The results in Table 1 show that only a total volume of 10 and 20 L/m² of hot water in single or split surge led to a temperature above 55 °C at a depth of 15 cm (Table 1). With better distribution and lower application rates, the water cooled down during application and the ballast reached a maximal temperature of only 47 °C at a same depth. Therefore, an effect of hot water on roots is expected at doses of 10 L/m² or more. As the temperature markedly decreased with increasing ballast depth, animals in deeper areas of the ballast bed and being exposed to the water will not be affected much by the heat.

If vegetation density was 100 %, 10 L/m² equals an application rate of 45,000 L water per 1 km ballast track bed at a width of approximately 4.5 m Matthews (2011), in other words, it comes to almost half the capacity of a typical 100 m³ tank wagon for transportation. If heat capacity of water is taken as 4,184 J/(kg·K), the energy required to raise the water temperature from 20 °C to 95 °C is about 14,121 MJ or 39,225 kWh. The method is promising if hot water is collected from industry waste or pre-heated by sun or renewable energy. Another aspect of saving resources is that pouring hot water on the sleepers can be avoided, and when vegetation density is low, weeds can be detected by sensors or cameras and treated individually.

After the temperature distribution test, experiments were carried out on plants on railway tracks at ambient temperature (15 °C) on dry day in early July. The above-mentioned effective water volumes of 10 L/m² and 20 L/m² were applied. The water was of average temperature of 90 °C when it left the applicator and 75 °C on the ballast surface after direct application. In some instances, we combined hot water application with cutting of plants to investigate whether the combination of approaches would synergistically increase effectiveness.

Table 2 lists the species of plant used in the experiments and the effects of hot water after 41 days of treatment. The condition of plant was monitored for two months after the application. During the period, regeneration of some plants was observed, which determined the end point of the assessment after 41 days. The control plants of each species showed continued growth during the experiment (CG).

In sum, the results of the hot water experiment show that hot water could partially keep the vegetation on track under control, but only at high doses and often for a limited period. Lower efficacy is seen with fast-growing plants such as grasses (upright brome) or plants that have widespread stolons on the surface and being only partially wooden (blackberry) that progressed in growth with damage (CGD) or regrew after treatment (RG). Only annual herbs such as willow herb and herb-robert did not regrow (NRG). In the case of plants such as field horsetail, the effect on the

surface was good, but new plants emerged from underground rhizomes (RGL). Cutting off plants before treatment achieved a better effect especially on plants that form shoots on the surface, such as blackberries.

It also became obvious that an amount of 10 L/m² is necessary for an effective effect of hot water treatment. The application of 20 L/m² showed only slightly better results when compared to 10 L/m².

Table 2. List of plant species used in experiments with hot water.

Scientific name (additional treatment)	Common name	Height of plant [cm]	Status after 41 days	
			10 L/m ²	20 L/m ²
<i>Bromus erectus</i>	Upright brome	10 - 25	CGD	CGD
<i>Bromus erectus</i> (+ cutting)	Upright brome	5	RG	RG
<i>Epilobium hirsutum</i>	Great willowherb	10 - 20	RGL	NRG
<i>Geranium robertianum</i>	Herb-robert	5 - 20	RGL	NRG
<i>Geranium robertianum</i> (+ cutting)	Herb-robert	5	NRG	NRG
<i>Rubus fruticosus</i>	Blackberry	20 - 40	CGD	CGD
<i>Rubus fruticosus</i> (+ cutting)	Blackberry	5	RG	RG
<i>Quercus rubra</i>	Northern red oak	15	RG	CGD
<i>Equisetum arvense</i>	Field horsetail	10 - 20	RGL	RGL

CG: Continued growth; CGD: Continued growth with damage; RG: regrowth; RGL: regrowth low; NRG: No regrowth

3.2. Freezing

To measure the temperature distribution of the method freezing, the same track-like experimental setup was used as for hot water. No specific temperature was targeted or volume applied, but an amount of dry ice sufficient to cover the surface uniformly (5 kg solid CO₂ per m²) was used in this experiment. The dry ice was applied as nuggets (16 mm) and pellets (6 mm) to determine whether a larger shape would produce longer-lasting frost or cold or whether the smaller shape would be more effective by trickling into the ballast.

The results obtained show that smaller pellets could be better distributed. However, neither the dry ice nuggets or pellets changed the temperature in deeper layers of ballast. Only on the ballast surface, a temperature of approximately -78 °C was measured (Fig. 3). This surface temperature lasted for about 30 seconds and then remained at -55 °C to -28 °C for a longer time. Therefore, no direct effect on roots or plant parts in deeper ballast layers was expected. Since dry ice remained on ballast surface during the entire experiment, we did not test the effect of higher dry ice volumes.

