UIC SUSTAINABILITY

Future vegetation control of European Railways
State-of-the-art report
(TRISTRAM Final Report)

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TRISTRAM

TRANSITION STRATEGY ON VEGETATION MANAGEMENT

UIC

INTERNATIONAL UNION OF RAILWAYS

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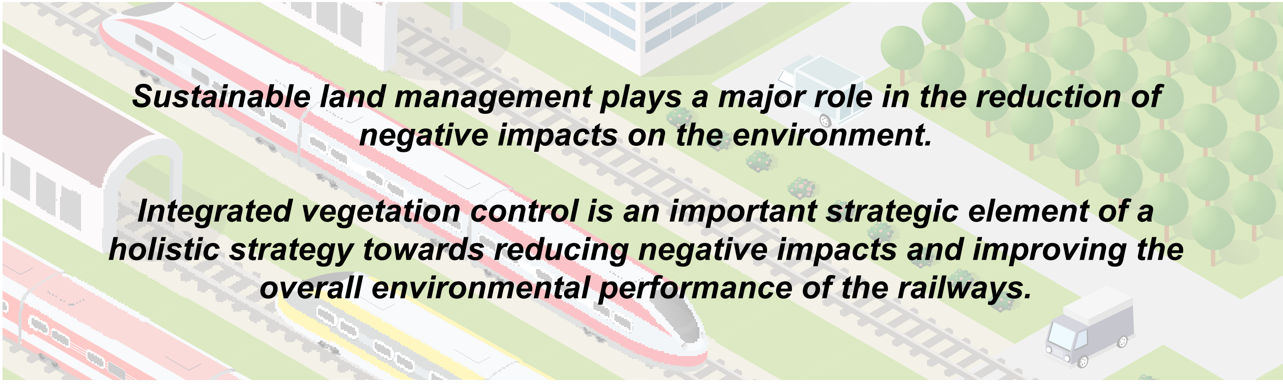
Executive summary

Railways are the most sustainable mode of mass transport of people and goods, with the highest energy efficiency and the lowest overall environmental footprint compared to other modes of transport. European Railways have a long tradition and ambition to further improve their environmental performance and reduce their environmental impact. They remain committed to these objectives by actively addressing all aspects of environmental performance such as carbon footprint, energy efficiency and renewable energies, adaptation to climate change, biodiversity and sustainable land use. In all these major areas European railways have dedicated strategies and a broad spectrum of projects and activities to substantially contribute to a sustainable development and design a future-proof transport system.



Sustainable land management plays a major role in the reduction of negative impacts on the environment.

Integrated vegetation control is an important strategic element of a holistic strategy towards reducing negative impacts and improving the overall environmental performance of the railways.

The transition from a vegetation control mainly based on a few commonly used conventional chemical herbicides to a vegetation control that makes use of a mix of different operative and preventive (i.e. chemical, physical, mechanical, biological, constructive) methods, constitutes a great challenge for the railways, especially in terms of financial and personnel resources, Research & Development (R&D) capacity and adaptation of established procedures. Nevertheless, with regard to true sustainability and also the high and still increasing public and political pressure on the use of conventional chemical herbicides, this transition strategy has to be developed and implemented now in order to prepare the railways for the future.

The European Railways are the pioneering sector for this transition strategy. They are pro-actively undertaking research, testing, adaptation to railway conditions and implementation of new methods and technologies as well as intensively networking, cooperating and fostering knowledge exchange in this highly complex and innovative field. The intense cooperation goes well beyond that between various European railway companies and also comprises other relevant stakeholders such as the industries providing technologies for vegetation control and their application, as well as research institutes and academia. Thus, the European railways have created a very active network of vegetation management experts across the companies and developed new relationships and alliances with industry and the private sector.

Within the framework of the predecessor UIC HERBIE project (2017-2018) [1] a broad spectrum of technologies and methods for vegetation control for the railways has been assessed and the most promising technologies have been identified. The TRISTRAM project goes well beyond this approach and focuses on the testing of methods and technologies under realistic operational conditions, adaptation to railway needs and requirements as well as practical implementation of the high potential methods for vegetation control. Furthermore, a consistent framework for integrated multimethod vegetation control focusing on alternative methods and supported by powerful digital tools has been developed.

As a result, a great variety of projects and activities have been launched by the railways in the area of integrated vegetation control with different railway companies focusing on different technologies, methods and approaches in order to generate the best overall impact, progress rapidly and use resources most efficiently. Active networking, intense cooperation and effort-sharing are the key elements for success.

The tangible results of TRISTRAM are:

- A status quo analysis of vegetation control techniques investigated by various UIC members and currently used,
- A UIC Strategy on the Future of Vegetation Control [2] based on an "Integrated vegetation control management" approach,
- A further assessment of the most promising alternative methods for vegetation control especially regarding operational performance, economic performance and adaptability to railway needs and requirements,
- A platform for the exchange of detailed information on alternative vegetation methods as well as affordable and effective solutions for the vegetation managers of railways,
- Recommendations for the future integrated, condition-based and multi-method vegetation control for railways supported by different digital tools such as GPS and GIS,
- First steps in challenging the traditional paradigm of vegetation control of zero tolerance in the tracks, towards an approach that defines standards adapted to different needs.

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Glossary

Terms	Definition /description
Pesticides	are a large group of chemical substances which are used to kill harmful insects, small animals, wild plants and other unwanted organisms (it includes Plant Protection Products (PPP) and Biocides).
Plant Protection Products (PPP)	are one of the two groups under the umbrella of pesticides; they protect plants against harmful organisms or combat vegetation.
Herbicides	are one group of the plant protection products (PPP); they are an agent, usually chemical, for killing or inhibiting the growth of unwanted plants, such as residential or agricultural vegetation and invasive species.
Conventional chemical herbicides	for the purposes of this report, this term covers all chemical herbicides used by railways up until today in traditional vegetation control within the rail track; the term chemical is used because nowadays one also speaks about digital vegetation control, which covers a broader spectrum of different methods managed by digital tools
Alternative chemical herbicides	for the purposes of this report, this term covers all chemical herbicides which are still under investigation or already in the registration process; they mostly belong to the “organic acids” group (see “Bio-Herbicides”)
Organic acids	in terms of chemistry, most of the herbicides belong to the group of organic acids; in some cases, the term is used in the sense of an agent which is originally extracted from plants such as pelargonic acid, but which is manufactured on a large industrial scale.
“Bio herbicides”	the term “Bio herbicides” is used with different meanings; sometimes “organic acids” (see above) derived originally from plants are called “Bio herbicides” even if manufactured on a large industrial scale.
Systemic substance /method	is a substance or method having an overall effect on the plants treated due to its interaction with metabolic processes; therefore, it works independently of where it meets the plants (e.g. glyphosate, electro-weeding) - as opposed to a non-systemic substance or method, which destroys only the part of the plant to which the substance /method is applied (e.g. pelargonic acid, hot water).
Vegetation management	is a management process that includes the identification of plants, the planning and application of measures for controlling plant growth within the railway infrastructure and properties and, finally, the determination of the effectiveness and documentation of the measures carried out.
Vegetation control	is the operative implementation/application of measures to control plants; it is embedded in the maintenance processes of railways.

Abreviations

Abbreviation	Description
CAM	Minimum Environmental Criteria in Italy
CER	Community of European Railway and Infrastructure Companies
DB	Deutsche Bahn AG
EC	European Commission
EU	European Union
CP	Cost of products
GHG	Greenhouse gas
GIS	Geographic Information System
GPS	Global Positioning System
GRI	Global Reporting Initiative
ha	hectare
HERBIE	UIC-Project, which covers best practices, benchmarking, guidelines and recommendations for vegetation control and sustainable use of **HERBI**cid**E**s
HGV	Heavy goods vehicles
IC	Indirect cost
IEA	The International Energy Agency
Infrabel	Belgian government-owned public limited company
INRAE	Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (France)
IPM	Integrated Pest Management
IZT	Institut für Zukunftsstudien und Technologiebewertung / Institute for Futures Studies and Technology Assessment
IWT	Inland waterway
JKW	Japanese knotweed (*Fallopia japonica*)
KPI	Key Performance Indicators
LCC	Life Cycle Cost
LDV	Light duty vehicles,
MC	Motorcycles
MH	Man-hour
MHC	Man-hour cost
MUV	Motor universal truck
NAP	National Action Plan
NGO	Non-governmental organisation
NT	Number of treatments per year
OA	Organic Acids
ÖBB	Österreichischen Bundesbahnen / Austrian Federal Railways
ÖBB-Infra	ÖBB-Infrastruktur AG / Austrian Federal Railway Infrastructure
PPP	Plant Protection Products
PQ	Product Quantity
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006
RFI	Rete Ferroviaria Italiana / Italian Railway Infrastructure manager
RISE	The Research Institute of Sweden
SBB	Schweizerische Bundesbahnen / Swiss Federal Railways
SDG	Sustainable Development Goals
SIGMA	The French national geographic information system
SLU	UIC Sustainable Land Use Sector
SNCF	Société nationale des chemins de fer français /French National Railway Company
SZCZ	Správa železnic / Czech Railway Administration
TRISTRAM	UIC-Project: **Tr**ans**I**tion **STR**ategy on veget**A**tion **M**anagement
TRV	Trafikverket / The Swedish Transport Administration
TWh	Terawatt-hours
FOT	Federal Office of Transport (Switzerland)
FOEN	Federal Office for the Environment (Switzerland)
UIC	Union Internationale des Chemins de fer / International Union of Railways
UN	United Nations
UV-C	Ultraviolet-C radiation
VHR	Very high resolution

Target audience

This report is designed for anyone interested in, involved or concerned with railway maintenance and in particular vegetation management within the track, including walkways and gravel bed. It sets out the state-of-the-art innovations and alternative vegetation control in European railways. The report includes the latest trends and alternative methods to conventional, chemical herbicide-based treatments used in traditional vegetation control, as well as future perspectives and opportunities. This report will be useful for EU and national policy-makers involved in sustainable land use topics, representatives of railway companies and vegetation management specialists, but also for other interested parties, such as environmental NGOs or citizens who want to know more about why and how railways have to undertake vegetation management within their tracks.

1. Key areas for a sustainable future

Transport networks, with their activities and infrastructures, impact on the environment of the landscapes they cross. The growth in demand for mobility of people and goods poses new challenges with regard to climate change, ecosystem degradation and biodiversity loss, which are existential environmental threats to mankind. Therefore, the environmental performance of railways concerning the protection of life on land is equally as important as its positive contribution to other ecological resources and climate protection.

The resilience of Earth against environmental and natural hazards is limited but today we are also facing tremendous challenges concerning the global economic and social crisis. Therefore in 2015 the United Nations (UN) adopted the resolution for transforming our world - namely “The 2030 Agenda for Sustainable Development”. The resolution includes 17 Sustainable Development Goals (SDGs) and 167 targets to stimulate action in areas of critical importance for humanity and the planet. At the international level and from a sector perspective, UIC members are committed to working towards achieving the UN SDGs and their respective targets for the “2030 Agenda for Sustainable Development” through the activities and projects they are conducting.

At continent level, the European Commission (EC) has developed an action plan for enabling the European economy to respond to the environmental challenges. Through the EU Green Deal [3] and its EU Biodiversity Strategy [4] for 2030, it aims to provide a wide range of contributions to human life (i.e. restoration of damaged ecosystems, growth of biodiversity in cities). Among other things, the Green Deal is aimed at triggering actions to promote more sustainable means of transport and helping Europe become the world's first carbon neutral continent by 2050. Increasing rail market share is an important part of the solution to climate change. Considerable efforts must be made to shift passengers and goods traffic from polluting transport modes to railways to achieve a Green Deal compliant transport system. Therefore, the sector should engage its activities towards “cleaner, inexpensive and healthier forms of private and public transport”.

If transport is a part of the problem, railways are a part of the solution!

Railways are frontrunners in global climate action and as such they must continue to play a central role towards a climate-neutral transport system. If the sector is to remain the champion of transport, a holistic approach is necessary [5]. The sector is indeed aware of its responsibility to provide safe and reliable operations with optimum environmental performance. As stated in the UIC-IEA (International Energy Agency) “Future of rail” [6] report, railways are already the most carbon-efficient motorised means of transport while reducing greenhouse gas (GHG) emissions and local pollutants. The sector carries 8% of the world’s motorised passenger movements and 7% of freight transport, but accounts for only 2% of energy use in the transport sector. In addition, the EU Transport statistical pocketbook [7] states that rail accounts for less than 0.5% of GHG emissions from transport although it carries 17% of inland freight and 8% of passengers in Europe.

Transport has different effects on nature, landscape and natural habitats. The main effects are habitat loss (ecosystem loss), habitat fragmentation and negative effects on ecosystems due to the emission of air pollutants (e.g. biodiversity loss). However, among the different modes of transport, railways have the least impact on nature and landscape [8].

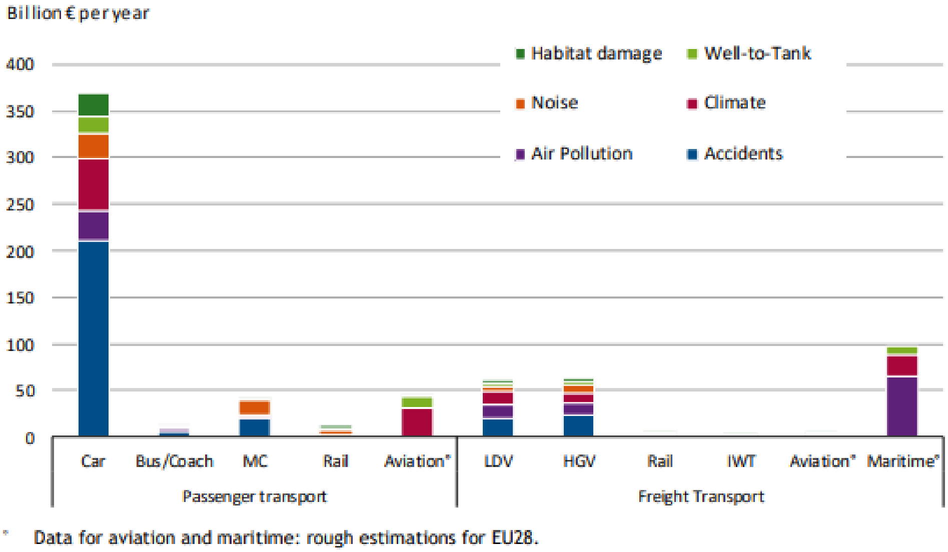
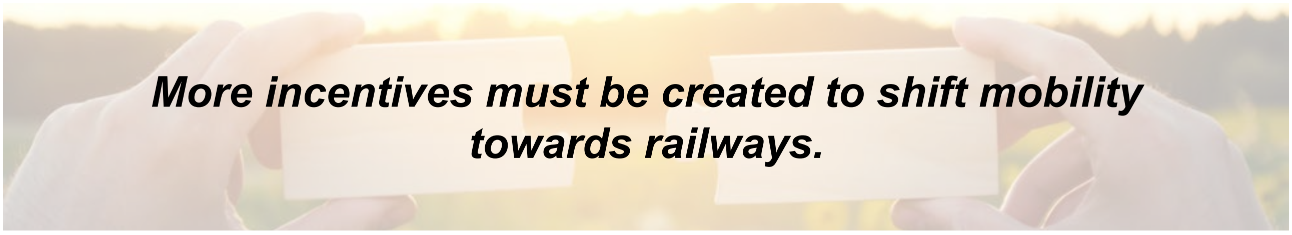


Figure 1: Total external cost 2016 for EU 28 (excluding congestion). MC: Motorcycles, LDV: Light duty vehicles, HGV: Heavy goods vehicles, IWT: Inland waterway [8]

Railways also help to preserve ecosystems by maintaining "green corridors" that preserve biodiversity in many ways. Rail is a high-capacity mode with comparatively low land take. Space requirements for railway-infrastructure per passenger-km are about 3.5 [9] lower than for road-infrastructure, which makes railways highly efficient with respect to the use of one of the most limited resources, especially in urban surroundings. Areas around the tracks are inhabited by a rich diversity of species that struggle to find adequate habitats in the intensively used landscapes. Railways do not pose as major a threat as other means of transport. Moreover, since railways consume around 290 terawatt-hours (TWh) of electricity (about 1% of global electricity use), rising interest in operating railways with renewable energy would help to avoid the disastrous impacts on the biosphere caused by the fossil-fuel industry [6].



UIC supports all efforts made by its members to increase the effectiveness, sustainability and profitability of rail transport for the benefit of customers and the whole of society as well as the environment.

Although the future plans for mobility indicate a necessity for a shift to more sustainable modes of transport and railways in particular, the sector is facing several market constraints such as a lack of level playing field for fair competition with other transport modes, insufficient funding for an ecological transition and progressive market liberalisation. In addition, the transport market is characterised by a massive externalisation of costs, which have to be borne by society and future generations.

2. Sustainable land use of railways

Railway operators and infrastructure managers must assess the biodiversity on their land and neighbouring plots and maintain and enhance it without compromising the operational and safety performance of their networks. For transparency, the sector communicates its economic, social, and environmental performance through annual and sustainability reports covering specific key performance indicators (KPIs). For instance, every single railway publishes its reports with key environmental figures, for example the amount of herbicides used, track length treated, points of contact with conservation areas, amount of water used and recycling rate [10] [11] [12]. Such a high level of transparency, particularly concerning the use of herbicides, is not common in other sectors.

The Global Reporting Initiative (GRI) is the most widely used or referred to international sustainability reporting standard which gives qualitative information (i.e. energy consumption, water use, waste production and biodiversity) [13] [14] [15] [16] [17] [18]. Within their annual integrated reports, railways publish, for example, the length of railway track in protected areas.

New and practical key performance indicators (KPIs) are needed to underline the environmentally friendly mode of transport.

Sustainable land use control and management is fundamental for helping the sector to achieve ambitious targets, and to scale up and extend some of the effective land management practices and pilot programmes. However, vegetation and tree risk management of railways is frequently overlooked as a priority. Although it is an integral part of the safety requirements and maintenance tasks of railways, there is a lack of recommendations on management solutions that are efficient, cost-effective and legally compliant as well as applicable to railways.

Conventional chemical herbicides for vegetation management on railway tracks are currently known to be the most effective method; however, their use is under discussion as highly controversial. Regulations on the use of herbicides, as one group of pesticides in the EU, have become increasingly stringent following the Directive 2009/128/EC [19] establishing a framework for Community action to achieve the sustainable use of pesticides.

The increasing understanding of the necessity of safeguarding ecological connectivity and the growing desire to preserve health and wellbeing has led to the progressive rejection of conventional chemical herbicides by EU's civil society. In this perspective, European railways prepare a transition strategy for vegetation management and develop a holistic approach to an integrated vegetation management which makes them a global leader for new concepts of sustainable transport. The objective is to progress from a single method-based concept - spraying of conventional chemical herbicides - to an integrated, flexible, multi-method-based approach, strongly adapted to local situations and needs.

UIC with its members within the Sustainable Land Use (SLU) sector has collaborated to develop a holistic approach to an integrated vegetation control management on railway tracks. Since 2019 through the **Tr**ans**I**tion **STR**ategy on veget**A**tion **M**anagement (TRISTRAM) [20] project, UIC with its project participants has been aiming at progressing from purely operational vegetation control to an integrated approach comprising preventive and operational measures. The objective of the TRISTRAM project is therefore to promote innovation and develop activities of common interest in the field of alternative vegetation control measures. This report intends to help railway stakeholders understand the current status and evaluate the interplay between their strategic plans and practical implementation for future vegetation controls. Alternative measures are understood here as methods that are different from the traditional methods based on conventional chemical herbicides such as glyphosate.

The traditional vegetation management approach using conventional chemical herbicides is expanded to new technologies comprising also on non-chemical methods. Members of the UIC SLU sector are undertaking great efforts to boost research as well as practical implementation of alternative measures. This new attempt also requires a modification of the planning process. The detection and monitoring of vegetation within the track area in combination with a forecast of plant growth for the planning process should be the basis for the application of vegetation control measures in future. This information combined with data about superstructure, ballast, operational data, environmental issues such as protected areas, meteorological data, etc. and the operating conditions of the available measures will lead to an optimised vegetation control for the track area. For a further improvement of the environmental performance of railways, the sector requires a comprehensive and reliable database. At the same time, the huge amount of data must be stored for documentation purposes and for future planning in the short and long term, as well as developing new environmental KPIs to underline the environmental advantages of railways.

3. Contribute to sustainable development goals

Railways as the backbone of sustainable transport are strongly committed to a number of the sustainable development goals and supporting targets, notably: energy efficiency (SDG 7), resilient infrastructure (SDG 9) and access to sustainable transport (SDG 11), resilience to climate-related hazards (Goal 13) promote environmentally sound technologies and multi-stakeholder partnerships (SDG 17).

Actions have to be prioritised towards adaptation or enhancing the resilience of transport infrastructure and services to climate change. Resilient infrastructure and services developed with regard to the 3R strategy - readiness, response and recovery - can help to combat the negative impacts of climate change. Besides constructive measures such as dams and bridges for new lines, other measures are also needed on existing lines to guarantee a safe and working operation at a high level (SDG 9). This includes a broad mixture of different measures such as adaptive maintenance of all affected infrastructure components, highly sophisticated monitoring systems for meteorological and climatological developments and natural hazards, adapting technical standards and improving ditches, etc. One step in this direction has already been made with the concept of an integrated vegetation management described within the TRISTRAM project (SDG 13). UIC published the Rail Adapt report [21] which aims at keeping UIC Members informed and prepared in support of national adaptation plans, UN agreements and EU encouragement to reduce risks and costs while improving railways' resilience in the face of climate change.

