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Rating-Based Design of a Vehicle for Herbicide-Free Vegetation Control on Rails

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Abstract

Railway lines are susceptible to adverse effects from vegetation, posing risks to infrastructure and operational safety. Traditional herbicide-based control methods face growing environmental and health concerns, potentially jeopardizing their future approval and societal acceptance.

This study explores an innovative approach to vegetation control on railway lines by combining non-chemical methods. A systematic review of thermal, mechanical, electrical, and radiation-based techniques, totalling 18, was conducted, evaluating their suitability for rail maintenance. Mechanical weeding, pressurised water, and electroweeding emerged as the top-performing methods, subsequently developed, manufactured, and integrated into a versatile test vehicle. This integration allows for comprehensive treatment of the entire track area within the vehicle clearance and diverse plant species.

The primary objective of this research is to develop and test sustainable, economically viable procedures for vegetation control on railway tracks.

Keywords: infrastructure, maintenance, vegetation, herbicide-free, non-chemical, mechanical, weeding, pressurised-water, electroweeding

1 Introduction

The operation of railways demands high standards of safety, not only for rail vehicles but also for the track infrastructure. Vegetation management is key to maintenance, as unchecked growth leads to the accumulation of organic material in the ballast bed, compromising drainage capacity and overall stability. This poses risks to infrastructure longevity and safety, including restricted access for employees and passengers [1].

Currently, in many European countries, vegetation management relies heavily on herbicides, with glyphosate being a commonly used synthetic herbicide, recently granted a 10-year extension by the European Commission until 2033 [2]. However, concerns about its potential risks persist [3]. Stringent regulations, particularly in nature conservation areas and water protection zones, limit herbicide use on railway tracks. For example, 10% of the lines of DB InfraGO AG (formerly DB Netz AG) run through such areas, where the application of herbicides is already heavily restricted [4].

Efforts to develop herbicide-free methods for railway track weed management have intensified. Despite progress in agriculture and urban areas, finding an herbicide-free alternative with equivalent advantages remains a challenge [5]. This necessitates a prior evaluation to identify promising methods for the railway sector, combining knowledge from biology, agriculture, railway technology, and mechanical engineering. This work outlines a methodology to summarise the state of herbicide-free methods, compare their performance, and rate them. Three selected methods, currently undergoing verification and testing on the track, offer a potential combination addressing various challenges, akin to the practice in chemical weed management.

2 Search for Solutions

The assessment of non-chemical methods and the design of the test vehicle both followed the systematic approach outlined in the general design process acc. to VDI 2221 [6]. Although primarily applied in product development, this process offers comprehensive guidelines for specifying tasks and prompts the exploration of multiple solutions. Hence, it was employed in the selection of a non-chemical combination of methods, as depicted in the detailed steps presented in Figure 1.