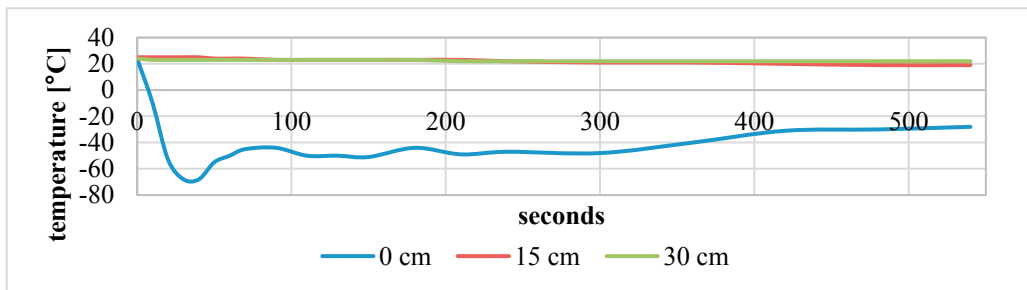


Fig. 3. Temperature curve - 5 kg/m² dry ice.

As for the hot water treatment, experiments were done to evaluate the approach on plants in track bed. Track sections with seemingly uniform vegetation were selected for these experiments. The dry ice was used as 6 mm pellets and at -78.5 °C. The tests were carried out in mid-July at an ambient temperature (17 °C) on the track. We selected different plant species for evaluation (Table 3).

Three different dosages of dry ice, that is 2.5 kg/m², 5 kg/m² and 10 kg/m², were applied. The fate of obvious plant condition was monitored during 38 days after ice application.

Table 3. List of plant species used for experiments with freezing.

Scientific name	Common name	Height of plant [cm]	After 38 days		
			2,5 kg/m ²	5 kg/m ²	10 kg/m ²
<i>Bromus erectus</i>	Upright brome	10 - 20	CG	RG	RG
<i>Epilobium hirsutum</i>	Great willowherb	10 - 20	CGD		
<i>Geranium robertianum</i>	Herb-robert	5 - 20	RG	RGL	NRG
<i>Rubus fruticosus</i> (+ cutting)	Blackberry	5	CG	CG	CGD
<i>Equisetum arvense</i>	Field horsetail	10 - 20	RGL	RGL	NRG

CG: Continued growth; CGD: Continued growth with damage; RG: Re-growth; RGL: Re-growth low; NRG: No Re-growth

Table 3 discloses that dry ice at 2.5 and 5 kg/m² only affected field horsetail and small herbaceous plants like herb-robert. At 10 kg/m², a stronger effect was seen for most plant species tested. For the grasses and blackberries even the high doses were inactive as plants regrew (RG) or continued growth with only minor damage (CGD).

Calculating 10 kg/m² for 1-km tracks with 4.5-m wide, gives a total of 45,000 kg. Due to the high dosage, the corresponding direct emission of CO₂ needs to be considered, as it has environmental relevance as a climate-damaging gas. Alternative to dry ice, freezing could be gained using liquid nitrogen, which could reach deeper ballast layers. However, because of its low temperature (-196 °C) liquid nitrogen is considered dangerous for transportation thus requiring special equipment also for application.

3.3. Mechanical methods

When measuring the force needed to uproot plants, it became obvious that the success of the technique relies not only on force, but also on the way how plants are gripped, the speed at which they are pulled out, and the strength of stem resilience. Results of the experiment can be seen in Table 4. In many cases, only the shoots were torn off. The plant size did not influence the experiment as much as the species did. Upright brome with a maximum height of 30 cm could be completely uprooted at less than 100 N; meanwhile field horsetail of the same size was removed just a few centimetres into the ballast, as its branching growth habit allows pulling out of only individual shoots and rhizomes.

Same for herb-robert; the central stem or the thickened branching point was torn off. However, only a low force of 40 N was required for this. The force needed to pull out blackberries with their roots required an application of about 340 N and slow tearing off to prevent the stem from tearing off.

Table 4. Results of the force measurement test.

Species	Height of growth [cm]	Force [N]	Roots removed?
Blackberry (<i>Rubus fruticosus</i>)	20 - 40	62 – 341	Almost not
Field horsetail (<i>Equisetum arvense</i>)	15 - 27	23 – 110	partly
Upright brome (<i>Bromus erectus</i>)	30	58 – 96	yes
Herb-robert (<i>Geranium robertianum</i>)	15 - 30	15 – 37	partly

In sum, the effectiveness of uprooting can be assessed differently. Plants with deep-growing roots and rhizomes (e.g. field horsetail) or stolon-forming plants (e.g. blackberries) proved to be very difficult to remove. In contrast, plants with a smaller root system could be removed better. Another challenge to this technique is the height to grip the plants, which must be as close as possible to the roots.