European railways remain committed to doing business in a responsible way due to their role in providing a safe working environment and environmentally-friendly passenger and freight transport. Although railways are already implementing strict regulations and improvements for lineside and vegetation management, members of the SLU sector are going an important step further and developing ground-breaking approaches for the vegetation control of the track area, given that future vegetation control will be directly and indirectly affected by the expected changes to our climate. The climate crisis will also have an impact on the properties of soil and water as well as on the composition of vegetation stock and on biodiversity. Therefore, railways are affected in many different ways: vegetation management within the track itself (TRISTRAM) and alongside the tracks as well as other sites owned by railway companies has to be adapted for expected future demands. European railways are initiating sustainable land use programmes which aim to protect ecosystems and create habitats for plants and animals on their networks.

New approaches for vegetation management are needed. These challenges offer the chance to support biodiversity and at the same time (linked to SDG 15 "Protect, restore and promote sustainable use of terrestrial ecosystems, …") reduce the risks for rail operation due to falling trees by creating open landscapes with bushes and grassland. In parallel, a high biodiversity is supported, because these kinds of landscapes have become rare nowadays due to intensive usage by humans and a high level of eutrophication with agricultural fertilisers and atmospheric nitrogen overload. In addition, this secures a high quality of soils by guaranteeing vegetation cover and environmentally compatible land use. (SDG 15 "… halt and reverse land degradation …"). The quality of water is a very sensitive issue, especially in dry regions, but also in general, because clean water is classified as a very important natural resource for human beings. In this case railways may contribute in two ways (SDG 6 "Ensure availability and sustainable management of water …"). On the one hand, they may save water within their production processes such as train washing, workshops or office buildings. On the other hand, they may enhance the quality of drainage e. g. from tracks. They can also help to retain water in the landscape by carefully draining it into retention basins from their sites and from there into aquifers and surface water.

Social and environmental dumping are part of the business model in many cases and these conditions are well documented by the media, politicians, stakeholders and authorities. Railways are not normally part of that game, as long as the principles of a completely liberalised market are not forced on this sector as well, without considering the negative side effects. Liberalisation and deregulation in the transport sector unleashed the counter-productive driving forces for social and ecological dumping. Railways still have a lot of internal barriers to overcome, e.g. with regard to interoperability, flexibility, capacity management and regulations. Without a transport world characterised by full cost transparency, true costs, the polluter-pays principle and social fairness, rail will not be able to take on the role that it should have in order to meet the UN Agenda-2030 [22].

4. EU Green Deal

In December 2019 the EU adopted the “Green Deal” with several actions. The objective of the Green Deal is to achieve climate neutrality by 2050. Moreover, the Green Deal announced measures for “preserving and protecting biodiversity” alongside headline actions “towards a zero-pollution ambition for a toxic free environment”. Therefore, the EU Commission proposed the 8th Environment Action Programme to 2030 and is currently working on various proposals for implementing the EU’s green agenda (i.e. [4], [23] [24]).

Furthermore, the EU commission released the factsheet [25], stimulating measures and actions to reduce the overall use of - and risk from - chemical pesticides by 50% until 2030 with a special focus on the more hazardous pesticides.

- The “EU Biodiversity Strategy” [4] will help identify additional protected areas and ecological corridors which can contribute to the EU 2030 nature protection targets. From the perspective of the EU, there will be an assessment of the EU’s progress in meeting its 2030 targets on protected areas and whether additional action, legislative or other, is needed (2024).
- In the context of the vegetation management of railways, the future revisions of the Directive 2009/128/EC on “Sustainable Use of Pesticides” and the “Integrated Pest Management (IPM)” provisions will be important in 2022.
- A proposal for EU nature restoration targets should be set up in 2021 alongside the revision of the “Thematic Strategy for Soil Protection”.
- Species and habitats should be selected to ensure that at least 30% of protected species and habitats not currently in a favourable status are in that category by 2030 or show a strong positive trend (2020).

The changes in the regulatory framework will require a prompt response from the railways regarding activities that have the potential to strengthen the environmental advantage of railways compared to other modes of transport and to minimise the externalities of rail transport.

In 2019, UIC members were invited to sign UIC’s Railway Climate Responsibility Pledge which aims go one step further by aligning its 2050 CO_2 emissions target to achieve the Paris Agreement: “carbon neutrality by 2050” (instead of 75% by 2050) [26]. UIC, together with its signatories to this pledge, is fully committed to deploying efficient and sustainable methods to reduce the environmental impacts of railways and to continue to develop its work with other members.

In addition, UIC welcomes that 2021 is the “European Year of Rail”. Even if railways are already energy efficient, European railways will work on transforming their rail systems by identifying the key barriers and shifting finance from destructive activities towards nature-based solutions, such as alternative vegetation control as focused on in this report.

4.1. EU policy and regulations

The sustainable use of plant protection products (PPPs) has become one of the priorities of environmental policy at a national and European level. The European policy on the use of pesticides has been changing dynamically in recent years. The EU chemicals policy underwent a major change with the introduction of the Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006 [27] (REACH) which entered into force on 1 June 2007 [28].

Moreover, the change in pesticide regulations within European countries has accelerated since the Directive 2009/128/EC [29]. With this Directive, EC aims to achieve a sustainable use of pesticides in the EU countries by reducing the risks and impacts of pesticide use on human health and the environment, as well as promoting the use of IPM [30] and of alternative approaches or techniques, such as non-chemical alternatives to pesticides. Many of the actions taken under the Directive are also relevant to the Biodiversity Strategy which includes the adoption of pesticide reduction targets. EU countries have drawn up National Action Plans (NAP) to implement the range of actions set out in the Directive [31]. The implementation of NAPs, however, differs among EU member states.

In 2017, after a lengthy consultation and discussion process, the European Commission extended the license for the use of glyphosate for only 5 years until December 2022. In 2020, the renewal process for this licence has started. Possible scenarios for the new period starting in December 2022 range from limited use options and corresponding strong restrictions in many areas to a total ban [32].

4.2. National approaches

Despite EU regulations, the attitude of civil society, private users, as well as local or national legislations towards chemical herbicides varies across the EU. Nonetheless, the general tendency in Europe is of a growing concern about the use of pesticides in general, especially glyphosate - the world's most widely-used conventional chemical herbicide. The interest and involvement of civil society in particular has been spreading since 2015, when the World Health Organisation's International Agency for Research on Cancer declared glyphosate as probably carcinogenic. The growing social rejection of pesticides is reflected in actions such as total ban of pesticide use, strong pressure towards more transparency on pesticide use and requirements on larger safety distances along public and private properties[1]. On a national level there is a wide range of policies, measures and practices with regard to glyphosate use.

- Germany, Austria, Italy, France and Denmark are all planning or considering a full ban on glyphosate by the end of 2022 at the latest. Luxembourg has already banned glyphosate (phasing-out by 31 December 2020) and the Netherlands is considering a full ban from 2025.
- In many countries such as France, Italy, Belgium, Germany, the Netherlands and Austria, PPPs are already banned, for example, in public areas such as squares, yards, parks, cemeteries, internal station areas and areas frequented by people. In Belgium, all PPPs are forbidden for the whole public sector including the railway track area. Exceptions to this regulation are only possible with a special exemption issued by the regional authorities (Brussels, Wallonia and Flanders). In Belgium, France and Germany products based on glyphosate are already banned for private use, whereas in Czechia, Hungary, Finland, Latvia, Norway, Portugal and Spain this use is still allowed.
- The number of restrictions, partial and total bans on PPP use as well as public pressure have significantly increased in recent years.

The strategies of the companies vary according to their NAPs, specific legislation and regulations. Although European railways currently regulate and limit the use of conventional chemical herbicides to the absolutely necessary level, most of them have gone a step further and are already actively preparing the exit phase. Since there is no single road map for the transition from traditional vegetation control with conventional chemical herbicides to an integrated vegetation management with a strong focus on alternative methods, these regulations and bans on several products may pose a great environmental, economic, safety and operational challenge for European railways.

4.2.1. Professional use: special focus on railways

In France, SNCF is committed to terminating glyphosate use by the end of 2021. **SNCF** is running two actions or research programmes in parallel: the first one - "to be ready in 2021" - aims at rapidly deploying maintenance solutions without glyphosate; the second one focuses on developing solutions without conventional chemical herbicides (medium to long term). **SNCF** is obliged to adapt to new regulations in a context of strong ecological awareness. In this regard, two major changes should be noted:

- Removal of marketing authorisations for products containing glyphosate leading gradually to its ban. Also, the use of glyphosate at **SNCF** is planned to end before the end of 2021 (announcements made by **SNCF's** President).

[1] In their letter to the Commission's First Vice-President Frans Timmermans and EU health chief Vytenis Andriukaitis, the six ministers of agriculture or environment of France, Belgium, Greece, Luxembourg, Slovenia and Malta reiterated their "concerns" about the risks of the use of glyphosate.

- The French General Food Council's (EGalim) law for the application of PPPs in 2020 has set minimum spreading distances of between 5 and 10 metres away from housing to protect residents. This regulation sets up safety distances which may be reduced to 3 m if a controlled and low drift can be proven for a given product. With the non-treatment zones defined by 5 m safety distances, those due to hydraulic works and all others, the existing prohibited zones already add up to nearly 100,000 treatment cuts for the SNCF network.

In Germany, DB announced a reduction in glyphosate use in 2020 by half and plans to stop usage by the end of 2022.

Several railway companies have already significantly reduced the use of conventional chemical herbicides and are announcing further significant reductions, e.g. in 2018/2019 **Banenor in Norway** used approx. 3 tonnes of conventional chemical herbicides compared to 5.5 tonnes in 2014 [33]. This reduction is due to better management and a targeted environmental focus.

In Belgium, Infrabel has been able to significantly reduce the use of chemical herbicides since 2008 due to the early implementation of vegetation detection systems for the spray-train (on main tracks). Recently, they announced the reduction of the surfaces treated with conventional chemical herbicides on secondary tracks by 25% in 2020 and gradually increasing to 50% by 2023.

In the Netherlands, although all PPP's are already forbidden for professional use in public spaces since 2017, some exceptions apply, e.g. for certain parts of the railways (trackside walkways and the track bed), defence runways, and (some) dikes.

In Italy, railways have to adopt mandatory Minimum Environmental Criteria ("CAM") regarding the use of phytosanitary products along rails. The main issues in this respect are:

- Specific phytosanitary products are forbidden and limits on the application are applied,
- Construction specs for spray trains or machinery are defined and annual reports on the quantity and frequency of treatments are required,
- Awarding criteria for invitation to tender (ITT) packages aimed at limiting or excluding the use of phytosanitary products are applied to contactors' bid proposals,
- In addition, restricted areas are defined and specific training of personnel is demanded.

4.2.2. Water and nature protected areas along railways

The main objective of railways is the reduction of PPP use within and along rail tracks by implementing alternative methods and optimising PPP use by, for example, improved targeting of vegetation. Special attention has to be paid to water and nature protection areas. The focus of the railways on an environmentally-friendly vegetation control in these areas is particularly important in order to minimise any leaks of potentially harmful substances into the environment.

For instance, **in Italy**, since February 2017, it is mandatory for Contract Authorities to integrate the "CAMs" into Invitation to Tender procedures and awarding criteria. The main scope is to reduce the environmental impact of phytosanitary interventions along rail tracks by using alternative methods. The use of alternative methods is mandatory for **RFI** inside protected and vulnerable areas such as surface and groundwater protection areas with use for human consumption. PPPs are forbidden in the areas within 10 metres of water bodies (5 metres if anti-drift devices are used) and in yards and internal rail station areas where the public can have access. The Italian Public Authorities can amend this only for public safety aims.

In Germany, only a few conventional chemical herbicides are registered and approved for railway use. In addition, for chemical vegetation control treatment there is a general requirement for **DB** to get permission from the German Railway Administration and in the case of contact with nature, such as in water protection areas, from local authorities responsible for these areas.

In Austria, ÖBB-Infra has to work with the few conventional chemical herbicides that are registered and approved for railway use. All requirements that are defined in the official herbicide register have to be followed strictly and the use has to be recorded accordingly. There are specific requirements for water protection zones, but the most important regulations are defined by notifications from the local authorities in charge for water resources. In some cases, local authorities declare a total ban on specific chemical herbicides in water protection sites and sometimes stricter requirements for usage have to be followed.

In Switzerland, the use of conventional chemical herbicides is forbidden in all groundwater protection zones. **SBB** is to work out an overall concept to clarify and categorise the environmental concerns regarding

- track wastewater,
- platform roof wastewater,
- platform wastewater,
- wastewater from underpasses,
- wastewater from tunnels, bridges and forecourts

and ultimately to determine the need for investigation.

In Sweden, it is in principle possible to obtain a permit to spray in groundwater protection zones. However, **TRV** has chosen not to apply for those permits but to instigate no-spray zones. In Sweden, the use of conventional chemical herbicides is generally forbidden with the exception of uses within the framework of the vegetation maintenance programme. To protect especially sensitive areas including groundwater protection areas, **TRV** has developed a method for their identification. No herbicides will be spread in these restriction areas.

In France, the older restrictions relate to groundwater, safety distances to watercourses and a ban on the treatment of hydraulic structures. Regarding the newer restrictions concerning the protection of people, the 2017 law imposes safety distances from establishments housing vulnerable people to be extended in 2020 by the implementation of safety distances for all built properties. The recent strengthening of regulatory restrictions leads to a significant increase in the overall areas where treatment is prohibited. The new regulation also requires PPP users to draw up, after consultation, a charter of commitments specifying the terms for information on treatment dates, the means implemented for the protection of individuals and the terms for dialogue and conciliation with residents.

In Belgium, in the railway area, only foliar herbicides are used in the protection zones of water catchments and protected nature areas. Some of these zones are not treated. Other restrictions are derived from the conditions of regional exemptions. Buffers are considered to preserve surface water. The presence of herbicides outside the treated track area (surface water, ground water, ground in nature area) was checked in 2019 with no results exceeding detection or acceptance levels. As a preventive measure, mainly asphalt, limestone or concrete and ternary materials are used for walkways to limit vegetation growth. These preventive measures are included in the technical requirements. More information is given in Chapter 7.3.1.

To summarise, despite the many peculiarities, as well as specific national legislation and regulations frameworks and strategies concerning the use of conventional chemical herbicides and especially glyphosate, the overall picture shows some common denominators: growing awareness, public and political pressure and opposition as well as partial and total bans on PPP used by the railways are leading to increasing barriers and restrictions and rapidly decreasing acceptance of the use of conventional chemical herbicides. Against this background, the development and fast implementation of transition strategies from conventional chemical herbicide-based to integrated alternative vegetation management strategies are of utmost importance. (7.2.2 Chemical methods)

5. Big challenge: Effective Vegetation Control Methods

An efficient vegetation control constitutes a great challenge for the railways due to the special construction and properties of the rail track area based on a ballast bed with embedded sleepers and rails. The active ingredients of herbicides and especially alternative /non-conventional chemical technologies used in other sectors such as agriculture or on municipal hard surfaces thus cannot be transferred directly to use on rail tracks, but need either an extensive adaptation or cannot be used at all.

5.1. Dealing with the Market

The market for vegetation control measures for railways is not a very lucrative one for the industry since the railway's share of herbicide consumption is very low. Chemical herbicides are primarily developed for agricultural uses. Separate registration, additional studies and approval steps are needed to get a licence for "railway-herbicides". Therefore, the development of new herbicides or even non-chemical technologies for railway use is very expensive and constitutes a high barrier for small and medium-sized companies mainly active in the non-chemical sector. Thus, the railway sector has to develop alternative approaches for getting new (non-chemical) technologies into operational use.

Contracts: Traditionally, contracts of railway companies with service providers for vegetation control on their network were based on the general treatment of the entire network by herbicides. These framework conditions led to a developmental lag on herbicide-free methods. One of the factors causing this was:

- The availability of a sufficient number of herbicides for railways provided by the chemical industry due to the limited market segment,
- The resistance of the existing chemical market,
- The bias of the existing market toward the sector with feasibility analysis based on limited budget and time.

Until recently, this was further aggravated by the fact that most developers of non-chemical methods are small-scale businesses and even start-ups.

A new approach to contracts could improve the situation for alternative methods of vegetation control. New contracts could explicitly include railway lines or line sections which have to be treated with non-chemical methods, such as water protection areas, due to the presence of restrictions on conventional chemical herbicides use. Furthermore, it might also be possible to tender a whole network - including lines with restrictions or bans on conventional chemical herbicide use - for vegetation control without defining specific methods. Here, the only demand could be the definition of a certain track quality in terms of a maximum degree of vegetation coverage to be met by the service providers. Such signals to industry would underline the urgent need for non-chemical methods for railway use.

In-house development: Due to the market situation described above, the option of an "in-house development" - i.e. the development of non-chemical methods by the railway companies themselves - should be considered as well. It could be an appropriate solution for meeting the individual requirements of each railway company. This option requires that railway companies have innovation departments with responsible personnel with the appropriate technical and operational know-how on vegetation control as well as development and testing facilities. Large railway companies may have an advantage here since they usually have relevant resources and in-house knowledge. If the development of alternative technologies requires very specific and detailed knowledge, cooperation with a developer and/or a research institution might be a viable approach, which is often implemented in the course of R&D projects.

Cooperation with developers: As an initial step, a market investigation of the non-chemical methods and other institutions such as universities or research institutes should be carried out. This preliminary work helps to identify potential partners who are able to fulfil the requirements of the railway company and the favoured technology. Due to the legal conditions concerning competition, e.g. in the respective country, a collaboration contract might close the knowledge gap between the railway technicians and the vegetation control experts of other institutions.

Tendering the development of new technologies: If there is any issue with the collaboration contract depending on competitive or other legal conditions, the entire technological development for the selected or favoured technologies can be tendered. In this case it must be clarified in advance whether the railway company has already chosen a specific technology. In both cases the requirements have to be defined in as much detail as possible, including the expected operating speed, the operating area (ballast and walkways or one of each), the exclusion of such zones that may cause operational impairments (i.e. due to signalling problems), the accepted maximum frequency of treatment per annum, and environmental issues such as water protection and nature conservation aspects, etc.

5.2. UIC Strategy on the Future of Vegetation Control

In the beginning of 2020, UIC prepared a Strategy for the future of Vegetation Control [2] for the next few years. This document presents the holistic approach to integrated vegetation management on railway tracks. The objective of the European Railways is to progress from a single method-based concept - spraying of conventional chemical herbicides - to an integrated, flexible, multi-method-based approach. This new approach allows treatment to be fine-tuned to a large variety of conditions.

The aim of this strategy is to progress from:

- a static approach to a dynamic, condition-based approach,
- a single method to a flexible mix of methods; from conventional chemical herbicide treatments to alternative, herbicide-free methods,
- purely operational vegetation control to an integrated approach comprising preventive and operational measures, including impact assessment, as well as continuous monitoring of the track,
- specialised single-method application vehicles and equipment to versatile and flexible multi-method technologies for application,
- digital systems for monitoring, reporting and impact assessment to automated digital solutions integrating all of the functionalities required for integrated vegetation control,
- vegetation control to plant-specific measurements, taking individual plant physiology, ecology and dispersion strategies into account.

5.3. Railway activities - an overview

UIC and its members are striving to get new methods and technologies for vegetation control into operational use. Inspired by the HERBIE [1] project and its identification of promising methods and technologies, they actively test a variety of operative and preventive methods concentrating on environmentally beneficial solutions, develop the most promising candidates further and adapt them for use under specific railway conditions. They also investigate appropriate combinations of different methods. Currently, the focus of activities is on chemical treatments with plant-derived chemical herbicides (such as pelargonic acid) and new chemical substances, as well as selected thermal, biological, and mechanical treatments, and preventive measures such as selecting the best type of ballast gravel and root barriers.

Figure 2: Pilot system for electro-weeding on a road-rail vehicle

As regards preventive construction methods, the impact of different materials for ballast and walkways on plant growth is being investigated. The aim is to identify materials suitable as a coverage layer to inhibit or at least minimise vegetation growth. In addition, root barriers (made of polypropylene and rubber materials) are being tested, which could amplify the effect of the coverage materials. There are already many test side walkways established by **DB, ÖBB-Infra, SNCF Réseau, SBB, ProRail** and **Infrabel**.

Although the range of operative measures investigated includes chemical as well non-chemical methods, the focus is on non-chemical methods since chemical vegetation control has already reached a high level of maturity and includes features such as selective spraying systems based on camera detection with integrated GPS and GIS systems. Digital tools for integrated vegetation control can minimise herbicide use and be used to draft detailed documentation. Additionally, the railways' testing and research efforts and their commitment to developing alternative methods encourage the industry to develop herbicide-free methods of vegetation control and to search for new, more environmentally-friendly active substances.

Figure 3: Road-rail vehicle equipped with vegetation detection

The current selection of non-chemical methods covers three different physical mechanisms. The most well-known is hot water (examined by **SBB, TRV** and **DB**), which is already used on hard surfaces in municipal areas. While SBB is already running a pilot-train system for hot water, **DB** is investigating the effects on different plants occurring in the track area. Therefore, model surfaces with “track plants” are used to obtain detailed information about temperature course, e.g. from the nozzles over the plant into the ground (ballast and walkways) - important information for the future development of hot water systems for railway use.