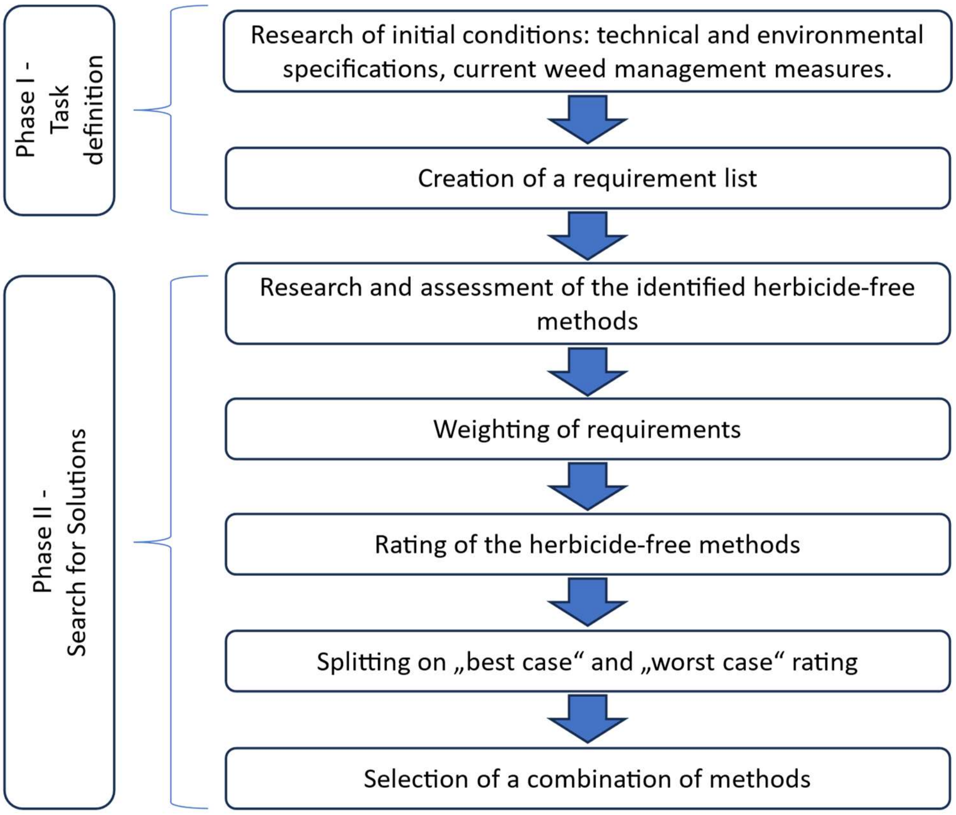

Figure 1 – Process diagram of the selection of the most promising, non-chemical methods adapted from phase I and II of the product development process acc. to VDI 2221.

The selection process comprised two primary phases: the definition of the task and the exploration of solutions [7]. During the task definition phase, a comprehensive requirements list, encompassing the purpose and constraints of non-chemical weed management on railway lines, was compiled. In the subsequent phase, non-chemical methods were researched in alignment with the defined requirements. A self-defined assessment scale was established for each requirement, with weights assigned based on their relative importance.

To rate the herbicide-free methods, the gathered information, assessment scale, and weighted requirements were utilised. However, owing to inconsistencies in the literature, the rating had to be bifurcated into 'best case' and 'worst case' categories. This assignment incorporated the best and worst performance scenarios of each method found in the literature into the rating.

Following the rating, a combination of methods was selected, ensuring that the chosen methods complemented each other. The rating offers a comprehensive overview of available information and the current state of the art in herbicide-free methods. Further details on each work phase are provided in the subsequent sub-chapters.

2.1 Phase I – Task Definition

In a prior study [8], the requirements for implementing non-chemical weed management on railway tracks were thoroughly investigated. This research encompassed considerations such as plant species, infrastructure components, and the specific vegetation control methods, addressing the associated necessities, restrictions, and expectations. Moreover, the imperative need to factor in environmental protection was highlighted. The culmination of these considerations led to the creation of a comprehensive requirement list, comprising approximately 80 criteria.