An experimental comparison between mowing and weeding was performed as well. In Fig. 4, the results obtained

from the grass upright brome treatment can be seen. The blue line shows the fresh weight of the mown plants whereas the red curve displays the fresh weight of the manually-weeded plants. It is obvious, at first instance, that more plant mass was removed by manual weeding than by mowing. However, the regrowth after manual weeding has been minimal in the following months. In comparison, the amount of plant material mowed off is lower, but the regrowth is higher because grasses sprout again due to their meristem (tissue of growth) being close to the ground.

Repeated cutting usually causes the plant to resprout. After any single cutting, the plants spend energy and metabolic resources to regrow. Thus, several cuttings are likely to weakening the plants.

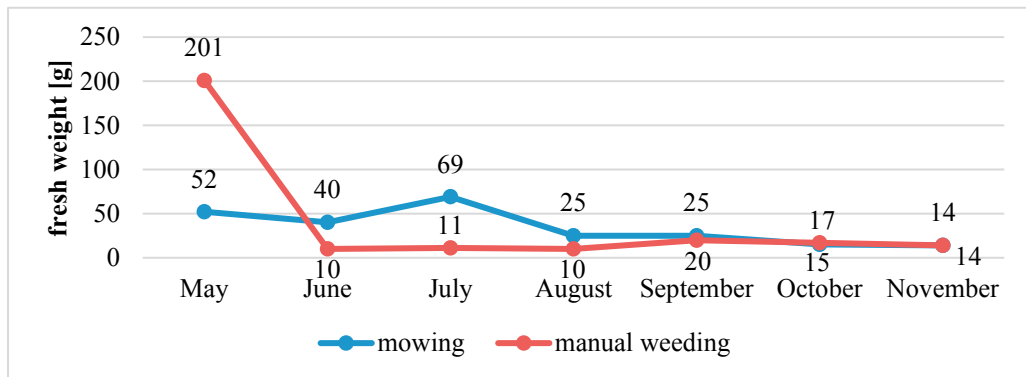


Fig. 4. Upright brome, total fresh weight mowing: 240 g, uprooting: 283 g.

In general, manual weeding seems to be more effective in limiting regrowth of plant. By further monitoring of the vegetation, the natural growth of the plants can be followed site-specifically. Regular treatment might lead to possible weakening of the plants due to a long-term effect.

4. Conclusions and future work

The specific aspects investigated in this work contributed to the systematic definition of thermal and mechanical methods for weed management on railway tracks. In general, thermal methods require high dosage to achieve a recognisable effect on vegetation. For hot water treatment, much of the data reported in the literature appears to be averaged over large areas because the functional dose of treatment we found was often higher than those published. Due to the large quantities of water needed, the energy required for heating, and the associated environmental impact, the method can only be considered applicable for special areas in which mechanical or electrical methods cannot be implemented. As this is not in line with the scope of the project, no further investigations will be done on this approach. For dry ice, the experiments showed that the functional dose also was high and did not hit all plant species analysed. This was probably because dry ice could only achieve an effect on the surface. Therefore, we will not follow up this methodology further, especially also because of the environmental impact (CO₂ emission) it may cause.

Regarding mechanical methods, mowing achieved rather short-term effects and would have to be used more than once per year, which could impair traffic much. As deep cutting with fast-rotating aggregates (mulching) increases the risk of collision and flying ballast stones, only non-rotating tools could be used for this application. Pulling out plants with their roots was more effective, so it would be used less frequently at different growth stages. Since manual labour is becoming more expensive and less available, mechanisation of the method would be necessary. For the removal of plants, the challenge is to grab the plants in a type-specific manner, far down and to adjust the tear-off speed so that as much as possible plant is torn out without break off. This can become problematic at higher driving speed. In general, care needs to be taken to not damage the track infrastructure and stability of the ballast bed.

Concerning the impact on railway infrastructure, the examined methods, if properly working, may contribute to maintaining enough drainage capacity of the ballast bed and preventing track-alignment errors due to severe vegetation. However, the methods all face various challenges that need to be addressed. Future work will include the evaluation of effectiveness on longer stretches of track and impact on infrastructure with the most suitable methods

for vegetation control on railway tracks. Therefore a prototype with a selection of the various alternative methods will be developed.

This study addresses the identification of urgently needed solutions for synthetic herbicide-free weed management on railway tracks. We acknowledge the support of Rurtalbahn GmbH enabling the use of their railway tracks as well as the support of C. Langenbach and the DZSF.

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