A new technology (electro-weeding) - occasionally used in agriculture and based on the flow of electrical currents through the treated plants - is being examined by **DB, ProRail, Infrabel,** and **ÖBB-Infra**. The first tests with electro-weeding are being carried out at **DB** and **ÖBB-Infra** with their service providers on a road-rail vehicle on tracks. Besides these examinations, this measure is also being investigated on model-surfaces to obtain more information about the mechanisms for further development and adaptation for use in rail tracks.

The third mechanism is based on UV-C radiation (examined by **DB**), which “burns” the treated plants. The UV-C investigations by **DB** are currently being conducted in the laboratory to estimate the general effects on plants occurring within the railway track area.

In France, **SNCF Réseau** forges partnerships with key specialist research institutes. **SNCF Réseau** is preparing a feasibility study in collaboration with INRAE [34] on vegetation control using electromagnetic waves. This study involves testing the effect of thermal waves on the vegetation on tracks. As a result, the system could be mounted onto a train and the vegetation control can be performed at speed. This technology could also be used in vehicles to control the vegetation near service roads. In terms of the operational constraints, typically the speed of implementation, the protection of the environment and the safety of those around, these issues are thereby reduced. **SNCF Réseau** is testing a prototype to address this method.

Even though the above-described alternative methods of vegetation control are in different stages of development, all must be adapted for the use in rail tracks. In order to reach further reductions in herbicides and to apply non-chemical measures there is an important basic question to be answered: Where and to what extent does vegetation control have to be carried out (addressed in “**Chapter** 6**:** Need for vegetation control”). Investigations in this respect are either planned or under way by **DB, SBB, TRV, ÖBB-Infra, ProRail** and **RFI**) as an important issue for their future strategy for vegetation control on railway tracks.

These different methods (if working properly) and the results concerning the “need for vegetation control” complemented by detailed information on vegetation growth and coverage, track classification and environmental issues should be integrated into a vegetation management system. Therefore, the existing planning tools based on GIS (**SNCF Réseau, DB, Infrabel,** and **SBB**) must be developed towards an integrated vegetation management system. It combines all important parameters needed for planning and carrying out effective and sustainable vegetation control in the future.

After positive feedback on two UIC International Workshops on Vegetation Management organised in 2013 and 2016, UIC is leading a variety of active projects to find alternative solutions to conventional chemical herbicides. In the last few years, there have been regular experts’ meetings and active cooperation within the framework of two projects: HERBIE project (2017-2018) and TRISTRAM project (2019-2020).

The HERBIE project delivered guidelines, state of the art of vegetation control and management for railways, as well as an overview of future Methods and Technologies for the Railways [1].

Within the framework of the TRISTRAM project, the UIC SLU sector with its members established a broad exchange of practical experience on alternative vegetation control methods currently used and investigated within the European Railways. Table 1 shows the research on vegetation control methods in the network of TRISTRAM project participants. Regular meetings of an international working group and a dynamic exchange of information helped to identify more sustainable solutions in vegetation management for the railway sector. This level of cooperation as well as operational expertise is unprecedented in other branches in Europe and, thus, makes the railway sector a prime candidate for initiating the transition towards an integrated vegetation management focusing on alternative methods and transferring the results to all other relevant sectors.

Table 1: Research on vegetation control methods in the network of TRISTRAM project participants

	Chemical methods	Biological methods	Thermal methods	Electrical and radiation methods	Mechanical methods	Construction-reconstruction methods	Digital tools for integrated vegetation control
DB	Conventional chemical herbicides and organic herbicides	Biomineralisation	Hot water	UV-C Electro-weeding	-	Walkways covers /various mats and layers	Vegetation mapping and digital tools for an integrated vegetation management Examination of track section without vegetation control
ÖBB INFRA	Conventional chemical herbicides and organic herbicides (incl. eco-toxicological tests)	Grazing; biological treatment of tree of heaven, targeted sowing	-	Electro-weeding	Mulching mowing	Root barriers and rubber mats (incl. ecotoxicologycal tests) Ballast material	-
ProRail	-	-	Hot water/ combination with electricity Liquid nitrogen against JKW	Electro-weeding	Covering grow space against JKW	Anti-vegetation mat	-
RFI Rete Ferroviaria Italiana	Conventional chemical herbicides		Hot foam	-	Mulching mowing	-	-
SBB CFF FFS	Conventional chemical herbicides and organic herbicides	Greening Allelophatic plants, Others Targeted sowing	Hot water	-	Mowing	Walkway covers Geotextiles Ballast material and amount	-
SNCF Réseau	Conventional chemical herbicides and organic herbicides	Selected vegetation on service tracks (by seeding) Grazing	-	Microwaves	Mowing (associated with the optimisation of safety devices)	Geotextiles, and other walkway cover solutions	GIS management tool connected to processing equipment (already operational)
Trafikverket	-	Targeted sowing	Hot water Hot foam	-	Mechanical vegetation control		-
Infrabel	Conventional chemical herbicides	Grazing, controlled vegetation development	Outside the track area (warm water, etc.)	Electro-weeding	Mowing, hoeing, manually pulling out vegetation	Mineralisation Anti-vegetation mat	Follow-up of chemical use with vegetation mapping

5.4. Funded Projects and Activities in European Railways

For many years, UIC and its members have been making great efforts to identify and develop solutions for effective and sustainable vegetation control as part of an integrated vegetation management.

Due to the national legislation and the framework conditions in the respective countries, railways are forced to carry out investigations individually. The results are reported on a regular basis and communicated via UIC. Hence all member railways benefit from these outcomes. If necessary, the measures are adapted to the respective national conditions.

A multitude of funded projects is currently carried out within the European Railways. The projects differ in terms of financing scheme and sources, budget and the methods investigated. The wide spectrum of activities shows the commitment of European railways to a greener, more sustainable and environmentally-friendly vegetation management.

In Austria, ÖBB-Infra - Green Logix: The project goal is the evaluation of different alternative methods for vegetation control on transport infrastructure areas (railways, roads and highways) in order to find the most effective and environmentally-friendly solutions for the respective requirements of a route section (rail or road). The results will provide support for infrastructure operators to decide which methods of vegetation control can be used depending on the different targeted areas. The following alternative methods were investigated within the project:

- Construction-reconstruction methods: tests of root barrier materials and materials that are used for the ballast bed and service walkways,
- Mechanical / electrical methods: tests of electro-weeding and mowing,
- Chemical methods: tests of different herbicides and wetting agents (conventional and alternative chemical herbicides) with a focus on organic acids and their combination with conventional chemical herbicides,
- Biological methods: targeted sowing with tests of seed mixtures of plants for border areas with low maintenance effort.

Furthermore, as a part of the project, ecotoxicological studies for the chosen herbicides and root barrier materials were also carried out (on algae and fish embryos).

- Collaboration of private institutions, transport-infrastructure operators (rail and road), technical universities,
- Tests at shunting yards and main lines (but also road infrastructure sites),
- Total project cost €346k (net), funding rate 50% from Ministry for Transport, Infrastructure and Technology,
- Period: 2018 - 2020,
- Maintenance and operating costs were not investigated.

In Belgium, Infrabel: In 2020, calls for tenders for the vegetation management of secondary tracks were issued to fulfil the national and regional legal requirements. The same subcontractor to be selected has been requested to carry out the maintenance works with herbicide or herbicide-free alternative methods. These studies for the application of chemical and alternative methods started in September 2020. The goal is to progressively increase the share of surfaces (Zone A to C) treated with alternative methods from 25 % in 2020 up to 50 % in 2023. By that time, more than 5 km^2 of secondary tracks will have been treated with alternative methods. The following herbicide-free methods will be applied:

- Mowing,
- Manual hoeing (i. e. pulling out the plants by hand or a mechanical action).

The prediction is that the most used method will be mowing. A strong increase in costs is expected due to the need for repeated treatment in comparison with conventional chemical herbicides and the higher cost per m^2 of alternative treatments. It involves a full-scale implementation of mechanical methods on secondary tracks. As a follow-up in the coming years, all observed results due to a change in vegetation management need to be evaluated, for instance the change in vegetation coverage, the effect on safety issues and the stability of the railway infrastructure. Risk assessment is needed for operational safety and to preserve the assets. Depending on the outcomes of these assessments, readjustments will be made regarding the required application frequency of vegetation treatment by alternative methods.

Thermal methods such as steam and hot water are implemented on small surfaces outside the tracks (Zone E) as herbicide-free methods. A reduction in the use of herbicides is also expected by more targeted manual spraying and the use of vegetation detection on vehicles. Further improvements on the spray train with vegetation detection systems are expected, for example by using pelargonic acid as soon as it becomes authorised and to improve the follow-up of the treatments. Furthermore, other methods and techniques such as electro-weeding and “bio herbicides” will be investigated for use at Belgian railways.

Construction measures for walkways (use of concrete, ternary materials, etc.) are progressively being implemented when track renewal is done. Outside the track area (Zone D), sheep and goat grazing are possible alternatives which are beginning to be implemented on embankments if the conditions are favourable (size of the parcel, accessibility, etc.). Research is also being conducted on dealing with invasive species such as Japanese knotweed (JKW).

In France, SNCF has been engaged in an active search for viable alternative solutions and a proactive policy of limiting the use of plant protection products. It maintains a high level of requirements while adopting a responsible vegetation control policy, with a concern for health protection and consideration of the environment.

The post-glyphosate programme in France is divided into two initiatives carried out in parallel.

The first initiative, "To be ready for 2021", has been structured to meet this regulatory requirement and the commitments made by the Presidency of **SNCF** [34]. It is divided into four main parts:

- Monitoring and integrating regulations into practices, particularly by adapting the existing management tool connected with the means of treatment,
- Implementing phytosanitary products without glyphosate: this aim is linked with the acquisition of new vegetation control trains, allowing a reduction in the sprayed surfaces thanks to the detection of the vegetation present, to comply with the regulations and to strengthen the protection of operators,
- Developing mechanical solutions: most of the alternatives to glyphosate increase human interventions and equipment implemented close to the danger posed by a circulating line (danger zone). In addition, increased maintenance of close embankments will be necessary (by mowing); It will be necessary to ensure the safety of mowing sites (walkways and adjacent green edges) or to robotise the process. To ensure the safety of mowing works (walkways and adjacent green edges) **SNCF Réseau** has worked on a staff safety system and traffic announcements to allow a greater number of operators to work simultaneously,
- Establishing a new culture of vegetation control: changes to standards (partial acceptability of vegetation, depending on the category of tracks), strengthening preventive solutions (installation of geotextiles on walkways during track renewal projects).

The second programme **in France** is focused on research, development and innovation to develop solutions without conventional phytosanitary products, considering the overall risk with respect to mid-to long-term loss of marketing authorisations. This programme is not intended to select a single solution but aims at a combination of solutions adapted to different perimeters and use cases: 100% biocontrol products, vegetation control by electromagnetic waves, seeding chosen on service tracks.

In Germany, DB has set up a project called “Ausstieg Glyphosat” (Exit Glyphosate) due to the announcement that **DB** will phase out glyphosate use by the end of 2022. Although the project also addresses a broad spectrum of conceptual and strategic questions concerning vegetation control in general, the pragmatic focus is on the glyphosate exit in 2022.

The currently most widely-used and effective technology (chemical vegetation control) will be developed further with respect to new active ingredients. Pelargonic acid will play a very important role here. In addition, the recently identified non-chemical measures with promising potential for use in railway tracks, such as hot water, electro-weeding and UV-C light, are examined in depth. Besides these operative measures, constructive and preventive measures will be investigated.

Another key area for investigation is the possible limits on vegetation coverage without compromising track integrity and performance. This perspective will be investigated in a separate study and will be needed as a parameter for vegetation control management if limits can be set. In connection with this issue, it will be proved whether existing or future detection systems can feed the planning process of vegetation control with information about vegetation coverage within the rail tracks.

Finally, the results of the project will be implemented into an integrated vegetation management system based on a GIS-system already existing within **DB**.

In Italy, at the moment there are no specific funded experimentation projects in progress in **RFI**. However, for some time, mechanical methods (for example cutting, mowing, shredding) have been used as an alternative to chemical treatments. In addition, the use of non-chemical methods has been included among the awarding criteria in the latest tenders.

In the Netherlands, ProRail has set up the so-called Proeftuin Testinggarden “Duurzame bestrijding Aziatische Duizendknoop” (25.11.2019- 31.12.21), a test garden for the sustainable treatment of Japanese knotweed (JKW) at "Zuilen” station in the city of Utrecht. Six commercially available alternative (non-chemical) methods of vegetation management are being tested on the JKW for use on the railway embankment. **ProRail** invited commercial parties to register for the tender for the “Proeftuin Duurzame bestrijding Aziatische Duizendknoop”. They also contracted an ecological research bureau to develop a plan of action for this test with them. Together the project group reviewed the proposals which entered via the tender. This resulted in a choice of six methods that are currently being investigated in the testing garden. As part of this test, key parameters such as the operating speed, treatment frequency and operating and maintenance costs are studied with the objective of combining all these key indicators in an application matrix. Using this matrix, it will be possible to filter the different choices to determine which is the best method to be used in a particular situation.

- Total cost of this project: €60k.

In Sweden, TRV has set up the project “Development of methods for mechanical vegetation control in tracks and improving the efficiency of existing vegetation control methods” (01.01.2019 - 31.12.2021). The project has three main parts:

- Development and testing of non-chemical methods for vegetation control with a focus on mechanical alternatives but also including further evaluation of hot water treatments,
- Analysis of vegetation distribution data recorded by the herbicide spraying train in order to improve the understanding of how and where vegetation grows, how effective the vegetation control methods are long-term and how vegetation presence influences other track quality indices,
- Field scale wind drift tests of the herbicide spraying train in order to improve risk characterisation of environmental impact from wind drift.

The study is conducted in collaboration with researchers from the Swedish University of Agricultural Sciences and the Research Institutes of Sweden (RISE).

- Tests at main tracks and shunting yards,
- Total project cost €308 k,
- Period: 2019 - 2021

In Switzerland, SBB started the “NoHerbie” project in 01.01.2018 and it will be completed by 31.12.2022. In order to guarantee the safety of rail operations, SBB has to constantly monitor and regulate the vegetation in the area of its more than 7,600 kilometres of track. To ensure that this essential work can be carried out in as environmentally-friendly as possible, SBB is examining and testing various alternatives to the herbicide glyphosate used up until now. The aim is to stop using glyphosate in the track area by 2025.

Funded by the Federal Office of Transport (FOT) and Federal Office for the Environment (FOEN).

- Test at main and side tracks,
- Total project cost: €4,000 k - Funding rate 28% from FOT and FOEN.

** More information on these activities in European Railways is available in the A1 Case studies.*

5.5. Need for funding

The current situation shows that the investigations on alternative methods represent an immense effort which could not be carried on by a single railway company. The investigation and development of new methods of vegetation control on a large scale need intense international cooperation and shared work between the railway companies. Looking ahead to the European Year of Rail 2021, UIC with its members support the European Commission and the Shift2Rail Joint Undertaking in their efforts to foster innovation to transform Europe's railways into the backbone of sustainable European mobility. The EU Commission should develop the scope of major research programmes, which present an important opportunity for the technical development of sustainable land management. A financial plan for both the short and long term is necessary to foster technical research on "environmentally-friendly technologies" for vegetation management methods and to improve a number of alternative methods for railway tracks.

The railways are a pioneer sector in terms of herbicide-free land use management. There is already a very active, international group of experts working on vegetation control topics that needs a better frame for their action. Moreover, through the lessons learnt from the first generation of Shift2Rail, the future activities must be 'user-first oriented'.

In the near future, railways will have to play a crucial role in a climate-neutral transport system. Huge efforts have to be taken to shift passengers and goods from other modes of transport to rail. Every obstacle that keeps us from reaching a level playing field concerning various market disadvantages that railways have to face today in comparison with other modes of transport, will also keep us from reaching the ambitious goal of developing a transport system that is compatible with the ecological boundaries of our planet. Costly vegetation control on the transport infrastructure is one of these obstacles.

6. Need for vegetation control

The need for vegetation control in the railway track area is based on the paradigm that vegetation growth yields negative impacts on the safety and performance of railway operation as well as infrastructure integrity. To this day, it is considered a necessity to keep the track area 100 % vegetation free, although, reality shows a much more differentiated picture with different actual levels of vegetation growth in the track area ranging from almost 0% on highly-used lines, e.g. high-speed lines, to considerable vegetation cover, e.g. in tracks with very low usage and priority. In the current highly dynamic and complex situation, the zero-growth paradigm has to be reassessed.

The Railways are at a turning point: the new strategy of integrated vegetation control, current EU legislation and regulations, increasing national political and stakeholder pressure as well as the issues faced in developing cost-effective alternative methods are a big challenge for railways.

Railways requires a holistic innovative and radical approach with regard to vegetation control in general and paradigm-zero vegetation growth in the track area.

The new vegetation control approach of the railways based on a flexible, multi-method-based model also needs a change to this paradigm and its better adaptation to the geographical, topographical and climatic conditions of railway networks. These new standards have to be defined in accordance with safety demands, track category and priority of requirements for track quality under current operational patterns - frequency, speed, schedules, etc.

The question about the need for vegetation control has to be viewed from two aspects. One is the differentiation into embankment and track areas, and the other is the short and long-term effects.

Keeping the current paradigm of 100% vegetation-free zones and changing to the application of alternative methods such as mowing, hot water, electro-weeding, etc., especially in Zone A and B, would result in an increase in costs for vegetation control and make the railways uncompetitive.

Due to the existing gaps in knowledge about direct links between plant coverage and stability in the long term, no railway company is currently able to set well-defined limit values for plant coverage derived from an objective database. The issue is complex because many influencing factors affecting each other have to be considered.

Some railway operators and infrastructure managers in Europe (e.g. **DB, SBB, ÖBB-Infra, Infrabel** and **TRV**) have started or are planning research projects which aim to investigate the impact of the presence of vegetation in the tracks and walkways and establish quality standards concerning plant coverage. The expected results will only be available in the mid- and long-term due to the long-lasting and complex interactions between type and age of track, frequency of train traffic, climate conditions, biological processes, etc.

Therefore, the systematic lowering of the frequency of vegetation control measures or even the suspension of actual treatment in selected track areas poses a number of open questions which have to be investigated very carefully. In this regard, the railway companies currently investigating the need for vegetation control are focusing on the following topics and possible impacts:

- Stability of the railway superstructure (ballast bed),
- View/visual impairment on low signals,
- Occupational and operational safety.

Track functionality/ballast bed is the most important due to the expected:

- Faster degradation of railway components,
- Track misalignment due to unstable/ weakened substructure,
- Drainage problems,
- More frequent maintenance works on the railway superstructure (e.g. by using tamping machines).

The following indicators are taken into account:

- Percentage of the fine (organic) fraction in the ballast bed,
- Vegetation cover,
- Degree of track alignment.

7. Currently-investigated alternative methods

7.1. Introduction

A number of activities and projects on vegetation control and management methods on railways are being studied in the UIC SLU Sector. As a result of an important recent study at UIC - the HERBIE[2] project - a final report was published, based on a survey among participants about vegetation control and management methods, a literature study, and the knowledge of railway experts on vegetation management. Moreover, the multi-dimensional assessment results for the whole range of alternative methods for vegetation control and management (including alternative active substances) has identified four promising alternative methods regarding active substances for further investigation, which have a high potential to be a part of an integrated vegetation management:

- Hot water,
- Wet steam,
- Electro-weeding,
- Organic acids.

Since 2019, the UIC SLU Sector has identified other specific methods in the European region (see chapter 7.2.) which may also have the potential to complement the method-mix of an integrated vegetation management in the future.

The present report reflects the current development state of alternative methods and its adaptation for use in different zones or protected areas based on investigations conducted within European railway companies.

The sector's strategy is to divide vegetation control into two general types of methods:

- **The operative methods** are designed to remove the existing vegetation on tracks (Zone A and B) and other areas (Zones C and D) (Figure 4). An important focus is the avoidance or restriction of colonisation of ballast bed and slab track (Zone A and B with walkways Zone C) from neighbouring unsealed (Zone D) and sealed surfaces (Zone E). This is most often the case on older railway tracks, where the only possibility to guarantee the safety of the track is to remove plants using different methods, which can be chemical, mechanical, biological, thermal or electrical.
- **The preventive methods** are focusing on creating hostile conditions for plants to settle. The focus is to avoid or at least significantly inhibit the vegetation's growth due to appropriate design and construction. However, this is only possible when new lines are built or during the reconstruction of existing lines. Preventive methods include the use of horizontal barriers, geotextiles, growth-inhibiting mats, biomineralisation, concrete barriers, different types of ballast, allelopathic plants, etc.

The most promising methods and technologies are being investigated and tested in zones where they potentially have the best performance. This includes the use of hybrid methods - i.e. the simultaneous application of two methods in one process (e.g. organic acids for ballast shoulder and walkways and electro-weeding for the ballast bed), as well as alternating between different methods over the years. The new tests on alternative methods and techniques take these specific areas into account and adapt the type of treatment to specific zones.

7.1.1. Characterisation of railway corridors for vegetation control

Railways have to manage different types of areas due to special protection obligations which are determined by legislation and regulations.

[2] https://uic.org/sustainable-development/environment/article/sustainable-land-use

As explained in the HERBIE report in Section 5.2 [1], in order to ensure the operational, safety, and reliability requirements, vegetation management on railways requires different methods for specific zones (A, B, C or D). In this report, the track area and neighbouring sectors are divided into different zones as shown in Figure 4 with their specific needs and requirements for vegetation control.