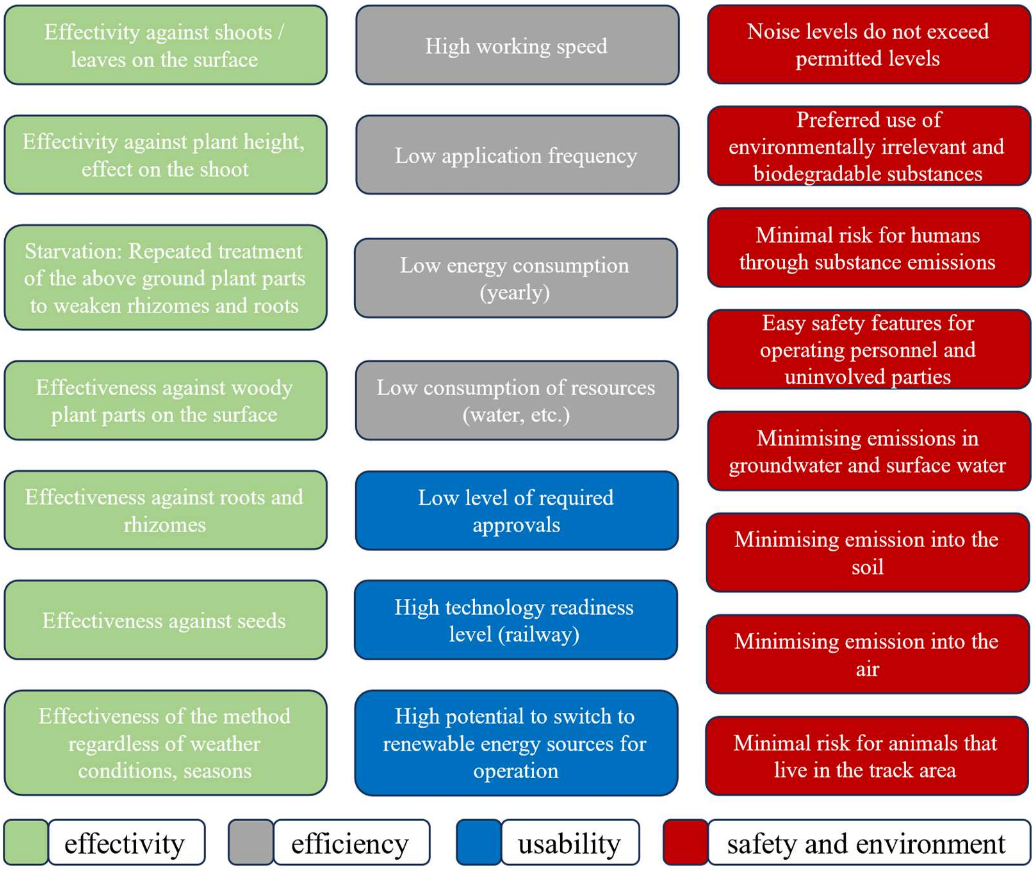

Figure 2 – 22 requirements for the assessment of herbicide-free methods for vegetation control on railway tracks.

While conducting the information search to compare herbicide-free methods based on each requirement, a notable gap emerged, particularly concerning the methods' impact on railway infrastructure. To address this, we have carefully chosen 22 general criteria to assess the overall effectiveness, efficiency, environmental impact, and considerations for future usage and safety. Figure 2 delineates these diverse requirements, categorised into four distinct groups.

2.2 Phase II – Search for Solutions

The selection of an alternative method for vegetation control on railway tracks involved comprehensive research spanning various fields of vegetation management. This encompassed an extensive review of existing studies on alternative methods within the railway sector [5, 9–11], as well as exploration into other domains such as agriculture and municipal applications where herbicide-free methods are employed. Additionally, technologies still in the research phase and adaptations of existing machinery, not yet applied in weed management, were also taken into account. A total of 18 alternative weed management methods, potentially applicable to railway tracks, were identified and subjected to further analysis. Figure 3 provides an overview of these methods, encompassing technologies based on radiation, as well as those utilising mechanical, thermal, and electrical working principles [8].

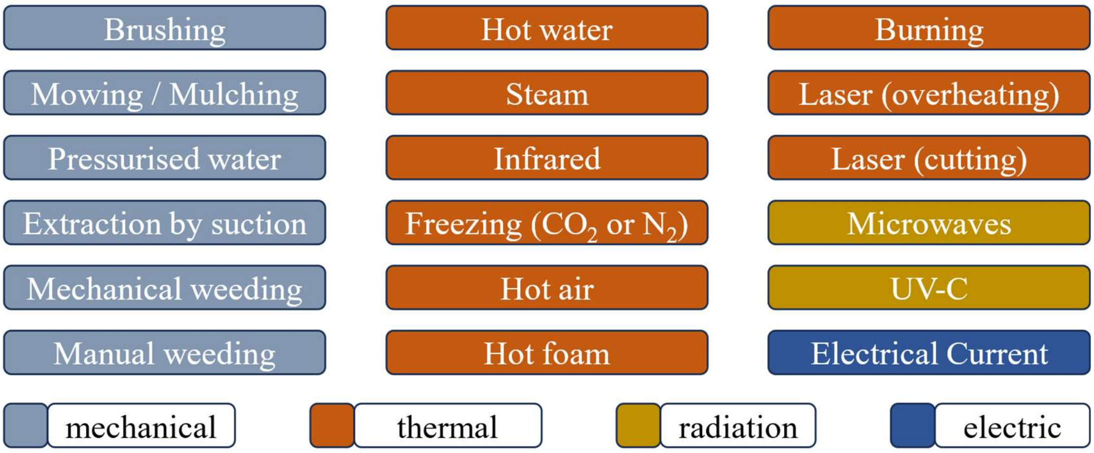

Figure 3 – Overview of the 18 identified herbicide-free methods.