Area	Terminology			Description
A	Ballast bed			Part of the track bed made of ballast or gravel, including embedded sleepers and rails
	Slab track			Concrete track bed structure
B	Ballast shoulder			Part of the track bed covering the slope on both sides of the ballast bed
	Slab track			Different concrete track bed structure types are possible and, in some cases, may include a ballast shoulder
C	Transition area	C1	Spacing area	Part of the track abutting the slope on both sides of the ballast bed and including a footpath for maintenance/ inspections, as well as walkways and spacing areas between tracks in the case of double or multiple tracks. In some cases, drainage ditches are also constructed in Area C.
		C2	Side walkways	
D	Lineside (cuttings or embankments)			Slopes alongside the track adjoining Area C, in which vegetation may affect the operational envelope (A/B + C).
E	Unsealed area outside of the tracks			Power stations, service facilities, unsealed paths, areas around substations, unsealed areas around railway stations, forest land, meadows and unsealed fallow land.
A/B + C	Operational envelope			The area within which the railway infrastructure sits
A/B + C + D	Railway corridor			Operational envelope and lineside

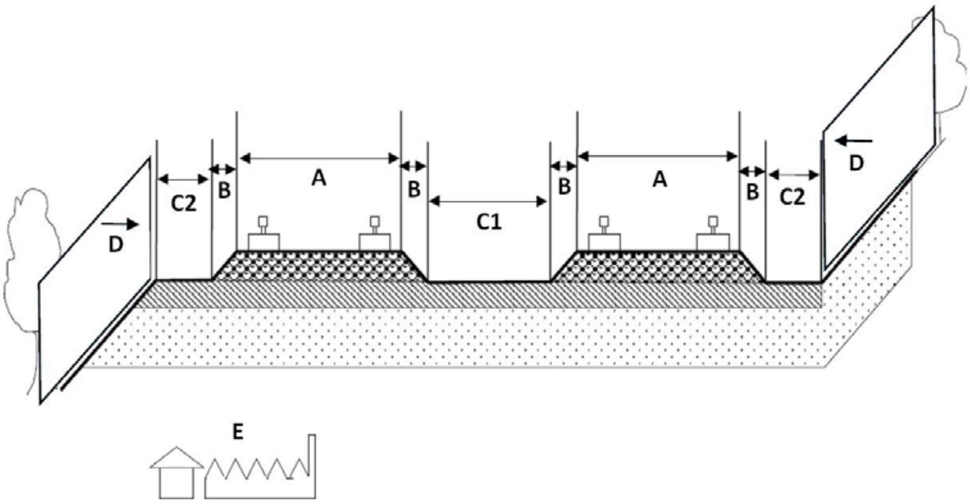


Figure 4: Different types of area for application of vegetation control methods

7.2. New research on operative methods

7.2.1. Thermal methods

Thermal methods aim to remove the vegetation or damage plant tissue at high or low temperatures. The three main thermal alternatives investigated during the project are hot water, hot foam and liquid nitrogen.

Currently, five companies are investigating alternative thermal methods: **SBB, DB, ProRail, RFI** and **TRV**. Tests were conducted in different Zones (A, B, C and D) up to 3-4 m to the side of the track, with manual application, small equipment, road-rail vehicles and trains.

Key benefits:

As stated in the HERBIE Report [1], the thermal method (i.e. hot water) has a very good score for environmental performance (environmental & health hazard and degradability (4.2 out of 5 points) and a high score for social performance (safety, legislation and regulation acceptance 4.4 out of 5 points). The further improvement potential with respect to costs, application method and operational speed makes the method very promising for the long-term substitution of herbicide-based methods. However, multiple treatments over the year are very likely.

Advantages of thermal methods:

- Non-toxic,
- Have an immediate impact on vegetation,
- Few emissions of harmful substances to the environment,
- No soil pollution,
- It seems that treated plants generally (with very few exceptions[3]) do not develop genetic resistance,
- No restriction on entering the treated areas.

Hot water

The hot water method seems to be a good alternative to conventional chemical herbicides especially under railway conditions:

- There is only sporadic vegetation to combat,
- There are no relevant weight restrictions due to the logistics via rail,
- Hot water technology in case of low vegetation density has very low environmental effects compared to other methods,
- Water can be easily heated using renewable energy sources,
- Reasonable operational speed is feasible in combination with multiple applications.

Figure 5: SBB - Track on the left: Treated with hot water. Track on the right: Not treated. The species type is Senecio inaequidens. Taken by Lukas Tanner on September 22nd, 2020

[3] *Logfia arvensis* seemed to be favoured by hot water treatments. It increased in the experimental plots where we had applied hot foam more often (field observation from TRV).

The hot water method is currently being investigated by **SBB, DB** and **TRV**.

The first tests conducted by **SBB** showed that the hot water method yields comparable results to the manual spraying of conventional chemical herbicides (see Figure 5). The tests were carried out with a prototype of a hot water spray train with vegetation detection. Optimum results were achieved at speeds of up to 20 km/h (see in Figure 6). Quantities of 10 litres of water per m^2 were tested. However, the evaluation is not yet completed, and automation is challenging.

Figure 6: SBB - Hot water spot-spray train prototype

** More information on this method is available in the A1 Case studies - **SBB** (Switzerland) - Hot Water method.*

In Sweden, TRV evaluated the use of hot water using smaller scale equipment (custom-built by a small company) at a shunting yard in 2020.

** More information on this method is available in the A1 Case studies - **Trafikverket** (Sweden) - Hot Water.*

Recent improvements:

- A new test proved that the application of the hot water method is also possible with a spray train which allows a significant improvement in the operational speed (speeds up to 40 km/h, SBB) and might reduce application costs,
- The application of hot water was being tested with different application technologies, such as spray train and road-rail vehicle. This allows greater flexibility, higher speeds and a wider range of application areas,
- The application of new methods was tested at various locations: tracks, main track and secondary tracks in order to adapt the best application device to the corresponding area and track zone.

Limitations:

- Danger to reptiles and small creatures: reptiles and small creatures are injured or killed by hot water,

- Multiple applications are likely,
- Disturbance of railway installations: Railway installations can be disturbed by the ingress of hot water jets. Protection against "splash water from all sides" must therefore be ensured,
- Interactions with overheated wheels and fixed brake detection devices are possible due to the spraying vehicle,
- The hot water can cause burns to people. Personal protection must be ensured,
- High energy and water consumption: estimated about 1.8 m^3 of water and 180 kWh per kilometre of track if the vegetation density is 4%,
- Possible systemic effect if hot water has a lethal effect down to the roots depending on the nature of the soil (gravel, etc.), duration of exposure, plant species, etc.

Future improvements and process:

- More tests on impact on the environment and biodiversity are required,
- Further reduction in water consumption by improving the vegetation detection systems,
- Use of rainwater and solar energy for application (a future vision of **SBB**),
- Leaching effects should be investigated,
- Genetic resistance on plants should be investigated,
- The purchase of electricity from renewable energy sources should be promoted,
- Reduction of the water temperature without reducing efficacy.

Hot Foam

The Hot Foam method is being investigated by **RFI** in Italy and **TRV** in Sweden. The product used in the experimentation is biodegradable foam. The tests in Italy were conducted in Zone E and showed promising results.

Limitations:

- Similar to the limitation for the Hot Water method mentioned above.

Future improvements and process:

- Automation,
- Application with a train or road-rail vehicle.

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** More information on this method is available in the A1 Case studies - **RFI** (Italy) - Hot Foam Method.*

Other thermal methods - Liquid nitrogen

In the Netherlands, ProRail is investigating liquid nitrogen against invasive species such as JKW. The method is currently used in Zone D and the test in the “experimental garden” will run until December 2021. In the meantime, the plan for testing on sealed surfaces is under consideration for 2021. The prototype for treating sealed areas is already available.

This method is being developed by a private company and **ProRail** provides testing/research areas. In addition, another company is undertaking the monitoring of the test results.

Recent improvements:

- Further development and improvement are underway during the implementation and testing of the method.

Limitations:

- The development of the technology and testing in real conditions requires a strategic approach and investment,
- Applicable only in small areas/surfaces,
- Currently there are 2 types of machines which can be used for the liquid nitrogen method.
  - One of them is for specific targeting of invasive plants such as JKW and giant hogweed,
  - The other one is for targeted use on sealed zones (Zone E).
- Limited to targeted plants (i.e. JKW, giant hogweed),
- High energy consumption.

Future improvements:

- The machine for use on sealed zones (Zone E) will be available in two versions,
- Increase the efficiency of the method.

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** More information on this method is available in the A1 Case studies - **ProRail** (Netherlands) - Thermal method against Japanese knotweed.*

Strategic summary for thermal methods

Among the thermal methods, hot water currently has the highest potential for improvement and application and is the best candidate to partially replace the conventional chemical herbicide method on the appropriate stands/locations. Practical tests have already been conducted in real conditions on more than 200 km tracks and showed good results.

The efficacy of thermal methods ultimately depends on the amount of energy transferred to the plant. However, there is no clear recommendation of what energy dose is required to kill the plant or what combination of energy dose, number of treatments and treatment interval would be more effective for different situations. Thus, different operators apply as much water as they think is required - and the results are therefore highly variable in energy/water consumption and highly variable in vegetation control efficiencies.

Regarding genetic resistance, plants are probably less likely to develop genetic resistance since the mechanism is not specific to only one species. However, this requires further investigation. Also, plants may adapt in other ways than through acquiring genetic resistance, already non-sensitive plants may be favoured, etc.

7.2.2. Chemical methods

Inspired by the effectiveness of the conventional chemical herbicide method and its application techniques, the use of alternative active substances is being investigated in different projects. Among them are, for example, pelargonic acid mixed with other substances such as Flazasulfuron, Fulfonylurea, Diflufenican, Iodosulfuron, Flumioxazin, 2,4-D.

Currently, several companies, among them **ÖBB-Infra, DB, SBB** and **SNCF Réseau**, are investigating the potential of alternative chemical agents such as pelargonic acid. The substances investigated are at the "Development and testing" and "Research" stages. The tests are conducted in Zones A, B and C on different track categories such as Main tracks, Secondary tracks and Shunting yards. Currently tested application technologies are by train, small equipment and road-rail vehicle and backpack.

From 2018 to 2020 **ÖBB-Infra** has been conducting investigations on the potential of 20 different herbicide-products (conventional and alternatives), tested in different mixtures and with different wetting agents. As a general result, it was found that all the products tested are less efficient than the mixtures **ÖBB-Infra** is currently using (containing glyphosate). **ÖBB-Infra** has also included active agents in research projects, which have not been investigated as herbicides so far, such as plant extracts/essential oils (with allelopathic properties) and electrochemically-oxidised water containing sodium chloride, for conductivity reasons. The last-mentioned method uses special diamond electrodes, which are particularly efficient in producing oxidising agents from water. As a future strategy, **ÖBB-Infra** would recommend obtaining approval for several of the tested products for railway uses, in order to be able to alternate the composition of the herbicides and to prevent resistance. This would also guarantee a high efficiency of the treatments.

Comparable observations were made by **SNCF Réseau** - a new combination of pelargonic acid and sulfonylurea shows good results, comparable with conventional chemical herbicides, but requires two treatments per year. Additionally, **SNCF Réseau** is also testing with two private companies the effectiveness of organic substances (biocontrol alone). To be able to use the new products (particular characteristics of viscosity and on-board volume for pelargonic acid) and to respect all the regulations, **SNCF Réseau** needs to change or adapt vegetation control trains to enable the following advances:

- Spot spraying on the vegetation present, and no longer "in full" on the entire perimeter of the tracks,
- Move towards a spraying system adapted to new biocontrol herbicide products and in particular to pelargonic acid,
- Respect all the conditions regarding the protection of operators,
- Upgrade of the geographic information system (GIS) to integrate the new non-processing zones defined by the new law on the protection of residents (safety distances),
- Have the controlled drift values validated in accordance with the reduction in the safety distances along built areas.

Infrabel is also taking pelargonic acid into consideration. Pelargonic acid in combination with conventional chemical herbicides is seen as a possible alternative to glyphosate. Nevertheless, there is currently no product with pelargonic acid as the active ingredient authorised in Belgium and compatible with the use on the spray train. The formulation on the spray train needs to be more concentrated. The use of pelargonic acid also requires exemptions for use in the three regions of Belgium like any other conventional chemical herbicide.

The investigation conducted within the framework of **DB** and **SNCF Réseau** projects showed that methods based on alternative chemical substances and applied by spray trains can reach operational speeds of 40 to 60km/h. According to the recent status report, **SNCF Réseau** has passed the experimental stage and started on the industrial deployment phase.

Important research was conducted in 2016 by **SBB** on the effects of the use of conventional chemical herbicides and organic acids and their leaching into groundwater [35].

Key benefits:

- Alternative chemical herbicides are the most suitable and most efficient,
- Alternative chemical herbicides may be used in areas where the use of conventional chemical herbicides is prohibited due to application regulations (at least for some member railways),
- Alternative chemical herbicides can be used against problem and invasive plants.

Disadvantages of alternative chemical herbicides:

- Much larger quantities of substances may be needed to give similar results to conventional chemical herbicides,
- Odour nuisance especially in inhabited areas may be a disadvantage,
- The application could promote leaching of heavy metals due to a reduction in pH-values (there are also products available which do not lower the pH-level),

- The quantities of herbicides (in solution volume and active substances) are much greater than for the current product (5-10 L/ha for glyphosate). It is about 16 to 22.5L/ha for the best performing products,
- Difficulties in keeping the solution active in some cases, because of poor miscibility with water (organic substance in water); but there are products with good water solubility, and mixing of the active ingredient and water at the nozzle immediately before application also seems possible,
- More efficient when mixed with conventional chemical herbicides. Without them, there is no systemic effect.

Recent improvements:

- New tests proved that the application of alternative chemical herbicides is also possible with a spray train which improves the operational speed (speeds up to 40 km/h, **DB**) or even up to 60km/h (**SNCF Réseau**) and may reduce the amount of substances used compared to manual use, due to automatic plant detection systems,
- Spray trains are equipped with a plant detection system and GPS recording of data of the sprayed areas, which avoids duplication of treatment by automatically closing the relevant nozzles,
- GPS also ensure that the nozzles close automatically in all sensitive zones, like for example protected areas due to water or nature resources, etc.,
- **Drift measurements:** Several companies have analysed the impact of wind drift on the track-surrounding zones as part of the registration process of plant protection products (**DB**). In the distance range of 3 m based on the 90th percentile, the results from Germany show sedimented amounts of dye (in percent of the applied amount) ranging between 0.041 and 0.022%. The drift of herbicides applied from spraying trains has been investigated, focusing on the drift to ground along the track and to rivers under the track in Natura 2000 zones (**Infrabel**), or along agricultural fields. Field tests conducted by **TRV** during 2019 and 2020 also show limited drift from the herbicide spraying train, with the 90th percentile of deposited amounts of glyphosate at a 3 m distance from the sprayed area of 0.025% of the applied dose with wind speeds of 0-2 m/s.

Figure 7: Modern spray train equipped with cameras for vegetation detection and GPS for taking protected areas into account

Progress has been made in this area. Some companies are recording wind speed and above a certain limit the nozzles must be switched off (**ÖBB-Infra**); at **DB** and **Infrabel** the wind speed threshold is defined and above a certain speed the application of herbicides has to be stopped. **SNCF Réseau** has good results for the drift measurement for glyphosate.

Future improvements and process:

- More harmonised regulations and legislation on registration at European member state level is requested,
- More research is needed on active substances with a potential for the Railway sector,
- Implementation of plant species recognition and automatic adaptation of the applied substance in accordance with the targeted plant will improve the efficiency of the substances used,
- All trains using chemical methods should be equipped with a plant detection system and in the future, when technology allows, with a plant species recognition system.

i ** More information on this method is available in the A1 Case studies - **SNCF Réseau** (France) - Alternative chemical methods.*

Strategic summary for chemical methods

Alternative chemical herbicides are showing good potential for partially replacing conventional chemical herbicides. Currently, for railway purposes, conventional chemical herbicides, especially for the ballast bed (Zone A and B), still have the best economic and operational performance. However, the railways are making big efforts to minimise the total amount of application. Several European companies (**Infrabel, TRV, DB, SNCF Réseau** and **ÖBB-Infra**) are already using an automatic plant detection system which ensures that herbicides are only used where and when needed. In this way, the volume of herbicides used can be reduced by 50% compared with spray trains without any selective spraying [1].

The trend in recent years is clear: better application techniques and reduction of the amount of herbicides used. For example, **BaneNor** used approx. 3 tonnes in 2018/2019, compared with approx. 5.5 tonnes in 2014 [36]. At **DB**, the amount has also decreased from 67 (2018) [37] to 50 (2019) [38]. The reduction of the last few years is due to meteorological conditions (dry summer), better management and targeted environmental focus. **ÖBB-Infra** managed to cut herbicide use by almost 50% in the last few years with different measures for optimising application efficiency and also as a result of meteorological conditions.

Moreover, the legal and social barriers for the use of organic acids such as pelargonic acid seem to be lower than those for conventional chemical herbicides, at least for some member railways.

7.2.3. Electrical and radiation methods

Currently, electrical and radiation methods are being investigated within several study programmes by DB, ÖBB-Infra, ProRail, SNCF Réseau and Infrabel.

Key benefits:

- Electro-weeding is the only systemic method of all non-chemical alternatives,
- Method is nontoxic for the environment and can also be used in water protection zones, where chemical methods are forbidden,
- Immediate impact on plants,
- No existing restrictions on entering the treated areas,
- No soil pollution expected,
- No development of genetic resistance observed,
- Can be used against invasive species and problem plants,
- Hand-operated devices available,
- Electro-weeding seems to be quite effective in eradicating horsetail, which is chemically-resistant to glyphosate.

Limitations:

- Speed limit and frequency of usage need to be measured and optimised,
- Interaction with signalling and railway safety systems needs to be tested,
- Risks of fire must be checked,
- Impact on reptiles and soil has to be investigated,
- If direct contact between applicators and plants is reduced, e.g. when plants of different heights are on the same site, effectivity on smaller plants is limited,
- Conductivity of the soil may have an impact,
- Direct contact between applicators and rails should be avoided (safety distance leaves a space where vegetation can grow unaffected.

Electro-weeding

As stated in the HERBIE report [1], the electro-weeding method has a promising combined economic and operational performance and development potential.

DB in cooperation with Julius-Kühn-Institute and private enterprises is investigating this method in the track area with application by a road-rail vehicle. The efficiency of the method regarding plant control seems to be close to that of glyphosate, while the application speed is currently only between 3 and 5 km/h as compared to 40 km/h for glyphosate. Tests concerning possible impacts on the signalling system and other infrastructure are still in progress.

ProRail is testing the electrical method on the growth space of invasive species such as JKW. The site (Zone D) is treated with a vehicle-mounted electrified machine. An interim report from our "Testing Garden" is currently being prepared. Sadly, due to corona-restrictions the company that will be testing this method with us was not able to receive the ordered machine in time to start treating this year.

ÖBB-Infra is currently testing on the whole track area (Zone A/B+C) with the same road-rail vehicle used by **DB**. The operational speed is approximately 5 km/h (see Figure 8). Efficiency on railway vegetation only has been tested and appeared to be less than herbicides containing glyphosate. This observation may be due to the chosen test site, which showed a high vegetation density and plants of different heights. Therefore, it could be an advantage if the treated sites are mowed before the electro-weeding starts. **ÖBB-Infra** also observed a very high efficiency on horsetail.

Figure 8: ÖBB-Infra - Road-rail vehicle electro-weeding Certis-Zasso University of Applied Sciences Carinthia

Since guarantees have to be obtained concerning the compatibility of electrical methods with track equipment (signalling, etc.), **Infrabel** is testing the electrical method outside the track area.

Future improvements and process:

- A higher degree of automation possible,
- More tests on impact on the environment and biodiversity are required,
- Application with a train,
- Applicators need to be designed in a way that provides optimum contact with the plants in the tracks,
- Combinations of electro-weeding with mowing and herbicides would improve the efficiency and duration of impact.

Radiation method

In cooperation with a university, **DB** is also investigating the UV-C method. As a first step, typical plants occurring in the tracks are radiated with short-wave UV-C light under laboratory conditions. The initial results show differences between the various plants tested as well as an influence of plant age. The next step will be to carry out field investigations.

At a research level, **SNCF Réseau** is currently testing the microwaves on Zone A and Zone C2. Compatibility with railway equipment and environmental risks is investigated in this study.

Future improvements and process:

- The effectiveness of UV-C light must be tested under realistic /field conditions,
- If the effectiveness is satisfactory, the next step would be to install this technology on a road-rail vehicle and, then in combination with a plant detection system.

Strategic summary for electrical and radiation methods

Electro-weeding seems not to be a stand-alone solution for effective and long-lasting vegetation control. Combinations with mowing and chemical herbicides would improve the performance. This is also recommended by service providers, who will have to come up with a lot of innovative solutions for the application of this method in an electrified railway environment.

7.2.4. Mechanical methods

European railways have always used mechanical methods for vegetation control, both with small equipment and manual application, but with an almost exclusive focus on walkways and embankments (Zones C and D). Recent activity by railways has focused directly on vegetation control of ballast bed and ballast shoulder (A and B), and at the same time on significantly increasing the efficiency and reducing the costs of mechanical methods by means of automation.

Mechanical methods, particularly mowing and mechanical vegetation control methods, are currently being tested or applied in railway programmes. These methods are being investigated by **SBB, DB** and **SNCF Réseau** in the Spacing Area and walkways (Zones C1, C2), Lineside (Zone D), on the whole track area (Zones A, B, C) by **TRV** and **RFI**, which also mechanically-treats parts of Zone D and E (see Figure 4).

The range of application technologies is very broad: from manual application and small conventional equipment to small self-propelled equipment and road-rail vehicles. **TRV** is testing different techniques of root pulling, scraping and ploughing with an adapted road-rail vehicle. **SNCF Réseau, SBB** and **DB** are investigating the performance and limits of autonomous robots for mowing within the track and side areas (Zone C and D).

Infrabel is implementing mechanical methods on a large part of the surfaces in Zone A, B and C of the secondary tracks (up to 50% of the total surface in 2023 or at least 5 km^2). Until recently, only surfaces in Zones D and E were treated with mechanical methods. In Zone E, except for some specific high-voltage areas, herbicides are banned on the whole network from 2021.

At **Infrabel**, the following herbicide-free methods will be applied to control vegetation: mowing, manually pulling out by hand or hoeing by mechanical action on the ground surface (see Figure 66 to Figure 68). The prediction is that the most commonly used method will be mowing (manual or mechanised). A sharp increase in costs is expected due to the need for repeated treatment in comparison with herbicides and the higher cost per m^2 of the alternative treatments. Another consequence will be the greening of tracks because mowing is not a systemic method. Pulling out or hoeing allows a systemic result but will be implemented on smaller surfaces due to the costs and technical difficulties.

i ** More information on this method is available in the A1 Case studies **SNCF** Réseau (France) - Alternative chemical methods and **Infrabel** (Belgium) - New tenders for vegetation management and Construction Methods.*

In the Czech Republic, SZCZ uses new technologies for less accessible and more distant areas. For mechanical control of vegetation, mechanical arms connected to a Motor Universal Truck (MUV) are used for application to Zones B, C and D. Mowers of the remote-controlled spider-type [39] are used for less accessible terrain - Zone D (embankment and cuttings). At the same time, it is possible to use this technology to remove overgrown trees up to trunk diameters of 5 - 8 cm.

Key benefits:

- Method is non-toxic for the environment and thus can also be used in water protected zones,
- Immediate impact on plants,
- No restrictions on entering the treated areas,
- Few emissions of substances harmful to the environment,
- No soil pollution,
- No development of genetic resistance,
- Can be used against invasive species and problem plants,
- Possible impacts on animal species have to be taken into account when applying.

Recent improvements:

- Direct application of mechanical methods to the ballast bed and ballast shoulder,
- Autonomous robots for walkways (Zone C) and for siding areas (Zone D).

Limits:

Mechanical methods, which mostly remove the overground parts of plants only, have the following disadvantages in terms of their efficiency:

- No removal of plant roots, which leads to plant regrowth,
- Can promote the development of seeds.

Future improvements and process:

- Checking the autonomous use of robotics in the safety-relevant track area for approval,
- Operational speed of the robots should be increased, but is not absolutely necessary if the system is allowed to work autonomously.

The use of **Robotics** as a new and potentially highly-efficient application technology, especially for mechanical methods of vegetation control, is currently being investigated by two railways. In future highly-automated systems, robotics could play a key role. Currently, **SBB** is testing the use of autonomous robots for the edge area and for siding areas in the Spacing Area (Zone C1) and walkways (Zone C2). In France, autonomous GPS-guided mowing robots are being tested on high-speed lines. **SNCF Réseau** is testing small self-propelled equipment for mowing on walkways (Zone C2). At present, the operational speed of this mowing method is limited to 0.7 km/h.

Since robotics and digital tools have the potential to revolutionise vegetation management for railways in general and more broadly, especially as application technologies for alternative methods, they should be given wide attention in the future. European Railways should not hesitate to cooperate with research institutions, start-ups and established high-tech providers in order to adapt the new platform technologies to the specific needs and operational conditions of railways as, for example, SBB has been doing in its recent activities in this area.

Covering growing space

ProRail is testing another mechanical method involving covering up problematic growth areas. In a concrete test setting, a growing space for JKW is covered with biodegradable cloth and the surface is then sown with the seeds of natural competitors.

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> ** More information on this method is available in the A1 Case studies - **ProRail** (Netherlands) - Thermal method against Japanese knotweed.*

Strategic summary for mechanical methods

Mechanical methods such as mowing and hoeing are already widely used by railways for vegetation control outside the track area, on unsealed surfaces as well as on embankments (Zone D). There are many providers available for these services and railways issue contracts on a regular basis. These conventional approaches are known to have a low operative speed and a rather high frequency of treatment is needed in order to keep regrowth to a minimum. New developments in this field focus on improving operating speed, effectiveness and cost efficiency by means of automation, e.g. by using advanced robotics and plant identification. Another focus of investigations lies in increasing the efficiency by combining mechanical methods with other methods of vegetation control. Furthermore, there is a trend for using improved mechanical methods in the core part of the track area (Zones A, B and C).

7.2.5. Operational biological methods

The use of biological methods in vegetation control is not new, but this alternative to conventional chemical herbicides has severe limitations for railway use. Safe and effective biological vegetation control methods are only effective against specific plants while inefficient in others. This method is very complex and contains potential biocontrol agents such as insects, fungi, bacteria, nematodes or other plants. Moreover, the first results may not be obtained for long periods.

Currently, several biological methods are under investigation in different projects by the members:

- Fungi against Tree of Heaven (**ÖBB-Infra, SBB**),
- Grazing with sheep and goats (**SNCF Réseau, SBB ÖBB-Infra**: only for embankments) to keep temporarily closed lines free from trees and bushes.

Fungi against the Tree of Heaven

During the last 8 years, **ÖBB-Infra** has been a partner in an R&D project aimed at utilising abundant natural wilt-fungi as a “biological-weapon” against the Tree of Heaven. This cooperation successfully resulted in an innovative new agent to effectively control this very invasive, non-native tree.

At the moment the product, called Ailantex, is on the way to being registered and approved as an authorised herbicide for the Austrian market.

** More information on this method is available in the A1 Case studies -* ***ÖBB-Infra*** *(Austria) - Biological method against Tree of Heaven (Ailanthus altissima).*

Grazing

SNCF Réseau is using grazing with sheep or goats on some difficult (very inclined) areas or zones where herbicide use is strictly prohibited (cities) and, more generally, in many situations such as for controlling invasive plants. More than 50 hectares (ha) are already managed by grazing. This method is used mostly for Zone D. Several small companies in France are contractors for this method.

Figure 9: SNCF (France)- Highland cattle on an abandoned railway plot

Figure 10: SNCF (France)- Sheep on embankments and tracks

ÖBB-Infra started a pilot project in 2014 to test grazing as a biological method to control the JKW on an embankment.

** More information on this method is available in the A1 Case studies -* ***ÖBB-Infra*** *(Austria) - Biological method against Japanese knotweed (*F. japonica*)*

Infrabel aims to improve grazing with sheep and goats in some favourable locations (D or E surfaces), for example in easily accessible and sufficiently large parcels of land, encouraging local shepherds (Figure 11). The main points for the application of grazing are as follows:

- The installation of the fences is the responsibility of **Infrabel**,
- Depending on the location, the shepherd may be charged a rent, or an intervention by **Infrabel** may be required.

Figure 11: Infrabel - Goats and sheep on the embankment

Key benefits:

- This biological method can be used in areas where conventional chemical herbicides are banned and can be used against problem and invasive plants,
- No biomass waste requiring costly disposal,
- Very positive for the company's image,
- Grazing can generate income for small farmers,
- Grazing can have a positive impact on biodiversity, particularly if it is applied on sites dominated by monotonous stands of invasive alien plants.

Limitations:

- Time-consuming method, often requires good knowledge of species biology, requires lengthy research,
- Stringent requirements for safety, to prevent animal-vehicle collisions,
- Availability of reliable and willing farmers is very limited in the most regions,
- In urban and suburban areas, passers-by are the most dangerous threat for the animals, with their dogs and their unstoppable desire to feed the animals with unsuitable food or even free them by pulling down fences.

Future Process:

- Cooperation with research units on other substances with potential for the Railways.

Strategic summary for operational biological methods

Due to its limitations, it seems unlikely that full vegetation control for the track area can be achieved with this method alone. However, it seems to have some potential for application under specific circumstances (such as targeted areas for certain problems, e.g. invasive plants).

7.3. New research on preventive methods

7.3.1. Construction-reconstruction methods

Constructional measures are highly effective for preventing in-growth of vegetation into the track area because they either provide physical barriers impenetrable to plants or reduce water availability in the track area to a large extent. However, because of the high cost, they are almost exclusively used for the construction of new or rebuilt tracks or in areas with total bans on herbicides. These measures are mainly:

- Lateral plant barriers such as porous concrete barriers,
- Amount and type of ballast,
- Plant barriers beneath the track,
- Slab track,
- Asphalt under the track bed,
- Concrete barriers along the track bed,
- Barrier between the ballast and embankment,
- Foil under the walkways.

Currently, several companies are testing a variety of new preventive methods, among them **DB, ÖBB-Infra, SBB, SNCF Réseau** and **Infrabel**.

- Growth-inhibiting fleeces/geotextiles made of polypropylene or rubber compounds (**DB, SNCF Réseau, SBB, ÖBB-Infra** and **Infrabel**),
- Porous concrete barriers (**SBB**),
- Vegetation-inhibiting effect due to a special pH value (**Infrabel**),
- Investigation of the vegetation growth properties of all materials that are used for the ballast bed and service walkways (**ÖBB-Infra**),
- Plant inhibiting design for transition area - Zone C (**DB, SBB,** and **Infrabel**).

A sufficiently thick asphalt layer under the ballast both prevents water accumulating in the track and inhibits in-growth of vegetation for a long time. In Switzerland, tests conducted by **SBB** show that even ten years after its installation on new SBB tracks, the tracks have significantly less vegetation.

Concrete barriers installed since 1991 during bed reconstruction also serve as footpaths, and thus have largely prevented plants from growing into the track. To optimise prevention of in-growth, the embankments bordering the concrete must be mowed periodically.

In addition, well-placed cable ducts also can be used between the embankment and ballast as side obstacles to in-growth of plants. Their effectiveness is increased by periodic mowing of the bordering embankments. Foil is used on the walkways to impair growth in zones with groundwater protection where herbicides are banned and in places with strong growth of horsetail, which propagates by underground rhizomes. The foil has remained effective for more than two years but requires weighting with ballast so that it does not blow away; it must also be strong and impermeable to light so that plants cannot grow through it. Based on the positive experience of **SNCF Réseau** as well as pilot tests carried out in Switzerland, the growth-inhibiting fleece will in future be installed as standard in SBB bank renovations.

Many construction measures (especially asphalt layers and concrete barriers) are not installed only to control vegetation; they also have other important track technology functions, but slight adaptation enables them to control vegetation as well.

Infrabel is also implementing preventive methods for walkways using asphalt, concrete or ternary materials. These are made of a mixture of coarse sand, 2/4 crushed stones, granulated blast furnace slag, lime and water. A 12 cm compacted layer is applied to form the walkways surfacing. These are long-term solutions (except ternary materials) to reduce the need for intervention on vegetation. Implementation takes place gradually during renewal work and more specifically to equip sensitive areas as a matter of priority (water catchments). Further tests will concentrate on “Anti-Vegetation Mats” - a permeable elastomer mat for coverage of walkways.

Lean concrete or cemented granular materials are also currently used for the renewal of walkways. The test results from the past two years are positive.

In Belgium, various new lines over the past decade have been equipped with a layer of asphalt as a sub-ballast layer with good results for preventing the development of vegetation. Even in this case, the presence of trees in the surrounding areas is not favourable due to the deposit of organic materials such as leaves, etc.

SNCF Réseau uses geotextiles on walkways. Covered with 2 to 3 cm of sand or gravel to ensure their durability over time, the geotextiles are laid in the sub-layer during walkway repairs, which may accompany track renewals. The advantage of this technique is that it avoids treatments between two renewal cycles. The aim is to integrate them into all walkway repair operations.

Since 2016, **ProRail** has released a product called an "Anti-Vegetation Mat" made of recycled rubber compounds (see in Figure 12). It is not yet widely used due to a sceptical attitude towards new products and the cost-benefit analysis (i.e. high installation costs vs 25-45 years of lifecycle or virtually non-existent maintenance costs). At the moment, extra testing locations are sought for use on walkways in railway and shunting yards.

Figure 12: Anti-vegetation mats - ProRail (a) October 2009, (b) June 2010, (c) December 2010, (d) November 2013, (e) July 2019

** More information on this method is available in the A1 Case studies:*

- ***SBB** (Switzerland) - Construction Methods*
- ***ÖBB-Infra** (Austria) - Construction Methods*
- ***SNCF Réseau** (France) - Construction Methods*
- ***ProRail** (Netherlands) - Construction Methods*
- ***Infrabel** (Belgium) - New tenders for vegetation management and Construction Methods.*

Key benefits:

- Very long durability,
- Good long-term results.

Recent improvements:

- Different types of growth-inhibiting mats, fleeces and geotextiles are tested in situ and compared to other methods such as mowing and greening of the walkway and spacing area, on two different sites.

Limitations:

- Limited costs only on new construction or reconstruction sites,
- High costs, if not planned for future/renovation works,
- Not applicable on all sites,
- Use of a wide variety of materials may cause some other risks, i.e. safety, environmental impacts.

Future improvements and process:

- Improvement of construction technology,
- More research and cooperation with research centres.

7.3.2. Preventive biological methods

Biological methods are also used as preventive vegetation control. In this case, biological control means planting and maintaining greenery adjacent to the track, so that only desirable plants are present there.

Currently, several biological methods are under investigation in different projects by the members:

- Biomineralisation (**DB**),
- Greening, allelopathic plants, sowing special seed mixtures (**SNCF Réseau, SBB, ÖBB-Infra** and **TRV**).

Biomineralisation

In Germany, DB is investigating the use of certain soil bacteria on Zone C2. The bacteria create a water-permeable but vegetation-resistant lime layer.

Figure 13: Biomineralisation - Preparation of working path

Greening, allelopathic plants, sowing special seed mixtures

This method is used in the railway sector as a way of blocking the ecological niche to prevent unwanted plants from growing. Moreover, competitive plants and low vegetation help to limit mowing operations. Natural plant succession often results in a mixture of species with a high percentage of problem plants such as horsetail, so areas near embankments (5 to 7 m from the track centre) should be seeded with a mixture of species that compete with the problem plants and are adapted to the location.

Greenery requires periodic maintenance and two mowings near the embankment during the growing season promote grass cover which inhibits problem plants.

In Switzerland, SBB is investigating its potential on three test areas (Walkways only - Zone C2) which were cleaned and seeded with selected plants. The "competing " seed mixture prepared by SBB will also be tested by **SNCF Réseau** in autumn on the LGV-Atlantique line, about 60 m^2 on the trackside in four test fields.

Moreover, **ÖBB-Infra** is testing the “greening” or targeted sowing method with two different types of seed mixtures. A typical seed mixture for soccer fields and a seed mixture for natural meadows, also containing herbs, have been compared. Targeted sowing can serve as a preventive method, to enhance a fast recolonisation of open or new-built soil surfaces and to prevent unwanted vegetation as well as invasive alien plants from occupying the niche. It has to be pointed out that this method would not be compatible with the current internal standards for Zones A, B and C. In fact, targeted sowing/greening is already a standard method for Zone D. These methods are part of biological engineering, which is an import bio-technological treatment commonly used in Zone D.

In France, SNCF Réseau is testing the method on secondary tracks and shunting yard on a whole track area.

Figure 14: SNCF- Seeding on walkway of high-speed line

Figure 15: SNCF- Hydroseeding works on service tracks

In Sweden, TRV has established two field experiments that test mechanical ballast-ploughing and/or scraping in Zones B and C in combination with sowing of three different combinations of grass or grass-dominated biodiversity-enriched seed mixtures in Zone C. The composition of the seed mixtures and their ability to inhibit the establishment of unwanted vegetation such as pine and birch-seedlings will be evaluated.

In Belgium, Infrabel is currently studying the impact of the greening of tracks by spontaneous vegetation due to the herbicide ban and is investigating the possibility of sowing some concurrent seed mixtures in the walkways (zone C).

Key benefits:

- This biological method can be used in areas where conventional chemical herbicides are banned and could be used against problem and invasive plants,
- **SNCF Réseau** considers that the effects of the greening method could be "possibly permanent with regular maintenance".

Limitations:

- Time-consuming method, often requires good knowledge of species biology, requires long research.

Future Process:

- Cooperation with research units on other substances with potential for the Railways.

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** More information on this method is available in the A1 Case studies - **ÖBB-Infra** (Austria) - The Green-LOGIX project - Ecotoxicological tests.*

Strategic summary for preventive methods

Due to the limitations, it seems unlikely that full vegetation control for the track area only will be achieved with these methods in the near future. However, application under specific circumstances and construction of new lines seems to have potential.

8. Digital tools for integrated vegetation control

Integrated vegetation management is increasingly supported by digitalisation and powerful digital tools.

By taking advantage of new digital solutions, Railways will remain an attractive part of the transportation chain in the future.

The use of digital tools and technology in Railways is not new. For instance, a plant detection system was introduced during the 1990s and is now widely used by European Railway companies.

The next big step was the use of GIS, initially for sensitive areas, such as nature conservation areas and water protected zones, followed by the combination of both technologies: Plant Detection System and GIS. These actions and technological developments significantly improved the use of conventional chemical herbicides and lead to around a 50% reduction in the volume of herbicides used. In the future, digital tools for monitoring and reporting as well as planning and impact assessment will be integrated. The corresponding unified digital systems will provide all functions and automated digital solutions required for an efficient integrated vegetation control.

The most powerful drivers for this development are ecological, economic and qualitative aspects, as well as legislation and regulation. The latter require documentation and reporting systems. In addition, the process of applying for exemptions for vegetation control (especially herbicide-based measures) is becoming more and more complex. These requirements cannot be fulfilled any longer on a case-by-case level and by handling data manually, but have to be addressed in a coordinated way at system level by means of efficient tools. This means, for example, that applications for exemptions for herbicide-based treatments in sensitive areas could be undertaken at company level by submitting a complete list of sections with planned herbicide treatment to the authorities well in advance of the start of the vegetation control period. In the future, relevant treatment data will be systematically linked to areas with specific protection requirements, such as nature conservation and water protection areas. A systematic and coordinated approach to documentation, reporting and application for exemptions can be effectively supported by powerful digital tools such as tailored GIS solutions with integrated digital databases related to railway infrastructure, current and historic treatment data and plant inventories, as well as different types of protection zones.

In addition to enabling railway companies to address legal and regulatory requirements efficiently, digital tools are a prerequisite for the significant improvement in cost-efficiency and the operation and performance of alternative methods of vegetation control in particular, by means of continuous monitoring and impact assessment of treatments with respect to actual ambient conditions, modes of operation, quantities used, etc. Thus, they provide the needed informational basis for the transition from a single method to an integrated condition-based multi-method approach to vegetation control.

Digital transformation is a major lever for the future technical and economic performance of railway companies.

Moreover, railway infrastructure managers and operators have a clear ambition to facilitate the convergence of the railway sector towards a digital system to enhance their management systems such as vegetation management. In combination with integrated digital tools, the use of highly-automated technical solutions such as robotics platforms as application technologies can have a very positive impact on the efficiency and capacity of the different methods of vegetation control.

Digital tools allow a reduction of herbicides and other resources such as water and energy for alternative methods of vegetation control. The quality of service could be improved by providing better options for impact assessment and creating a better overall understanding. Furthermore, they help by reducing costly unnecessary on-site visits and the more precise and specific application of vegetation control measures, e.g. by systematic use of plant and even species detection systems. They also permit better, faster and effective vegetation control in protected zones and help to better protect human health in inhabited areas.

Moreover, **Digital Tools** allow:

- a better and immediate documentation of current activities and measures for vegetation control (applied measures, exact locations, for herbicide-based measures: quantity of herbicides used),
- reporting of activities to the authorities and the public,
- application for exemptions for treatment of sensitive or protected areas with herbicides for example.

Digital solutions for integrated vegetation management could also be used for:

- mapping of locations and distribution patterns, as well as treatment status for invasive species, continuous monitoring of vegetation control activities and mapping of plant growth status,
- impact assessment and control of quality level and target fulfilment for the application of single measures or bundles of measures of vegetation control per track area and on an aggregated level,
- strategic planning of measures and activities for vegetation control on the basis of current and historic data from impact assessment as well as data concerning track type and track quality requirements.

8.1. Vegetation detection system

Vegetation detection systems including a **vegetation mapping unit** are currently widely used by European Railways. In Belgium and in Germany spray-trains are already equipped with plant detection systems. In Sweden, both the herbicide-spraying train and smaller all-terrain vehicles (ATVs) that are used on rail yards use infrared (IR)-based vegetation detection systems. In the future, it is likely that these systems will evolve into vegetation recognition systems - that will detect not only the presence of vegetation but also be able to recognise at least key species.

Figure 16: ATV equipped with vegetation detection system

8.2. Geographic Information System

The use of digital tools such as the Geographic Information System (GIS) is an essential solution for fostering integrated vegetation management. Besides the need for open collaboration between the various actors, railways are taking a positive step to have sustainable vegetation management through innovative solutions.