The assessment of methods involved an evaluation of their compliance with established requirements. Initially, extensive literature research was conducted. Due to limited available information regarding the application of methods on the ballast bed, experiments were carried out in a test stand in an artificially created indoor environment and on test tracks with small equipment [12, 13].

Subsequently, each method was individually rated based on its fulfilment of each requirement. A scoring system ranging from three to five steps (e.g., 1P; 0.75P; 0.5P; 0.25P; 0P) was employed, where 1P represented complete fulfilment and 0P indicated insufficient fulfilment. The number of steps was determined based on the complexity of the requirement and the available information for evaluation.

To reflect the varying importance of fulfilment of the requirements, a weighting process was implemented. A priority ranking was established by comparing and assessing requirements in consultation with the project team, railway operators, and stakeholders, following the approach outlined by Breiing and Knosala [14]. The final weighting was determined as the average value. While recognising the importance of all requirements, specifications related to safety and the environment received the highest priority, followed by a blend of efficiency and effectiveness requirements. The least prioritised considerations pertained to the usability of the methods.

Figure 4 illustrates the rating process using an exemplary problem with three methods and three requirements. In total, a matrix of 396 values (22 requirements x 18 methods) was evaluated.

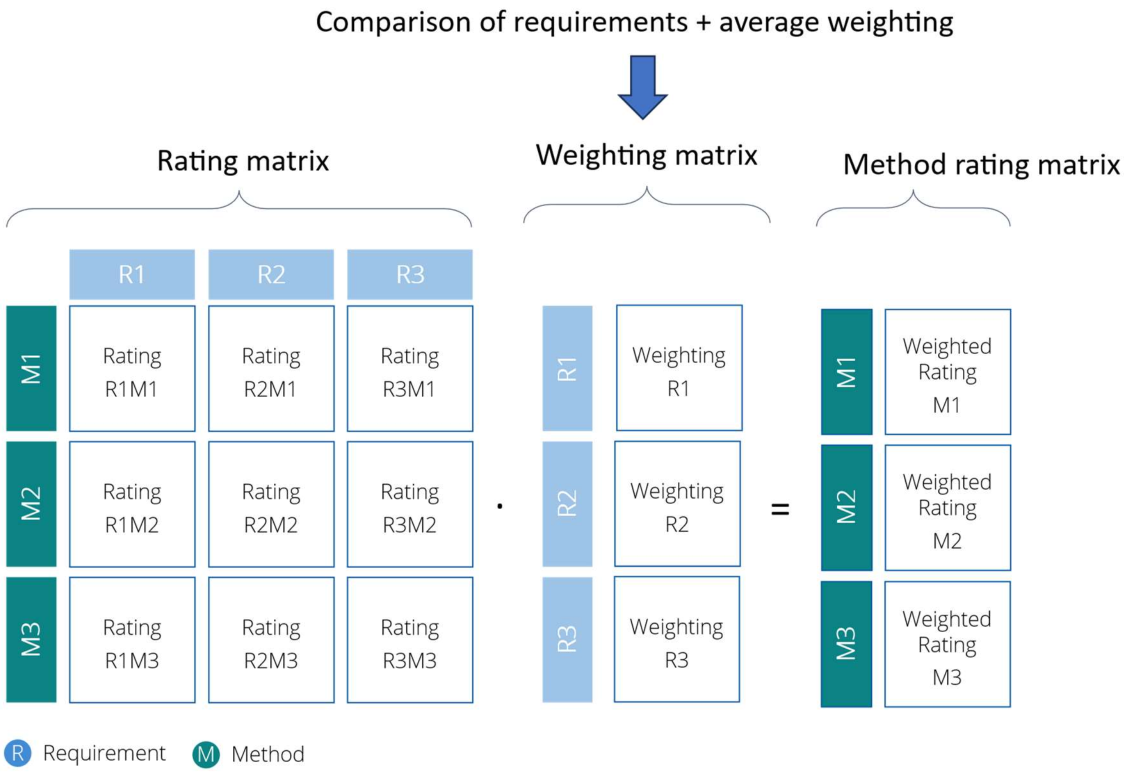

Figure 4 – methodology for rating the methods with weighted requirements.