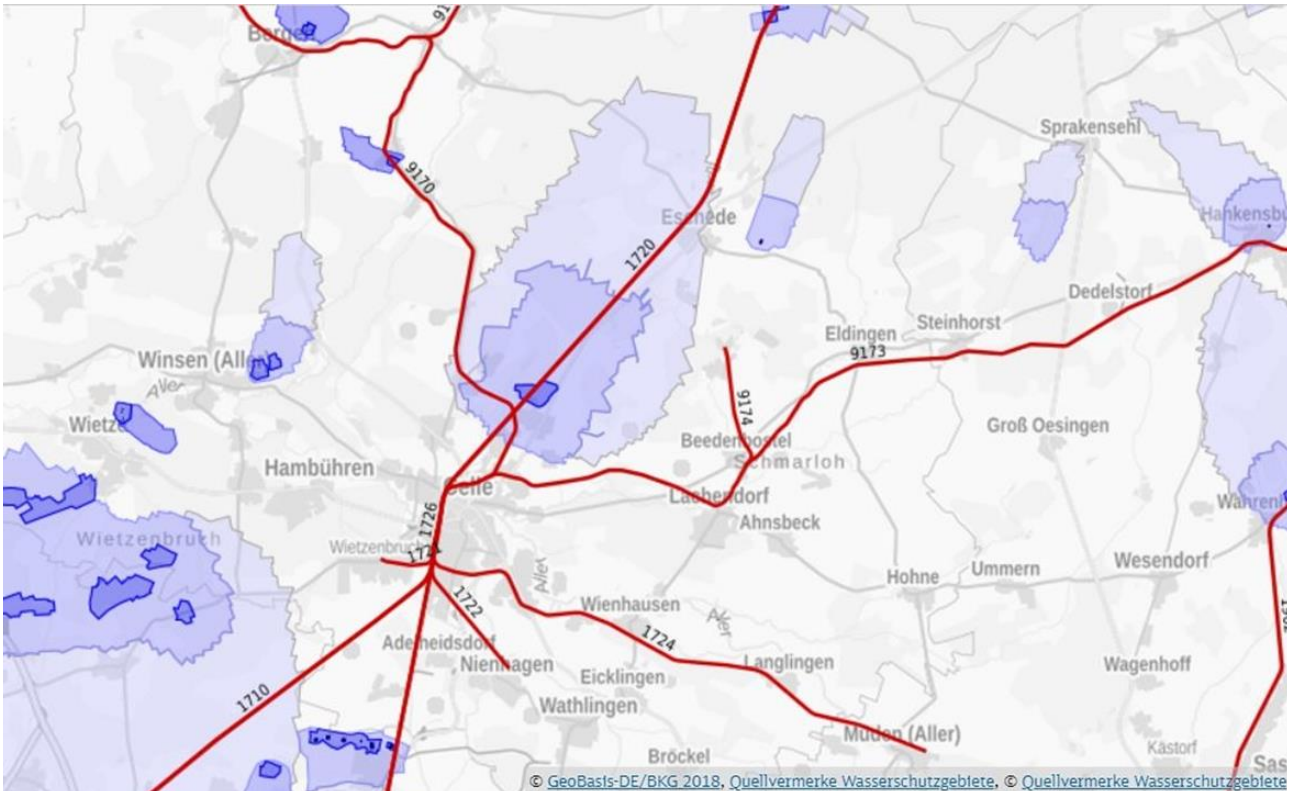


Figure 17: GIS-platform showing water protection areas in the vicinity of or linked to the network

European Railways using GIS systems are **DB, ÖBB-Infra, SBB, SNCF Réseau, Infrabel** and **TRV**.

In Germany, DB: Currently, the system is used for the planning process of vegetation control, taking care of sensitive areas (nature, water) and planned superstructure works as well as the documentation required for herbicide application. At the same time, it forms the basis for applying for the necessary exemption applications to the authorities.

In France, SNCF Réseau already has a system in operation to link its databases with processing equipment and ensure automatic shutdown in protected areas. A precise traceability of treatment is then mapped in its GIS tool.

In Austria, ÖBB-Infra is using GIS to record the spray-train route, the areas sprayed and the spray protocols.

In Switzerland, SBB is using the IVEG - Railway Vegetation Management Tool, a modern GIS application to monitor and manage the vegetation along all of SBB's railway lines [40] [41].

In Belgium, Infrabel is using GIS data to inform the spray train about sensitive areas and restrictions and about tracks and other equipment.

In Sweden at **TRV**, GIS data is used to automatically generate no-spray zones on the railway based on the proximity to surface water or other areas deemed to be sensitive. The maps generated showing no-spray zones as well the areas that are to be treated are used by the herbicide applicators, and also for communication with local municipalities.

8.3. Integrating GIS systems with the Global Positioning System

Global Positioning System (GPS) localisation is increasingly used. **In France, SNCF Réseau** is already using good GPS positioning, which is particularly important for zones excluded from treatment, such as habited areas, nature protected zones, etc. In the areas where the safety distance is imposed or near to watercourses, it is possible to accurately halt herbicide application. **In Germany, at DB**, the GIS in combination with GPS on the spray trains is used for executing herbicide application in sensitive areas (provided by the GIS-database) and documentation processes feeding data back to the GIS database. Such mixed techniques will be used in the future, for example, with automatic switching- off of herbicide spraying in water protected areas.

Figure 18: Modern spray train equipped with cameras for vegetation detection and GPS for taking protected areas into account

In the Netherlands, ProRail is investigating the use of satellite images for automatic identification of JKW in the Testing Garden. This to see if it is possible to build up an automated register of growing places.

In Belgium, the spray train identifies its position on the network from a GPS localisation device and applies the restrictive rules related to sensitive areas linking its location with the GIS data pre-programed to protect them. In return, spray data linked with geographical data is recorded.

In Sweden, TRV uses GIS-data to create zones where spraying is prohibited ("no-spray zones") and to produce maps showing these zones. The contractors also use GPS systems to position themselves accurately on the rail network. Vegetation detection data from the train on vegetation coverage and spraying zones is also reported and can then be partially displayed on the map-tool, which provides monitoring of subsequent actions. The GIS-maps are also available as a mobile application, making it possible for manual operators to locate themselves in relation to "no-spray zones" and directly report the presence and geographic position of stands of invasive species etc. using their smartphones.

In Italy, RFI has launched a project for the development of a vegetation detection and territorial analysis system based on high-definition satellite images; the outputs of the surveys could be subsequently integrated in the GIS platform. Some contractors already use GPS systems in carrying out the vegetation control service.

In France, GPS is currently used in treatment equipment. The recommendations, rules and regulations on chemical-free zones are constantly being renewed or changed in France. These changes require the constant updating of the GPS systems currently used for field analysis. In addition, restrictions in many different regions will make it difficult for GPS systems to analyse these limited areas and memorise all new restrictions in the system. For several years, **SNCF Réseau** has been implementing strict control measures and reducing the use of plant protection products by automatic interruption of spraying to protect drinking water catchments, watercourses, etc. using GPS connected to the national geographic information system (SIGMA) [34].

In Switzerland, SBB has launched several activities for the development of a vegetation detection system based on high resolution orthographic images (resolution < 1 cm per pixel). The images are, for example, recorded with drones and evaluated with artificial intelligence (see in Figure 19). The aim is to create accurate GIS maps of the vegetation, which can then be used directly to control the spraying vehicles ("variable rate application" technology with position determination by GPS).

Figure 19: Mapping vegetation with artificial intelligence based on high-resolution orthographic images (example SBB)

8.3.1. New tools

New tools based on the GIS and GPS systems will be used with the integration of robotics and other herbicide/herbicide-free methods. The railway sector is exploring the application of autonomous systems and especially advanced robotics for vegetation management activities and the potential impact they could have on efficiency and capacity. The potential of robotics and digital tools is currently being investigated in several research programmes by the following companies: **SBB, DB,** and **SNCF Réseau**.

Recently, **Very High Resolution (VHR)** satellite imagery has been adopted by railway companies across Europe in an effort to develop remote sensing methods for more efficient control of vegetation encroaching on the tracks [42].

8.4. Ranking System - proposal by RFI

Field tests carried out by the different railway companies should be systematically assessed since they produce valuable information about the operational and economic performance of the methods applied. This especially holds for the actual efficiency of the applied method, real costs of the entire treatment and the degree to which they meet the special needs and requirements of the railways. These three key criteria should be at the centre of a decision-making strategy for choosing the most effective method of vegetation control by each Rail Infrastructure Manager. Based on these three core criteria, a simple ranking procedure and tool is proposed to assess the applicability and convenience of each method of vegetation control to be used by each Rail Infrastructure Manager. By following three steps:

1. Summary of the field test campaigns
2. Scoring by applying the proposed formula
3. Classification of the scoring results

companies can obtain a clear picture of the methods of vegetation control that could be successfully used under their actual conditions and meeting their specific requirements).

** More information is available in the A2 Proposal for a ranking system for methods of vegetation control.*

Summary of digital tools for integrated vegetation control

Advantages:

- Self-collection of data,
- Bring automation to the difficult tasks which require high man-hours, more time,
- Reduce occupational safety risk,
- Minimal pre-& post processing,
- All in one system: planning & measuring and reporting.

Potential improvements:

- Cooperation with universities and private companies on research on tools with potential for adaptation to the different terrain topography of railways (difficulty of working in a steeply sloping area),
- Monitoring and record-keeping of all aspects of each treatment, including total volume administered,
- Better knowledge base with effective follow-up and adverse impact assessment, and subsequent lesson-learning for future treatments integrated in the application tool,
- Integrated system of local regulation and laws for treated zone.
- Railways evolve through continual digital transformation.

The railway sector requires future developments to enable rapid digitalisation, helping vegetation management systems to recognise changes in the railway corridor (Zones A/B+C+D), mitigate risks and plan ahead. Thanks to rapid progress and improved integration of digital tools (e.g. GIS, Vegetation Mapping and detection system), vegetation control in different areas and zones (protected areas, habitats, cities, etc.) is able to provide greater safety for the environment and residents, achieve better performance, and the possibility of regulating the amount of conventional chemical herbicides used. Targeting of treatment helps to significantly minimise conventional chemical usage and waste. Since autonomous systems and digital tools are not the core focus of the railways, an interdisciplinary and collaborative study is required to improve this method.

9. Summary of all methods under investigation or in use

Thermal methods: Among the thermal methods, hot water has the highest overall performance potential and is also closest to large-scale implementation in the railway track area. But there are also challenges to overcome which currently compromise in particular the cost efficiency and environmental performance of the new solutions. The high amount of energy and water required can be considerably reduced when using vegetation detection systems and spot spraying. Questions remain concerning the optimum amount of energy transferred to the plants as well as the optimum frequency of treatment and in addition to the legal protection of species.

Chemical methods: Currently, for railway purposes and especially the track area, conventional chemical herbicides have the best economic and operational performance. Here, the railways are focussing on further reducing the amount of herbicides used and the environmental impact by means of better application techniques, plant detection beyond spray trains and environmentally less harmful active substances. Alternative chemical herbicides such as pelargonic acid are showing good potential for partially replacing conventional chemical herbicides. Although they have a lower risk classification, they are still far from being harmless. Challenges for its future use include different logistics and adaptation of the spraying equipment to much larger volumes and quantities of the ready-for-use product, as well as multiple treatments per year.

Electrical and radiation methods: Electro-weeding is the most promising method here but seems not to have the potential for a stand-alone solution for effective and long-lasting vegetation control especially due to a rather low operative speed. Combinations with chemical herbicides would improve the performance and will therefore be investigated. Open questions concern the impact on the signalling system.

Mechanical methods: New developments in the field of mechanical methods focus on improving operative speed, effectiveness and cost efficiency, especially by means of automation technologies, and on transfer to the core part of the track area. The overall efficiency of mechanical methods could also be increased by combining these with other methods of vegetation control.

Biological methods: Due to operative limitations, it is unlikely that full vegetation control for the track area can be achieved with biological methods alone. However, application under specific circumstances - e.g. targeting specific invasive plants - seems to have some potential.

Preventive methods: Preventive methods are far too expensive to form the basis of full vegetation control for the track area in the future. But under specific circumstances, and especially in combination with track renewal and new construction of track, these methods can play an important role in a future integrated approach to vegetation control.

As can be seen from this compilation, the different alternative measures of vegetation control all have their advantages and disadvantages. Although many challenges and open questions remain, it is already clear that a future system of vegetation control will not rely on a single method, but comprise multiple methods which will be used according to their respective strengths depending on the specific context (plant growth, climate conditions, track requirements and category, etc.) - either as single methods, in combinations or alternating. Such a future system will be backed by powerful digital tools in order to have a good overall performance and especially cost efficiency. Another important factor for the economic performance of the new system is the actual requirement for vegetation control, which will be systematically investigated and re-evaluated in the coming years.

10. Outlook

In the coming years, the railways will

- Further improve their overall environmental performance with a special focus on sustainable land use in general, and integrated vegetation control in particular,
- Integrate the different high-potential methods for vegetation control into a consistent framework of condition-based vegetation control especially for the railway track area,
- Further test, adapt and improve the most promising methods, such as hot water, electro-weeding, and alternative chemical herbicides combined with conventional chemical herbicides,
- Implement alternative methods on larger scales,
- Condition-based vegetation control (active status monitoring and impact assessment),
- Create a framework of powerful supporting digitalisation tools (GIS, GPS, monitoring and reporting, impact assessment, etc.) with a focus on further integration, automation of data processing and optimisation of interfaces,
- Systematically re-assess the need for vegetation control for the railway track area from a mid- to long-term perspective - revise the current standards accordingly without compromising safety, integrity of infrastructures and operational performance of railways,
- Remain open to any innovative, new approaches that may arise,
- Further develop and test preventive methods especially for new or renewed infrastructure,
- Study the consequences for the railway system of the greening of tracks due to bans on herbicides,
- Continue to research cost-effective measures to ensure their competitiveness.

Appendix

A1 Case studies

All case studies in the TRISTRAM report are intended to demonstrate the current or ongoing research in European Railways.

The case studies provided were not selected according to the companies' final decision on alternative methods in Europe, and no priority was given to any method in this report. For this reason, railway companies do not have any responsibility for the methods they tested.

As an outcome of this report, railway companies should develop their experience of a variety of methods, as well as some methods which are currently on the market in 2021.

1. SBB (Switzerland) - Hot Water method

For the experiments with hot water, a special prototype spray vehicle was developed at SBB (see Figure 20. **SBB** Prototype "Hot water spot-spray train"). The tests were carried out at various locations on the SBB network (main tracks, regional tracks, side tracks). The train composition consists of two spray cars and two tank cars with thermal insulation (see Figure 20). The prototype is equipped with a (simple) vegetation detection system and can carry 120 tons of hot water. The water is heated to 95 °C with 100% electricity before use (heat power 500 kW). Maximum working speed is 40 km/h and maximum working width is 5.8 m. The spray output through the 128 nozzles is limited to 60 litres per second.

Figure 20: SBB Prototype "Hot water spot-spray train

Figure 21: Wagon arrangement of SBB Hot water spot-spray train

Results of the test (see Figure 22 to Figure 27):

- The vegetation can be significantly destroyed with hot water. The method gives results comparable to conventional herbicides,
- The applicability is primarily limited by the logistics,
- Automation for speeds over 20 km/h is very challenging. Optimum results were achieved at speeds of up to 20 km/h,
- Hot water is not recommended for dense vegetation on tracks (dense vegetation can only be treated at walking pace),
- The effect depends significantly on the soil texture: if the substrate is not permeable to water, the effect is significantly reduced,
- The effect depends on the physiological properties of the plants, e.g. plants with rhizomes are not effectively destroyed,
- Quantities of 10 litres of water per m^2 are recommended,
- The production of hot water is crucial for the ecological footprint (e.g. electricity mix).

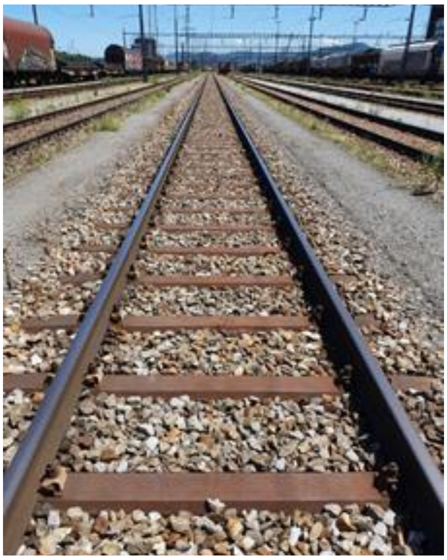


Figure 22: SBB Hot water case study - with hot water-maintained track (2 treatments)

Figure 23: SBB Hot water case study - Reference track, not treated

Figure 24: SBB Hot water case study - before treatment

Figure 25: SBB Hot water case study- 20 days after treatment

Figure 26: SBB Hot water case study - Wood vegetation, 50 days after treatment

Figure 27: SBB Hot water case study - 22 days after treatment

2. Trafikverket (Sweden) - Hot Water

During 2020, equipment built by the private contractor Ramvik Entreprenad, and in use since 2019 in combination with mechanical mowing to provide vegetation control on the shunting yard in Östersund was evaluated. The equipment consists of a Hy-Rail® type vehicle capable of flexibly treating a roughly 1-metre wide section of track at a time.

Figure 28: TRV - Hot Water - the equipment that was evaluated in Östersund

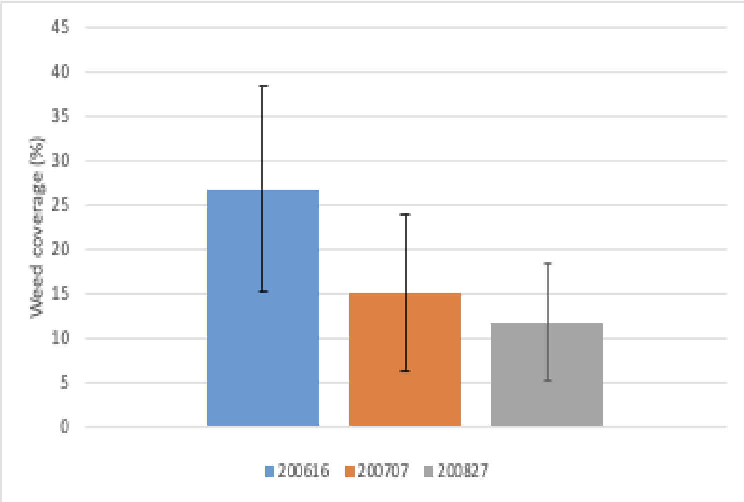


Figure 29: Trafikverket - Hot Water - the vegetation coverage in the experimental plots before the first treatment, and roughly 1 month after the first and second treatments, respectively

Water application rates of between 0.6 - 1.5 litres per square metre (l/m^2) were evaluated and the water temperature was determined at the point of application. This turned out to be only about 86 - 88°C. The equipment was capable of delivering about 15 litres of heated water per minute, so the practical maximum working speed is about 1,200 square metres per hour (m^2/h) or about 0.24 km/h assuming a treatment width of 5 metres.

Based on the results of the two treatments, which took about a month between them, this test was able to reduce the vegetation coverage on the test fields; however, the vegetation was not completely removed. For this reason, it is likely that more treatments or the amount of energy applied (increasing temperature/ application rate) should be increased in order to achieve effective vegetation control.

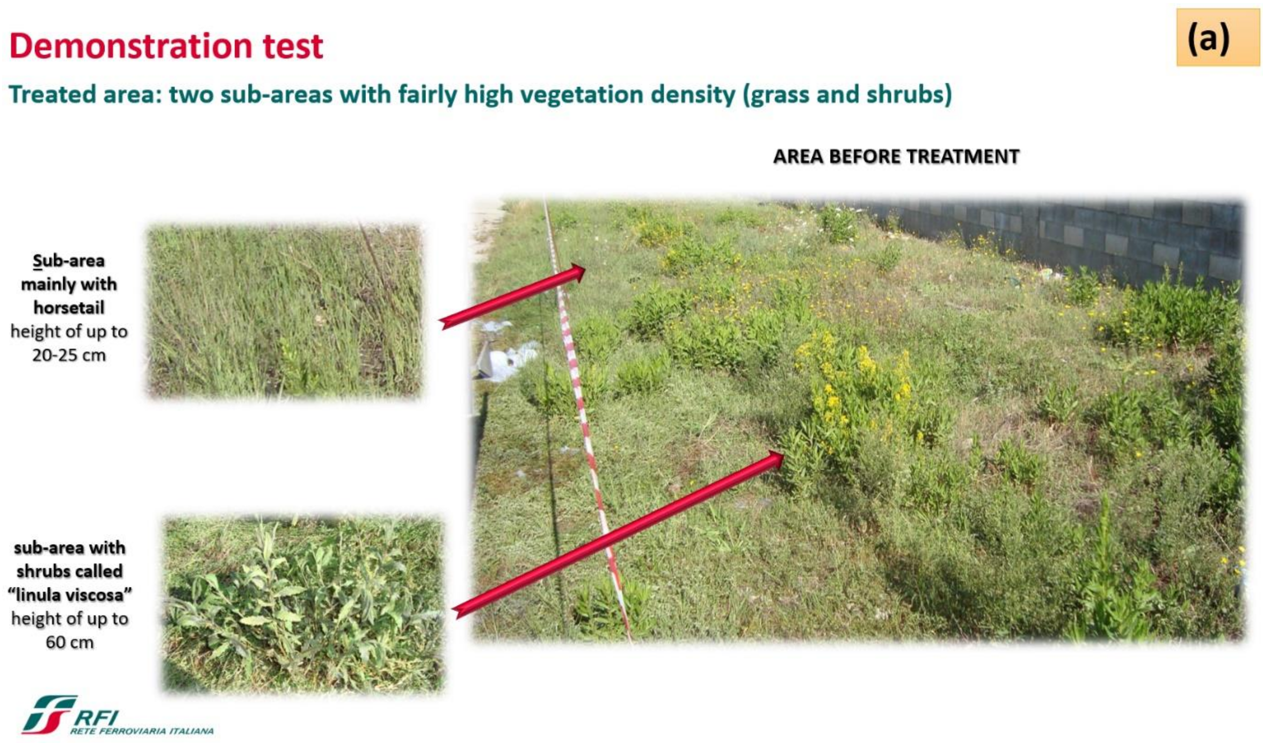
3. RFI (Italy) - Hot Foam Method

- A test field had been set up in Pisa, Tuscany, Italy,
- It consisted of only one application, in October 2019, on an unsealed area (Zone E) outside of the rail-track of about 67 square metres,
- The treated area included two sub-areas with high vegetation density (grass and shrubs). One sub-area mainly comprised horsetail (*Equisetum*) and other shrubs called *Linula viscosa*, with a height of up to 60 cm,
- The mixture of water and foam at high temperature was applied manually, with small equipment.
- The whole area was treated in about 1 hour.