As previously noted, the available data on the methods' performance exhibited some variability, although it did not reach a level suitable for statistical analysis. To accommodate this variability, the rating process was bifurcated into two parts: one representing the best-case scenario identified in the data, and the other reflecting the worst-case scenario. Table 1 presents the results of the rating for both the best and worst cases.

Best Case			Worst Case		
Rank	Normalised score	Ranking	Rank	Normalised score	Ranking
1	100,0	Mech. weeding	1	100,0	Elecroweeding
2	91,3	Electroweeding	2	95,0	Mech. weeding
3	90,1	Manual weeding	3	93,1	Pressurised water
4	86,5	Pressurised water	4	92,7	Laser (cutting)
5	86,2	Hot foam	5	87,4	Mowing
6	85,7	Brushing	6	96,0	Manual weeding
7	84,6	Hot water	7	87,9	Brushing
8	82,7	Mowing	8	86,1	Laser (overheating)
9	79,8	Laser (cutting)	9	85,2	Suction
10	75,2	Laser (overheating)	10	84,7	Hot foam
11	72,0	Hot air	11	81,6	Hot water
12	71,1	Suction	12	77,1	UV-C
13	70,8	UV-C	13	72,0	Hot air
14	69,6	Steam	14	70,0	Freezing
15	66,3	Infrared	15	67,0	Infrared
16	61,2	Freezing	16	66,0	Steam
17	58,7	Microwaves	17	56,6	Microwaves
18	51,0	Flaming	18	49,9	Flaming

Table 1 – Results of the rating (divided into best and worst case).

As observed, electroweeding, mechanical weeding, and pressurised water emerge as the top-ranking methods in both the best-case and worst-case scenarios. These methods operate as follows:

- Electroweeding – Damaging plants with electricity (voltage-based method),
- Mechanical weeding – plucking the plants with counter-rotating cylinders,
- Pressurised water – defibring plants with a pressurised water jet combined with abrasive material.

Although manual weeding demonstrated satisfactory performance, it was omitted from further consideration as it is intended to be mechanised by the method 'mechanical weeding'. This decision was made to ensure economic viability and minimise risks to workers.

In a general assessment, each method exhibited distinct strengths and weaknesses. Mechanical weeding, for instance, proved effective against tall plants and grasses, while electroweeding demonstrated efficiency with small plants. Pressurised water, on the other hand, was suitable for areas close to the rail, addressing concerns related to electrical arcing (electroweeding) and geometrical constraints (mechanical weeding). Recognising the complementary nature of these methods, they were chosen for the development and manufacturing of a test vehicle. This vehicle will enable the assessment of the methods under realistic conditions.

3 Design of Test Vehicle

The selected methods were further developed into a technical system applicable on railway tracks by partially applying the same methodology from VDI 2221 again to the single methods. Now requirements concerning more specific technical parameters (dimensions, power, materials, etc.) were gathered. They were then used to find the best solutions for the technical realisation of the selected methods. Further requirements arose from the fact that the vehicle is used for tests that need a control area for efficiency evaluation. Therefore, it was decided to leave certain areas untreated and use them as control area.

Vegetation in the track area tends to grow more homogeneously in the cross direction than along the track's length. Hence, control areas were strategically placed to mimic similar conditions as the treated areas, eliminating local side effects that could compromise result validity. Figure 5 visually illustrates the track area and the application of technologies on different zones.

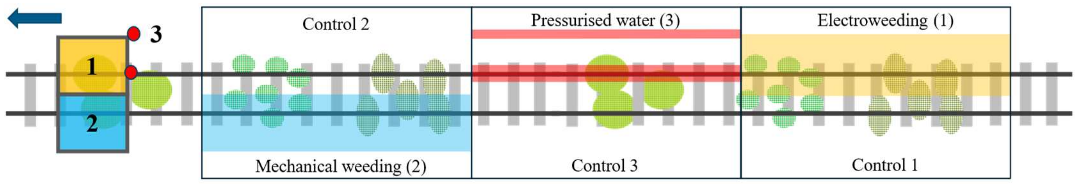

Figure 5 – Illustration of half-sided test procedure (yellow: method 1, blue: method 2, red: method 3).

The design of the test vehicle was elaborated based on this test layout. To ensure that a treatment on both sides of the track is still possible, the test vehicle can be turned around, allowing for the repetition of the treatment on the opposite side.

Specifically, for the large-scale treatment facilitated by electroweeding and mechanical weeding, the modules were designed to treat one half of the track area with one method and the other half with the second. This design consideration is influenced by limited installation space and the need for a control area during test runs to measure method effectiveness. Figure 6 shows the general layout of the test vehicle.

The design comprises a road-rail vehicle equipped with a towed carrier module. The vehicle houses the energy and water sources, while the trailer carries the applicators for weed control. The choice of a road-rail vehicle allows for convenient transportation of equipment to test locations by road, with the added capability of driving on rails. The carrier module is designed to adhere to standard lorry dimensions, facilitating both road transport and railway track manoeuvrability.

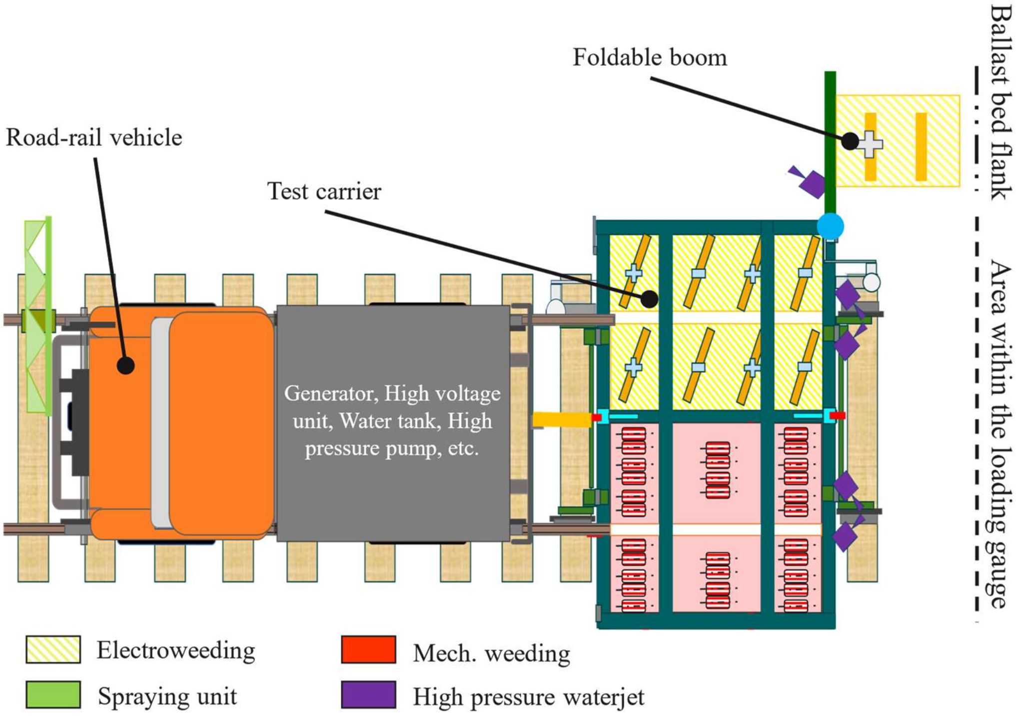

Figure 6 – Illustration of the test vehicle (road-rail vehicle and test carrier).

Each module for mechanical weeding consists of eight pairs of counter-rotating gears designed to grip and pull plants out of the ballast bed. These pairs are strategically positioned in an alternating layout to maximise the probability of plants being gripped by at least one pair. Figure 7 displays a detailed view of the mechanical weeding module.