Figure 30: RFI - Hot Foam Method: Aerial picture from the test area in Pisa, Tuscany, Italy

Results of the application:

- As can be seen from the pictures, within about 30 minutes of the application, the horsetail (*Equisetum*) was already limp,
- About 1 hour after the treatment, the shrub vegetation had already collapsed and was partially devitalised and the action of the treatment could be seen up to 1-2 cm below the ground surface,
- After 3 days, the whole treated vegetation was dry,
- About 20 days after application, a small vegetative reappearance was noticed, but only of grass,
- After about 45 days, there was a re-growth of grass in about 80% of the treated area,
- As per the results, we believe that around 5-6 treatments per year could be necessary,
- The actual number of treatments may depend on climatic regions and weather conditions.



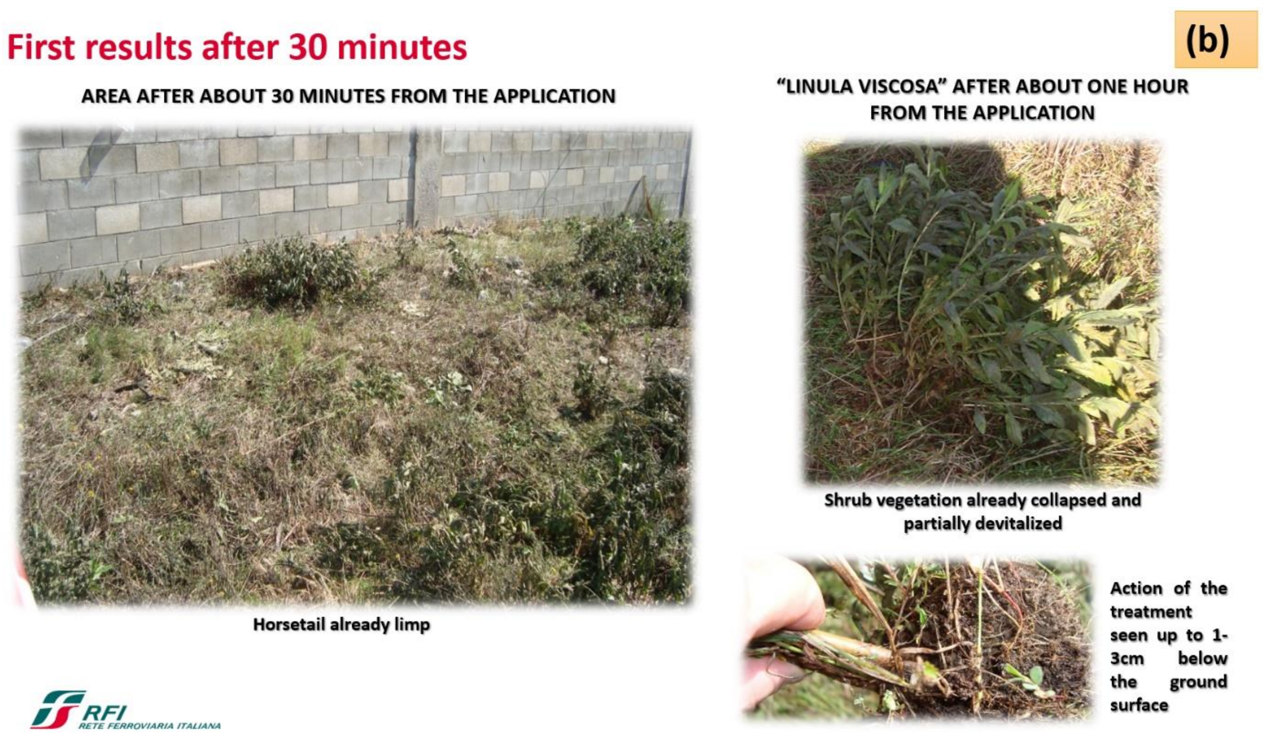


Figure 31: RFI - Hot Foam Method-1 - (a) demonstration test, (b) first results after 30 minutes

Figure 32: RFI - Hot Foam Method-2 - (c) results after 3-7 days from the application, (d) results after 10-12 days from the application

Figure 33: RFI - Hot Foam Method-3 - (e) results after 17-25 days from the application, (f) results after 45 days from the application

4. ProRail (Netherlands) - Thermal method against Japanese knotweed (*F. japonica*)

In 2019 ProRail started to organise a ‘testing garden’ in which they wanted to start testing alternative/non-chemical methods against JKW together with commercial companies. An ecological research bureau wrote a testing plan, and then ProRail launched the call for tenders. A team of specialists then chose six contractors from the registrations received.

In January 2020 ProRail started the testing garden with an introductory meeting and drafting of the treatment plan. The interim report for 2020 has now been drawn up and in January 2021 it will start the second year.

Figure 34: ProRail Method against JKW- Aerial picture of ProRail “testing garden” and the placement of the testing plots in yellow

Figure 35: ProRail Method against JKW - Some pictures of treatments. (a) hot water root treatment, (b) hot water ground level treatment, (c) nitrogen treatment and (d) electricide treatment

At the request of one of the contractors, they managed to organise a trial plot being dug in the Testing Garden to see how the roots of the knotweed behave in the embankment. This showed that most of the roots followed the cultivation layer and grew no deeper than 70 centimetres. This was about the same outcome as a trail plot dug a few years before in Amsterdam.

Figure 36: ProRail Method against JKW - some images of the trial plot and the material that came out of it

An important topic for **ProRail** is another invasive alien plant, the giant hogweed (*Heracleum*). The company makes efforts to create more sustainability in trackside vegetation management. We do this in various different ways, but one is by contracting technical requirements for the control of invasive alien plant species. One of the tools we are developing for our trackside vegetation management in general, and so including these plants, is a Quality Catalogue for the various elements of trackside vegetation. This catalogue gives a standardised number of quality categories with technical requirements per element that you can choose from for specific parts of the trackside. All requirements are accompanied by pictures that show what is meant by the technical requirements in letters and numbers. This method is already widely used for Dutch public spaces and makes it a lot easier for contractors to interpret the technical requirements and discuss them as client and contractor.

Table 2: ProRail Method against JKW - example of the technical requirements on invasive alien plant species in ProRail's "Quality Catalogue for trackside vegetation"

Vegetation	**Invasive alien plant species-coverage**			
A+	A	B	C	D
				
There are no invasive alien plant species	There are some invasive alien plant species	There are quite a lot of invasive alien plant species	There are a lot of invasive alien plant species	There are very many invasive alien plant species
Coverage invasive alien plant species: 0% per 100 m^2	**Coverage invasive alien plant species:** < 1% per 100 m^2	**Coverage invasive alien plant species:** < 5% per 100 m^2	**Coverage invasive alien plant species:** < 10% per 100 m^2	**Coverage invasive alien plant species:** ≥ 10% per 100 m^2
Measurement instruction: Vegetation-invasive alien plant species-coverage				

5. DB (Germany) - Information about the DB Project “Exit Glyphosate“

provided by Juliane Bade, DB Sustainability and Environment

Deutsche Bahn AG (**DB**) has set up the project “Exit Glyphosate” in 2020 to cease the use of glyphosate by the end of 2022. The project is dealing with different measures of vegetation control as well as expanding the existing management approach based on a digital system.

Within the project the **DB** analyses the development of **alternative methods** to the application of glyphosate and examines the use of **alternative substances**.

In the field of **herbicide-free measures, DB** is examining several methods for the track area:

Electro-weeding: The new technology of electro-weeding (plant treatment with electrical current) is being investigated. However, there is still a need for further investigations to answer some remaining questions. In addition, model areas have been set up in cooperation with one of the German registration authorities (Julius Kühn-Institute) to simulate different track sections and treat the different plant species occurring within railway lines under standard track bed conditions and well-known weather conditions. The information gained will be used for the further development of this technology.

Hot water: Hot water technology, quite often used in municipal areas for vegetation control on hard surfaces, has yet to be adapted to the special use on railway tracks. Therefore, it is also being investigated on the model sites at the Julius Kühn-Institute. The focus is on estimating the optimal temperature and water amount to yield best results in efficiency and to save water and energy at the same time. Further development is needed in order to bring the results from Julius Kühn-Institute into practical use. All these outcomes will be shared with the Swiss Federal Railways (SBB).

UV-C light: UV-C light is currently used for plant protection issues such as treating fungi, water disinfection etc. Due to these effects, it will be studied whether this technology can be used for vegetation control within railway tracks as well. Thus, the University of Osnabrück is examining under laboratory conditions whether there is a general effect on the different plant species occurring within railway tracks. Furthermore, it has to be explored whether signalling installations within the tracks are affected by the radiation.

Preventive Measures: The aim of using preventive measures is to reduce the growth of vegetation onto the gravel bed. Therefore, tests with different construction measures and materials for the walkways are are in progress and are monitored frequently.

The management approach will be expanded towards an **integrated vegetation control management**, based on the digital system.

6. ÖBB-Infra (Austria) - Biological method against Japanese knotweed (*F. japonica*)

In 2014, the ÖBB-Infra started a pilot study alongside the “Koralmbahn” railway line to the east of Klagenfurt. Test sites were installed on two railway embankments to assess the effect of grazing by goats and sheep on the existing population of *Fallopia* spp. Both sites have been grazed for six years. Over a period of three years, scientific monitoring was carried out to evaluate the impact of different grazing intensities, as well as additional measures such as mowing and the application of different seed mixtures. Additionally, faunistic assessments were carried out to assess the biodiversity of arachnids and beetles in dense *Fallopia* stands and on the pastures. Due to grazing activity, a higher structural diversity can be found compared to monodominant stands of *Fallopia* spp., which indicates an improvement in the local biodiversity.

In order to analyse social acceptability, 30 qualitative interviews were conducted in the surroundings of the project site. The survey indicates that the resident population shows a high interest and acceptance towards the approach. To reach this acceptance, extensive public relations activities were initiated, such as the distribution of project leaflets and installation of information boards. Furthermore, content was shared on social media platforms and in the local media such as newspapers, television and radio.

The vegetation monitoring indicates that high grazing intensities in the beginning can significantly reduce the abundance and vitality of *Fallopia* spp. to a degree that it locally diminishes completely. To avoid recolonization from adjacent stands or even recuperation of existing rhizomes, it seems enough to reduce the ongoing grazing intensity to a level which can be considered economically sustainable.

In terms of ecological impact and economic perspective, grazing could be identified as a very promising approach to deal with *Fallopia* spp. Since grazing as a form of animal husbandry is a productive rather than a destructive management measure such as mowing, threshing or herbicide use, positive side effects could be identified. As there are also limiting factors, such as the presence of farmers in the near vicinity or infrastructural limitations and specifications, the preconditions must be thoroughly audited.

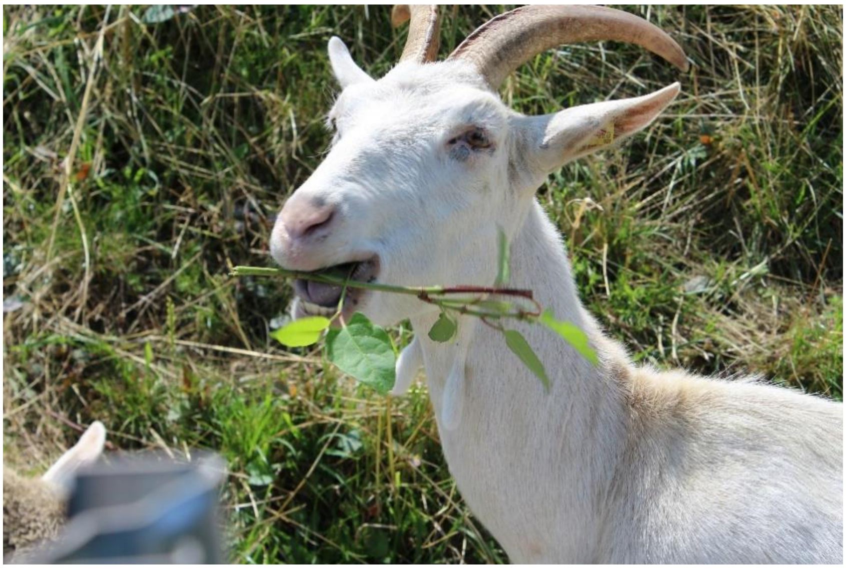


Figure 37: ÖBB-Infra- Biological control of Fallopia

7. ÖBB-Infra (Austria) - Biological method against Tree of Heaven (*Ailanthus altissima*)

In the late 1990s it was discovered that wilt fungi (*Verticillium nonalfalfae*, *V. dahliae*) are pathogenic to the Tree of Heaven (A. altissima) (Figure 38). These wilt fungi are naturally present in Tree of Heaven, are very host specific and can be isolated from affected trees.

Oliver Maschek, a student at the Vienna University of Natural Resources and Life Sciences, started to investigate the potential of *Verticillium* as a biological herbicide against this problematic and highly invasive non-native tree. Together with other institutions and companies from the infrastructure and forestry sector, **ÖBB-Infra** supported the scientific work of the University from 2012 until 2019. Intensive tests and studies have been carried out, a couple of well-received scientific papers have been published [43] [44] [45] [46] [47] [48]. The main focus was on laboratory cultivation methods for the fungi, practical methods for agent application, efficiency and non-target effects.

After a remarkably short period of only about six years, these efforts resulted in a biological herbicide that was put on the market under the name Ailantex by an SME specialising in biological treatments and methods for agriculture, horticulture and gardening (Figure 39). The national authority in charge of the registration and approval of herbicides agreed to issue a so-called “emergency approval” for Ailantex, which enabled more extensive field-testing. All tests have been very promising and positive (Figure 40). The active agent (fungi solution) is easy and fast to apply, the method is effective and will become increasingly economic as soon as mass production of the agent is set up. A big advantage of this method is that every tree that is connected with the treated tree through the root-system will be affected as well and also die off quickly.

So far there is also no evidence of non-target effects, which means no other plants seem to be vulnerable to these fungi.

Figure 38: Die-back Tree of Heaven Univ. Natural Resources

Figure 39: Biohelp Ailantex

Figure 40: ÖBB-Infra - Ailantex test site Univ. Natural Resources

8. ÖBB-Infra (Austria) - The Green-LOGIX project - Ecotoxicological tests

It is important to consider the possible effects and impacts of herbicides on the environment and human health. These range from acute effects such as poisoning of non-target organisms to long-term accumulation and changes in biodiversity.

During the Green-LOGIX project, it was the aim of the University of Applied Sciences (UAS) Technikum Wien to perform an ecotoxicological assessment of various selected herbicides. For this purpose, a test battery was selected, which includes tests according to OECD guidelines for the determination of acute toxicity on embryos of the zebrafish *Danio rerio* [49], on the fibroblast cell line BALB/c 3T3 of the house mouse *Mus musculus* [50] (OECD Guideline No. 129, Neutral red uptake assay [NRU]), and on algae of the species *Raphidocelis subcapitata* [51]. Various mixtures of the herbicides biohelp Finalsan® Plus, Touchdown Quattro, Nozomi, Valdorflex, Chikara and the adjuvants Wetcit and Karibu, as well as various size fractions of the weed barrier BSW (BSW Regupol growth-inhibiting mat type 767) were tested. The test results were used to create dose-response curves and the EC50 values for the different formulations were calculated.

Comparisons of the EC50 values of Touchdown Quattro (NRU: 0.73 g/L, AGI: 0.45 g/L, FET: 0.038 g/L) and biohelp Finalsan Plus (NRU: 1.37 g/L, AGI: 0.37 g/L, FET: 0.21 g/L) showed that Touchdown Quattro was more toxic to cells and fish embryos than biohelp Finalsan® Plus. This was not the case for algae. The EC50 values of the herbicides Valdorflex, Chikara and Nozomi indicate a very weak-to-absent toxicity to cells and *Danio rerio* embryos but showed very strong toxicity to algae. Tests with the Regupol growth-inhibiting mat type 767 showed no acute toxicity on any of the model organisms.

Based on the results obtained and the information available from the published literature, biohelp Finalsan® Plus with the active substance pelargonic acid and maleic acid hydrazide is recommended for use on railways. Pelargonic acid exhibited the lowest toxicity and the lowest persistence (< 1 day) compared with the active substances of the other formulations tested (e.g. persistence of glyphosate: 15-1,000 days).

9. SNCF Réseau (France) - Alternative chemical methods

In 2018, **SNCF Réseau** carried out small-scale tests on the network, in association with providers, on a combination of two products: biocontrol (pelargonic acid) + Flazasulfuron (sulfonylurea); these were followed in 2019 by 85 km of tests spread over the different climatic and soil zones of France, with speeds varying from 30 km/h (regional train) to 60 km/h (national train).

Used alone, biocontrol acts only by contact by burning the affected parts of the leaves, without lasting effectiveness (less than 1 month). The combination allows a synergy between the molecules which makes it possible to obtain acceptable results as long as the vegetation is not too developed.

Example of results in Brittany for KATOUN 16 L/ha + PALMA 7.5 L/ha

- Operates at 60 km/h and at high anchorage (500 L/ha),
- No effect of product dilution,
- Acceptable control at 90 days,
- Good results on ferns, *Erigeron*, *Senecio*,
- More effective than glyphosate on *Equisetum*, *Senecio inaequidens*, *Melilotus*

Limitations:

- Zero vegetation impossible (reduction of vegetation cover),
- Visuals: affected plants stay at the stage of development,
- Low on *Rubus* and zero on *Hedera*,
- Optimum conditions and severe summer drought (weak regrowth)

Figure 41: SNCF - Alternative chemical methods - Day 7

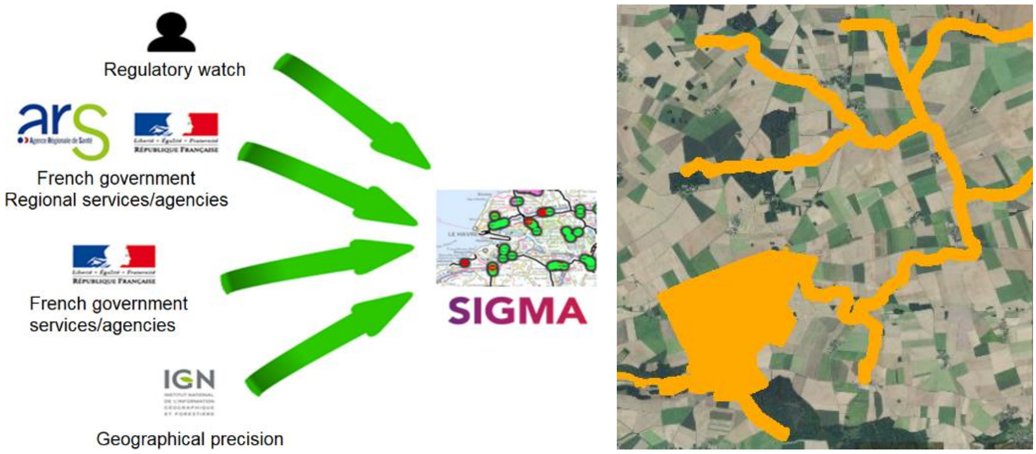
Figure 42: SNCF - Alternative chemical methods - Day 45

Figure 43: SNCF - Alternative chemical methods - Day 90

Figure 44: SNCF - Alternative chemical methods - Day 140

10. SNCF Réseau (France) - SIGMA

The SIGMA application is a "geographic information system” dedicated to the maintenance of vegetation control. The application makes it possible to adapt relevant regulations in geographical areas where the use of PPPs is prohibited.



Construction of regulatory data *Mapping of ban areas*

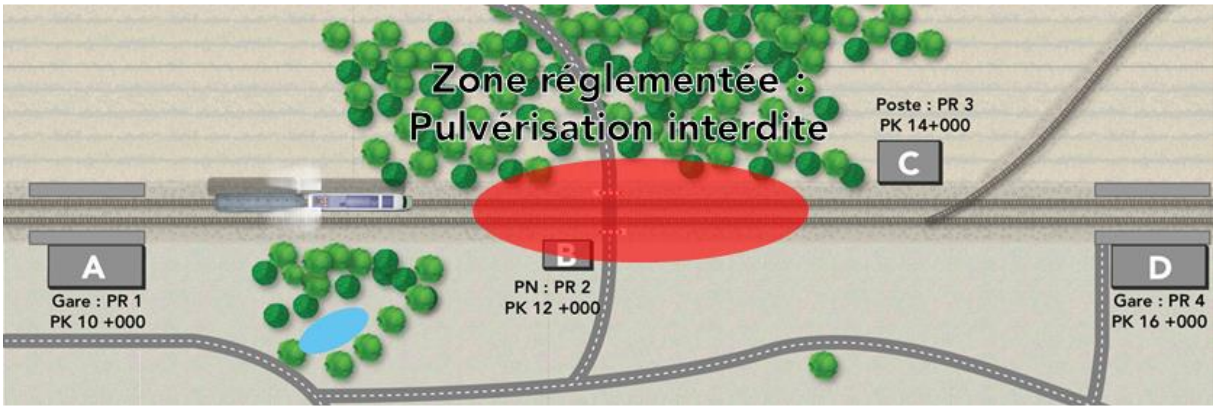
Figure 45: SNCF- SIGMA [34]

These regulations arise from the work carried out by central government, regional agencies and other government/non-government agencies. In addition, these are also updated by internal regulatory monitoring systems.

National regulations for the use of PPPs are registered centrally to the SIGMA application developed by **SNCF Réseau**, and thus allow for homogeneous mapping. The regulated areas are mapped by geographic coordinates (Figure 45).

These maps created by SIGMA are sent to the GPS positioning systems of the machines used for vegetation control (Figure 46). As a result, the regulation map is updated, allowing each vegetation control machine to know its position in relation to the restricted/regulated areas.

Figure 46: SNCF - Connection between database and train GPS



Visual alert system when approaching the ban area | *Switching off the spraying system* | *Continuing to spray while exiting the ban area*

Figure 47: Automatic cut-out on ban area

When a vegetation control train approaches an area where the use of PPPs is prohibited, the visual alert system warns the operator of the vegetation control machine (Figure 47). Based on the geographic location, when approaching the area where the PPP applications are regulated, the system on the train automatically stops spraying.

Figure 48: Return of treatment traceability data

At the end of each vegetation control treatment, all information is transferred to the SIGMA application which processes and archives the information (Figure 48). It also enables a precise traceability of treatments for which PPPs are being used (Figure 49).

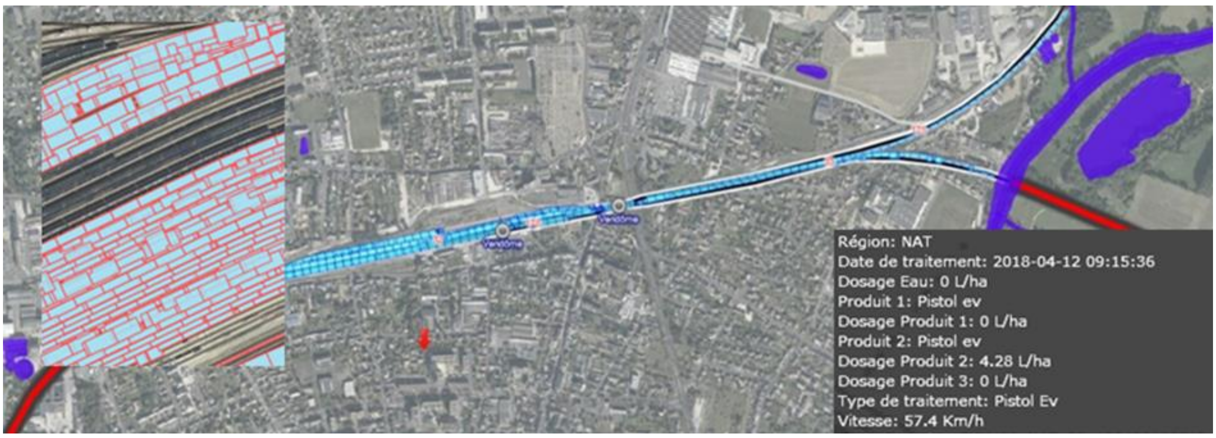


Figure 49: Traceability mapping

11. SNCF Réseau (France) - Construction Methods

Geotextiles

The laying of geotextiles under the walkway and covering them with sand to prevent the growth of vegetation is being tested during track renewal projects and must be integrated into all walkway repair operations in **SNCF Réseau's** network.

SNCF Réseau has carried out a comparative study on manufactured products (waterproofing geomembranes, elastomer mats, separation and filtration geotextiles) based on adaptability/ensile strength - punching/durability criteria, and has also studied the possibility of adapting standards to needs or supplier specification tests.

Two main types of uses have been identified:

- **Uncovered "carpets"**

These are materials that are both flexible and thick and heavy enough to press against the ground with the use of staples. They must allow movement without risk for agents (slip) and be UV-resistant: "weight" materials, bituminous sheets (covered with mineral flakes) or preferably elastomeric mats. The disadvantages lie in the high cost, their packaging generally in small rolls (7 to 10 m long), random durability (UV aging), working constraints related to weight (bitumen sheet especially), fittings, staples, etc. They appear interesting for treating short runs for protecting small equipment: suitable conditioning, no entry of granular material on the site, visibility of the equipment to assist spotting to prevent treatments (of tracks or surroundings).

- **Geotextiles covered with "sand"**

This use opens up many possibilities for finer materials, in packaging. Better suited to processing long sections on the occasion of renewal projects (rolls up to 100 m in length, variable widths), for a lower cost than the above products.

The thickness of the sand should not exceed 3 cm so as not to provide a favourable substrate for undemanding plants.

Thermo-bonded non-woven polypropylene geotextiles are highly suitable:

- products are specifically root-resistant, waterproof and flexible;
- filtering products avoid waterproofing and the possible risk of obstructing drainage to the outside of the platform. They remain flexible and root-resistant when the weight is great enough (240 gr/m^2).

All the technical implementation principles have already been defined. It remains to optimise and industrialise the works process for integration into renewal works.

Figure 50: Geotextile laying and covering

Figure 51: Geotextile laying and covering after 5 years

12. ÖBB-Infra (Austria) - Construction Methods

As part of the GreenLogix-Project, seven different types of root barrier materials have been tested.

Six foils made of polypropylene and one rubber mat, partly made of recycled car tyres were tested (see Figure 52 to Figure 56).

All these root barriers were installed beside the track; the PP foils were covered with 5-10 centimetres of fine gravel used for service walkways, the rubber mat was nailed to the ground without any cover. The vegetation has been monitored. During the two years of investigation, no plants succeeded in growing through the materials but, of course, wind drift seeds have been able to germinate on the fine gravel cover of the foils. Vegetation management by mowing on adjacent sites can certainly help to maintain the root barrier zone and keep it free from invading plants.

There was no significant difference between the six foils. Plants cannot grow on the rubber mats, but these mats need to be installed very carefully on a smooth substrate, otherwise they can easily be damaged by sharp pointed stones. Stacks have to be supported with an additional mat underneath to bridge the gap. The rubber mats are resistant to de-icing-salt but the cannot be cleaned with mechanical snowploughs.

So far, **ÖBB-Infra** has no long-term experience with root barriers such as the above-mentioned materials, but they seem to be a practical measure to reduce pressure from the surroundings.

Figure 52: ÖBB-Infra Installation root barriers Nov 2018 University of Applied Sciences Carinthia

Figure 53: ÖBB-Infra Installation rubber mat Nov 2018 University of Applied Sciences Carinthia

Figure 54: 4-ÖBB-Infra root barrier status after 2 years University of Applied Sciences Carinthia

Figure 55: ÖBB-Infra rubber mats status after 2 years University of Applied Sciences Carinthia

Figure 56: ÖBB-Infra Root barrier status after 2 years University of Applied Sciences Carinthia

GreenLogix also investigated the vegetation growth properties of all materials used for the ballast bed and service walkways. These materials are of various geological origin, due to the location of the quarries from which they are sourced. In Austria, the ballast gravel and material used for service walkways mainly consist of granite, basalt, diabase, limestone and calcareous schist.

As well as clean ballast material, ballast contaminated with organic material has also been tested to simulate growth conditions in aging tracks. Recycling materials such as recycled concrete and asphalt have also been included in the test procedure.

The University of Applied Sciences Carinthia, one of the GreenLogix partners, ended up building 36 test boxes (see Figure 57 and Figure 58) that were filled with the different materials and sown with the same standard seed mixture consisting of 82% grasses and 18% herbs. All trials were duplicated, with one box exposed to full sunlight and one box placed in the shade.

In June 2019, the 36 test boxes were equipped with temperature data loggers.

The data loggers were placed at a depth of 10cm and permanently recorded the temperature. Infrared sensors recorded the surface temperatures, which differed greatly from the temperatures inside the boxes depending on the material.

Basalt and recycling asphalt can reach surface temperatures of more than 60°C (with an air temperature of 29°C), which is definitely destructive for living plant cells. Also, the other ballast materials can reach more than 50°C on the surface, which plants cannot withstand either. The temperatures at a depth of 10cm are, by contrast, rather moderate at around 35°C, which means that roots and rhizomes are not damaged at all.

The results can be summarised as follows. Clean material is obviously less suitable for plant growth than material that is contaminated with organic material. Diabase is the least attractive for vegetation development. The more lime, the better for vegetation development. Vegetation grew more densely in the shade than in full sunlight, obviously because of the very hot surface temperatures.

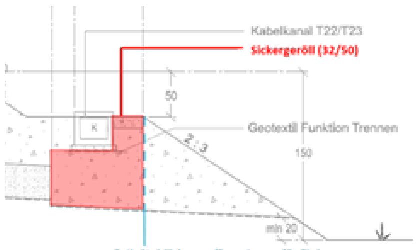
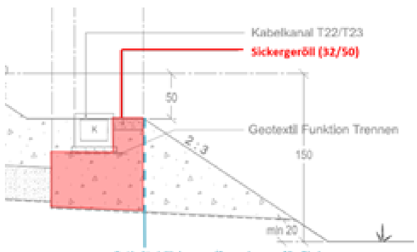
At this point, it is important to underline that railway companies have very limited possibilities for a free choice of the kind of ballast material they want to put on their tracks. Ballast is needed in huge amounts and has to be purchased from regional quarries in order to reduce transport costs and the ecological impacts of long transport distances!

Figure 57: ÖBB-Infra test boxes overview
University of Applied Sciences Carinthia

Figure 58: ÖBB-Infra detail of test boxes
University of Applied Sciences Carinthia

13. SBB (Switzerland) - Construction Methods

Construction methods for reducing vegetation have already been implemented on the **SBB** network in the past. However, systematic monitoring of these areas was either inadequate or not carried out at all. Thus, the long-term effectiveness cannot be assessed. In 2018, all known vegetation-inhibiting construction methods were analysed and evaluated in a basic study. Six promising measures were identified for the trackside area. These are vegetation control fabrics that inhibit vegetation growth, asphalt cover, coarse-grained structure (as a variant superficially-bonded with resin for bonding of ballast), porous concrete bars and superficial rubber mats. Based on the positive experience of **SNCF Réseau** and pilot tests carried out in Switzerland, vegetation control fabrics will be installed as standard in future SBB trackside renovations. A business case has been used to demonstrate that this can also save costs over the entire service life. Most of the other variants will be installed in a track renewal in 2020 / 2021 and monitored over the coming years. Chemical vegetation control will no longer take place in these areas.

Vegetation control fabrics on trackside	Horizontal, near-surface, water-permeable and root-tight fleece with low overlap. Economic efficiency (LCC) proven in business case. Advantage: only minor additional effort for trackside renewals Disadvantage: Rollout takes place over a very long time. Standard for banquet renewals.	 *Figure 59: SBB - Construction Methods - Vegetation control fabrics on trackside*
Seeper pack with resin for bonding of ballast	Coarse-grained structure from seeper pack to trackside. Surface stabilised with resin for bonding of ballast. Effect: coarse-grained separating layer (water drainage)	 *Figure 60: SBB - Construction Methods - Seeper pack with resin for bonding of ballast*
Seepage packing	Coarse-grained structure from seepage packing to trackside. Effect: coarse-grained separating layer (water drainage)	 *Figure 61: SBB - Construction Methods - Seepage packing*

Rubber mats	Surface cover with water-permeable rubber mats. Effect: No rooting. No light in the soil substrate	 Figure 62: SBB - Construction Methods -Rubber mats
Bituminous vegetation barriers	Trackside surface cover with asphalt. Effect: horizontal barrier. No floor substrate.	 Figure 63: SBB - Construction Methods - Bituminous vegetation barriers
Porous concrete barriers	Trackside is constructed with porous concrete. Horizontal and vertical ingrowth barrier.	 Figure 64: SBB - Construction Methods - Porous concrete barriers

14. ProRail (Netherlands) - Construction Methods

In 2016, the "Anti-Vegetation Mat" was approved for use in the Dutch Railway infrastructure after extensive testing over five years. The "Anti-Vegetation Mat" is a mat made out of recycled rubber compound and is used to cover surfaces such as walkways to prevent vegetation growth (see Figure 12). The product was released by **ProRail** through a set of company rules with a certification obligation. This means that every product that can meet our company rules will have to have a certification body test their product in order to obtain a certificate (of product- and railway usage safety, currently there is one certified product). **ProRail** is currently looking for further testing locations on shunting yards, as those are the railway terrains with the most walkways. Use of the "Anti-Vegetation Mat" will not only prevent vegetation from growing there, but will also result in:

- Wider walkways, so train personnel can reach their trains more easily,
- Softer walkways, so when trains need to be inspected it is more comfortable to kneel and look under them,
- Water-permeable walkways. No walkway material under the mat but a finer fraction of ballast is used and this is covered with a mat, rainwater can drain through the mat and the walkway. In this way, it is also an anti-flooding measure,
- Much more durable walkways, since we require a lifespan of 25-45 years. This that cannot be achieved with our current walkway materials.

15. Infrabel (Belgium) - New tenders for vegetation management and Construction Methods

To reduce the use of herbicides, **Infrabel** is concentrating on secondary tracks combining herbicide use targeting the vegetation by means of vegetation detection and manual application, as well as alternative methods where possible. There is still a need for research on new methods, especially for the main tracks for which high requirements are to be fulfilled. A follow-up will be necessary since these changes in vegetation management are expected to increase the presence of vegetation in the track area with all the associated consequences (presence of fine materials in the ballast, increased risk of fire, difficulty of detecting faults on the equipment, etc.). Preventive methods are also being progressively implemented on the walkways along the main tracks.

1. Tenders for vegetation management

Three types of tender are the tool for ensuring vegetation management for the different vegetation areas (Figure 65):

- Tender 1: Spray train with vegetation detection (since 2008) on the main tracks due to lack of alternatives and high technical requirements.
- Tender 2: On secondary tracks (shunting yards, etc. including walkways allowing the use of herbicides targeting the vegetation (manual application or with vehicles equipped with vegetation detection) or alternative methods, mostly mechanical such as mowing and hoeing (Figure 66 to Figure 68), or manual by pulling out vegetation. Outside the track area, alternative methods are systematically implemented including limited use of thermal methods such as hot water (Figure 69). In 2023, the target is 50% of secondary tracks treated by means other than chemical herbicides.
- Tender 3: Only mechanical and manual methods to the exclusion of any other method.

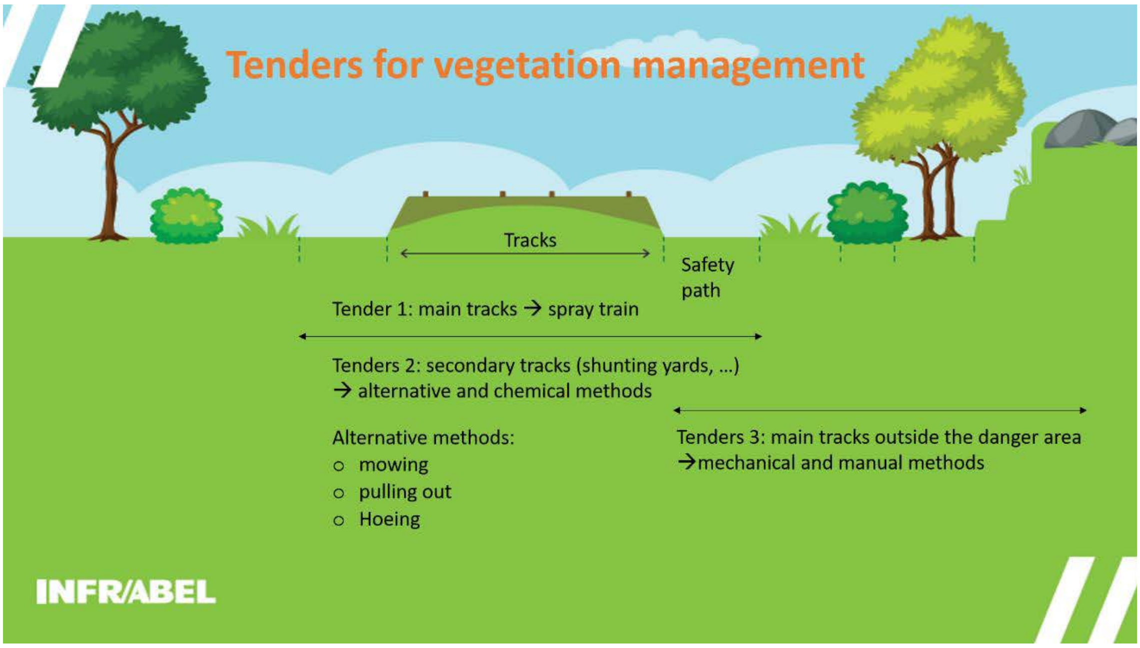


Figure 65: Infrabel -Tenders for vegetation management

Figure 66: Infrabel-Hoeing

Figure 67: Infrabel-Brush cutter

Figure 68: Infrabel-Flail trimmer

Figure 69: Infrabel-Hot water

2. Preventive methods

The internal guidelines have been revised by **Infrabel**. This gives an opportunity to progressively improve the walkways.

The materials recommended for the walkways are specified as hard materials to hamper plant growth. For instance, the possibilities recommended are concrete, concrete paving, asphalt and mixtures of materials with basic pH values.

The combination of a geotextile with 5 cm of fine gravel is not considered effective on account of vegetation development due to wind drift of seeds.

In addition, anti-vegetation mats in elastomer materials complement the long-term solution mentioned above. However, open rubber mats with geotextile were not added to **Infrabel's** list of recommended materials for walkways during the development of technical specifications, due to the labour-intensive installation and cost, as well as the development of vegetation through the open structure. Mats without an open structure give better guarantees against vegetation but are only beneficial for short zones due to cost and labour-intensive installation.

Priority areas were determined as the process of improving the ground covering requires a high level of investment. As a result, these materials will definitely be used in water catchment areas and for planned or future renovation works, such as sleeper renewal, ballast cleaning or switch renewal.

On some lines, an all-in-one solution is applied. The walkway, cable and drainage ducts are provided by one large concrete element. The installation is, however, labour intensive and demands a lot of track traffic interruptions.

Figure 70: Infrabel - Preventive methods- materials for walkways

- Ternary materials (construction height 12 cm) - (Figure 71)
- Composition: coarse sand, crushed stones gauge 2/4 mm, granulated blast furnace slag, chalk and water,
- One layer of 12 cm (thickness after compaction). The layer should be compacted by either a vibration plate or a vibrating roller,
- This material reduces the growth speed of vegetation for a limited time. After 1.5 years the evaluation is semi-positive. However, this solution remains a temporary transitional material. The advantages are fast installation and cost.

Figure 71: Infrabel - Preventive methods - ternary materials

A2 Proposal for a ranking system for methods of vegetation control

Each field test and test campaign carried out by the different railway companies produces valuable information about the operational and economic performance of the applied methods - especially about the actual efficiency of the method, real costs of the entire treatment and the degree to which it meets the special needs and requirements of the railways. These three key criteria should be at the centre of a decision-making strategy for choosing the most effective method of vegetation control by each Rail Infrastructure Manager. Based on the three core criteria, a simple procedure and tool is proposed at the Sustainable Land Use working group meeting to assess the applicability and convenience of each method for vegetation control to be used by each Rail Infrastructure Manager. The purpose of the idea is that each company can obtain a clear picture of the potential methods that could be successfully used, according to their own needs. the aim of this approach is to produce a ranking table for different methods of vegetation control to be used in the decision-making process. Therefore, the following three steps should be performed once the results have been collected from the field tests:

Step 1. Collect data from the field test campaigns

Step 2. Calculate the score by applying a proposed formula

Step 3. Make a classification list of the scoring results

The variables used in the proposed approach will be easily adjusted and integrated according to the specific needs and requirements of the respective countries.

Step 1: Table of the field test campaign data	All the results of each field test campaign are collected and documented in a structured way in a "Summary Table", containing as a minimum the following paragraphs: ▪ name of the method, ▪ location, ▪ application details, ▪ effectiveness, number of treatments needed, ▪ product/material/facility quantities and costs, ▪ labour hours and costs, ▪ indirect costs, ▪ annexes, ▪ others.
Step 2: Score calculation by proposed formula	$SCORE = E \times \left[\left(\sum_{1}^{N} PQ_i \times CP_i\right) + \left(\sum_{1}^{M} MH_j \times MHC_j\right) + \left(\sum_{1}^{L} IC_k\right)\right] \times NT$ **Variables of the proposed formula** Available data at the end of the field test campaigns performed: **E:** the effectiveness E of the method; **PQi:** Product Quantity; **MHj:** Manhour; **NT:** Number of treatments per year Currently available data by each Infrastructure Manager: **CPi:** cost of products; **MHCj:** Manhour cost; **ICi:** Indirect Cost
Step 3: Classification of scoring results	Once the score has been calculated for each treatment using the proposed formula, the railway company will be able to choose methods of vegetation control. The SCORE unit will be monetary (e.g. €) but can be considered dimensionless for calculating purposes.

Since the decision-making procedure is always related to the strategic approach towards integrating business policies and maintenance activities, the selection process of the appropriate and best method for railway companies is a complex one. Although activities using the proposed formula and ranking system are not included in this report, the members of the SLU sector have expressed their interest in such ranking systems. This proposal will be considered as a new project idea for the SLU sector to work on when required.

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