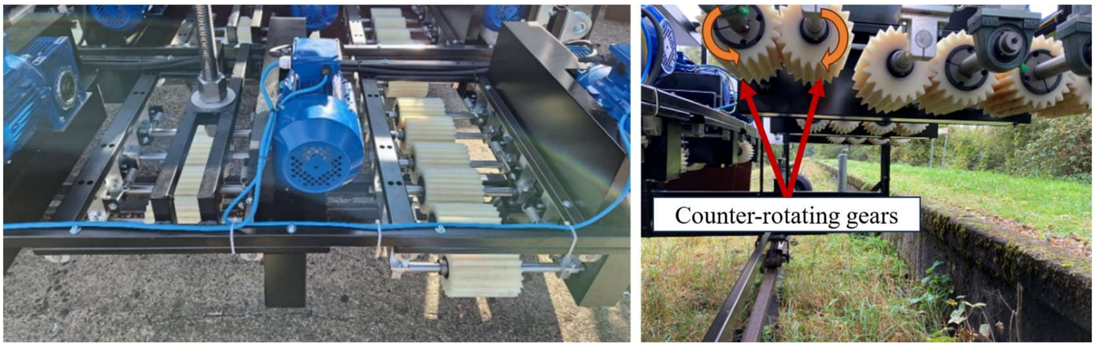

Figure 7 – Module for mechanical weeding.

The modules for electroweeding consist of multiple sets of metal fins with alternating polarity. These fins are dragged along the ballast bed surface, making contact with plants. The electric current flowing through the fins interrupts the water-conducting bundles in the plants, leading to their dehydration and eventual demise. Figure 8 shows the electroweeding modules in the lowered position.

Figure 8 – Fins of the electroweeding module (left) and complete module (right).

In contrast, the pressurised water system operates independently of the four application modules used in the other two methods (mechanical weeding and electroweeding). It can cover the entire width of the ballast bed by adjusting the nozzle's installation and alignment at various points on the back of the frame. Figure 9 illustrates the design of the adjustable nozzle holder.

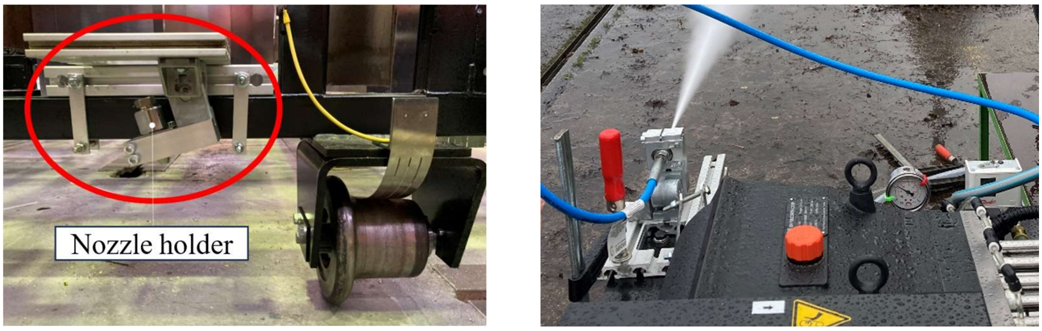

Figure 9 – left: Nozzle holder for pressurised water jet, right: Nozzle test.

The water jet is primarily positioned close to the rail to address areas that may be inaccessible to the other two methods. Additionally, the pressurised water method offers versatility, as it can be employed with a pure water jet or enhanced by adding an abrasive substance. The complete vehicle is shown in Figure 10.

Figure 10 – Test Vehicle on Railway Tracks.

4 Conclusions and Contributions

In conclusion, numerous information gaps persist concerning the effectiveness, mode of action on ballast surfaces, worker safety, and the impact on rail infrastructure and the environment for herbicide-free methods. These gaps pose challenges to the advancement of these technologies.

This work has provided significant contributions by identifying and addressing information gaps within existing scientific analyses related to herbicide-free methods. The most promising methods were carefully selected through an extensive evaluation of available scientific data, and a unique rating system, considering both best-case and worst-case scenarios, was employed to accommodate data variations and contradictions in the selection process.

Furthermore, this study developed a practical approach for realising these technologies for use on railway tracks. The designed test vehicle not only provides a platform for large-scale testing in the correct environment but also offers the opportunity to collect railway-specific data that is not comprehensively available in current literature. This marks a crucial step toward advancing and improving the performance of herbicide-free methods on railway tracks.

Acknowledgments

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